Factor Proportions and the Structure of Commodity Trade

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Abstract

This paper derives and empirically examines how factor proportions determine the structure of commodity trade. It combines a many-country version of the Heckscher-Ohlin model with a continuum of goods developed by Dornbusch-Fischer-Samuelson (1980) with the Krugman (1980) model of monopolistic competition and transport costs. The commodity structure of production and bilateral trade is fully determined. Two main predictions emerge. There is a quasi-Heckscher-Ohlin prediction. Countries capture larger shares of world production and trade of commodities that more intensively use their abundant factors. There is a quasi-Rybczynski effect. Countries that rapidly accumulate a factor see their production and export structures systematically move towards industries that intensively use that factor. Both predictions receive support from the data. Factor proportions appear to be an important determinant of the structure of international trade.

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1 Introduction

The Heckscher-Ohlin model is one of the pillars of international trade theory. The insight that commodity trade embodies factor services is a profound one, underpinning important theorems relating factor abundance, factor prices, product prices, production and trade. Predictions for the commodity structure of production and trade are generally limited to correlations between production or net exports and generally unobservable autarkic relative prices.[1] This paper seeks to extend our understanding of the effect of factor proportions on the commodity structure of production and trade. It develops a model where the structure of production and bilateral trade is completely determined. The model is a combination of the Dornbusch-Fischer-Samuelson (1980) model with a continuum of goods and the Krugman (1980) model of monopolistic competition and transport costs. Two important predictions emerge. Countries capture larger shares of world production and trade in commodities that more intensively use their abundant factor. This is the quasi-Heckscher-Ohlin prediction of the model. Countries that accumulate a factor faster than the rest of the world will see their production and export structure move towards commodities that more intensively use that factor. This is the model's quasi-Rybczynski effect.

The quasi-Heckscher-Ohlin prediction is examined using detailed bilateral trade data for the US. The prediction receives strong support from the data. Countries that are abundant in skilled labor and capital do capture larger shares of US imports in industries that intensively use those factors. The effect is particularly pronounced for skilled labor. Figure 1 gives an example using Germany and Bangladesh. Germany, where the average adult has in excess of ten years of formal education, captures large shares of US imports of skill-intensive commodities, and much smaller shares for commodities that sparingly use skilled labor. Bangladesh, where the average adult has just two and a half years of formal education, exhibits the opposite trade pattern, with exports concentrated in commodities that require little skilled labor.

The quasi-Rybczynski effect also receives support from the data. Rapidly growing countries have seen their export structure change towards more skill and capital intensive industries. This effect is illustrated in Figure 2 for the case of the 'miracle' economies of East Asia; Singapore, Hong Kong, Taiwan and Korea. Their rapid accumulation of human and physical capital has not simply led to more skill intensive and capital intensive production of the same goods, with a consequent reduction in marginal products. Instead, ability to trade has allowed them to shift production to more skill and capital intensive industries. As noted by Ventura (1997), this process is a critical feature of their growth experience. The Rybczynski effect helps countries avoid diminishing returns and sustain high growth rates.

[1] See Deardorff (1980, 1982) for the most general theoretical results. See Noussair, Plott and Riezman (1995) for experimental results using Cal Tech undergraduate students, or Bernhofen and Brown (2000) who examine Japan's opening to trade in the 1860s and find that Japan's trade was correctly predicted by autarky prices.

This paper draws from a strand of literature that found that factor proportions were a determinant of the commodity structure of international trade. Keesing (1966) calculated simple correlations of US export performance with skill intensities. The largest positive correlations occurred at the highest skill levels, while export performance was negatively correlated with the unskilled labor share. Baldwin's (1971) regressions of US bilateral net exports suggested that US net exports were negatively related to capital intensity and positively related to how intensively industries used some types of skilled labor, especially scientists and engineers. Harkness (1978) was the first to use factor shares as the measure of factor intensity. Wright (1990) ran regressions for six time periods from 1879 to 1940 to search for sources of US export success. The US tended to export capital intensive goods in the early periods, but capital intensity became a source of comparative disadvantage by 1940.[2]

The problem that rendered cross-commodity comparisons unfashionable was that they had an unclear theoretical foundation. This argument was forcefully made in a number of studies by Leamer, who demonstrated that export performance did not depend on the input characteristics of the industry.[3] By contrast, in this paper, conditional on factor endowments, export performance is determined by industry input characteristics. Leamer (1984) generates a linear relationship between output or trade and factor supplies by assuming identical constant returns technology, homothetic preferences, frictionless trade, and that the number of industries equals the number of inputs. His regressions find that a brief list of factor endowments provide a reasonable explanation of net trade. Harrigan (1997) derives his empirical model from an approximation to a firm's revenue function, and using OECD production data finds that relative productivity and factor supplies are important determinants of how countries specialize.

This paper is also related to the factor content of trade studies that examine a similar implication of the Heckscher-Ohlin model; that a country's net trade embodies the services of its abundant factors. The first factor content study was Leontief (1953), who found that US imports were more capital intensive relative to labor than US exports, contrary to expectation. A number of studies surveyed in Leamer (1984) followed Leontief's approach. But Leamer used Vanek's (1968) equations to establish that in a multi-factor world these studies also lack adequate theoretical foundation. Factor content studies since then increasingly tended to be multi-country studies firmly based on the Heckscher-Ohlin-Vanek (HOV) theorem equating factors embodied in net trade to excess factor endowments. Empirical HOV studies use impressive data sets on exports, imports, factor endowments and technology for a large number of countries. Early studies based on HOV performed poorly. Bowen, Leamer and Sveikauskas (1987) used 1967 data on 12 factors and 27 countries. They tested sign and rank propositions derived from the HOV theorem, but found, at best, only modest support for the factor proportions model. Trefler's (1993, 1995)

[2]See surveys by Deardorff (1984), Leamer (1984) and Leamer and Levinsohn (1995).

[3]See, for example, Leamer and Levinsohn (1995).

examination of 1983 data on 10 factors and 33 countries accounting for 76% of world exports found zero factor content in net trade.

Subsequent work by Davis, Weinstein, Bradford and Shimpo (1997), Davis and Weinstein (2000, 2001), and Wolfson (1999) have shed light on why the early work failed to find factor content. A key explanation is that countries appear to use different production techniques. Early studies assumed that all countries used the same techniques, and estimated these using US input-output matrices. Examination of input-output matrices for other countries show that countries do use different techniques, and that these differences reflect factor endowment differences. Under these conditions, factor content studies that use a common technology matrix will systematically understate actual factor content. Davis and Weinstein (2000) show that for a sample of 10 wealthy countries, use of actual technology matrices lifts estimates of net factor content of trade to typically 10 to 12 percent of national endowments, and to a substantial 38 to 49 percent of endowments devoted to tradeables. The other important explanation for the early failure to find factor content is an apparent 'bias' in consumption towards locally produced goods.

The use of different production techniques is very interesting because it suggests that there may be a failure of FPE. Repetto and Ventura (1998) confirm that factor prices do differ systematically across countries, even after controlling for productivity differences. Locally abundant factors have lower prices. The failure of FPE can be accommodated by factor content studies by use of a multi-cone Heckscher-Ohlin model. Without a more precise model, empirical implementation is limited by access to input-output tables. Although these tables are becoming available for more countries, they are arguably not the highest quality economic data available. But the failure of FPE provides us with another opportunity, because without FPE, the commodity structure of production and trade is determined, and commodity trade data is some of the best and most abundant data we have. There is an opportunity to explore just how pervasive the effect of factor proportions is on the structure of international trade.

There are many ways to generate a failure of FPE in a Heckscher-Ohlin world. One way is to assume that factor proportions are sufficiently different that they are outside the FPE set. Another way is to introduce costs to international trade, which could have a strong effect on trade volume.[4] This paper takes the second route. It generalizes the Heckscher-Ohlin model of Dornbusch-Fischer-Samuelson (1980) and explores the effects of these generalizations on trade structure. The starting point is a many-country version of the Heckscher-Ohlin model with a continuum of goods. I integrate this with the Krugman (1980) model of intraindustry trade generated by economies of scale and product differentiation. Finally, I allow for transport costs. The Heckscher-Ohlin model of Dornbusch-Fischer-Samuelson can be seen as a limiting

[4]See McCallum (1995), Helliwell (1999), Parsley and Wei (2000) and Anderson and van Wincoop (2001) for the effects of borders on trade volumes.

case of this model with zero transport costs and perfect competition. The generalizations are made to obtain predictions of the factor proportions model in all commodity markets, so that its performance can be assessed using the very detailed trade data that Leamer and Levinsohn (1995) claim has been "measured with greater accuracy over longer periods of time than most other economic phenomena".

Predictions of the factor proportions model in commodity markets are primarily driven by the deviation from FPE caused by the transport cost. Monopolistic competition smooths some of the hard edges of the perfectly competitive model and determines bilateral trade.[5] In this model, the transport cost causes locally abundant factors to be relatively cheap. The location decisions of industries are affected by factor costs, so that countries tend to attract industries that intensively use their relatively abundant factors. The model also predicts some of the technology and demand modifications needed by the empirical factor content studies to make the Heckscher-Ohlin model fit the data. Every industry substitutes towards the relatively cheap, locally abundant factor. Consumers also substitute towards cheaper local varieties.

The closest theoretical papers to this are due to Deardorff (1998) and Helpman and Krugman.[6] The closest empirical papers are Baldwin (1971), Davis and Weinstein (1998b) and Petri (1991). Deardorff introduces trade impediments to a Heckscher-Ohlin model to determine bilateral trade volumes. Davis and Weinstein use Helpman's and Krugman's theory to find evidence that increasing returns help determine the structure of production and trade. Petri's study of Japanese trading patterns identifies cross-commodity regressions by relaxing the FPE assumption and by assuming that home goods are imperfect substitutes for imports. This paper goes further, it explicitly connects departures from FPE to factor abundance in a general equilibrium model, and uses the implications of that departure to examine the relationship between factor abundance and trade structure using detailed commodity trade data.

The paper is organized as follows. Section 2 develops the model. Section 3 examines the quasi-Heckscher-Ohlin effect. Section 4 examines the quasi-Rybczynski effect. Section 5 concludes.

2 The Model

A. Model Description

The model commences with a many-country version of the Heckscher-Ohlin model with a continuum of goods. Countries differ in their relative factor abundance. Factor

[5] Bilateral trade in general is not determined in the perfectly competitive model, unless no two countries have the same factor prices. The simple form of imperfect competition considered in this paper determines bilateral trade even when some countries have the same factor prices.

[6] See, for example, Helpman and Krugman (1985) for models with imperfect competition and more than one factor.

proportions will be one force generating international trade. I combine this with the Krugman (1980) model of intraindustry trade driven by scale economies and product differentiation. Scale economies are the second force generating international trade. Finally I add 'iceberg' transport costs. The transport costs will determine the commodity structure of production and trade by generating a departure from FPE. The model assumptions are set out in detail below.

1. There are $2M$ countries, M each in the North and South. Southern variables, where needed, are marked with an asterisk.

2. There are two factors of production supplied inelastically; skilled labor and unskilled labor earning factor rewards s and w respectively. The total labor supply is 1. The proportion of skilled labor is denoted by β. Northern countries are relatively abundant in skilled labor; $\beta > \beta^*$. A third factor capital is considered at the end of this Section.

3. There is a continuum of industries z on the interval [0,1]. The index z ranks industries by factor intensity. Industries with higher z are more skill intensive.

4. All consumers in all countries are assumed to have identical Cobb-Douglas preferences with the function of income spent on industry z being $b(z)$ (Equation 1). Expenditure shares for each industry are therefore constant for all prices and incomes. All income is spent so the integral of $b(z)$ over the interval [0,1] is 1 (Equation 2).

$$U = \int_0^1 b(z) \ln Q(z) dz. \tag{1}$$

$$\int_0^1 b(z) dz = 1. \tag{2}$$

5. Monopolistic competition. In the traditional model each industry z produces a homogeneous good. In this model, there are economies of scale in production and firms can costlessly differentiate their products. The output of each industry consists of a number of varieties that are imperfect substitutes for one another. The quantity produced of variety i in industry z is denoted by $q^S(z,i)$, the quantity consumed by $q^D(z,i)$. $N(z)$ is the endogenously determined number of varieties in industry z:

$$N(z) = M\left(n(z) + n^*(z)\right). \tag{3}$$

As z is no longer a homogeneous good, $Q(z)$ can be interpreted as a sub-utility function that depends on the quantity of each variety of z consumed. I choose the symmetric CES function with elasticity of substitution greater than 1:

$$Q(z) = \left(\int_0^{N(z)} q^D(z,i)^\theta di \right)^{\frac{1}{\theta}}, \qquad \theta \in (0,1]. \tag{4}$$

Commodities are produced using both factors of production with a constant marginal cost and a fixed cost. Production technology, represented by a total cost function TC, is assumed to be Cobb-Douglas in both factors and identical in all countries:

$$TC(q^S(z,i)) = s^z w^{1-z}(\alpha + q^S(z,i)) \tag{5}$$

Average costs of production decline at all levels of output, although at a decreasing rate. This cost function has the convenience of generating factor shares that do not depend on factor rewards. The form of the total cost function causes the index z to rank industries by skill intensity, because z denotes both the industry *and* skilled labor's share of income in that industry. There is free entry into each industry, so in equilibrium profits are zero.

6. Costly international trade. There may be a transport cost for international trade. To avoid the need to model a separate transport sector, transport costs are introduced in the convenient but special iceberg form: τ units of a good must be shipped for 1 unit to arrive in any other country ($\tau \geq 1$).

B. Equilibrium in an Industry

In general equilibrium consumers maximize utility, firms maximize profits, all factors are fully employed and trade is balanced. The model solution proceeds in two steps. The first step is to solve for the partial equilibrium in an arbitrary industry. In particular, I solve for the share of world production that each country commands, conditional on relative production costs. I show that countries with lower costs capture larger market shares. The next step is to show that in general equilibrium, locally abundant factors are relatively cheap. Skilled labor is relatively cheap in the North, and unskilled labor is relatively cheap in the South. The North becomes the low-cost producer of skill-intensive goods, and commands larger shares of these industries. The South is the low-cost producer of low-skill goods, and produces relatively more of these.

The properties of the model's demand structure have been analyzed in Helpman and Krugman (1985).[7] Firstly, we need four additional pieces of notation. Denote the (constant) elasticity of substitution between varieties within an industry by $\sigma = \frac{1}{1-\theta}$; let $\widehat{p}(z,i)$ be the price paid by consumers, inclusive of transport costs, for variety i in industry z, let $I(z)$ be the set of all varieties in industry z, and let national income

[7]See Sections 6.1, 6.2 and 10.4 in particular.

be $Y = s\beta + w(1-\beta)$. Maximization of $Q(z)$ conditional on expenditure $E(z)$ yields the following demand functions:

$$q^D(z,i) = \frac{\widehat{p}(z,i)^{-\sigma}}{\int_{i' \in I(z)} \widehat{p}(z,i)^{1-\sigma}\, di'} E(z); \qquad i \in I(z). \tag{6}$$

A firm's share of industry revenues depends on its own price and on the prices set by all other firms in that industry. It is convenient to define the ideal price index $G(z)$:

$$G(z) = \left[\int_{i \in I(z)} \widehat{p}(z,i)^{1-\sigma}\, di \right]^{\frac{1}{1-\sigma}} \tag{7}$$

Due to the unit elasticity of substitution between industries, a constant function of income $b(z)$ is spent on industry z in every country. An individual Northern firm sets a single factory gate price of p. Its products sell in its own domestic market at p, but in the $M-1$ other Northern markets and the M Southern markets the transport cost raises the price to $p\tau$. The ideal industry price index G is given in Equation 8. G^* is symmetric. Implicit in these indices is the assumption that in equilibrium all Northern countries are alike and all Southern countries are alike. Except where needed, the 'z' notation is suppressed.

$$G = \left[np^{1-\sigma} + (M-1)\, n\, (p\tau)^{1-\sigma} + Mn^* (p^*\tau)^{1-\sigma} \right]^{\frac{1}{1-\sigma}}. \tag{8}$$

The revenue of a typical Northern firm that sets a factory gate price of p is given by Equation 9. The three terms reflect revenues in its domestic market, the $M-1$ other Northern markets and the M Southern markets. The equivalent Southern expression is symmetric.

$$pq^S = bY \left(\frac{p}{G}\right)^{1-\sigma} + (M-1)\, bY \left(\frac{p\tau}{G}\right)^{1-\sigma} + MbY^* \left(\frac{p\tau}{G^*}\right)^{1-\sigma}. \tag{9}$$

The production and trade structure has also been studied in Helpman and Krugman (1985).[8] Each firm produces a different variety of the product. Each country, if it produces in the industry at all, produces different varieties. Every variety is demanded in every country. Profit maximizing firms perceive a demand curve that has a constant elasticity, and therefore set price at a constant markup over marginal cost:[9]

$$p(z) = \frac{\sigma}{\sigma - 1} s^z w^{1-z} \tag{10}$$

[8]See Chapter 7.

[9]The demand curve faced by a firm has a constant elasticity if the set of varieties is of non-zero measure.

With free entry, profits are zero in equilibrium. The pricing rule, the zero profit condition and the special form of the fixed cost produce an equilibrium where all firms produce the same quantity of output:

$$q^S = q^{S*} = \alpha(\sigma - 1). \tag{11}$$

We now have everything we need to solve for the partial equilibrium in this industry. Notation is simplified by defining world income $W = M(Y + Y^*)$, the relative price of Northern goods $\widetilde{p} = \frac{p}{p^*}$ and the expression $F = 1 + (M - 1)\tau^{1-\sigma}$.[10] Conditional on relative prices, Equations 8 and 9 contain four equations in four unknowns n, n^*, G and G^*. These equations may not have positive solutions for both n and n^*. If they do not, the solution for n and n^* will either be Equation 12 or Equation 13. If $\widetilde{p}$ is low then Equation 12 is the solution; if $\widetilde{p}$ is high then Equation 13 is the solution.[11]

$$n = \frac{b(Y + Y^*)}{p\alpha(\sigma - 1)}, \qquad n^* = 0 \qquad \text{if} \qquad \widetilde{p} \leq \underline{p} = \left[\frac{\tau^{1-\sigma}MF\left(\frac{Y^*}{Y} + 1\right)}{\tau^{2-2\sigma}M^2 + F^2\frac{Y^*}{Y}}\right]^{\frac{1}{\sigma}}. \tag{12}$$

$$n = 0, \qquad n^* = \frac{b(Y + Y^*)}{p^*\alpha(\sigma - 1)} \qquad \text{if} \qquad \widetilde{p} \geq \overline{p} = \left[\frac{\tau^{2-2\sigma}M^2\frac{Y^*}{Y} + F^2}{\tau^{1-\sigma}MF\left(\frac{Y^*}{Y} + 1\right)}\right]^{\frac{1}{\sigma}}. \tag{13}$$

If both n and n^* are positive, Equations 8, 9 and 11 solve for $\frac{n}{n^*}$, which is given in Equation 14. This expression is derived by dividing the demand Equation 9 by its Southern equivalent; substituting for q^S and q^{S*} using Equation 11; substituting for G and G^* using Equation 8; and rearranging. The relative number of Northern firms declines in both the relative price of Northern goods and in the relative size of Southern economies.

$$\frac{n}{n^*} = \frac{\tau^{2-2\sigma}M^2\frac{Y^*}{Y} + F^2 - \widetilde{p}^{\sigma}\tau^{1-\sigma}MF\left(\frac{Y^*}{Y} + 1\right)}{\widetilde{p}\left(\tau^{2-2\sigma}M^2 + F^2\frac{Y^*}{Y}\right) - \widetilde{p}^{1-\sigma}\tau^{1-\sigma}MF\left(\frac{Y^*}{Y} + 1\right)}, \text{ if } \widetilde{p} \in \left(\underline{p}, \overline{p}\right). \tag{14}$$

Equation 14 can be used to solve for the share v of world revenues in that industry that accrue to firms in each Northern country. When solving for v, we have to account for the indirect demand for goods used up in transit. Each Northern firm's revenue

[10] F is the quantity of goods a Northern firm sells in all Northern markets divided by its domestic sales; $F > M\tau^{1-\sigma}$.

[11] The conditions for $\widetilde{p}$ are derived from Equation 14.

is given by pq^S, where q^S is the quantity produced, not the quantity consumed. Equation 15 is the definition of v. Equation 16 is the solution for v.

$$v = \frac{npq^S}{M\left(npq^S + n^* p^* q^{S*}\right)} \tag{15}$$

$$v = \begin{cases} \frac{1}{M} & \text{if} \quad \widetilde{p} \in (0, \underline{p}] \\ \frac{Y}{W}\left[\frac{-\widetilde{p}^{\sigma}\tau^{1-\sigma}MF\left(\frac{Y^*}{Y}+1\right)+\tau^{2-2\sigma}M^2\frac{Y^*}{Y}+F^2}{-(\widetilde{p}^{\sigma}+\widetilde{p}^{-\sigma})\tau^{1-\sigma}MF+\tau^{2-2\sigma}M^2+F^2}\right] & \text{if} \quad \widetilde{p} \in (\underline{p}, \overline{p}) \\ 0 & \text{if} \quad \widetilde{p} \in [\overline{p}, \infty) \end{cases} \tag{16}$$

The revenue share v declines in both the relative price of Northern goods $\widetilde{p}$ and the relative size of Southern economies $\frac{Y^*}{Y}$. The sensitivity of market share v to relative price increases with the elasticity of substitution σ and with the number of countries. To better illustrate this, Equation 17 gives $\frac{\partial v}{\partial \widetilde{p}}$ evaluated at $\widetilde{p} = 1$:

$$\frac{\partial v}{\partial \widetilde{p}}\Big|_{\widetilde{p}=1} = \frac{-\sigma\tau^{1-\sigma}F}{\left(\tau^{1-\sigma}-1\right)^2} < 0. \tag{17}$$

Market share responds negatively to relative price. But by Equation 10, relative price is equal to relative production costs, which depend on factor prices. This generates the role for factor abundance; I next demonstrate that in general equilibrium, locally abundant factors are relatively cheap. Therefore the relative price of Northern goods declines with the skill intensity of the industry, and every Northern country captures larger shares of more skill intensive industries.

C. General Equilibrium

All factors must be fully employed in all countries in equilibrium. With assumed preferences, the function of world income spent on each industry is invariant to prices and income. With the assumed production technology, factor shares in each industry are invariant to factor prices. Skilled labor's share of revenues in industry z is constant and equal to z. The balance goes to unskilled labor. Equations 18 to 21 are, respectively, the full employment conditions for: skilled labor in the North; unskilled labor in the North; skilled labor in the South; and unskilled labor in the South. The left side of each equation is factor demand, the right is factor supply. The wages of unskilled labor in the South have been normalized to 1. National income equals national expenditure in every country, so trade is balanced.

$$\int_0^1 \frac{1}{s} z b(z) W v(z)\, dz = \beta. \quad (18)$$

$$\int_0^1 \frac{1}{w}(1-z) b(z) W v(z)\, dz = 1-\beta \quad (19)$$

$$\int_0^1 \frac{1}{s^*} z b(z) W(\frac{1}{M} - v(z)) dz = \beta^*. \quad (20)$$

$$\int_0^1 (1-z) b(z) W(\frac{1}{M} - v(z)) dz = 1-\beta^*. \quad (21)$$

So long as M is finite, the failure of FPE can be demonstrated by contradiction.[12] With FPE, $\widetilde{p}(z) = 1$ by Equation 10, and $v(z)$ is constant over z by Equation 16. By Equations 18 to 21, relative factor demands in the North equal relative factor demands in the South. But the relative supply of these factors is not equal by assumption. Therefore we cannot have full employment equilibrium with FPE.

The North has more skilled labor; the South more unskilled labor. Full employment requires the North to either (i) have a larger share of skill-intensive industries, or (ii) use skilled labor more intensively in each industry than in the South. For the North to obtain a larger share of skill-intensive industries, Equation 16 requires that $\widetilde{p}(z)$ declines in z. By Equation 10, $\widetilde{p}(z)$ declines in z if and only if $\frac{s}{w} < \frac{s^*}{w^*}$.[13] Factor demands obtained by differentiating Equation 5 with respect to factor prices show that for any industry, the North will use skilled labor more intensively than the South if and only if $\frac{s}{w} < \frac{s^*}{w^*}$. Therefore skilled labor must become relatively cheap in the North, and unskilled labor relatively cheap in the South. The relative price $\widetilde{p}(z)$ declines in z, and every Northern country's share of world production in an industry rises with the skill intensity z of the industry.[14] The equilibrium is depicted in Figure 3.

D. *The Separate Contributions of Transport Costs and Monopolistic Competition*

[12] In the limit as $M \to \infty$, factor price equalization is again achieved. This is shown by proving that equilibrium in an arbitrary industry requires production costs to be the same in both the North and the South. The reason for FPE returning is simple. The domestic market becomes increasingly less important as M gets larger. In the limit everything is exported, so that transport costs affect locally scarce and abundant factors equally.

[13] This can be proved by differentiating the log of $\widetilde{p}(z)$.

[14] Conditional on σ and τ.

The Dornbusch-Fischer-Samuelson model is a special case of this model with no transport costs ($\tau = 1$) and perfect competition ($\alpha = 0$ and $\sigma = \infty$). It is therefore possible to consider the separate effects of transport costs ($\tau > 1$) and monopolistic competition ($\alpha > 0$, $\sigma < \infty$). In the traditional model with a continuum of goods, Dornbusch, Fischer and Samuelson (1980) show that FPE holds if factor endowments are not too dissimilar. Production costs are therefore the same everywhere because all goods can be produced just as well in any country. With zero transport costs, there is commodity price equalization. The geographic pattern of production and trade of a given commodity is therefore indeterminate. Overall patterns of production and trade are not totally indeterminate, because full employment of both factors requires the North to produce, on balance, more skill-intensive goods. This prediction is formalized in the standard HOV factor content of trade equations.

The addition of the transport cost makes the commodity structure of production determinate. The transport cost causes a departure from FPE, and therefore production costs differ between countries. Locally abundant factors become relatively cheap. Countries have a cost advantage in goods that intensively use their abundant factor. Consumers only purchase goods from the cheapest source, inclusive of transport costs. If factor proportions are sufficiently different, low skill goods in the interval $[0, \underline{z}]$ will only be produced in the South.[15] The cost advantage that the South enjoys in these goods outweighs the transport cost. High skill goods $[\overline{z}, 1]$ will only be produced in the North. Goods with intermediate skill intensity $[\underline{z}, \overline{z}]$ will be produced by all countries and will not be traded internationally because the transport cost outweighs any production cost advantage. The range of these non-traded goods increases as the countries' relative factor endowments become more similar or as costs of international trade become greater.

The addition of the transport cost to the traditional model therefore leads to the very stark structure of production and trade illustrated in Figure 4: there is a sharp pattern of specialization; there is no North-North or South-South trade; there is no intra-industry trade; and there is no trade at all in commodities with intermediate factor intensities. All trade is North-South in commodities that embody extreme factor proportions. There are no additional predictions beyond this. In particular, the bilateral pattern of trade is not determined.[16] These crisp predictions sit uncomfortably with the hard facts of trade. Much trade flows between countries with similar factor endowments and much of it appears to be intra-industry trade (Helpman 1999).

Now consider the case of monopolistic competition but no transport costs. The fixed cost of production limits the range of products that the market will profitably

[15] If $\frac{1-\beta^*}{\beta^*} > \frac{1-\beta}{\beta}\tau^2$, then this type of equilibrium emerges.

[16] If transport costs differed across each country pair then the bilateral pattern of trade would be determined. In any given country, all of a particular commodity would be sourced from the lowest cost source inclusive of transport costs.

support. Countries will specialize in different varieties. When consumers demand a wide spectrum of varieties, economies of scale generated by the fixed cost will lead to trade. Provided factor endowments are not too dissimilar, Helpman and Krugman (1985) show that FPE prevails. Production costs are identical in all countries. There is also commodity price equalization. The geographic pattern of production and trade of a given commodity is therefore indeterminate. Overall patterns of production and trade are again not totally indeterminate, because full employment of both factors requires the North to produce, on balance, more skill-intensive goods. The standard HOV factor content of trade equations hold but there is now an additional feature; these equations hold bilaterally. This can be seen in the HOV framework. All of the traditional assumptions are present. The bilateral prediction is a result of two features of this model: countries specialize in different varieties; and as long as there is commodity price equalization consumers will demand the same proportion of world output of *each variety* of every good produced. There is North-North and South-South trade, but the net factor content of any of these trading relationships is zero. Differences between factor endowments and consumption of factors is resolved entirely by North-South trade.

Transport costs generate sharp predictions for the location of production, but apart from ruling out trade between like countries, they generate no predictions for trade between country pairs.[17] Monopolistic competition generates predictions for the total volume and factor content of bilateral trade, but does not give sharp predictions for where individual industries locate. Simultaneous consideration of transport costs and monopolistic competition results in both sharp predictions for the location of production and for bilateral trade in each industry.

Figures 5 to 7 illustrate the influence of transport costs τ, the elasticity of substitution σ, and factor proportions β, β^* in the model. I use as a benchmark a model where transport costs are moderate ($\tau = 1.05$), the substitutability of varieties within an industry is substantial but far from perfect ($\sigma = 5$), and the North has twice the skilled labor of the South and half of the unskilled labor ($\beta = \frac{2}{3}, \beta^* = \frac{1}{3}$).[18] An increase in transport costs causes countries to become more diversified and reduces trade (Figure 5). An increase in the elasticity of substitution between varieties within an industry pushes the model towards the sharp pattern of specialization that characterizes the perfectly competitive model (Figure 6). Figure 7 illustrates the sensitivity of the model to relative factor abundance. Larger differences in factor abundance between the North and the South result in greater specialization in equilibrium.

E. The Three Factor Model

The role of physical capital in trade has traditionally been of great interest. It is possible to add additional factors to the model. The three-factor model with capital is the same as the two-factor model but with the following modifications:

[17] In this model there is FPE within the two subsets of countries.

[18] I also set $b(z) \equiv 1$ so that expenditure shares for all industries are identical, and $M = 2$.

1. There are three factors of production supplied inelastically; skilled labor, unskilled labor and capital earning factor rewards s, w and r respectively. The total factor supply is 1. The proportions of skilled labor and capital are respectively denoted by β and γ. Northern countries are relatively abundant in skilled labor and capital; $\beta > \beta^*$ and $\gamma > \gamma^*$.

2. There is a continuum of industries kz on the 2-dimensional simplex. The indices k and z will rank industries by capital and skill intensity respectively.

3. The utility function becomes:

$$U = \int_0^1 \int_0^{1-z} b(kz) \ln Q(kz) dk dz. \tag{22}$$

4. $b(kz)$ is the function of income spent on industry kz. All income is spent:

$$\int_0^1 \int_0^{1-z} b(kz) dk dz = 1. \tag{23}$$

5. The total cost function becomes:

$$TC(q(kz,i)) = r^k s^z w^{1-k-z}(\alpha + q(kz,i)) \tag{24}$$

A similar equilibrium emerges. In particular, Equation 16 relating the location of production to relative costs of production is unchanged. There are now six full employment conditions analogous to Equations 18 to 21. These are listed in Appendix B. By the same reasoning as in the 2-factor case, full employment equilibrium with FPE can not occur if factor proportions differ between countries. With FPE, relative factor demands are the same in every country. But relative factor supplies are not the same by assumption. However, unless more assumptions are made about the form of $b(kz)$ it is difficult to comment further on factor rewards. If $b(kz) \equiv 2$ then the function of income spent on each industry is identical, and this task is simplified. Full employment requires the North to either have larger shares of skill and capital intensive industries, or to use skilled labor and capital more intensively in each industry than in the South. Either of these things requires $\frac{s}{w} < \frac{s^*}{w^*}$ and $\frac{r}{w} < \frac{r^*}{w^*}$. In the North, skilled labor and capital must become cheap relative to unskilled labor. For a given skill intensity z, the relative price of Northern goods $\widetilde{p}(kz)$ declines with capital intensity k. Given z, every Northern country's share of world production in an industry is increasing in k. For a given capital intensity k, the relative price of Northern goods $\widetilde{p}(kz)$ declines with skill intensity z. Given k, every Northern country's share of world production in an industry is increasing in z.

3 The Quasi-Heckscher-Ohlin Prediction

A. Overview and Brief Data Description

The Heckscher-Ohlin prediction of the model is that countries capture larger shares of production and trade in commodities that intensively use their relatively abundant factors. Production of skill-intensive goods is concentrated in the North. The more skill-intensive the good, the greater is this concentration.[19] Given our assumption on preferences, this leads to a very sharp and convenient prediction for trade. Consider the consumers in any individual country C, which can be from the North or the South. Consumers in C will purchase some of every variety of every good, and given the elasticity assumptions, they spend relatively more on varieties that are relatively cheap. Northern countries produce more varieties of skilled goods and, due to the behavior of factor prices, do so more cheaply than in the South. Conditional on σ and τ, Northern countries' share of C's imports therefore increase with the skill intensity of the industry. The prediction holds for all of C's bilateral trading relationships. Each Northern country will command a higher share of C's imports of skilled goods than it will of unskilled goods; their market share will systematically increase with the skill intensity of the good. The reverse is true for Southern countries. Equation 25 is an expression for each Northern country's share by value of every other Northern country's imports of a particular commodity.[20] This share is increasing in the skill intensity z of the commodity as both $\frac{n^*}{n}$ and $\frac{p}{p^*}$ decline in z.

$$\widetilde{v} = \frac{1}{(M-1) + M\frac{n^*}{n}\left(\frac{p}{p^*}\right)^{\sigma-1}} \tag{25}$$

This Heckscher-Ohlin prediction can be examined using detailed commodity trade data and estimates of factor intensity and factor abundance. I use 1998 data from the USA Trade CD-ROM on US imports classified by detailed commodity and country or origin. There are over 16,000 commodities and 200 trading partners. This data is then mapped into 4-digit US SIC codes using a concordance maintained by Jon Haveman.[21] The shares of US imports by SIC industry are then calculated for each country.

The model assumes that there are no factor intensity reversals. Indeed, a property of the model is that factor shares are fixed for each industry. With this assumption, factor intensity can be consistently ranked using factor share data for just one country.

[19] This prediction is conditional on τ and σ, and this "chain" proposition would also be weakened if intermediate inputs were introduced into the analysis, see Deardorff (1979).

[20] $\frac{n^*}{n}$ can be easily substituted using Equations 12-14, but the resulting equation for $\widetilde{\nu}$ is not illuminating.

[21] Various concordances are available from the site www.haveman.org.

I choose US data both for reasons of availability and because the estimates are likely to be the most satisfactory due to the US being the largest and most diverse industrial economy. In this paper I mostly consider a two factor model with skilled and unskilled labor and a three factor model with capital. I also consider the robustness of the results to the inclusion of raw materials in a four factor model. All factor intensity data is derived from the US Census of Manufactures for 1992.

In the two factor model I follow Berman, Bound and Griliches (1994) and measure the skill intensity of industry z_2 as the ratio of non-production workers to total employment in each industry.[22] The unskilled labor intensity is $u_2 = 1 - z_2$. In the three factor model I have to account for the share of capital. Capital intensity k_3 is measured as 1 less the share of total compensation in value added. Skill intensity z_3 is now equal to $z_2(1 - k_3)$, and the intensity of unskilled labor is $u_3 = u_2(1 - k_3)$. Table 1 lists the 10 industries that most intensively use each factor and the 10 industries that least intensively use each factor. Many of the most capital intensive industries are also industries that most intensively use raw materials, generating the potential for bias if raw materials are omitted from the analysis. In particular, the concern is that many poor countries may be relatively abundant in raw materials and export simply transformed raw materials. These exports often end up being classified as capital intensive manufacturing.

Raw material inputs are derived from detailed Census of Manufactures data on intermediate inputs by industry. This data is screened to keep only food, forestry and mining industry output. Raw material intensity m_4 is measured as the value of raw material inputs divided by the sum of raw materials and value added. The industries that most intensively use raw materials come from the Food, Tobacco, Wood, Paper, Chemicals, Metals and Non-metallic Mineral Product groupings. Other factor intensities need to be adjusted to reflect the share of raw materials. Capital intensity becomes $k_4 = k_3\,(1 - m_4)$; skill intensity becomes $z_4 = z_3\,(1 - m_4)$; and unskilled labor intensity is $u_4 = u_3(1 - m_4)$. Tables 2 and 3 report summary statistics for the factor intensity estimates.

The model explains trade shares by an interaction of factor intensity and factor abundance. The abundance of skilled labor is measured by the human capital to labor ratio from Hall and Jones (1999), which is based on education levels reported in Barro and Lee (2000). The abundance of capital is measured by the investment based measure of the capital to labor ratio sourced from Hall and Jones. The Hall and Jones measures are available for a large number of countries, 123 in total. Relative GDP per capita is used as an alternative proxy for the abundance of physical and human capital.[23] Raw material abundance is measured by total land area divided by the total labor force sourced from the World Bank World Development Indicators

[22] This measure is correlated with another measure of skill intensity; average wages.

[23] GDP per capita in the Heckscher-Ohlin framework is a measure of the abundance of all factors relative to population.

2000 CD-ROM, a simple but imperfect estimate of the abundance of agricultural and mineral resources. All measures of abundance are relative to the US. Summary statistics for the factor abundance measures are reported in Tables 4 and 5.

The final sample includes 123 countries and 370 industries.[24] In all tests I estimate variations of Equation 26 for two-factor models, Equation 27 for three-factor models and Equation 28 for four-factor models. The model does not have a closed-form solution for market share as a function of factor intensity and factor abundance. I use simple linear specifications that impose a very rigid functional form and non-parametric techniques that do not impose a functional form. The regression estimates are interpreted as conditional expectations of US import market share given the factor intensities of the industry. $\widetilde{v}_{cz}$ is the share that country c commands of US imports in industry z. z, k and m are, respectively, the skill, capital and raw material intensity of industry z. The subscripts 2, 3 and 4 on the factor intensities denote the number of factors considered when estimating those intensities. I assume that $\widetilde{v}_{cz}$ does not affect the factor intensity of individual industries; that the production structure of an economy does not affect factor accumulation; and that any technology differences between countries are orthogonal to the input characteristics of industry.[25]

$$\widetilde{v}_{cz} = \alpha_c + \alpha_{1c} z_2 + \varepsilon_{cz} \tag{26}$$

$$\widetilde{v}_{cz} = \alpha_c + \alpha_{1c} z_3 + \alpha_{2c} k_3 + \varepsilon_{cz} \tag{27}$$

$$\widetilde{v}_{cz} = \alpha_c + \alpha_{1c} z_4 + \alpha_{2c} k_4 + \alpha_{3c} m_4 + \varepsilon_{cz} \tag{28}$$

B. The Aggregate North

The first regression is most closely connected to the model and is performed at a very aggregate level. I define the North to be any industrial country with per capita GDP at PPP of at least 50 percent of the US level. The countries are listed in Table 6. Characteristics of these countries summarized in Table 7 include high levels of physical and human capital. I calculate the share $\widetilde{v}_{nz} = \sum\limits_{c \in North} \widetilde{v}_{cz}$ for each industry z, and perform the regressions given by Equations 26-28. The results for the two-factor case are reported in Figure 8 and Table 8. The North's market share rises strongly with the skill intensity of the industry. Each 1 percent increase in skill intensity is estimated to add almost 1 percent to the North's market share. The predicted shares vary from 46 percent to all of the market. This coefficient is precisely estimated, with a t-statistic of over 9. I check the robustness of this result using a non-parametric procedure that estimates the North's market share for a given skill intensity z_o as a weighted average of all market shares. The weights are much greater for observations

[24] 120 countries when raw materials are included.

[25] These last two assumptions are, of course, very strong.

that have a skill intensity close to z_o.[26] The results are similar except for a few industries that use extreme factor proportions. Predicted market shares range from a low of 55 percent to a high of 88 percent. For most observations, the linear regression line is close to the non-parametric estimate.

In Table 8 I report the regression results for the 3 and 4-factor models. The results are again strong. The estimated coefficient on skill increases in magnitude and maintains its statistical significance, the North's market share increases by almost 2 percent for every 1 percent increase in skill intensity. The effect of capital is smaller, but is reasonably precisely estimated with t-statistics of about 5. Each 1 percent increase in capital intensity adds 0.5 per cent to the North's market share. The North's predicted shares range from 45 percent to all of the market.

C. Individual Country Results

The model performs well for the aggregate North and therefore for the aggregate South. To ensure that the result is not just driven by a few large trading partners I examine whether the effect is systematic across individual countries. I firstly rescale the equations to account for countries being of different sizes. The purpose of this rescaling is so that the coefficients α_c, α_{1c}, α_{2c} and α_{3c} should be comparable across countries regardless of country size. I define V_{cz} as $\widetilde{v}_{cz}$ divided by the average value of $\widetilde{v}_{cz}$ for country c.[27] Equations 29 and 30 are estimated for each country:

$$V_{cz} = \alpha_c + \alpha_{1c} z_3 + \alpha_{2c} k_3 + \varepsilon_{cz} \tag{29}$$

$$V_{cz} = \alpha_c + \alpha_{1c} z_4 + \alpha_{2c} k_4 + \alpha_{3c} m_4 + \varepsilon_{cz} \tag{30}$$

The results for the 123 countries in the sample are summarized in Figures 9 to 12. In Figure 9 I plot the estimated coefficients on skill intensity z_3 against the human-capital to labor ratio, a proxy for the abundance of skilled labor. The size of each country's label is inversely proportional to the standard errors of the coefficient estimate. The estimates are strongly related to skill abundance. Countries with high levels of human capital tend to export skill intensive goods, while countries with low levels export goods that more sparingly use skilled labor. Many of these coefficients are also very large. The equivalent standardized coefficient for the aggregate North

[26] I estimate the North's share for an industry with skill intensity z_o by

$\widehat{v}_{z_o} = \frac{\sum_Z w_{z_o} \widetilde{v}_{nz}}{\sum_Z w_{z_o}}$, where $w_{z_o} = \exp\left(-15\left|z - z_o\right|\right)$.

[27] A log-transformation can not be used because many of the import shares are 0. If a large country is simply the sum of smaller countries then the coefficients will be invariant to country size after the rescaling. If there really are border effects then large countries will be more diversified, reducing the absolute value of α_{1c}, α_{2c} and α_{3c}.

is 3. The results are similar in Figure 10 when raw materials have been included in the analysis.

The equivalent results for capital reported in Figures 11 and 12 are not as strong. Coefficients tend to be smaller and less precisely estimated. The 123 coefficients are barely correlated with per capita GDP, although the more precisely estimated coefficients are positively correlated. When raw materials are included the results improve. This improvement is likely due to a reduction in the bias generated by simply transformed raw materials being classified as capital intensive manufacturing in the 3-factor model. Coefficients tend to be more precisely estimated, and are positively correlated with capital abundance. This provides stronger evidence that capital abundant countries do export capital intensive products, and capital scarce countries export commodities that require little capital in their production. These results are more thoroughly explored next by pooling the data.

D. The Pooled Regression

The three-way relationship between trade shares, factor intensity and factor abundance can be explored more systematically by pooling the data. The model predicts that α_{1c}, α_{2c} and α_{3c} are positive for countries that are relatively abundant in skilled labor, capital and raw materials respectively, and negative for countries where these factors are scarce. The theory provides no closed form solution relating α_{1c}, α_{2c} and α_{3c} to factor abundance. I model these coefficients according to Equations 31 to 33. This results in the pooled regressions in Equations 34 and 35. The variables $skill_c$, $capital_c$ and raw_c are abundance measures for skilled labor, capital and raw materials in country c. Countries that are scarce in a factor will capture a large share of industries that use that factor sparingly: this implies $\beta_1, \beta_3, \beta_5 < 0$. Countries that are abundant in a factor should capture a large share of industries that use that factor intensively, implying $\beta_2, \beta_4, \beta_6 > 0$.

$$\alpha_{1c} = \beta_1 + \beta_2 skill_c \tag{31}$$

$$\alpha_{2c} = \beta_3 + \beta_4 capital_c \tag{32}$$

$$\alpha_{3c} = \beta_5 + \beta_6 raw_c \tag{33}$$

$$V_{cz} = \alpha_c + (\beta_1 + \beta_2 skill_c)\, z_3 + (\beta_3 + \beta_4 capital_c)\, k_3 + \varepsilon_{cz} \tag{34}$$

$$V_{cz} = \alpha_c + (\beta_1 + \beta_2 skill_c)\, z_4 + (\beta_3 + \beta_4 capital_c)\, k_4 + (\beta_5 + \beta_6 raw_c)\, m_4 + \varepsilon_{cz} \tag{35}$$

Equations 34 and 35 are estimated by weighted least squares.[28] I measure skill abundance $skill_c$ with the education based measure of human capital taken from Hall and Jones (1999). I measure capital abundance $capital_c$ with the capital-labor ratio from Hall and Jones. For comparison I also proxy skill and capital abundance with relative per capita GDP. The results are reported in Table 9. The results for skilled labor are strong. The exports of countries with low levels of human capital are extremely tilted towards goods that embody little skilled labor, with the reverse being true for countries with abundant skilled labor. The same effect is present for capital, but is weaker. The estimated effect of capital increases after accounting for raw materials, as expected, but capital abundance appears to be less important than skill abundance in determining the pattern of specialization.

4 The Quasi-Rybczynski Prediction

A. The Miracle Economies

The Rybczynski prediction of the model is that if a country accumulates a factor more rapidly than does the rest of the world, then that country's production and exports will systematically shift towards industries that more intensively use that factor. Consider the model when M is large and one of the countries makes the leap from the South to the North. The world equilibrium is scarcely upset because each country is small relative to the world. Essentially this country moves from a Southern pattern of production and trade to a Northern one, while the rest of the world carries on as before. The existence of a number of growth "miracles" that have joined the ranks of wealthy industrial economies with high levels of physical and human capital provides an opportunity to examine this quasi-Rybczynski effect. Ventura (1997) noted that the Rybczynski effect is a critical feature of the growth experience of the miracle economies. In a closed economy, rapid accumulation of physical and human capital could lead to falling factor prices. Small open economies can avoid this by shifting production to more skill and capital intensive industries and exporting the output. If M is large in this model, factor accumulation in one country has little effect on factor prices either locally or globally. The Rybczynski effect lets small countries beat diminishing returns.

There are 7 economies that made the cut-off for the North in 1998 that were not present in 1960: Japan, Singapore, Hong Kong, Taiwan, Israel, Spain and Ireland. Their substantial growth in real income relative to the US is shown in Table 10. I add Korea to Table 10 because of its extremely rapid growth since 1970. I perform the regression defined in Equation 26 for each country using data for 1960, 1972, 1980, 1990 and 1998.[29] The results summarized in Table 11 are suggestive of the

[28]The variance of V_{cz} is larger for countries that have less diversified exports. These countries typically have smaller trade volumes. Because the data underlying V_{cz} are market shares, there is some dependence between the observations that WLS does not acount for.

[29]Data for 1972 onwards is electronically available, therefore I use 1972 rather than 1970 data.

quasi-Rybczynski effect. In 1960 and 1972, market shares for these countries tend to be negatively related to skill and capital intensity. As these countries have grown the coefficients on skill and capital intensity have increased, so that by 1998 the picture has changed a lot. Positive relationships are more common. The only significant negative coefficients are for two of the poorer countries in the sample, Korea and Taiwan, and even there the change in the size of the coefficients makes it clear that production is moving towards more skill and capital intensive goods. These countries, once firmly rooted in the South, are developing Northern patterns of production and trade.

The Rybczynski effect can be represented graphically using the same nonparametric technique used in Figure 8. Some of the most pronounced changes in export structure occurred in two groups of countries that experienced unprecedented growth rates substantially attributable to rapid accumulation of human and physical capital: Japan and the four 'miracle' economies of Singapore, Hong Kong, Taiwan and Korea.[30] Between 1960 and 1998 Japan's income levels went from 54 per cent of Western-European levels to 114 per cent, with equality occurring in 1981. The four miracle economies moved from 21 per cent of European income levels in 1960 to 72 percent in 1998. The Rybczynski prediction would be a convergence in the production and trade structures of these economies towards European patterns. The prediction is supported by the data. Figures 13 to 15 show the trade structure of the four miracle economies, Japan and Western Europe in 1960, 1980 and 1998. Convergence is apparent. In 1960 the trade of the then poor miracle economies was concentrated in goods that used little skilled labor, while Europe captured larger market shares for skilled goods. Japan, with an intermediate income level, had a production structure neatly between the two. As the relative income levels of the economies converged, so too did their production structures. Japan's looks almost the same as Europe by 1980, the same time as income levels converged. The miracle economies appear to be systematically approaching Europe in terms of both income and trade structure, although as a group they still have some way to go. The results for physical capital are less pronounced, consistent with Table 11. Japan's exports actually appear to be less capital intensive now than in 1960.

B. The Pooled Rybczynski Regression

To more formally 'test' for the Rybczynski effect I estimate Equation 34 in differences:

$$\Delta V_{cz} = \Delta\alpha_c + (\Delta\beta_1 + \beta_2 \Delta skill_c)\, z_3 + (\Delta\beta_3 + \beta_4 \Delta capital_c)\, k_3 + \Delta\varepsilon_{cz} \qquad (36)$$

The Rybczynski prediction implies that $\beta_2, \beta_4 > 0$; countries that have accumulated skilled labor and physical capital faster than the rest of the world will see their

[30] For analysis of the growth experience of the Asian miracles, see Young (1992, 1993), Lucas (1993), and Krugman (1994).

production and trade move towards skill and capital intensive industries. The parameters $\Delta\beta_1$ and $\Delta\beta_3$ may not be zero because US factor proportions may have moved relative to the rest of the world and because the changes in factor abundance $\Delta skill_c$ and $\Delta capital_c$ are measured relative to the US. To maximize the number of comparable industries, I calculate ΔV_{cz}, $\Delta skill_c$ and $\Delta capital_c$ using a start date of 1972 rather than 1960. The end date is 1998. For $\Delta skill_c$ I use two education based measures from Barro and Lee (2000). One is the change in average years of college education between 1970 and 1995, and the other is the change in average total years of education for the same period. For $\Delta capital_c$ I use investment based measures of the capital-labor ratio from the Penn World Tables in 1972 and 1992. For comparison, I also use the more widely available change in relative GDP per capita as a proxy for both $\Delta skill_c$ and $\Delta capital_c$.[31]

The sample consists of 317 industries, with 49 countries when factor data is used to estimate factor accumulation, and 103 countries when income data is used as a proxy for factor accumulation. The results are reported in columns 1 to 3 of Table 12. The results for capital suggest that countries that rapidly accumulate capital move towards more capital intensive industries. The education based variables are insignificant. The human capital measures may not work well because years of formal education take no account of education quality, and because formal education accounts for only a fraction of human capital development.[32] Krueger and Lindahl (2000) suggest that measurement error in first-differenced cross-country education data is extreme. This would bias downwards the estimated coefficients. Table 13 is suggestive of this explanation. Changes in education levels are barely correlated with per capita income growth. It is hard to believe that human capital accumulation is truly uncorrelated with growth. The quality of education can to some extent be controlled for by the inclusion of scores from standardized tests administered internationally.[33] The problem is that the sample contracts greatly to 25 countries, mostly wealthy. When test scores are added to the regression in columns 4 and 5 of Table 12, the coefficients on human capital accumulation remain insignificant. Interestingly, the education quality measure itself is a significant explanator of the change in production structure. Countries that perform highly on international test scores have moved towards more skill intensive industries. Students in Japan and the Asian miracle economies perform best in these tests.

Columns 6 to 9 of Table 12 report results when education quality is controlled for using Hanushek and Kimko's (2000) estimates of education quality. This quality measure is based on test scores, resources available to schools and various socio-economic characteristics of each country's population, and is available for a larger

[31] This of course ignores any role for technological explanations of cross-country growth differences, and makes strong assumptions about how factors are accumulated.

[32] See, for example, Lucas (1993) and Barro and Lee (2000).

[33] The data on international tests of students in mathematics and science are contained in Barro and Lee (2000). I sum the two scores and divide the sum by its mean of 1000.

and more diverse group of countries. Controlling for this measure of education quality gives stronger results. In particular, there are significant positive coefficients on the average years of schooling variables, though not on the college graduate variables. This provides some evidence that countries that have upgraded the relative education levels of their workforces shift production and exports towards more skill intensive industries.

The income based measures are large and highly significant for both skill and capital intensity. Fast growing countries see their trade move towards skill and capital intensive industries. The coefficients β_2 and β_4 should be the same size as in the levels regression on Equation 34. The skill coefficient is the same size, but the capital coefficient is now noticeably larger. One possible explanation for the increase in the capital coefficient is that there is an omitted factor that is partly controlled for by the differencing employed in the Rybczynski regression.

5 Conclusion

The aim of this paper is to derive and examine predictions of the factor proportions model in commodity markets. All that is required to make these predictions are two reasonable modifications of the traditional Heckscher-Ohlin model. I introduce transport costs and monopolistic competition. This produces two main predictions. There is a quasi-Heckscher-Ohlin effect and a quasi-Rybczynski effect. Both of these predictions can be examined using detailed and high quality import data for just one country. The Heckscher-Ohlin prediction finds strong support in that data. The role of skill abundance appears to be especially pronounced. There is also support for the Rybczynski effect for fast-growing countries. Factor proportions appear to be an important determinant of the structure of production and international trade.

Appendix A: Data

Factor Abundance: The Heckscher-Ohlin regressions in Tables 8 and 9 use Human-Capital-to-Labor ratios and Capital-to-Labor ratios from Hall and Jones (1999). This data is available for 123 countries for the year 1988. Raw material abundance is estimated by total land area divided by the total labor force in 1998 sourced from the World Bank World Development Indicators 2000 CD-ROM. All measures of abundance are relative to the US.

The 1972 to 1998 Rybczynski regressions in Table 12 use Barro and Lee (2000) data for average total years of education and average years of college education for the population aged 15 to 65. For each country I calculate the average years of total education and college education relative to US levels. I then use the growth of these measures between 1970 and 1995 as my estimates of the change in relative skill abundance. The data on international tests of students in mathematics and science are from Barro and Lee (2000). I sum the two scores and divide the sum by its mean of 1000. Change in capital to labor ratios relative to the US are calculated using Penn World Tables 5.6 data for non-residential capital per worker (KAPW) for 1972 and 1992. For Botswana, Jamaica, Korea, Sri Lanka and Swaziland the latest observations on KAPW are 1990, while for Argentina and Portugal the latest observations are for 1991.

Factor Intensity: Factor intensity estimates are fully described in Section 3A of the text.

GDP Per Capita at PPP: World Bank World Development Indicators CD-ROM for 1998. Penn World Tables 5.6 for earlier years (pwt.econ.upenn.edu).

Imports: Trade data for the USA comes from the USA Trade CD-ROM for 1998; from Robert Feenstra's NBER Trade Database for 1972, 1980 and 1990; and from the United Nations Commodity Trade Statistics for 1960. The Feenstra database is already mapped into SIC classifications. The 1998 data is mapped from HS into SIC classifications using a concordance maintained by Jon Haveman (www.haveman.org). The 1960 data is mapped from SITC R1 to SIC using a concordance adapted from the SITC R2 to SIC concordance maintained by Jon Haveman. Only manufacturing industries are used (SIC codes 2000 to 3999).

Appendix B: Full Employment Conditions in the Three Factor Model

Equations 37 to 42 are the full employment conditions for the three factor model. The equations are respectively for: skilled labor in the North; capital in the North; unskilled labor in the North; skilled labor in the South; capital in the South, and unskilled labor in the South. The wages of unskilled labor in the South have been normalized to 1. The left side of each equation gives factor demand, while the right gives factor supply.

$$\int_0^1 \int_0^{1-z} \frac{1}{s} z b(kz) W v(kz) dk dz = \beta. \tag{37}$$

$$\int_0^1 \int_0^{1-z} \frac{1}{r} k b(kz) W v(kz) dk dz = \gamma. \tag{38}$$

$$\int_0^1 \int_0^{1-z} \frac{1}{w} (1-z-k) b(kz) W v(kz) dk dz = 1 - \beta - \gamma. \tag{39}$$

$$\int_0^1 \int_0^{1-z} \frac{1}{s^*} z b(kz) W \left(\frac{1}{M} - v(kz) \right) dk dz = \beta^*. \tag{40}$$

$$\int_0^1 \int_0^{1-z} \frac{1}{r^*} k b(kz) W \left(\frac{1}{M} - v(kz) \right) dk dz = \gamma^*. \tag{41}$$

$$\int_0^1 \int_0^{1-z} (1-z-k) b(kz) W \left(\frac{1}{M} - v(kz) \right) dk dz = 1 - \beta^* - \gamma^*. \tag{42}$$

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Table 1: Industries with Extreme Factor Intensities

10 Most Skill Intensive Industries		**10 Most Capital Intensive Industries**		**10 Most Unskilled Labor Intensive Industries**	
3764	Space propulsion units and parts	2111	Cigarettes	3321	Gray iron founderies
3826	Analytical instruments	2087	Flavoring extracts and syrups	3543	Industrial patterns
3769	Space vehicle equipment nec	2043	Cereal breakfast foods	2299	Textile goods nec
3812	Search and navigation equipment	2046	Wet corn milling	2397	Schiffli machine embroideries
3547	Rolling mill machinery	2047	Dog and cat food	3149	Footwear, except rubber, nec
2711	Newspapers	2879	Agricultural chemicals nec	3151	Leather gloves and mittens
3721	Aircraft	2095	Roasted coffee	2517	Wood TV and radio cabinets
3699	Electrical equipment and supplies nec	2085	Distilled liquor, except brandy	2393	Textile bags
3827	Optical instruments and lenses	2834	Pharmaceutical preparations	3544	Special dyes, tools, jigs and fixtures
3541	Machine tools, metal cutting types	2813	Industrial gases	3731	Ship building and repairing
10 Least Skill Intensive Industries		**10 Least Capital Intensive Industries**		**10 Least Unskilled Labor Intensive Industries**	
2111	Cigarettes	2299	Textile goods nec	2087	Flavoring extracts and syrups
2043	Cereal breakfast foods	3534	Elevators and moving stairways	2111	Cigarettes
2087	Flavoring extracts and syrups	3321	Gray iron foundries	2721	Periodicals
2032	Canned specialties	3543	Industrial patterns	2731	Book publishing
2047	Dog and cat food	3547	Rolling mill machinery	2834	Pharmaceutical preparations
2322	Men's and Boy's underwear	3731	Ship building and repairing	2879	Agricultural chemicals nec
2284	Thread mills	3542	Machine tools, metal forming types	2813	Industrial gases
2035	Pickles, sauces and salad dressings	3544	Special dyes, tools, jigs and fixtures	2046	Wet corn milling
2676	Sanitary paper products	2397	Schiffli machine embroideries	2095	Roasted coffee
2085	Distilled liquor, except brandy	3671	Electronic computers	3571	Electronic computers

Table 2: Factor Intensity Summary Statistics

	Mean	Std. Dev.	Min	Max
z_2	0.29	0.12	0.08	0.83
z_3	0.14	0.07	0.02	0.39
z_4	0.13	0.07	0.01	0.39
u_2	0.71	0.12	0.17	0.92
u_3	0.34	0.12	0.05	0.63
u_4	0.32	0.13	0.02	0.62
k_3	0.52	0.14	0.19	0.93
k_4	0.47	0.14	0.09	0.87
m_4	0.08	0.17	0.00	0.86

Table 3: Correlation and Variance of Factor Intensities

	z_2	z_3	k_3	u_3	z_4	k_4	u_4	m_4
z_2	0.015							
z_3	0.723	0.005						
k_3	0.115	-0.555	0.019					
u_3	-0.579	0.057	-0.862	0.014				
z_4	0.685	0.976	-0.567	0.086	0.006			
k_4	0.187	-0.301	0.669	-0.620	-0.175	0.020		
u_4	-0.434	0.163	-0.840	0.909	0.259	-0.351	0.016	
m_4	-0.134	-0.303	0.321	-0.200	-0.484	-0.474	-0.559	0.030

Table 4: Summary Statistics for Factor Abundance

Variable	Mean	Std. Dev.	Min	Max
H/L	0.567	0.168	0.325	1.017
K/L	0.286	0.323	0.004	1.236
GDPPC	0.272	0.280	0.015	1.132
LAND/L	1.841	3.195	0.004	18.20

Table 5: Correlation and Variance of Factor Abundance

	H/L	K/L	GDPPC	LAND/L
H/L	0.028			
K/L	0.799	0.105		
GDPPC	0.807	0.917	0.078	
LAND/L	-0.054	0.058	-0.025	10.21

Table 6: North and South

North	South		
Australia[1]	Algeria[3]	Guatemala[2]	Papua New Guinea[4]
Austria[1]	Angola[3]	Guinea[3]	Paraguay[2]
Belgium[1]	Argentina[3]	Guinea Bissau[3]	Peru[2]
Canada[1]	Bangladesh[3]	Guyana[3]	Philippines[2]
Denmark[1]	Barbados[3]	Haiti[3]	Poland[4]
Finland[2]	Benin[3]	Honduras[2]	Portugal[1]
France[1]	Bolivia[2]	Hungary[4]	Romania[3]
Germany[1]	Botswana[4]	India[2]	Russia[4]
Hong Kong[1]	Brazil[3]	Indonesia[3]	Rwanda[3]
Iceland[1]	Burkina Faso[3]	Ivory Coast[3]	Saudi Arabia[3]
Ireland[1]	Burundi[3]	Jamaica[3]	Senegal[3]
Israel[1]	Cameroon[3]	Jordan[3]	Seychelles[3]
Italy[1]	Cape Verde[4]	Kenya[2]	Sierra Leone[4]
Japan[1]	Central African Republic[3]	Korea[1]	Slovakia[4]
Luxembourg[4]	Chad[3]	Lesotho[4]	Somalia[4]
Netherlands[1]	Chile[3]	Madagascar[3]	South Africa[3]
New Zealand[1]	China[2]	Malawi[2]	Sri Lanka[3]
Norway[1]	Colombia[1]	Malaysia[3]	Sudan[4]
Singapore[3]	Comoros[4]	Mali[3]	Surinam[3]
Spain[1]	Congo, Democratic Republic[3]	Malta[3]	Swaziland[4]
Sweden[1]	Congo, Republic[3]	Mauritania[3]	Syria[2]
Switzerland[1]	Costa Rica[3]	Mauritius[2]	Tanzania[3]
Taiwan[1]	Cyprus[3]	Mexico[2]	Thailand[1]
United Kingdom[1]	Czech Republic[4]	Morocco[3]	Togo[3]
	Dominican Republic[2]	Mozambique[3]	Trinidad and Tobago[3]
	Ecuador[2]	Myanmar[3]	Tunisia[3]
	Egypt[3]	Namibia[4]	Turkey[2]
	El Salvador[3]	Nicaragua[3]	Uganda[3]
	Fiji[3]	Niger[3]	Uruguay[3]
	Gabon[3]	Nigeria[3]	Venezuela[2]
	Gambia[4]	Oman[4]	Yemen[4]
	Ghana[3]	Pakistan[3]	Zambia[2]
	Greece[1]	Panama[2]	Zimbabwe[2]

Notes: [1] denotes countries that are included in all Rybczynski regressions.
[2] denotes countries with factor data for Rybczynski regressions but no test scores.
[3] denotes countries with per capita GDP data only for Rybczynski regressions.
[4] denotes countries that are not included in any Rybczynski regression.

Table 7: Characteristics of North and South

	H/L	K/L	GDPPC	LAND/L
North	0.79	0.83	0.75	1.74
South	0.51	0.15	0.15	1.75

Table 8: Regression for the Aggregate North

(Dependent Variable: v_{nz})

	2 Factors	3 Factors	4 Factors
Constant	0.39***	0.12	0.05
	(0.04)	(0.08)	(0.08)
z_2	0.93***		
	(0.10)		
z_3		1.90***	
		(0.22)	
k_3		0.54***	
		(0.11)	
z_4			2.00***
			(0.22)
k_4			0.64***
			(0.11)
m_4			0.60***
			(0.12)
Observations	370	370	370
R^2	0.19	0.18	0.24

Note: robust standard errors in parentheses. ***,**,* denote significance at the 1,5,10 and percent level.

Table 9: Pooled Regression of Import Share on Factor Intensities

(Dependent Variable: V_{cz})

Variable	(1)	(2)	(3)	(4)
z	-16.66***	-9.52***	-16.72***	-7.74***
	(1.32)	(0.62)	(1.14)	(0.49)
Skill*z	23.26***		24.13***	
	(1.83)		(1.60)	
GDPPC*z		17.87***		15.46***
		(1.05)		(0.84)
k	-0.77***	-1.91***	-1.17***	-1.85***
	(0.26)	(0.31)	(0.24)	(0.27)
Capital*k	1.30***		2.22***	
	(0.37)		(0.35)	
GDPPC*k		3.66***		3.80***
		(0.53)		(0.45)
m			-17.26	-16.98
			(45.32)	(45.32)
Raw*m			0.38***	0.37***
			(0.04)	(0.03)
Country Dummies	Yes.	Yes.	Yes.	Yes.
Countries	124	123	120	120
Obs.	45,880	45,510	44,400	44,400

Note: standard errors in parentheses. ***,**,* denote significance at 1,5,10 percent level.

Table 10: Per Capita Real Income Relative to the US

	1960	1970	1980	1990	1998
Japan	0.30	0.56	0.66	0.79	0.79
Singapore	0.17	0.23	0.46	0.65	0.82
Hong Kong	0.23	0.35	0.57	0.82	0.70
Taiwan	0.13	0.17	0.29	0.45	0.54
Korea	0.09	0.11	0.20	0.37	0.46
Ireland	0.33	0.39	0.45	0.51	0.73
Spain	0.32	0.45	0.48	0.53	0.55
Israel	0.35	0.46	0.52	0.51	0.58

Table 11: Regression Coefficients of Market Share on Factor Intensities
(Dependent Variable: V_{cz})

Country	Factor	1960	1972	1980	1990	1998
Japan	Skill	-3.16	-1.62***	1.22*	3.10***	5.66***
		(3.78)	(0.57)	(0.71)	(0.78)	(0.95)
Japan	Capital	5.76*	-1.59***	-0.95***	-0.40	0.47
		(3.23)	(0.31)	(0.36)	(0.42)	(0.49)
Singapore	Skill	n.a.	3.04	-0.01	1.75	8.30***
			(4.94)	(2.11)	(2.48)	(2.42)
Singapore	Capital	n.a.	-1.48	-0.91	0.54	0.36
			(1.08)	(0.74)	(0.81)	(2.10)
Hong Kong	Skill	-6.88**	-6.64***	-5.77***	-5.68***	-2.54
		(2.76)	(1.63)	(1.24)	(1.52)	(1.92)
Hong Kong	Capital	-1.95*	-3.05***	-2.00***	-2.56***	-1.44
		(2.35)	(0.71)	(0.63)	(0.82)	(1.18)
Taiwan	Skill	-11.15***	-7.12***	-5.48***	-4.07***	-1.97**
		(2.91)	(1.70)	(0.82)	(0.70)	(0.85)
Taiwan	Capital	-6.18**	-3.71**	-3.07***	-3.12***	-2.54***
		(2.49)	(0.74)	(0.47)	(0.45)	(0.54)
Israel	Skill	-11.76***	-2.06	0.61	4.25***	7.46***
		(2.67)	(1.75)	(4.25)	(1.61)	(2.66)
Israel	Capital	-5.35**	-0.31	-1.50	0.03	1.41
		(2.28)	(0.76)	(1.82)	(0.65)	(0.96)
Ireland	Skill	-14.84***	1.35	-0.39	3.04***	4.80***
		(2.23)	(2.87)	(1.97)	(1.15)	(1.39)
Ireland	Capital	-3.29**	3.06	5.70*	6.25*	6.58**
		(1.48)	(2.15)	(2.95)	(3.41)	(3.07)
Spain	Skill	-5.71*	-3.35**	-1.23	-0.78	-1.2
		(3.35)	(1.48)	(1.56)	(1.69)	(1.60)
Spain	Capital	1.43	1.13	2.60*	1.24	0.62
		(2.24)	(0.92)	(1.33)	(0.81)	(0.92)
Korea	Skill	-14.91*	-10.53***	-6.70***	-5.39***	-3.52**
		(8.90)	(2.67)	(1.23)	(1.19)	(1.66)
Korea	Capital	-12.62*	-4.65***	-2.20***	-3.06***	-3.26**
		(7.61)	(1.10)	(0.63)	(0.56)	(1.49)
Average Skill Coefficient		-9.77	-3.37	-2.22	-0.47	2.12
Average Capital Coefficient		-3.17	-1.33	-0.29	-0.14	0.28
Number of Industries		151	376	376	366	370

Note: robust standard errors in parentheses. ***,**,* denote significance at 1,5,10 percent level.

Table 12: Pooled Rybczynski Regressions

(Dependent Variable: ΔV_{cz})

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
z	2.48***	2.37***	0.99**	-19.41**	-17.34**	-7.83***	-11.15***	-3.59	-4.44*
	(0.52)	(0.46)	(0.46)	(6.89)	(7.07)	(2.37)	(2.62)	(2.45)	(2.44)
ΔCollege*z	0.17			-0.73		-1.42		1.95	
	(3.43)			(3.51)		(3.45)		(3.50)	
ΔEducation*z		4.01			5.61		12.89***		7.11*
		(3.99)			(5.07)		(4.33)		(4.13)
TestScores*z				22.44***	20.21***				
				(6.91)	(7.07)				
EdnQual1*z						0.20***	0.26***		
						(0.05)	(0.05)		
EdnQual2*z								0.11**	0.12***
								(0.04)	(0.04)
ΔGDPPC*z			16.31***						
			(3.32)						
k	0.53**	0.53**	-0.05	0.77***	0.78***	0.49**	0.50**	0.47**	0.46*
	(0.24)	(0.24)	(0.23)	(0.26)	(0.26)	(0.24)	(0.24)	(0.24)	(0.24)
ΔCapital*k	1.35*	1.33*		1.68**	1.61**	1.70**	1.65**	1.82**	1.88***
	(0.70)	(0.70)		(0.78)	(0.77)	(0.71)	(0.70)	(0.73)	(0.73)
ΔGDPPC*k			6.70***						
			(1.62)						
Country Dummies	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.	Yes.
Countries	49	49	103	25	25	47	47	47	47
Obs.	15,533	15,533	32,651	7925	7925	14,899	14,899	14,899	14,899

Note: standard errors in parentheses. ***,**,* denote significance at 1,5,10 percent level.

Table 13: Correlation of Education and Capital Growth with GDP Growth

	Δrelgdppc7298	Δedn7095	Δcol7095	ΔK/L7292
Δedn7095	-0.01			
Δcol7095	0.13	0.24		
ΔK/L7292	0.33	-0.08	0.12	

Figure 1: Heckscher-Ohlin Effect for Germany and Bangladesh
Skill Intensity and US Import Shares in 1998

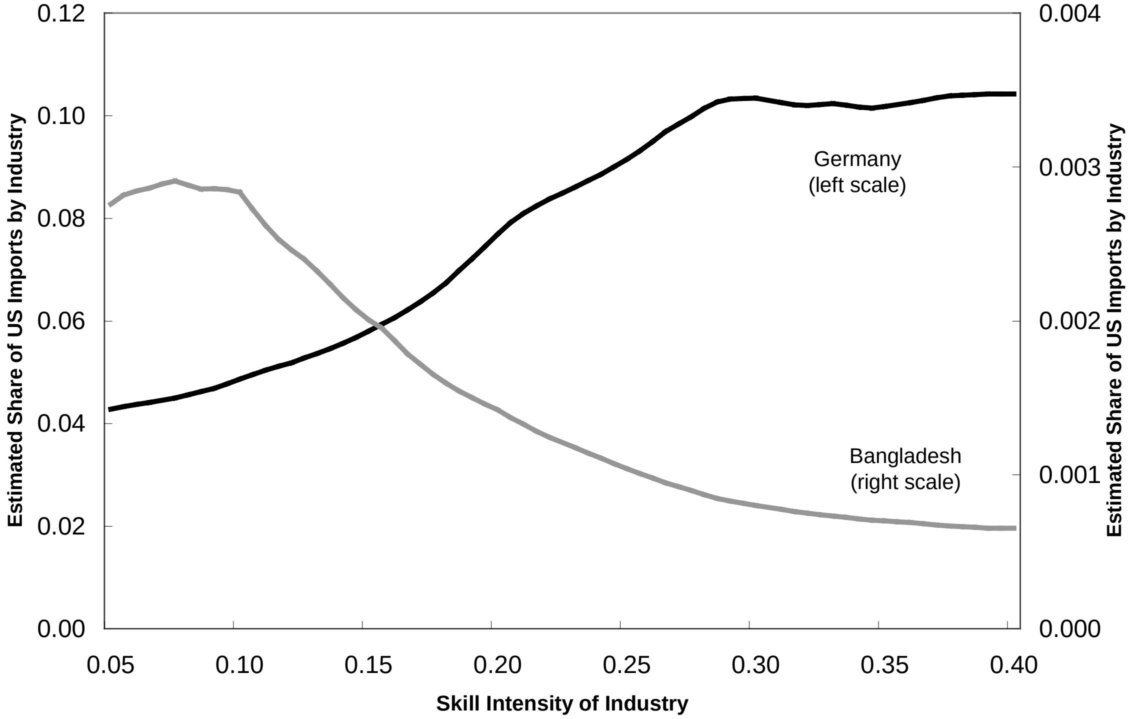


Figure 2: Rybczynski Effect for the Asian Miracle Economies*
Combined US Import Shares 1960-1998
(*Singapore, Hong Kong, Taiwan, Korea)

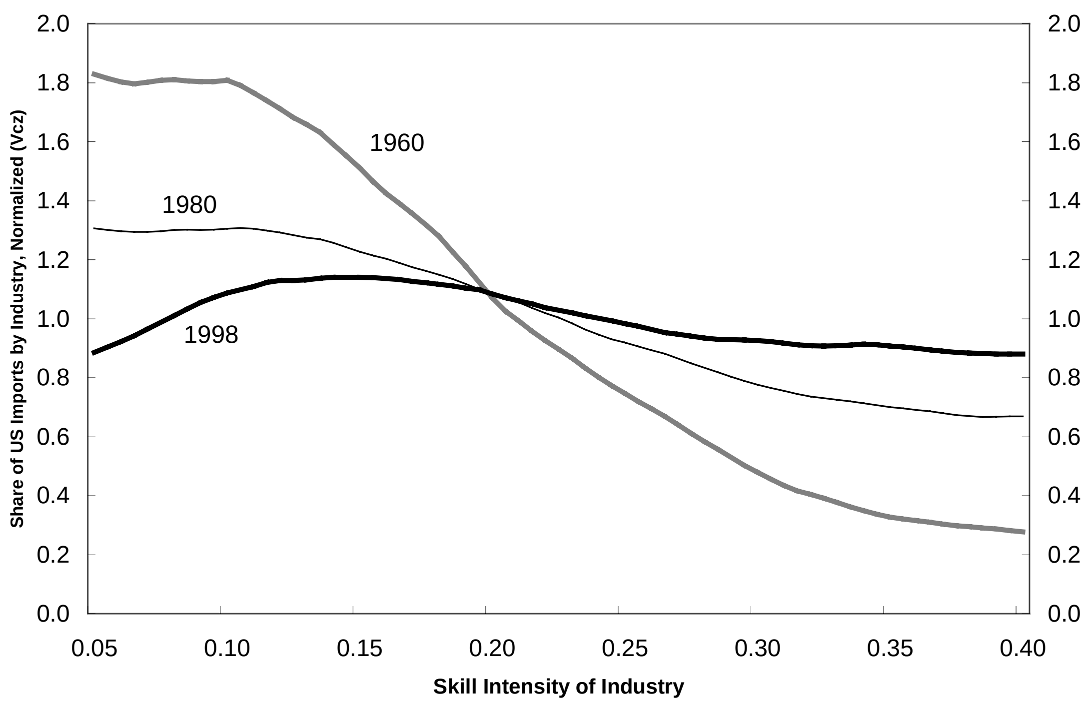


Figure 3: The Location of Production

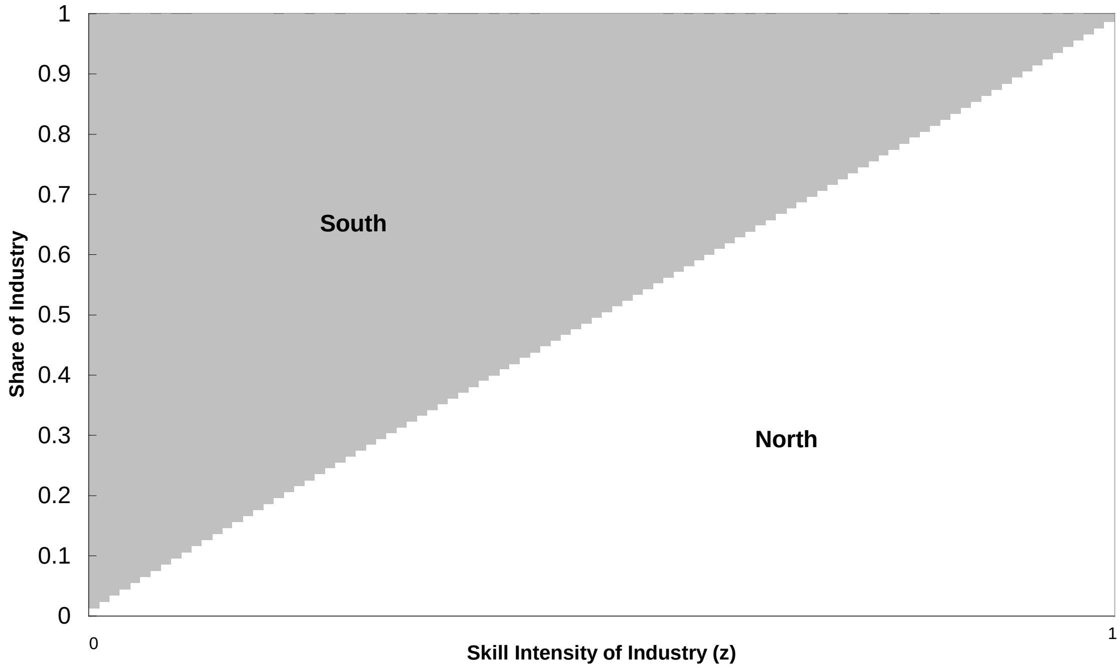


Figure 4: Location of Production in DFS Model With Transport Costs

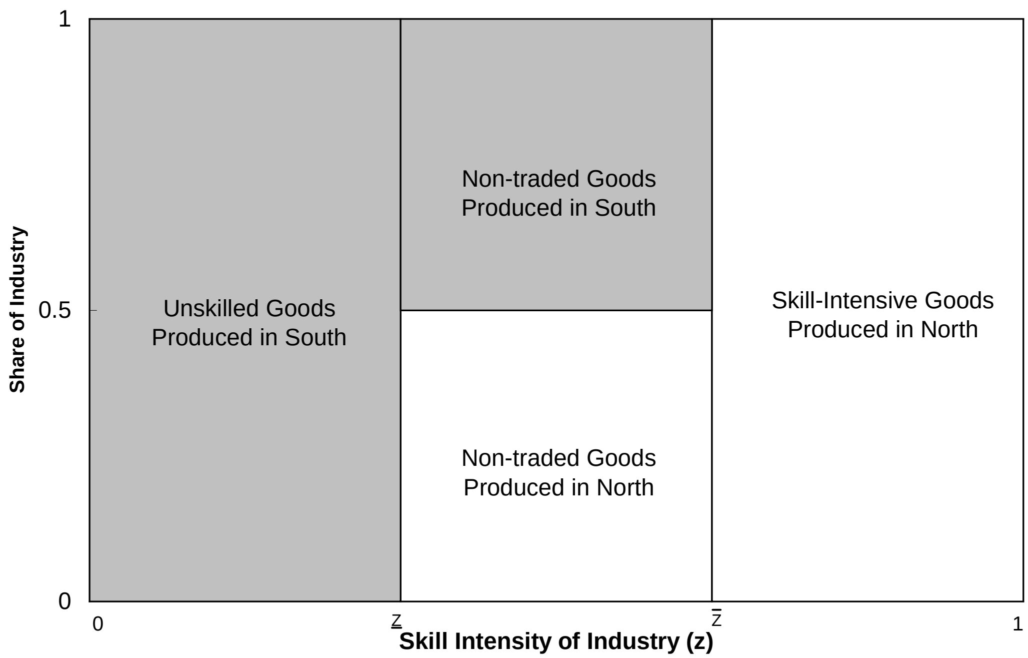


Figure 5: Effect of Transport Costs on the Location of Production

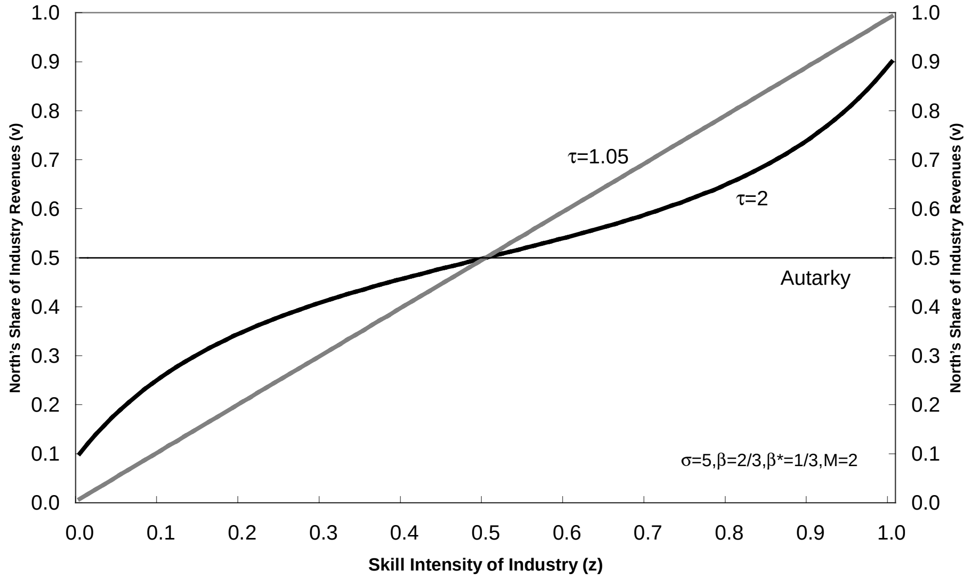


Figure 6: The Effect of σ on the Location of Production

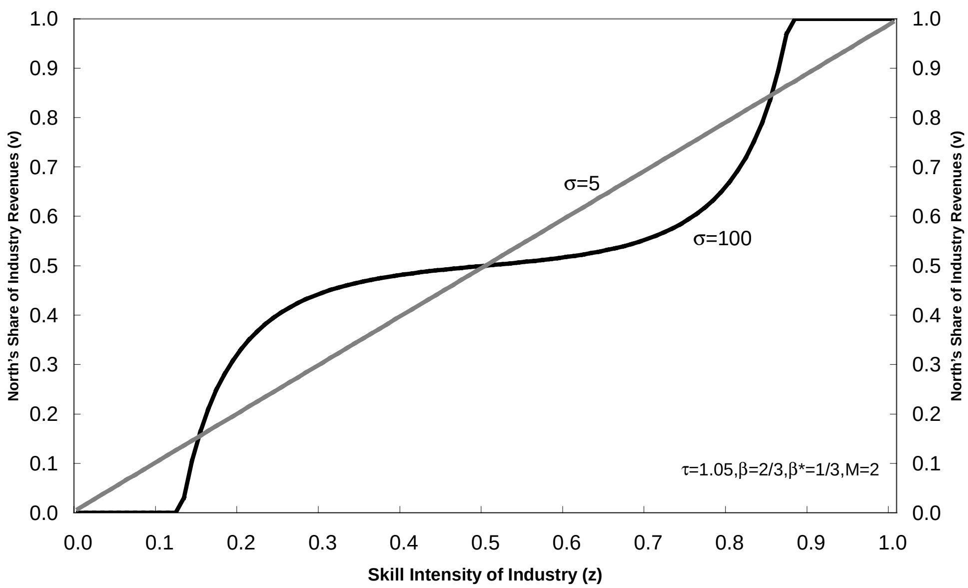


Figure 7: The Effect of Factor Abundance on the Location of Production

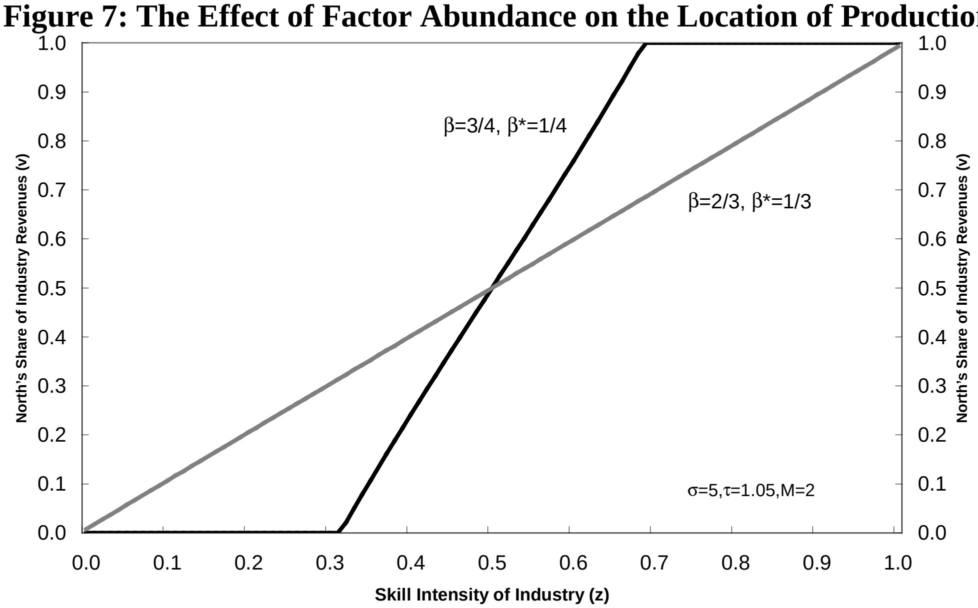
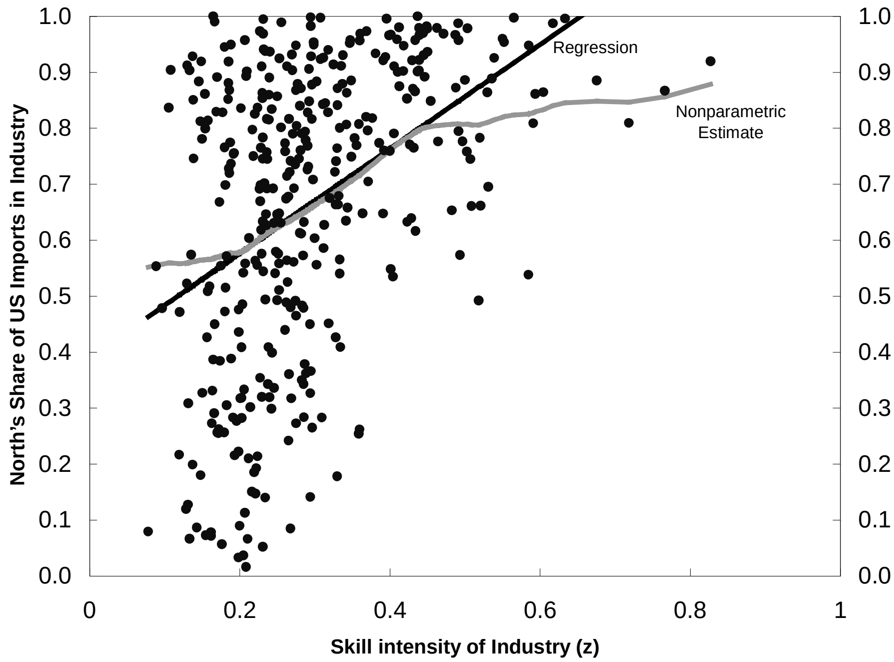


Figure 8: Factor Intensity and the North's Market Share



Figures 9 to 12: Coefficients from Regressions of Country's Share of US Imports by Industry (V_{cz}) on Factor Intensity of Industry

Figure 9: Skill Intensity; 3 Factor Model

WLS regression line: Coeff.= -19.75 + 27.89H/L
standard errors: (1.42) (1.97)

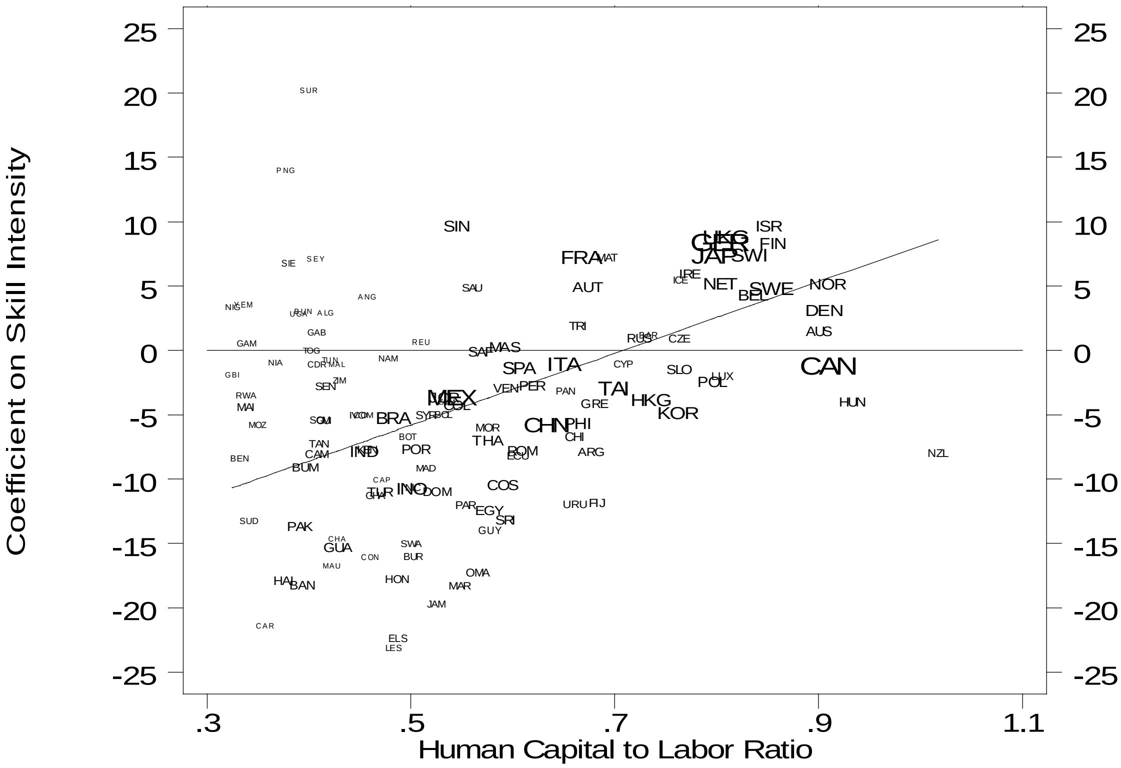


Figure 10: Skill Intensity; 4 Factor Model

WLS regression line: Coeff.= -19.55 + 27.66H/L
standard errors: (1.47) (2.04)

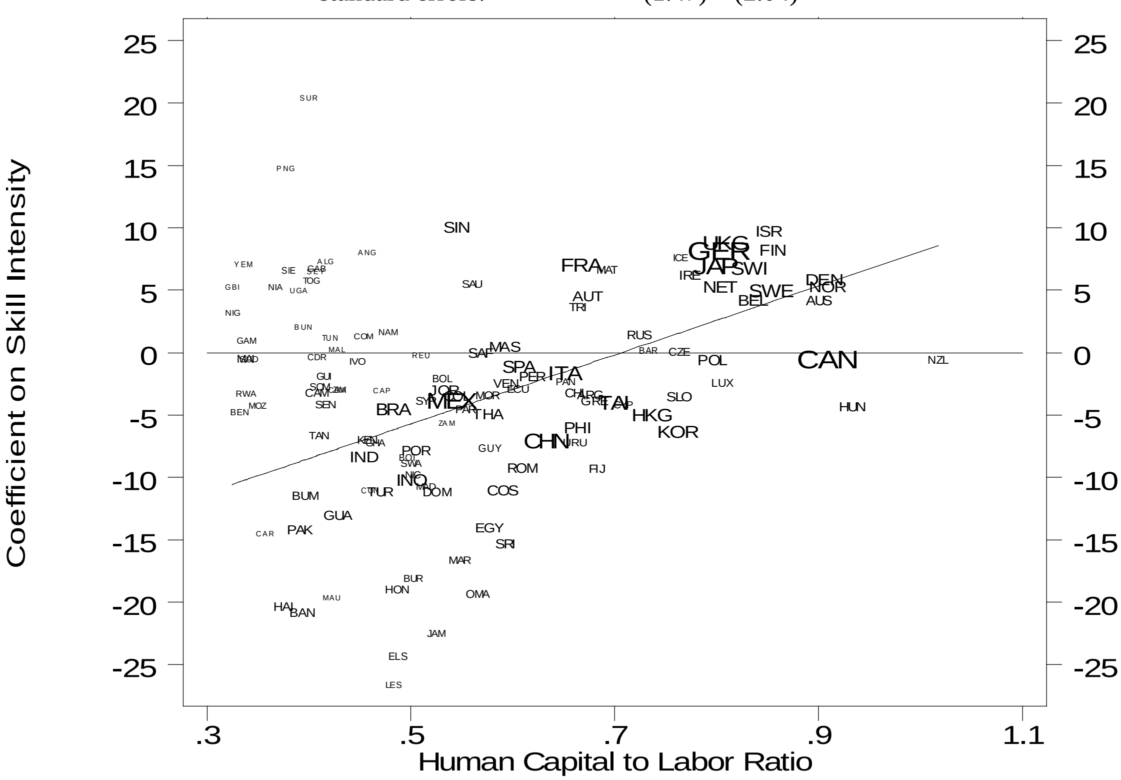


Figure 11: Capital Intensity, 3 Factor Model

WLS regression line: Coeff.= -1.77 + 3.07K/L

standard errors: (0.27) (0.40)

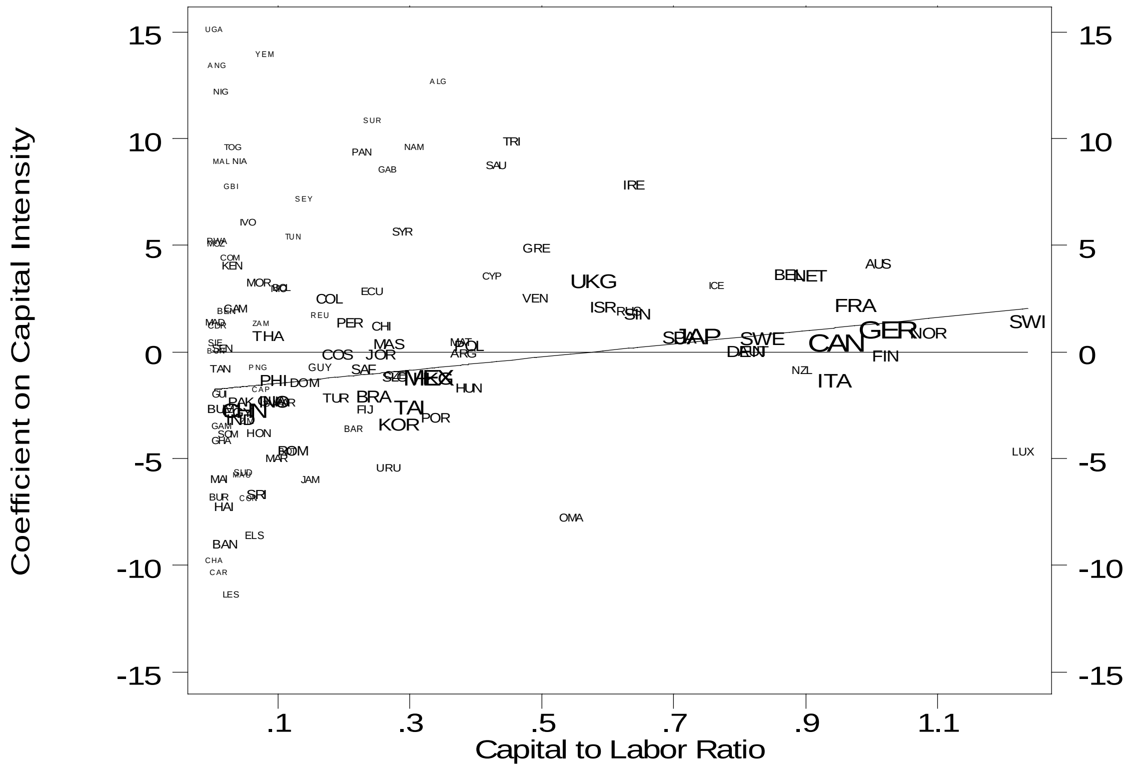


Figure 12: Capital Intensity, 4 Factor Model

WLS regression line: Coeff.= -2.30 + 3.80K/L

standard errors: (0.27) (0.40)

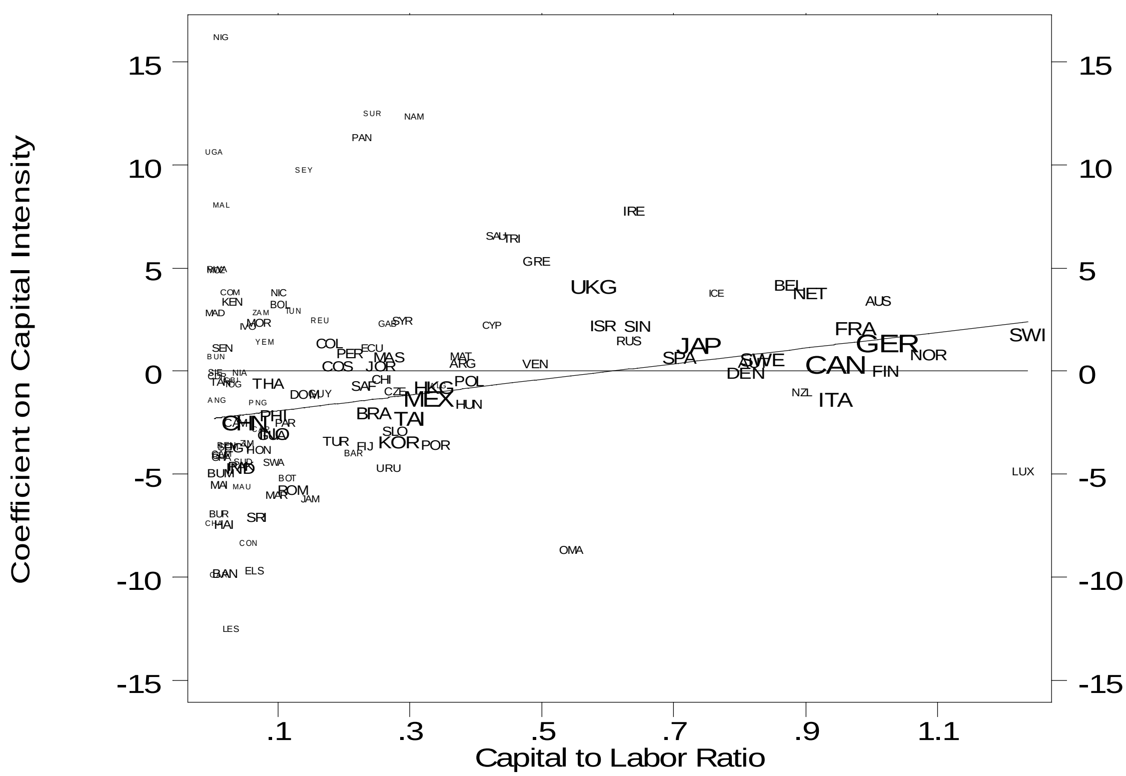


Figure 13: Skill Intensity and US Import Shares in 1960

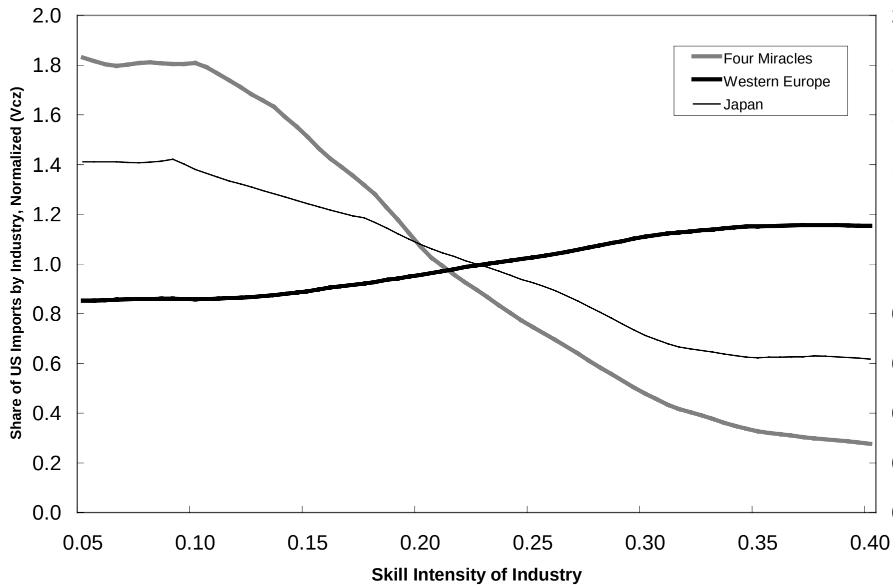


Figure 14: Skill Intensity and US Import Shares in 1980

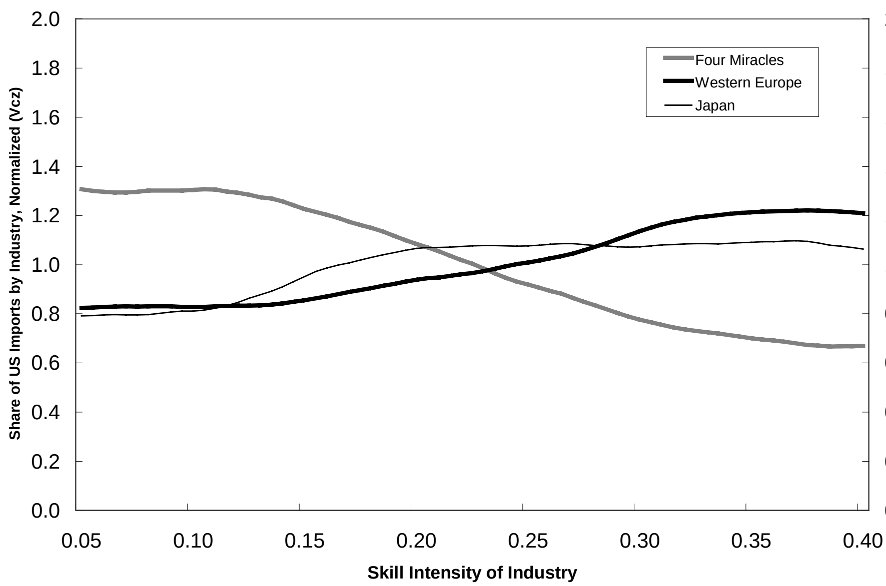


Figure 15: Skill Intensity and US Import Shares in 1998