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ONE SIZE FITS ALL?
HECKSCHER-OHLIN SPECIALIZATION IN GLOBAL PRODUCTION

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ABSTRACT

Many previous tests of Heckscher-Ohlin trade theory have found underwhelming support for the idea that countries' endowments determine their production and trade. This paper demonstrates that those efforts suffer from their focus on the narrower of the model's two potential equilibria, which assumes that all countries produce all goods. In this paper we introduce a more general technique for testing the model that allows for the possibility that countries with sufficiently disparate endowments specialize in unique subsets of goods. Results using this technique indicate strong support for Heckscher-Ohlin specialization versus one-size-fits-all homogeneity. Our results also demonstrate that the empirical evaluation of trade models has been hampered by the coarse aggregation of output inherent in existing datasets. Indeed, we show that traditional categorizations of goods hide a substantial degree of cross-country price and input intensity heterogeneity, violating the assumptions of the factor proportions framework and rendering previous estimation results difficult to interpret. To overcome this problem, we introduce a methodology for aggregating goods that corrects for underlying product variation. Estimation of the model using corrected aggregates reveals even stronger support for Heckscher-Ohlin specialization. The importance of specialization for the evolution of developed country wage inequality is also discussed.

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1 Issues

Existing attempts to find support for the idea that a country's endowments determine its production and trade have focused on the overly restrictive, "one size fits all" equilibrium of Heckscher-Ohlin trade theory.[1] That version of the model has all countries of the world producing all goods, so that both Japan and the Philippines, for example, are assumed to produce identical apparel and electronics goods. But a second, far richer equilibrium is possible within the framework. This equilibrium has countries specializing in the particular subset of goods most suited to their mix of endowments, so that relatively labor abundant Philippines might produce labor-intensive t-shirts and portable radios while capital abundant Japan manufactures capital-intensive semiconductors and chemicals. Ignoring such specialization undermines efforts to find support for the Heckscher-Ohlin model and clouds our thinking about the relationship between globalization and income inequality.

This paper introduces an empirical technique for testing the factor proportions framework that can differentiate the two versions of the model. This approach is more general than those employed in previous studies because it allows the effect of factor accumulation on a given sector's output to vary with a country's endowments. Apparel output, for example, might rise with capital accumulation in labor abundant developing countries like the Philippines, but fall with capital accumulation in relatively capital abundant countries like Japan. In this way, countries move in and out of sectors over time as their economies accumulate endowments. By estimating the capital per labor cutoffs where such changes in the derivative of output with respect to endowments take place, we can group countries according to product mix. Results indicate that in 1990 the world's countries can be neatly segregated into three such groups, each of which produces a unique mix of manufacturing aggregates.

A sensitivity to specialization highlights the inadequacies of existing categorizations of goods (e.g. the ISIC, SITC and SIC) for estimating trade theory. Under these schemes, aggregates like Food, Apparel and Machinery are formed by combining goods loosely according to end use. However, testing the key insight of trade theory – that the factor intensity of goods produced by a country be *similar* to that country's relative endowments – requires that we group together close substitutes that are manufactured

[1] Examples include the Heckscher-Ohlin estimations of Leamer (1984), Harrigan (1995), Trefler (1995) and Davis *et al* (1997), as well as the factor content study of Deardorff and Staiger (1988). Exceptions include: Brecher and Choudhri (1993), who relax the single cone assumption in estimating the implications of the model for production in the U.S. and Canada; Debaere and Demiroglu (1997), who exploit insights offered by Deardorff (1994) to demonstrate that observed country and sector capital labor ratios appear incompatible with the existence of a single cone of diversification; and Davis and Weinstein (1998), who allow technique to vary with country capital abundance. The latter is discussed in greater detail below.

with identical technology. Traditional aggregates can fail on both counts. The three-digit ISIC aggregate Electrical Machinery, for example, encompasses both portable radios assembled by hand and communications satellites. It seems reasonable to assume that countries will produce these goods at different stages in their development, and that they therefore should be grouped separately. Indeed, we present substantial evidence that three-digit ISIC manufacturing aggregates exhibit significant variation in both input intensity and price across countries. Interpreting both pieces of evidence as signals of underlying product mix heterogeneity, we introduce an empirical methodology designed to control for it. When the model is re-estimated using these corrected, "Heckscher-Ohlin" aggregates, support for the idea that output is a function of endowments – and that countries specialize – increases.

The emphasis in this paper on the production implications of the Heckscher-Ohlin model is most closely related to work by Harrigan (1995, 1997) and Bernstein and Weinstein (2000). Those studies, however, fail to allow for the possibility that coarse aggregation can obscure production patterns. Our focus on international specialization is complementary to recent research into the specialization of US regions by Hanson and Slaughter (2000) and Bernard, Jensen and Schott (2000). The latter, which relies upon much more detailed data than is available for a cross section of countries, shows that relative factor price disparity across US regions is at least partly responsible for heterogeneity in regional industry composition.

By putting specialization at center stage, this paper also illustrates how a failure to account for product mix heterogeneity has hampered efforts to verify the trade predictions of the Heckscher-Ohlin model and has perhaps lead to research over-emphasizing international technology differences as a cause. A principal conclusion of existing research is that observed trade flows are small relative to the disparity in countries' endowments (Maskus 1985; Bowen *et al* 1987; Trefler 1995; and Davis *et al* 1997). But this conclusion is based upon the joint assumption that every country produces all goods *and* that all countries employ the same technique for making them. Indeed, the US input-output matrix is often used as a proxy for these techniques. But if a labor abundant country like the Philippines produces labor-intensive electronics rather than the capital-intensive electronics upon which US techniques are based, both parts of this joint assumption are incorrect and the true labor embodied in Philippine trade will be underestimated. In this sense, we show that at least part of what Trefler (1995) has cogently dubbed the "Mystery of the Missing Trade" can be resolved by more careful consideration of specialization.

Of course, as Trefler and others have pointed out, technology can play a role in this mystery by leading us to over- or underestimate countries' factor endowments. If, for example, Philippine labor is less efficient than US labor, its efficiency-corrected labor abundance is less than its raw labor abundance and therefore closer to the "true" labor embodied in its trade. Our emphasis on specialization in this paper is not meant as an argument against a role for technology. Rather, it is to highlight an important part of the puzzle that has thus far largely been ignored.

Determining whether or not countries specialize has relevance beyond mechanical tests of trade models. It is a key factor, for example, in helping us understand current and future effects of globalization on developed country wages. If rich and poor countries export the same mix of goods in an open world economy, their workers compete directly. As a result, wage-price arbitrage mandates that a decline in the (world) price of labor-intensive goods – perhaps due to the reduction of trade barriers – forces rich country wages down if those sectors are to remain viable. However, to the extent that countries specialize, or are in the process of specializing, this price-wage link is weakened and may even be broken. Thus, if the US and other developed countries will soon abandon sectors also produced by developing countries, future price declines in these products may not have adverse consequences for unskilled workers in rich countries. Indeed, a recent study by Harrigan (1999) indicates that US prices were relatively unaffected by world price declines associated with the East Asian currency crisis.

The paper proceeds as follows: section 2 outlines the basics of the factor proportions framework and introduces the empirical specification designed to estimate it; section 3 tests the model on traditional ISIC aggregates, highlights the inadequacy of those aggregates and develops an alternate "Heckscher-Ohlin" aggregation scheme; section 4 re-estimates the model using the new aggregates; and section 5 concludes. To promote readability of the main text, detailed descriptions of the data and econometrics are reserved for two appendices.

2 Theory

2.1 The Two Factor Model

The core implication of the Heckscher-Ohlin framework is that countries produce a mix of goods most suitable to their relative factor endowments. This model assumes:

- *A1* Productive factors (e.g. capital, labor) are perfectly mobile from sector to sector within a country, but immobile internationally;
- *A2* Countries are small, open and possess perfectly competitive markets;
- *A3* Countries share identical, constant returns to scale technology.

The standard version of the model is known as a single cone equilibrium, the word cone referring to the set of endowment vectors that all select the same mix of products. In this version of the model, there is only a single mix of goods and all countries produce it.

With *A1* through *A3*, the mapping of endowments into output is a result of countries' maximizing GDP subject to the resource constraints:

$$Aq \leq v, \qquad 1$$

where A is the (FxI) inputs per unit of output technology matrix, q is the (Ix1) output vector, v is the (Fx1) endowment vector and F and I are the respective number of factors and sectors. If the number of factors equals the number of products (i.e. if A is square), and if there are no linear dependencies among the columns of A, then this system can be inverted to solve for output as a function of endowments, or

$$q = A^{-1}v, \qquad 2$$

where the elements of A^{-1} (known as the Rybczynski derivatives) relate the effect of factor accumulation on the output of each sector. In a two-good, two-factor world at constant commodity prices and within a given cone of diversification, these derivatives indicate that an increase in the supply of a factor leads to an increase in the output of the commodity that uses that factor intensively and a reduction in the output of the other commodity.[2]

In a world with more goods than factors, inspection of the GDP maximization problem indicates that countries may produce different subsets of goods (equal to the number of factors) depending upon endowments. In that case, the vector q in equation 1 contains a number of zeros equal to the number of non-produced goods, and the mix of goods with positive output changes as countries develop. Thus, with specialization, the vectors and matrix of equation 2 should be interpreted as containing only the rows and columns pertaining to produced goods. The allocation of production across sectors within a cone may be indeterminate if prices are such that more goods than factors are viable. This possibility of an *uneven* (i.e. more goods than factors) equilibrium is discussed further below.

Framing the a country's problem in terms of its dual (i.e. prices and wages), the (Fx1) vector of factor rewards (w) can be found by minimizing the cost of GDP ($w'v$) subject to the zero profit condition

$$A'w \leq p, \qquad 3$$

where p is the (Ix1) vector of world prices. The wages associated with each mix of products (i.e. each cone of diversification) are then

$$w = A'^{-1}p. \qquad 4$$

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[2] We can interpret q as value added if we recognize that the resulting Rybczynski coefficients are net of intermediate inputs (Davis and Weinstein 1998).

Note that within a cone of diversification, factor rewards do not respond to changes in endowments. This condition is often referred to as factor price equalization but has been more aptly labeled factor price insensitivity by Leamer (1995). Though partial equilibrium analysis suggests, for example, that an increase in the supply of labor reduces its reward, the general equilibrium formulation of the Heckscher-Ohlin framework has wages remaining constant within a cone due to concomitant shifts in output toward labor-intensive sectors. Thus, a world populated by countries with sufficiently dissimilar relative endowments may contain more than a single region of factor price insensitivity, thereby limiting or eliminating the tendency toward global factor price equalization. The empirical approach developed in this paper discerns these regions by identifying output specialization patterns in a cross-section of countries.

With an additional assumption about demand,

A4 All individuals share identical homothetic preferences,

the Heckscher-Ohlin-Vanek (1968) relationship between endowments and trade is

$$AN_c = v_c - s_c v_w , \qquad 5$$

where N_c is the $(I\text{x}1)$ vector of country *c's* net exports, s_c is country *c's* share of global output and v_w is the $(F\text{x}1)$ vector of world endowments. Within a two-country, two-good and two-factor framework, this relationship is captured in the Heckscher-Ohlin theorem: countries export the good employing intensively the relatively abundant factor and import the good using intensively the relatively scarce factor. In a world with more than a single region of factor price insensitivity, a country's mix of imports and exports changes, akin to production, as countries accumulate capital.

The traditional method of estimating standard trade theory is to examine the strength of the equality in equation 5 by using the US input output matrix as a proxy for *A*. One advantage of working with the production side of the model is that its message – that production depends upon factors – can be evaluated without any assumption about demand.

Figure 1, containing a Lerner (1952) diagram of a two factor, four sector world, illustrates the path of a small open economy accumulating capital relative to fixed labor. The four sectors, in order of increasing capital intensity, are Apparel, Textiles, Machinery and Chemicals. For simplicity of exposition and without loss of generality, each sector is displayed as having Leontief technology and factor intensity reversals are ruled out. As indicated in the figure, the four sectors' unit-value isoquants delineate three cones of diversification. An additional assumption (relaxed below) is incorporated in the figure:

A5 The world is "even" in the sense that there are an equal number of factors and goods in each cone.

Each cone represents all positive combinations of the input vectors of two of the four sectors. GDP-maximizing countries specialize by producing only the two goods anchoring the cone in which they reside: production of a good outside a country's cone results in negative profit. The capital-labor ratios marking the borders between cones are labeled τ_t for $t \in [0,3]$.

As capital is accumulated relative to labor, output in industry *i* and country *c* per total workforce (Q_{ic}/L_c) in each of the four sectors evolves as indicated in the four panels of figure 2 (Deardorff 1974; Leamer 1984).[3] Changes in the derivative of output with respect to endowments always occur at one of the four capital-labor ratios delineating cones. Note that development paths can contain "flat spots" where country *c* does not produce industry *i* and the derivative of output with respect to endowments is zero.

Capital accumulation also moves a country into cones with progressively higher wages and lower capital rental rates. This change in relative factor rewards can be seen by connecting isoquants with their respective isocost lines. Unit value isoquants are tangent to their respective isocost lines under perfect competition (assumption *A2*). One such isocost line, tangent to Machinery and Textiles, is present in the diagram. Note that the absolute value of the slope of this line indicates the ratio of wages to capital rental rates; since the isocost lines become steeper as countries move from the most labor abundant cone to the most capital abundant cone, relative wages rise. Examination of isocost lines also reveals that a decline in the price of Apparel lowers nominal wages in the labor abundant cone but does not affect nominal wages in the more capital abundant cones. Thus, if the US is sufficiently more capital abundant than the Philippines, their workers' nominal wages are not affected by, for example, a decrease in world apparel prices. (Indeed, their real wages rise.)

The four continuous, piece-wise linear relationships between output and capital abundance depicted in figure 2 summarize the basic development paths that can arise within the Heckscher-Ohlin framework. Sectors can be ranked according to capital intensity via either the capital-labor ratio at which peak output per worker occurs or the maximum output per worker attained in each sector. Both criteria are used below to evaluate model performance.

The Rybczynski relationships exhibited in figure 2 can be estimated using a cross section of countries' output and endowment data. If all countries in a dataset inhabit a *single* cone of diversification then output per worker (Q_{ic}/L_c) in each sector can be estimated as a linear function of the country's capital-labor ratio (K_c/L_c),

$$\frac{Q_{ic}}{L_c} = \alpha_{1i} + \alpha_{2i} \frac{K_c}{L_c}. \qquad 6$$

Generalized to control for additional factors such as human capital and natural resources, this specification has become standard for estimating the Rybczynski derivatives of the Heckscher-Ohlin model.

If countries are distributed among several cones of diversification, however, specification 6 is incorrect. The correct specification is that of a spline with T knots

$$\frac{Q_{ic}}{L_c} = \sum_{t=1}^{T+1} \beta_{1it} \mathrm{I}_t \left\{ \tfrac{K_c}{L_c} > \tau_t \right\} + \beta_{2it} \frac{K_c}{L_c} \mathrm{I}_t \left\{ \tfrac{K_c}{L_c} > \tau_t \right\}, \qquad 7$$

where $\tau_t \in (1, T-1)$ represents the capital-labor ratio of the t^{th} estimated interior knot and $\mathrm{I}\{\cdot\}$ is a vector of indicator functions whose elements are unity if the relationship in brackets is true and zero otherwise. This specification estimates a separate line segment for each cone.[4] With the appropriate continuity restrictions ($\beta_{1it} = \beta_{1i,t-1} + \beta_{2i,t-1}\tau_t$), this specification can be re-written as

$$\frac{Q_{ic}}{L_{ic}} = \alpha_{1i} + \alpha_{2i} \frac{K_c}{L_c} + \sum_{t=3}^{T+2} \alpha_{ti} \max\left\{ \tfrac{K_c}{L_c} - \tau_{t-2}, 0 \right\} \qquad 8$$

(Poirier 1976). This second specification is convenient because the slopes of successive cones are additive: the effect of capital accumulation on output in the most capital scarce cone is α_{2i} while the relationship in the n^{th} cone, for n>2, is $\alpha_{2i} + \sum_{t=3}^{n+1} \alpha_{ti}$. Both specifications allow the derivative of output with respect to endowments to change discretely at the knots.

Specification 8 can be estimated on a system of I equations with C observations via maximum likelihood, subject to the theoretically mandated, system-wide constraint that each knot in the development path occurs at the same capital-labor ratio in each industry $(\tau_{it} = \tau_t \forall t \in (1, T-1))$. In practice, the location of interior knots is estimated by gridding over all possible combinations of T knots for a given interval size. In the estimations to follow, a grid interval of \$500 capital per worker is used. Sensitivity analysis using grid values ranging from \$100 to \$2000 did not change results substantially. Note that a narrower grid can only increase evidence against the null.

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[3] The discussion in this section assumes away non-traded goods. See Leamer (1987) for a detailed discussion of their effect on development paths.

P-values for a classical likelihood ratio test can be computed to determine whether the null hypothesis of just one cone (i.e. $T=1$) can be rejected in favor of the nested alternative hypotheses of more than a single cone ($T>1$) for the system of I industries. These hypotheses can also be evaluated via posterior odds ratios, or Bayes Factors. Conceptually equivalent to Schwarz (1978) criteria, Bayes Factors have a natural degrees of freedom correction which accounts for the increase in parameters in moving from a null hypothesis with $2I$ parameters to an alternate hypotheses with $2IT+T$ parameters. A Bayes Factor equal to unity indicates that the alternate is just as likely as the null after correcting for degrees of freedom, while odds ratios greater than unity indicate the alternate hypothesis is more likely. Further detail on Bayes Factors is available in the Statistical Appendix.

An advantage of the empirical specification developed in this section is that it sets up a horse race between competing trade models, albeit models within the same factor proportions framework. Appropriateness of the multiple cone model at the sectoral level can be gauged informally by checking estimated splines for conformity with theoretical archetypes. More formally, partial odds ratios can be computed for each ISIC aggregate. However, because the development paths are estimated as a system, these partial odds ratios must be interpreted with caution: they are computed as if the location of knots were known. This assumption is not too severe, however, because information as to the location of knots in ISIC sector i is derived mostly from the other $I-1$ sectors.

2.2 What is an Industry?

Before proceeding with the estimation it is useful to consider how goods are defined. Surprisingly little attention has focused on their appropriateness for estimating trade theory.[5] The ISIC categories developed by the United Nations and used below, for example, group output loosely according to similarity of end use (e.g. Apparel, Machinery, Electronic Machinery), a procedure not necessarily consistent with the conceptualization of goods developed above. Reconciling the two requires two additional assumptions:

A6 Goods in country c within the same ISIC aggregate i have identical input intensities and prices.

A7 Across countries, ISIC aggregates have identical input intensities and prices.

The virtue of aggregating goods according to end use rather than input intensity, of course, is that they are more likely to be governed by the same price. Think, for example, of the high cross elasticity of substitution which presumably exists between white cotton tube socks made by hand and white cotton

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[4] In the estimation, τ_0 is assumed to be zero while τ_T is assumed to be the upper range of the sample capital-labor ratios.

[5] Dollar, Wolff and Baumol (1988) note the wide disparity of sectoral capital intensities across countries.

tube socks made by machine. But we usually think of these two kinds of socks as being produced by different techniques, where *technique* refers to the particular combination of inputs along an isoquant. (If the each type of sock were produced according to different *technology*, they would posses different isoquants.) Estimations in the next section rely upon assumptions *A6* and *A7*. In light of the ensuing results, as well as additional evidence culled from independent data sources, these assumptions are relaxed in section 4.

2.3 What Happens If There Are More than Two Factors or the World is Uneven?

With three or more factors or production, Leamer (1987) demonstrates that development paths with respect to any two factors, such as capital and labor, still take the shape of a spline. However, the location of a development path's knots as well as the slopes of its non-zero line segments are endogenous to all other factor abundance ratios. Land abundant countries, for example, might exit the labor-intensive Apparel sector at a higher capital-labor endowment ratio than land scarce countries. In a three factor model that includes land (T), for example, the correct specification is

$$\frac{Q_{ic}}{L_{ic}} = \beta_{1i} + \beta_{2i}\frac{K_c}{L_c}\left(\frac{T_c}{L_c}\right) + \sum_{t=3}^{T+2}\beta_{ti}\max\left\{\frac{K_c}{L_c} - \tau_{t-2}\left(\frac{T_c}{L_c}\right), 0\right\}. \qquad 8'$$

In this equation, both the knot and industry slope are a function of land abundance.

As a practical matter, estimation of equation 8' is quite difficult. In this paper, we focus on two shortcuts. The first, used in section 3, is to allow education per worker and crop- and forestland per worker ratios to enter specification 8 linearly, so that these other endowments merely raise or lower the estimated spline. The second shortcut, used in sections 3 and 4, follows Leamer (1987) and splits countries according to a third endowment, like cropland per worker.[6] Equation 8 is then estimated separately for each cohort of countries. Note that this procedure allows the splines' knots as well as their derivatives of output with respect to the capital-labor endowment ratio to vary crudely with land abundance.

An additional complication arises if the world is uneven in the sense that more goods can be produced at zero profit than there are factors in a cone of diversification. In that case, countries in the same cone may nevertheless produce a different subset of goods, and specialization is not a signal of a violation of the single cone model. Thus, a positive correlation of import mix and country endowments is necessary but not sufficient for the existence of multiple cones of diversification. Note, however, that any goods produced in common by countries in the same cone must sell for the same price, a condition, as we

[6] We do not use the second shortcut in the initial estimations in section three given the relatively large number of estimated knots.

illustrate below, that is violated by traditional aggregation schemes. The intuition for the effect of unevenness comes from the indeterminacy of equation (2) when $I>F$. Bernard, Jensen and Schott (2000) offer a more detailed discussion of the effects on factor price equality of relaxing traditional Heckscher-Ohlin assumptions.

3 Estimating the Multiple Cone Model using Traditional Aggregates

3.1 Data Description

Value added, capital stock and employment data for up to 45 countries in 1990 are used to estimate equation 8 for the null and nested alternate hypotheses. This relatively large sample of countries provides broader coverage than many previous examinations of the factor proportions framework, thereby increasing endowment diversity. As should be clear by now, this diversity is particularly important for the purposes of differentiating a multiple cone model from a single cone model.[7]

Value added data for 28 three-digit ISIC manufacturing aggregates are drawn from the UNIDO INDSTAT3 database, available on diskette from the United Nations. A drawback of having only manufacturing data is that it prevents verification of whether the model works across a broader range of sectors (i.e. mining, agriculture and services), where disparities in natural resources or education may be particularly important in inducing specialization. One potential benefit or our data constraint, however, is that manufacturing aggregates may contain fewer non-tradables than these other sectors, so that their actual development paths more closely resemble the theoretical archetypes described above.

Economy-wide labor statistics come from the World Bank CD-ROM. Manufacturing capital endowments are computed from UNIDO measurements of manufacturing gross fixed capital formation. An alternative is to use a measure of economy-wide capital, such as those found in Maskus (1991) or the Penn World Tables. The major difference between use of manufacturing versus aggregate capital is that the relative capital abundance of land rich countries (e.g. U.S., Canada, Norway, Australia, and New Zealand) declines when using manufacturing capital stock rather than total capital stock. This re-ranking can be used to our benefit: use of manufacturing capital to compute country capital abundance allows us to control for the influence on output of endowments other than capital and labor, like land.[8]

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[7] Focusing on a smaller set of countries does not necessarily increase the likelihood that they share the same cone of diversification, particularly if factors other than capital and labor are considered. Gabaix (1997), for example, firmly rejects the Heckscher-Ohlin model using a sample of the 12 wealthiest European countries. Even those 12 countries, however, vary significantly in natural resource endowments, which, as noted above, can have a significant effect on development paths. (See also Leamer *et al* 1999).

[8] Using country capital abundance also reveals evidence for specialization. Results using manufacturing capital stocks are reported because they are the most sensible in terms of having fewer outliers obviously due to land.

Estimations in this section control for additional factor endowments by including linear terms for forestland, cropland and higher education (secondary plus tertiary education attainment). As noted earlier, though theory indicates that these controls change the location of industries' knots, their linear specification here might be motivated by an assumption of production separability. In any case, the effect of land is dealt with more fully in the estimations on corrected aggregates in section 4. Data on land and education are drawn from the World Bank CD-ROM and Barro and Lee (1994), respectively. The countries and industries contained in the sample are listed in the Data Appendix. That appendix also contains a list of goods that can be found in each aggregate.

3.2 Estimation Results

The first important result of the paper is provided in table 1. This table compares the single cone null hypothesis to nested alternate hypotheses of from two to five cones (one to four interior knots). Because estimation of the alternative hypothesis for each model involves gridding over all possible combinations of T knots, computational constraints prevent estimating more than five cones in any reasonable amount of time. However, given that our main interest is in whether or not specialization exists this limitation does not appear to be too important.

The table provides strong evidence of specialization. The first column reports p-values for the classical likelihood ratio (LR) test and indicates that the single cone model can be rejected at the 99% level of significance for all alternate hypotheses. The posterior odds ratios indicate that this evidence persists even after correcting for degrees of freedom and that the four-cone model, which is highlighted, provides the best fit because the Bayes Factor decays after four cones.

Table 2 lists the partial Bayes Factor for each ISIC aggregate under the favored four-cone model. As discussed above, the partial posterior odds ratios are computed under the assumption that the location of knots is exogenous.[9] The left panel lists the 16 of 28 sectors favoring specialization while the right panel lists the 12 sectors favoring the null. The sectors most favoring specialization are Paper and Wood while the three sectors least favoring it are Nonferrous Metals, Iron and Petroleum Refining. A plausible explanation for this relative performance is that controls are included for forestland and cropland but not for other natural resources. That Machinery, Electronics and Transportation Equipment favor specialization does not seem too surprising since we expect capital abundant countries to focus on these (generally) capital-intensive sectors. More puzzling, however, is that there does not seem to be much evidence of specialization for sectors such as Apparel and Footwear that we expected to be labor-intensive.

Examining performance of the multiple cone model sector by sector highlights the mismatch between the large number of ISIC aggregates and the relatively small number of estimated cones. One way to preserve "evenness" (assumption *A5*) and also increase the strength of the estimation is to explore whether countries arbitrarily specialize in ISIC aggregates of similar capital intensity. Labor abundant countries might produce either Footwear or Apparel, for example, while capital abundant economies might manufacture either Machinery or Transportation Equipment. If that were the case, then merely combining Footwear and Apparel into one "super-aggregate", for example, and Machinery and Transportation Equipment into another might make specialization more noticeable.

Note that this reasoning is identical to that which supports aggregation schemes such as the ISIC. Indeed, any time a higher level of aggregation (e.g. three-digit ISIC) is chosen over a lower one (e.g. four-digit ISIC), the lower level aggregates are assumed to be redundant in the sense that their unit value isoquants lie atop one another. As a result, searching for redundancy may help us understand why support for specialization varies so much across ISIC sectors.

Inspection of the data underlying tables 1 and 2, however, provides the first hint that this line of reasoning is flawed. Figure 3 contains a scatter matrix of the underlying Q_{ic}/L_c versus K_c/L_c data for each ISIC category as well as that sector's estimated development path. Information in the upper right hand corner of each plot identifies the sector and ISIC code. Sectors are ordered in terms of increasing capital intensity from left to right, and down, according to maximum observed value added per worker. Thus Leather – the (1,1) element of the scatter matrix – is the least capital-intensive ISIC aggregate while Machinery – the (7,4) element – is the most capital-intensive. Scales are chosen to provide maximum detail; value added per worker increases substantially as one moves down the matrix.

As detailed in figure 3, estimated splines deviate substantially from the theoretical archetypes of figure 2. Many sectors, for example, exhibit positive value added per worker in more than two cones. Indeed, the Apparel spline (2,4) suggests that all countries have positive production in that sector. This result suggests that forming "super-aggregates" by summing over existing three-digit ISIC categories of similar factor intensity (e.g. Footwear (1,3) and Apparel (2,4)) is not likely to bring estimates closer to

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[9] As noted in the statistical appendix, the magnitude of Bayes Factors depends upon sample size. Note that the Bayes Factor of the favored four cone model in table 1 is merely the joint product of the partial Bayes Factors listed in table 2.

theory: output would remain positive for all countries.[10] Given the widespread use of high-level aggregates in testing trade theory, this feature of the data is quite important.

However, though estimated development paths are not a perfect match for theory, they do contain hints of underlying specialization. Labor abundant countries do not produce much of the most capital-intensive sectors, which is one of the reasons why the sectoral evidence for Printing (5,4) and Machinery (7,4) is so high in table 2. In addition, the oft-changing relationship between output and endowments in most industries is clearly suggestive of multiple cones and a sharp contrast to the impression given by earlier studies, where the derivative of output with respect to endowments is constrained to be a constant. Indeed, the twin-peaked development paths of the Transportation, Food, Electrical Machinery and Machinery sectors, all of which lie along the lowest row of the matrix, appear easily separable into two sub-ISIC sectors, one that is labor-intensive and one that is capital-intensive. This twin-peakedness is manifest in less capital-intensive aggregates as well, including Leather (1,1), Apparel (2,4), Furniture (3,1), Printing (5,4), Industrial Chemicals (6,1) and Paper (6,4).

Figure 4 illustrates how this twin-peakedness may result from grouping distinct products with different capital intensities in the same ISIC aggregate, a violation of assumption *A7*. The left panel of this figure traces out an Electronics development path with just two goods (e.g. portable radios and satellites), while the right panel illustrates the more general point that combining a continuum of distinct goods can lead to development paths with positive output in all cones, akin to those for Footwear (1,3), Pottery (1,4), Textiles (4,1) and Tobacco (3,2) in figure 3.

In highlighting the importance of aggregating goods according to input intensity *and* substitutability, Figure 4 motivates an inquiry into how well traditional aggregates conform with the model's assumptions. We are unique in taking this approach. Davis *et al* (1997), for example, move to evaluate the Heckscher-Ohlin framework at the (Japanese) regional level when their estimation of the trade side of the model provides disappointing results.[11] Working with a Japanese input-output matrix, they assume that this matrix is likely to be more appropriate within Japan than internationally. While that is no doubt true, their approach makes it more difficult to verify the model's key message: demonstrating that production and factors coincide domestically, where factors are substantially more mobile than internationally, leaves us wondering whether factors attract industry, as the model dictates, or *vice versa*.

[10] Because estimated splines are plotted as if countries contain no land and no skill, development paths for industries such as Printing (5,4) and Paper (6,4), where land and education controls are most significant, lie furthest from the data. Use of controls reduces the likelihood that displayed peaks and valleys are due to endowments other than capital and labor, but this assessment is likely truer for sectors like Transportation (7,1) and Machinery (7,4) than for Petroleum (1,2) and Nonferrous Metals (3,7) because the former are more apt to depend upon unobserved resources.
[11] Debaere (1998), on the other hand, responds to the poor performance of multi-lateral Heckscher-Ohlin estimations by focusing on how well relative factor abundance explains bilateral trade. Though his results, like those below, suggest that the model works well for disparately endowed countries, his bilateral focus diverts attention from the global perspective most useful for understanding issues of income inequality.

It is also common to treat traditional ISIC aggregates as sensible and use estimates based upon them to explore other violations of Heckscher-Ohlin assumptions, including Ricardian technological differences, home bias in trade and non-homotheticity of preferences (e.g. Bowen *et al* 1987; Trefler 1995; and Harrigan 1997). The danger in ignoring aggregation and examining those pathologies is that improper aggregation can bias construction of input per unit of output (A) matrices and render results uninterpretable. To see this problem more clearly, consider the twin-peaked Electronics development path in figure 4. If the A matrix constructed to determine the equality of $AN_c = v_c - s_c v_w$ is assumed to be an average of the two countries' individual A matrices, then capital intensity is underestimated in the capital abundant economy and over-estimated in the labor abundant economy. As a result, it may appear as if the factors embodied in Philippine trade, for example, are small relative to its manifest labor abundance, giving rise to a mystery of the missing trade (Trefler 1995). Mis-measurement can be even more severe for labor abundant countries if an A matrix from a capital abundant country like the US is used a proxy for all countries technology matrix, as is common practice. The solution to this problem is to consider a much broader A matrix that has multiple columns for each three-digit ISIC code, so one Electronics column, for example, might represent Philippine electronics goods while another represents Japanese electronics goods. Davis and Weinstein (1998) make a similar point in research complementary to that presented here. Extending their previous work, the authors take a more sophisticated approach to dealing with observed input-output heterogeneity, broadening their estimation of the Heckscher-Ohlin model to consider specialization. Indeed, one interpretation of their results is that each country is in a cone of its own.

3.3 Evidence of Intra-ISIC Output Heterogeneity

Figure 5, which plots sectoral capital intensities (K_{ic}/L_{ic}) for 39 of 45 countries for which data are available, provides an indication of the extent to which input intensities can vary across ISIC aggregates.[12] Countries are sorted in order of increasing capital abundance from Sri Lanka (LKA) to Belgium (BEL). Here, as above, manufacturing capital is used as the measure of country-level capital endowment. ISIC sectors are ordered in terms of average capital intensity from Textiles (Tex) to Petroleum (Pet). Note that the vertical scale has been censored at $60,000 to provide a clearer view of all sectors.

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[12] Sectoral capital stocks are constructed using UNIDO INDSTAT3 data on gross fixed capital formation by sector. Due to missing information, it is not possible to compute these stocks is not possible for all 45 countries in the sample. To compute 1990 capital stocks for sector i in country c (K_{ic}), gross fixed capital formation was accumulated and depreciated (at 13.3%) from 1975 to 1990, inclusive; results are not sensitive to the depreciation rate. In some cases, missing time-series observations were estimated non-parametrically, though the results in this section are in general not sensitive to the particular way in which this was done. A more complete description of how the sectoral capital intensity dataset was constructed is available from the author upon request.

If each sector represented the identical good in every country, the bars in figure 5 would line up like a wedge of cheese rising from the country axis toward the back of the plot. Actual intensities depart from this pattern in two ways. First, within-country sectoral capital intensity rankings are not uniform. Second, within-industry country rankings vary substantially: Germany's Apparel sector, for example, is almost 13 times as capital-intensive as Colombia's.

Table 3 provides a more precise illustration of the extent of this heterogeneity. The table displays the minimum, median and maximum capital intensity in each ISIC aggregate along with two measures of dispersion,

$$\frac{\text{Std}(k_{ic})}{\text{Mean}(k_{ic})} \text{ and } \frac{\text{Max}(k_{ic}) - \text{Min}(k_{ic})}{\text{Min}(k_{ic})},$$

where k_c is the capital intensity of country c in ISIC sector i. Large discrepancies between the two measures (e.g. for Machinery) are indicative of outliers or mis-measurement. Bolivia's Machinery sector, for example, has an estimated capital intensity of just \$32. Sectors are listed in ascending order of the first measure of dispersion.

In addition, data on four-digit ISIC aggregation and unit values indicates that intra-aggregate, across country input intensity heterogeneity is a signal that the goods produced by labor and capital abundant economies are not close substitutes. Table 4, for example, lists the correlation of country capital abundance and four-digit ISIC production shares within the three-digit ISIC Machinery aggregate. (The four-digit data originates from the same source as the three-digit data but cannot be used in the estimations above because country coverage is too sparse.) Correlations in the table are sorted from low to high and indicate that labor abundant countries tend to manufacture the first two types of machinery (non-electrical machinery and agricultural machinery) while capital abundant economies tend to manufacture the rest.[13] (We report correlations for the Machinery aggregate because it has the greatest number of sub-sectors and the most extensive country coverage of the pool of three-digit manufacturing categories; other sectors exhibit similar evidence.) Thus, to the extent that substitutability across four-digit aggregates is low, variation in sectoral capital intensity is a strong signal of specialization.

Evidence of unit value variation is culled from an independent dataset on US imports compiled by Feenstra (1996). This dataset identifies the origin, value and quantity of US imports at the 10-digit HTS level of aggregation (roughly 16,000 categories) for the years 1972 to 1994. This level of aggregation permits selection of a very specific good, like men's cotton shirts, to determine whether unit

[13] To complicate analysis even further, note that a given country's aggregate may incorporate sub-sectors of disparate input intensity as well.

values are correlated with source country capital abundance. Absence of correlation supports a null hypothesis of homogeneous output within sectors across countries. Positive correlation, on the other hand, is consistent with an alternate hypothesis of specialization, where shirts from capital abundant countries are poor substitutes of shirts from labor abundant economies and are therefore more likely to lie on distinct isoquants.

In 1994 the US imported men's cotton shirts from half of its 162 trading partners, a relatively large share for such a narrow good. The unit values of these shirts range from $56 (Japan) to $1 (Senegal). In support of specialization, the correlation of unit value with country capital abundance is 0.56, which is significant at the 99% confidence level. Indeed, as reported in Schott (2000), a positive relationship between unit value and source country capital abundance is found across a wide range of manufacturing aggregates and has been increasing for the last twenty years, a signal that specialization may be increasing with time. Furthermore, that study also finds that no significant relationship between unit value and source country capital abundance exists in natural resource goods such as iron ore and fuel.

Taken together, this new evidence of product heterogeneity strongly suggests that traditional aggregation schemes mask specialization and that they present a formidable problem for estimating trade models. A potential solution is developed in the next section.

4 Re-estimation the Multiple Cone Model with "HO Aggregates"

Given the evidence presented in the previous section, we now proceed as if cross-country heterogeneity within three-digit ISIC sectors is a principal cause of the underwhelming performance of the Heckscher-Ohlin model. Our first step, therefore, is to develop a technique for assembling "Heckscher-Ohlin Aggregates", hereafter referred to as HO Aggregates, which groups output according to country-industry input intensity rather than end use. We then use these new industries to re-estimate the model. Our approach in this section provides a useful contrast to the more traditional practice of assuming that observed input intensity heterogeneity is due solely to differences in international factor productivity. Thus, this section explores the gains to be had from proceeding in an alternate direction.

4.1 Constructing "HO Aggregates"

Relax assumption *A7* and use instead

A7' The further apart goods within the same ISIC category are in terms of input intensity, the more likely they are to be different "goods."

The most straightforward method of operationalizing this assumption is to rank the *(I*C)*x*1* list of country-ISIC capital intensities displayed in figure 5 in ascending order and split them into cohorts called

HO Aggregates. Let X_{nc} denote output of HO Aggregate *n* in country *c* and $k_{ic} = K_{ic}/L_{ic}$ represent the capital intensity of ISIC aggregate *i* in country *c*. Then a country's output of HO Aggregate *n* is the sum of that country's output in all ISIC aggregates with capital intensity between the maximum and minimum capital intensity for that aggregate,

$$X_{nc} = \sum_{k_{ic} \in (k_{n-1}, k_n]} Q_{ic} , \qquad 9$$

where k_{n-1} and k_n are the capital intensity cutoffs for aggregate *n*. Note that this technique preserves evenness within cones (assumption *A5*), so that *T=N-1*. This aggregation scheme relies upon an additional assumption,

A8 Prices are such that the unit value isoquants of all goods within a given derived aggregate are tangent to a single isocost line.

which guarantees that the relationship between derived aggregates and country endowments remains as described in section 2. The intuition for this guarantee comes from the assumption of constant returns to scale (*A3*): because the total output of any combination of goods along a single isocost line within a cone can be represented by the output of a single good tangent to that isocost line, the output of all sectors with capital intensity greater than k_{n-1} in aggregate *n* and country *c* can be attributed to X_{nc}. As a result, indeterminate output within a cone, even for a continuum of goods, is not problematic for our purposes so long as output deviates randomly from that necessary to place respective unit value isoquants along "true" isocost lines. Though this assumption is strong, it is important to note that it is no stronger than the assumption about prices which lurks behind every estimation relying upon ISIC aggregation. The three-digit Electronics ISIC, for example, assumes a common isoquant for both portable radios and satellites. Thus, our HO Aggregates are better than three-digit ISIC industries in terms of similarity of input intensity and no worse in terms of price heterogeneity.[14]

Finally, note that there is nothing about the procedure for forming HO Aggregates that renders verification of the multiple cone model a foregone conclusion. By definition, country *c*'s capital-labor ratio is a labor weighted average of the capital per labor ratios in each of its *I* industries, or

[14] In a dynamic context, our technique implies that the underlying prices of the goods in HO aggregates move together, so that, for example, labor-intensive apparel and labor-intensive electronics prices have a higher correlation than the correlations between either labor and capital-intensive apparel or labor and capital-intensive electronics. Leamer (1998) exhibits evidence supporting this assumption.

$$\frac{K_c}{L_c} \equiv \frac{\sum_{i \in I} L_i \frac{K_i}{L_i}}{\sum_{i \in I} L_i}. \qquad 10$$

Thus, with at least three HO Aggregates defining two cones of diversification, it is possible to test whether the factor intensity of goods produced by a country are similar to that country's relative endowments. This assertion relies upon the evidence reported in section 3, which associates heterogeneity of technique with the production of goods that are not substitutes.

4.2 A Simple Test for Specialization Using HO Aggregates

The simplest method for estimating whether countries fall into more than a single cone of diversification is to test if development paths based on extreme HO Aggregates contain a kink. The intuition for this test is summarized by three panels in figure 6, where each isoquant is meant to represent one of the *I*x*C* country-ISIC pairs from figure 5, $k_{\min}$ and $k_{\max}$ represent the minimum and maximum capital intensity of these *I*x*C* pairs and k_{cut} represents the capital-labor ratio bisecting the isoquants into *N=2* HO Aggregates.

Under the null hypothesis of no specialization (left panel), all countries have positive output of both HO Aggregates irrespective of how they are split by k_{cut} because all countries possess at least one ISIC industry with positive output in each HO Aggregate. As a result, adding a knot at $\tau = k_{cut}$ to the linear development path of each of the two HO Aggregates will not improve the model's fit after controlling for degrees of freedom.

However, under the alternate hypothesis of multiple cones (two right panels), there are two cleavages of the *I*x*C* country-ISIC isoquants that result in a better fit for the multiple cone equilibrium than for the single cone equilibrium. The first cleavage (middle panel) corresponds to a k_{cut} high enough to exclude any isoquants from a labor abundant country. The second cleavage (right panel) corresponds to a k_{cut} low enough to exclude any isoquants from a capital abundant country. Note that figure 6 is drawn under the assumption of a three good, two cone equilibrium, but this test is general to the actual number of goods.

This test uncovers evidence of a multiple cone equilibrium no matter how many cones actually exist because it focuses on finding only the most extreme HO Aggregates. We implement it by estimating the *N*=2 system of equations

$$\frac{X_{nc}}{L_c} = \sum_{t=1}^{T+1} \beta_{1nt} \mathrm{I}_t \left\{\tfrac{K_c}{L_c} > \tau_t\right\} + \beta_{2nt} \frac{K_c}{L_c} \mathrm{I}_t \left\{\tfrac{K_c}{L_c} > \tau_t\right\} + \Phi(Land, Skill), \qquad 10$$

for a grid of $\tau \in (k_{\min}, k_{\max})$ knots, where, as above, $\Phi(Land, Skill)$ represents the addition of linear control terms for cropland, forestland and higher education.[15] Note that the theoretically implied knot $(\tau_{nt} = \tau_t \forall t \in (0, T))$, continuity $(\beta_{1nt} = \beta_{1n,t-1} + \beta_{2n,t-1}\tau_t)$ and slope constraints are imposed on the alternate hypothesis as needed. We reject the null hypothesis of no specialization if the estimated Bayes Factors are higher than unity for two values of τ and do not reject the null hypothesis if the estimated Bayes Factors are less than unity for all levels of τ.

Results of this procedure are displayed in figure 7, which plots the posterior odds ratio of the alternate versus the null hypothesis as a function of the estimated knots (τ). The Bayes Factor for most levels of τ are less than unity, indicating a linear (no specialization) development path provides the best fit after controlling for degrees of freedom. However, they rise above unity for two intervals of τ: between \$1000 and \$2000 and between \$5000 and \$8000. Substantively, these high Bayes factors indicate that labor abundant countries do not produce goods with capital intensity greater than about \$6500, and capital abundant countries do not produce goods with capital intensity below \$1500. Thus, the capital intensity of countries' sectors tends to be near their capital abundance in factor space.

4.3 Grouping Countries into Cones

A more evocative evaluation of specialization is accomplished by re-running the estimation from section 2 with HO Aggregates. Using HO Aggregates in place of ISIC Aggregates, however, requires bootstrapping for calculating confidence intervals (Effron and Tibshirani 1993). Bootstrapping is necessary in this case because single and multiple cone models require different numbers of HO Aggregates: the single cone model is based upon two HO Aggregates while multiple cone models are based on three or more HO Aggregates. As a result, the null and alternate hypotheses are no longer nested and traditional test statistics do not apply.

Bootstrap p-values for the two and three cone equilibria are listed in table 5.[16] As indicated in the table, there is strong evidence for the two-cone model but little evidence for three cones. This result

[15] Inclusion of these controls does not alter the results substantively.

[16] A confidence interval for comparing the null and alternate hypotheses with Bootstrapping can be constructed by estimating the single cone model on two HO Aggregates and using the parameters from that estimation to generate a large number of "derived datasets". Repeated estimation of the null and alternate hypotheses on these derived datasets provides a distribution of relative fits. This distribution can be used to select Bootstrap p-values for the relative fit of the two hypotheses using the original data. (See Statistical Appendix for further detail.)

implies that none of the countries in the sample have a completely differentiated output mix because they all produce the second HO Aggregate.

A more suggestive presentation of this result is provided in figure 8, which plots the estimated development path and underlying data for each of the three HO Aggregates in the favored two cone equilibrium. In the display, HO Aggregates are ordered by increasing capital intensity from left to right, and each country observation with positive output is identified by the corresponding three-letter World Bank code. As noted above, total value added per worker (VA_{nc}/L_c) for each country *c* in each HO Aggregate *n* is computed by summing *c*'s production across all ISIC sectors falling within aggregate *n*. Cutoffs for HO Aggregates occur at roughly \$1000 and \$6000 capital per worker. These break points are consistent with the high posterior odds ratios noted in figure 7. The border between cones is estimated at approximately \$5000. Note that here as in section 2 the estimated development paths are plotted as if countries have neither land nor higher education. Including positive values of these endowments would lift the splines closer to the data.

All OECD countries in the sample except New Zealand inhabit the more capital-intensive cone, a result which suggests that by 1990 the US may have been sufficiently capital abundant for its workers to be insulated from price declines of the most labor-intensive products. This result is consistent with recent research into the effects of the 1997 Asian currency crisis on US industry. Harrigan (1999), for example, finds little evidence that the import price declines associated with this crisis affected US relative output prices. If this interpretation is correct, it casts doubt on the view that further globalization will negatively impact US income inequality.

If the two cone equilibrium explained the international distribution of production perfectly, each country would have positive output in just two of the three HO Aggregates: all countries are expected to appear in the middle panel, but only the most and least labor abundant countries, respectively, should be present in the first and third HO Aggregates. Inspection of figure 8 reveals that very few of the most capital abundant countries produce the first HO Aggregate, though Finland stands out due to its relatively labor-intensive textiles sector, an anomaly that may be driven by protectionism. The relatively high number of labor abundant countries producing the third, most capital-intensive HO Aggregate, on the other hand, might be the result of labor abundant countries attempting to "jump-start" entry into capital-intensive sectors by delving into them before their endowments render them profitable. This line of reasoning is not uncommon and has been attributed, for example, to South Korea's success.

The distribution of countries around the estimated development paths reveals that Germany, Ireland and Japan produce more than expected of the most capital-intensive aggregate. This observation dovetails nicely with their respective reputations for efficiency and skilled workers. Interestingly, Korea and Belgium produce less than expected of the capital-intensive output. Whether this result is due to inefficiency or to some other cause merits further examination.

The highest producers of the middle HO Aggregate are the US, Sweden, Australia and Canada. These countries also have high land to worker ratios; if splines are re-plotted with non-zero values for land, they will be closer to this group of countries.

As detailed in section 2, we can also estimate the effect of land on development paths by estimating them separately for high and low cropland abundant countries. Figure 9 plots the results of this estimation and indicates that land scarce countries exit the labor-intensive HO Aggregate enter more capital-intensive goods at lower capital per labor endowment ratios than land abundant countries.[17] This result is consistent with the observation that land abundance retards growth (Jones and Hall 1999). Leamer *et al* (1999), for example, argue that the sectors associated with natural resource abundance absorb capital that might otherwise flow to manufacturing, depressing workers' incentives to accumulate skill and delaying industrialization.

Finally, figure 10 provides a feel for the country-sector pairs that make up each HO Aggregate in figure 8. This figure illustrates that a relatively labor-intensive ISIC sector for Sweden, like Textiles, is combined with a relatively capital-intensive ISIC sector for Malaysia, like Transportation, in a medium capital-intensive HO Aggregate. The presence of several of a country's ISIC sectors in the same HO Aggregate (e.g. Japanese Chemicals and Japanese Transportation in the most capital-intensive HO Aggregate) presumes, rather stringently, that the choice between these sectors is arbitrary. Though such arbitrariness is almost certainly not the case in the real world, the results of this section demonstrate that it is a useful construct for thinking about the issues motivating this paper.

Figure 10 also highlights the assumption that the prices of goods with diverse end use (e.g. apparel and electronics) move together. A justification of this assumption as it applies to the kinds of Stolper-Samuelson income inequality effects discussed above is that trade negotiations may have stimulated price reductions across a wide range of labor-intensive goods prices during the 1970s and 1980s. As noted above, evidence presented in Leamer (1998) indicates that this is not an unreasonable assumption.

5 Conclusion

Previous empirical evaluations of the Heckscher-Ohlin model have focused on its least realistic equilibrium, namely that all countries produce all goods and offer their workers the same quality adjusted wages. This paper, in contrast, develops a technique that is sensitive to a richer version of the model

[17] The definition of aggregates is the same for both country cohorts in figure 9, but different than the HO Aggregates used in figure 8. For figure 9, each cohort significantly beats its associated null hypothesis.

where countries are allowed to specialize in distinct mixes of goods depending upon their relative endowments. We demonstrate strong empirical support for specialization and are able to break countries into three distinct groups according to their output mix.

In addition, we have introduced a technique to control for the substantial intra-ISIC variation across countries in both observed input intensities and goods prices. This heterogeneity is starkly apparent in odd combinations of goods within the same industry (e.g. portable radios and satellites within Electrical Machinery) and violates the assumptions of the Heckscher-Ohlin framework. When we employ this technique to re-form ISIC aggregates in a manner more consistent with the assumptions of the model, we find even stronger support for the idea that output mix is a function of relative endowments.

Because of their very different implications for the effect of international trade on income inequality, determining which of the two Heckscher-Ohlin equilibria binds is of more than academic interest. If all countries produce all goods, unskilled workers in the US can be affected adversely by a drop in the world price of labor-intensive imports. This effect is mandated by price-wage arbitrage: US firms competing with cheap imports from labor abundant countries require wage concessions to remain viable. Specialization, however, means that US firms produce a capital-intensive mix of goods and are therefore not threatened by cheap imports. Evidence presented in this paper indicates that the US in 1990 was sufficiently capital abundant to insulate its workers from competition with labor abundant countries. If correct, these results cast doubt on the claim that further trade liberalization will adversely affect US income inequality.

That the US is much closer to the border between high and low wage cones of diversification than other OECD countries (e.g. Germany and Japan), however, may be an indication that its insulation from emerging market competition is relatively recent. If that is the case, US workers may have been affected by competition from workers in labor abundant countries in the 1970s and 1980s as the US was moving between cones. Toward that end, research into the evolution of US specialization over time is likely to yield useful insight.

Appendix A: Data

The countries and sectors included in the estimation are listed in tables 6 and 7. In some cases, information on a particular sector is unavailable for all countries. Table 7 also provides examples of they types of goods found in each three-digit ISIC sector.

Appendix B: Statistics

1 Spline Estimation on Existing ISIC Aggregtates

Consider the output of a particular country $c \in C$ in all ISIC industries $i \in I$. For a development path containing *T* knots we can arrange the observation of one country horizontally, such that

$$[y_1 \quad y_2 \quad \ldots \quad y_I]_c = x_c'[\pi_1 \quad \pi_2 \quad \ldots \quad \pi_I] + [\varepsilon_1 \quad \varepsilon_2 \quad \ldots \quad \varepsilon_I]_c\,, \qquad \text{B.1}$$

where x_c is the (2+*T*)x1 vector of independent variables, π is the (2+*T*)x*I* vector of slopes and ε is the 1x*I* vector of output measurement errors. Note that there are k_c=2+*T* parameters to be estimated for each industry (an intercept plus a slope for each cone). If measurement errors are normally distributed, the density of output y_c given x_c is

$$f(y_c \mid x_c) = \left(2\pi\sigma^2\right)^{I/2} \exp^{-(\varepsilon_c'\varepsilon_c)/2\sigma^2}. \qquad \text{B.2}$$

If we now consider the likelihood of output across all countries, *Y*, given the set of explanatory variables *X*, we have

$$f(Y \mid X) = \prod_{c \in C} f(y_c \mid x_c) = \prod_{c \in C} \left(2\pi\sigma^2\right)^{I/2} \exp^{-(\varepsilon_c'\varepsilon_c)/2\sigma^2}, \qquad \text{B.3}$$

which yields the log likelihood (*L*)

$$L = \log f(Y \mid X) = -\frac{IC}{2}\log(2\pi) - \frac{C}{2}\log|\Sigma| - \frac{1}{2}\sum_{c \in C} \varepsilon_c'\Sigma\varepsilon_c\,, \qquad \text{B.4}$$

where Σ is $E(\varepsilon_c'\varepsilon_c)$. A is well known, this expression can be reduced to the concentrated log likelihood

$$L = -\frac{IC}{2}\log(2\pi) - \frac{C}{2}\log|\Psi|\,, \qquad \text{B.5}$$

where $\Psi = \dfrac{\varepsilon'\varepsilon}{C}$. If industries are independent, then

$$\log|\Psi| = \sum_{i \varepsilon I} \log\frac{ESS_i}{C}. \qquad \text{B.6}$$

A classical estimate for a given *T*>0 knots (i.e. more than a single cone of diversification) versus a null of *T*=0 knots can be performed by comparing a Likelihood Ratio (*LR)* test statistic to a chi-squared distribution with *TI*+*T* degrees of freedom (the extra slopes plus the number of estimated knots). Inspection of B.5 and B.6 reveals that this test statistic is equal to

$$LR = C\left(\left(\sum_{i\varepsilon I}\log\frac{ESS_i}{C}\right)_{Null} - \left(\sum_{i\varepsilon I}\log\frac{ESS_i}{C}\right)_{Alternate}\right), \qquad \text{B.7}$$

where ESS_i is the sum of squared errors across countries *c* in industry *i*.

A more informative comparison of the alternate versus null models, however, accounts for the latter's increased number of parameters. This problem is most coherently thought of within a Bayesian framework where an odds ratio, or Bayes factor, can be computed for the alternate versus null hypothesis. This odds ratio incorporates a specific penalty for the increase in parameters. For diffuse conjugate priors on all parameters

$$\begin{gathered}\beta \sim N\left(b^*, \left(\sigma^2\right)^{-1} N^{*-1}\right) \\ \sigma^2 \sim \Gamma\left(s_1^2, \upsilon_1\right)\end{gathered}, \qquad \text{B.8}$$

the predictive density of *Y* is a multivariate Student function

$$\begin{aligned} f(Y) &= \iint f\left(Y \mid \beta, \sigma^2\right) f\left(\beta, \sigma^2\right) d\beta d\sigma^2 \\ &= k(\upsilon_1, C)\left|\frac{M}{s_1^2}\right|^{1/2}\left(\upsilon_1 + \frac{Q}{s_1^2}\right)^{-(\upsilon_1 + C)/2} \end{aligned} \qquad \text{B.9}$$

where

$$\begin{aligned} M &= I_T - X\left(N^* + X'X\right)^{-1} X' \\ k(\upsilon_1, C) &= \frac{\upsilon_1^{\upsilon_1/2}\left(\frac{\upsilon_1}{2} + \frac{C}{2} - 1\right)!}{\pi^{C/2}\left(\frac{\upsilon_1}{2} - 1\right)!} \end{aligned} \qquad \text{B.10}$$

Leamer (1978) demonstrates that the posterior odds ratio is equal to

$$\frac{f\left(y \mid H_i\right)}{f\left(y \mid H_j\right)} = \frac{k\left(\upsilon_{1i}, C\right)}{k\left(\upsilon_{1j}, C\right)} \frac{\left|N_i^*\right|^{1/2}}{\left|N_j^*\right|^{1/2}} \frac{\left|N_i^* + X_i'X_i\right|^{-1/2}}{\left|N_j^* + X_j'X_j\right|^{-1/2}} \frac{s_{1i}^{-C}}{s_{1j}^{-C}} \frac{\left(v_{1i} + \frac{Q_i}{s_{1i}^2}\right)^{-(\upsilon_{1i} + C)/2}}{\left(v_{1j} + \frac{Q_j}{s_{1j}^2}\right)^{-(\upsilon_{1j} + C)/2}}. \qquad \text{B.11}$$

For the specifications used in this paper, this equation can be reduced to

$$\frac{f(y \mid H_{Alternate})}{f(y \mid H_{Null})} \cong \prod_{a \in A} \gamma C_a^{\left(k_{a,Null} - k_{a,Alternate}\right)/2} \left(\frac{ESS_{a,Null}}{ESS_{a,Alternate}} \right)^{C_a/2}, \qquad \text{B.12}$$

where $f(.|.)$ is the marginal density of the observed data conditional on the hypothesis i, k_i is the number of parameters in model i, a represents aggregates and γ is a sample-size-invariant constant that is dominated by the other terms in the expression. For constant C and k_i across aggregates, the log of this expression reduces to

$$\frac{f(y \mid H_{Alt})}{f(y \mid H_{Null})} \cong A \frac{\left(k_{Null} - k_{Alt}\right)}{2} \log(C) + \frac{C}{2}\left(\log\left(ESS_{a,Null}\right) - \log\left(ESS_{a,Alt}\right)\right). \qquad \text{B.13}$$

This formulation of the odds ratio has the advantage that

1 The posterior probability of a model is invariant to linear transformations of the data; and
2 There is a degrees of freedom correction: of two models that both yield the same error sum of squares, the one with the fewer number of explanatory variables has the higher posterior probability.

This degrees of freedom correction is similar in spirit to the correction suggested by Akaike (1981).

2 Boostrapping with HO Aggregates

A direct comparison of the single cone versus multiple cone equilibria involves comparing non-nested hypotheses where the dependent variable is formed from different subsets of the underlying country-ISIC sector production data. A confidence interval for this comparison can be made via bootstrapping (Effron and Tibshirani 1993) as follows:

1 Estimate the relative fit of a null hypothesis (two HO Aggregates and one cone) versus an alternate hypothesis (*N* HO Aggregates and *N-1* cones) using the observed ISIC sectoral capital intensities and output.
2 Assume the parameters of the null hypothesis to be true and use them to draw a *Cx1* vector of country-HO Aggregate outputs, $X_{nc}^{*} = \beta_{n,Null}^{'} V_c + \varepsilon_n^{*}$ for $n \in (1,2)$, where ε_n^{*} is distributed normally with mean zero and standard deviation equal to the standard error of the HO Aggregate *n* regression. *V* represents the regressors in equation 10.
3 Use the X_{nc}^{*} to compute an *ICx1* vector of country-ISIC sector outputs, Q_{ic}^{*}, where $Q_{ic}^{*} = s_{ic} X_{nc}^{*}$ and $s_{ic} = \frac{Q_{ic}}{X_{nc}}$ for the ISIC sectors *i* in HO Aggregate *n*.

4 Use the Q^*_{ic} to compute output in N^* HO Aggregates, X^{**}_{nc}, where $X^{**}_{nc} = \sum_{k_{ic} \in (k_{n-1}, k_n]} Q^*_{ic}$ for $n^* \in (1, N^*)$.

5 Estimate the fit of the alternate hypothesis of N^* HO Aggregates and N^*-*1* cones as in section 2.

6 Repeat steps 2 through 6 to create a confidence interval and compare the relative fit in step 1 to this interval.

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Figure 1: Two Factor, 4-Good Lerner Diagram

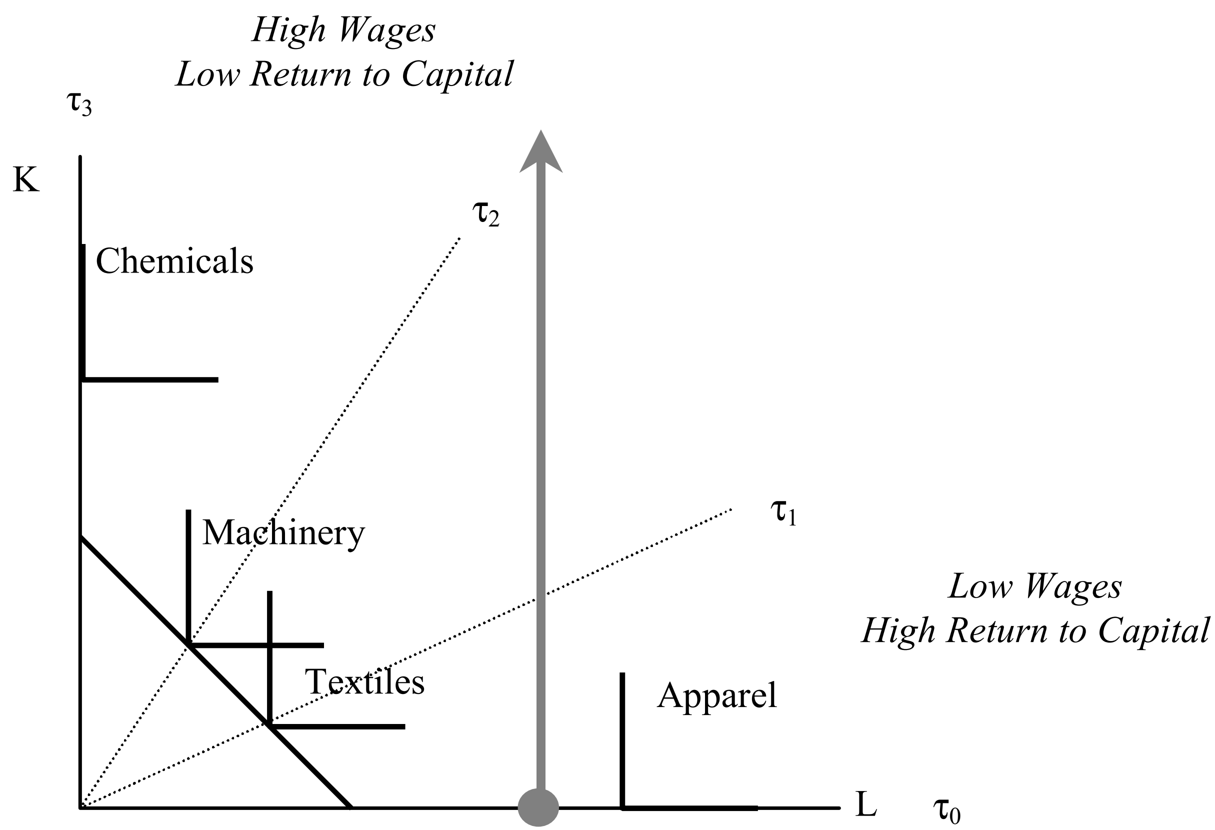


Figure 2: Development Paths for Industry *i* in Country *c* Implied in Figure 1

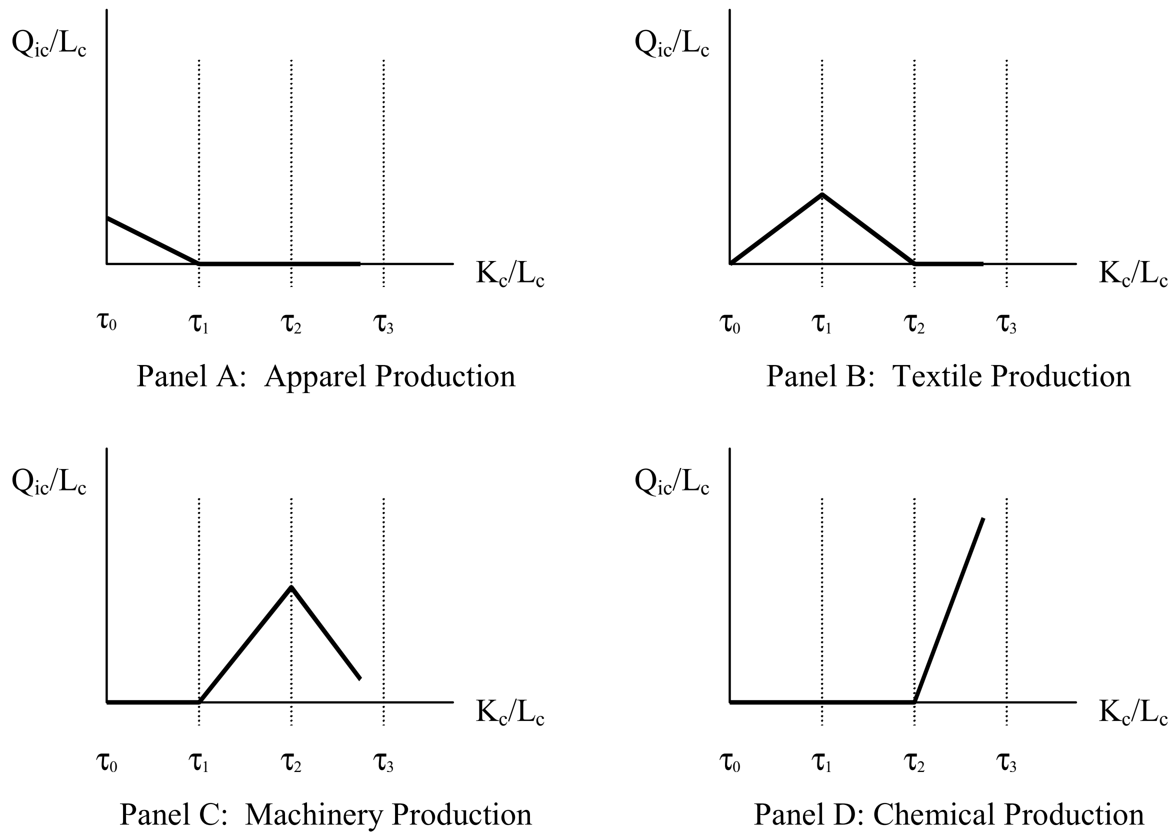


Figure 3: Estimated Development Path by 3 Digit ISIC Aggregate, Four-cone Model, 1990
(Q_{ic}/L_c versus K_c/L_c in \$000)

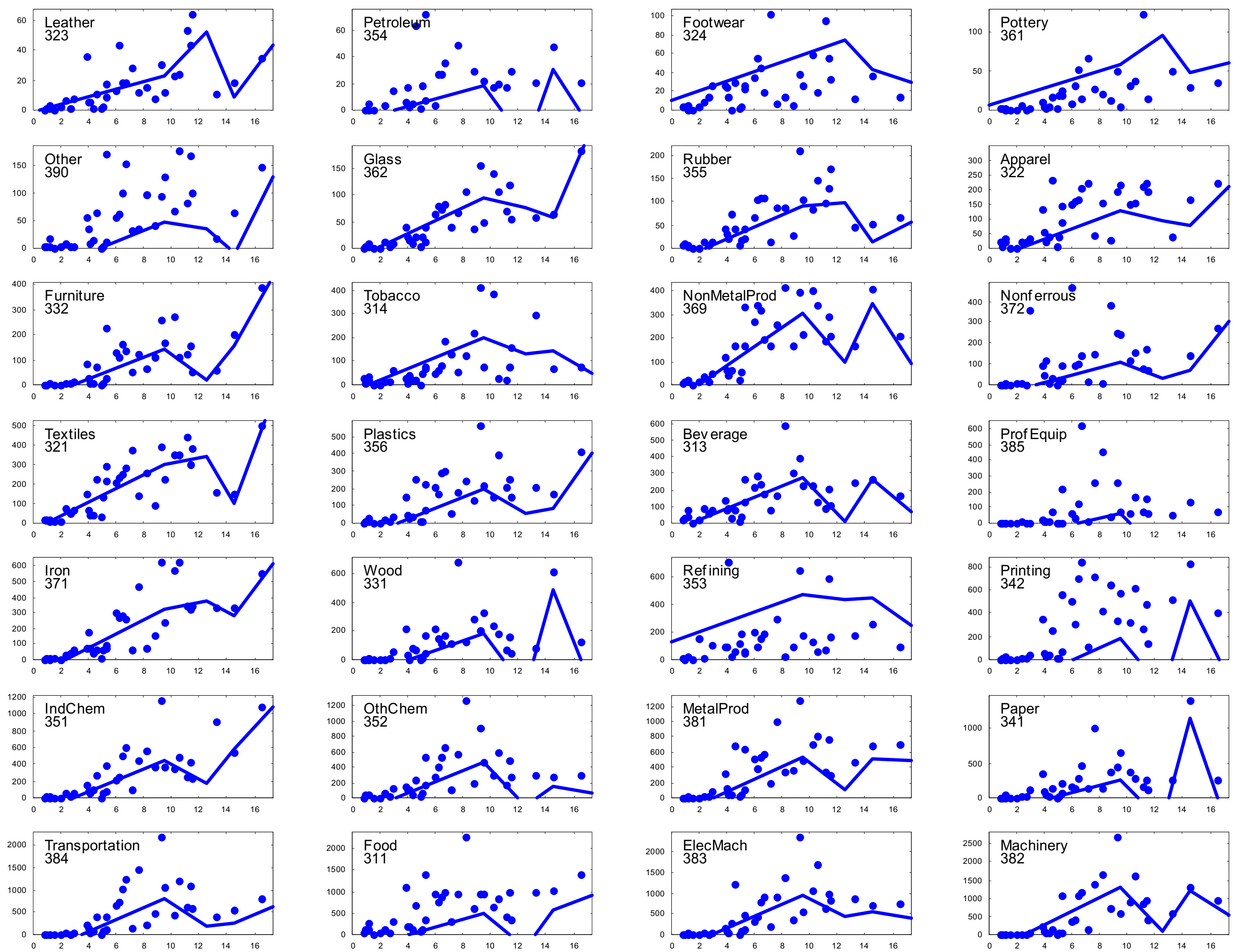


Figure 4: Potential Development Paths When Goods are Aggregated According to End Use

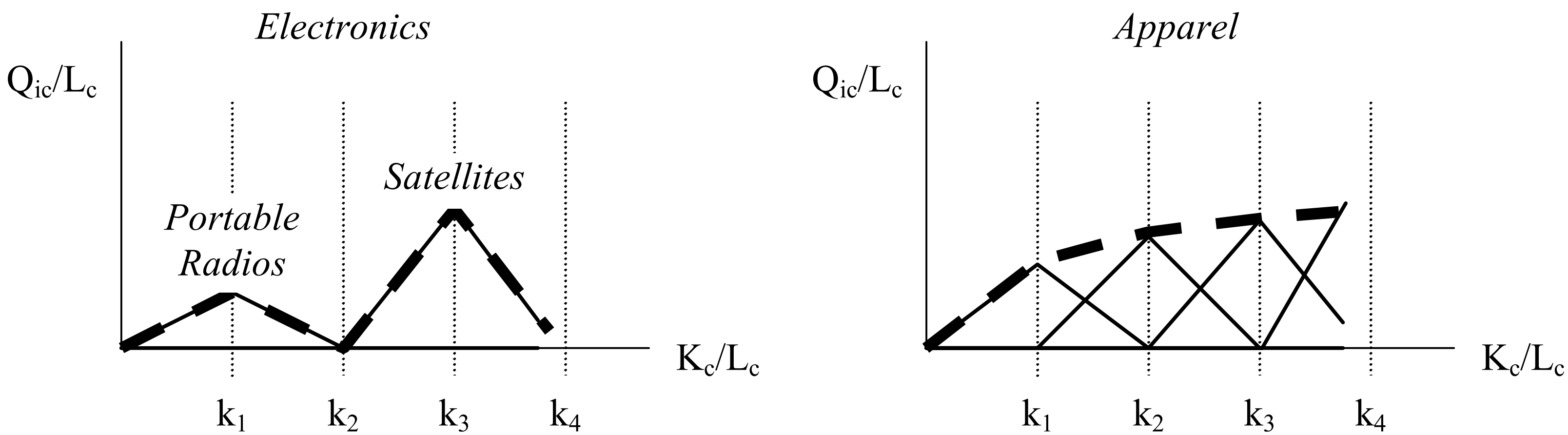
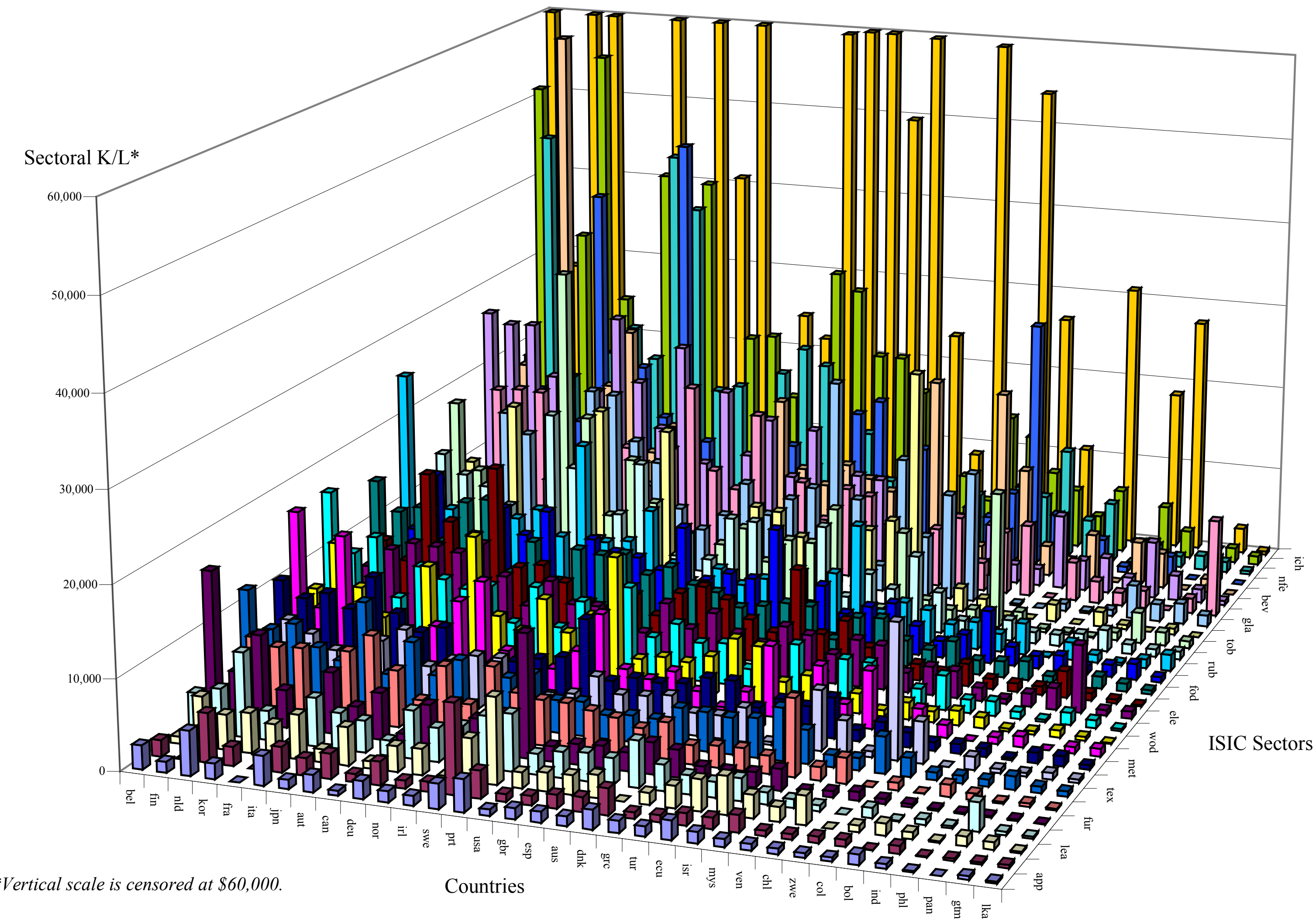
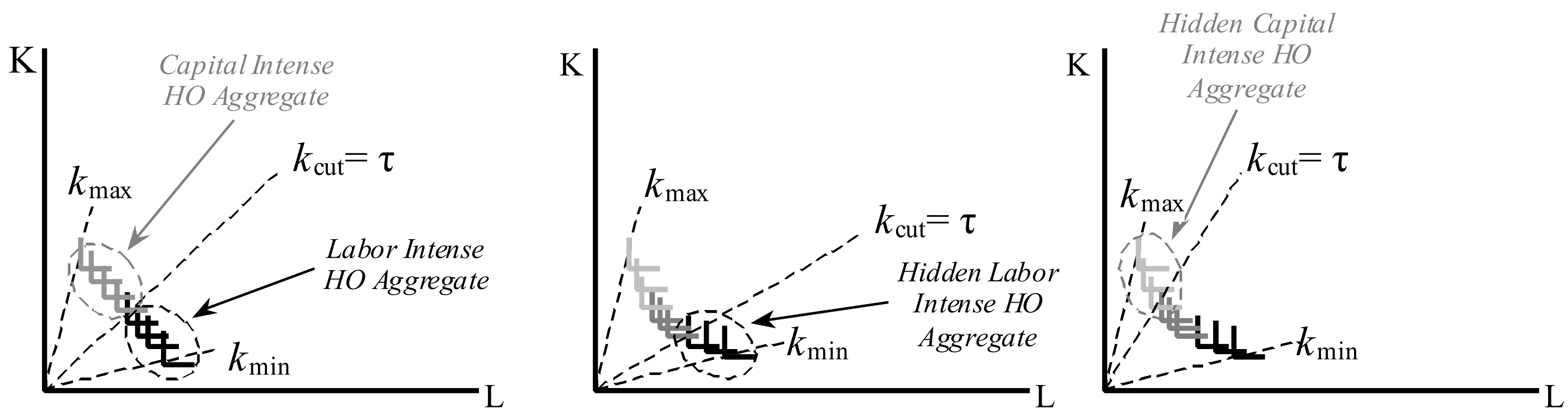


Figure 5: Country-ISIC Sector Capital Intensities, 1990



**Vertical scale is censored at $60,000.*

Figure 6: Finding Evidence of Multiple Cones Using Just Two HO Aggregates



Single Cone
Spline Does Not Improve Fit

Multiple Cones
Finding Evidence of At Least One More Good

Figure 7: Posterior Odds Ratios as a Function of τ Using Two HO Aggregates

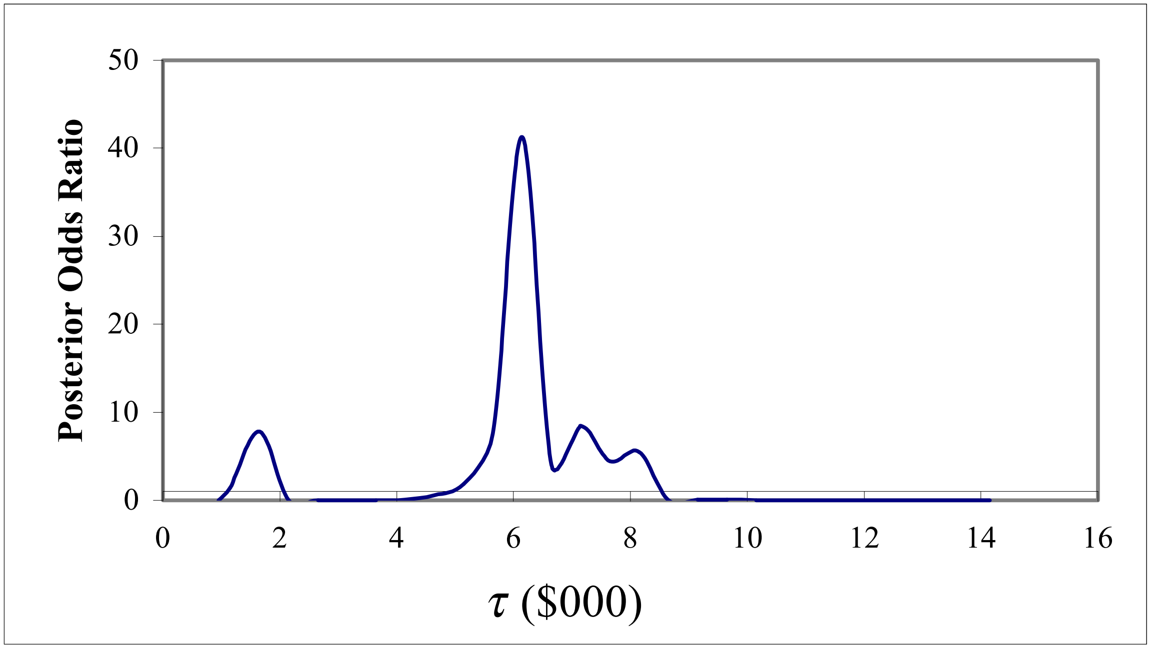


Figure 8: Estimated Development Paths in a Two Cone Equilibrium, Using HO Aggregates
(All Aggregates Plotted on Same Scale)

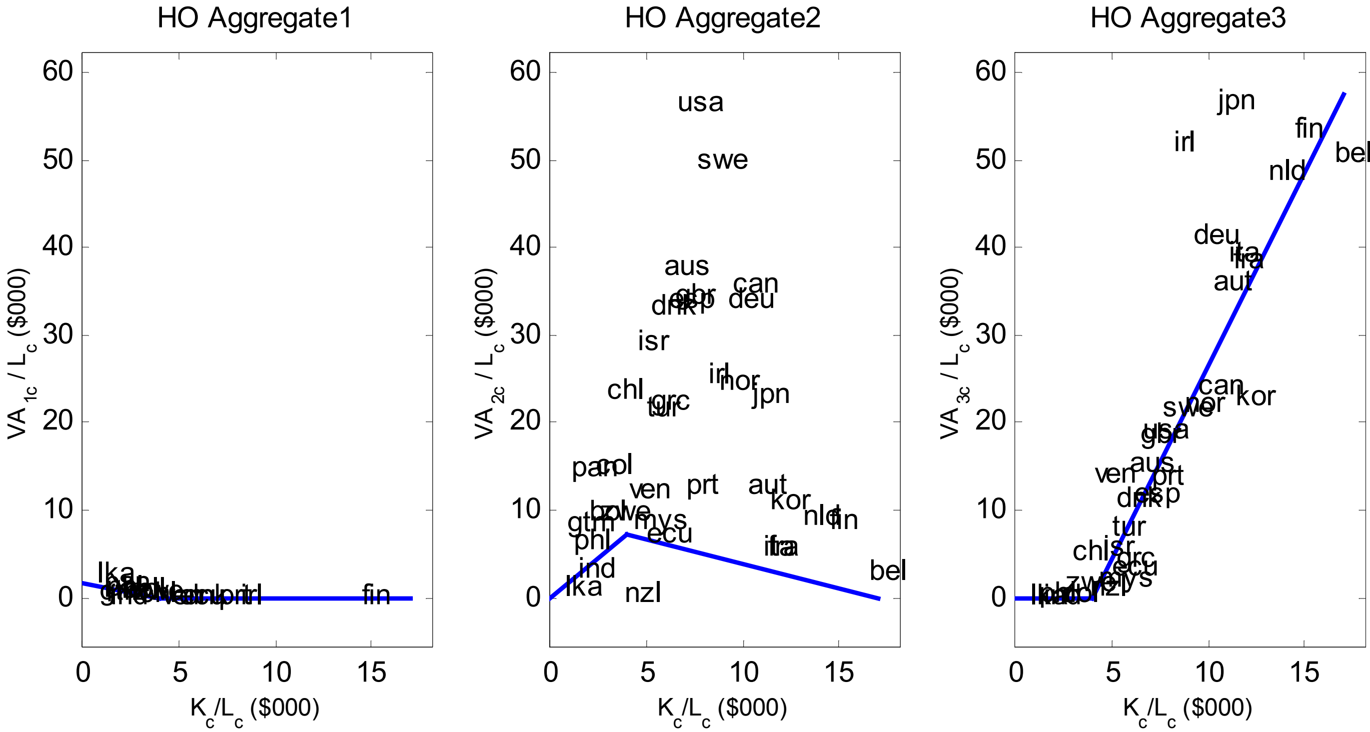
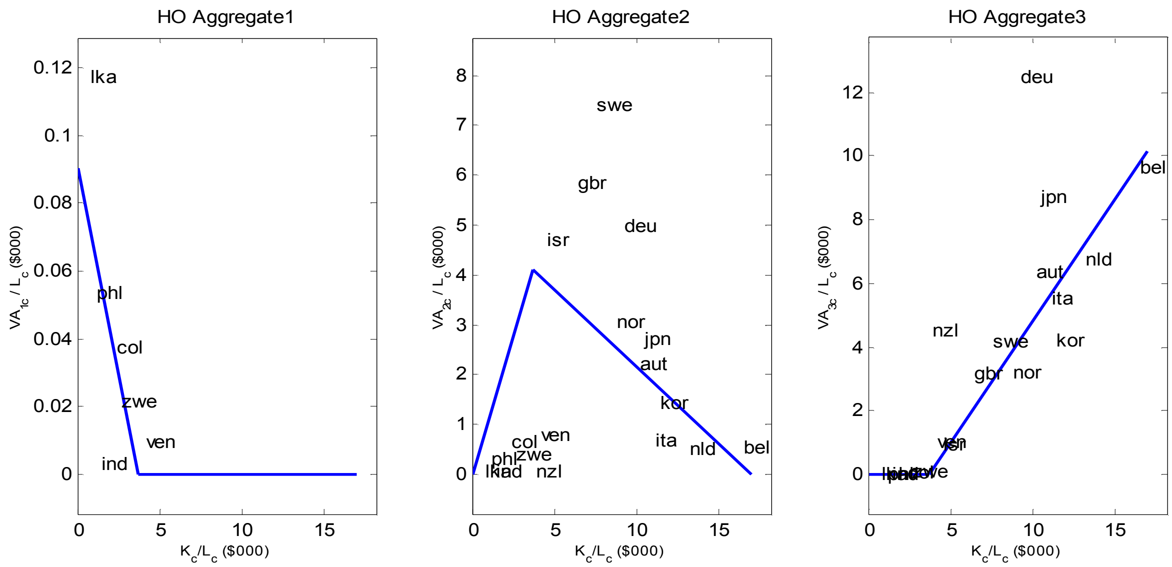


Figure 9: Separate Development Paths For Land Scarce and Land Rich Countries (Each Aggregate Plotted on Its Own Scale)

Land Scarce Countries



Land Abundant Countries

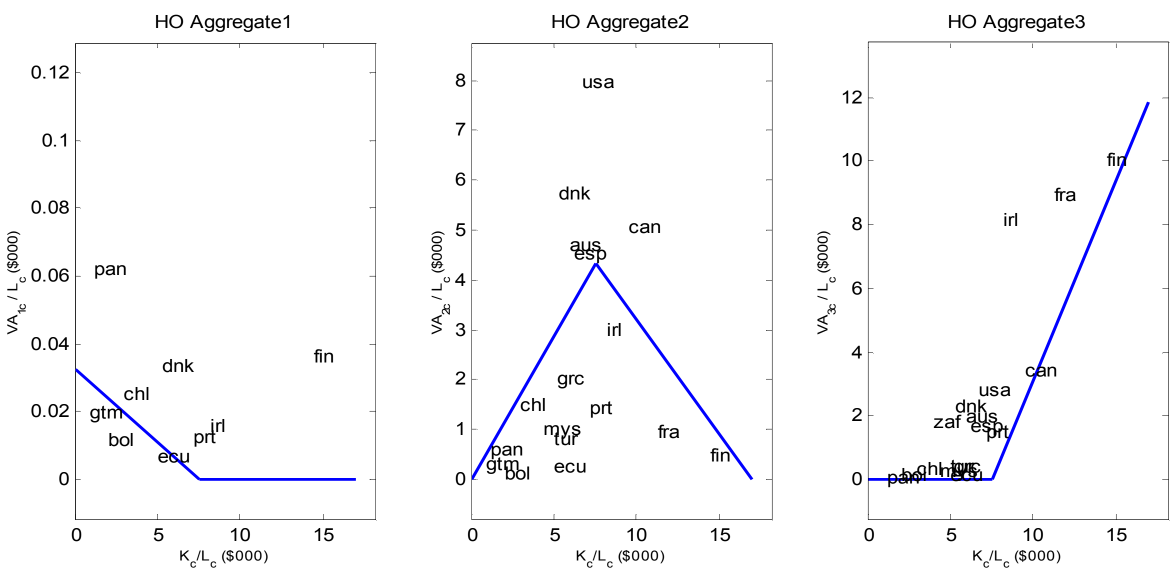


Figure 10: Examples of Country-Industry Pairs in Figure 8's HO Aggregates

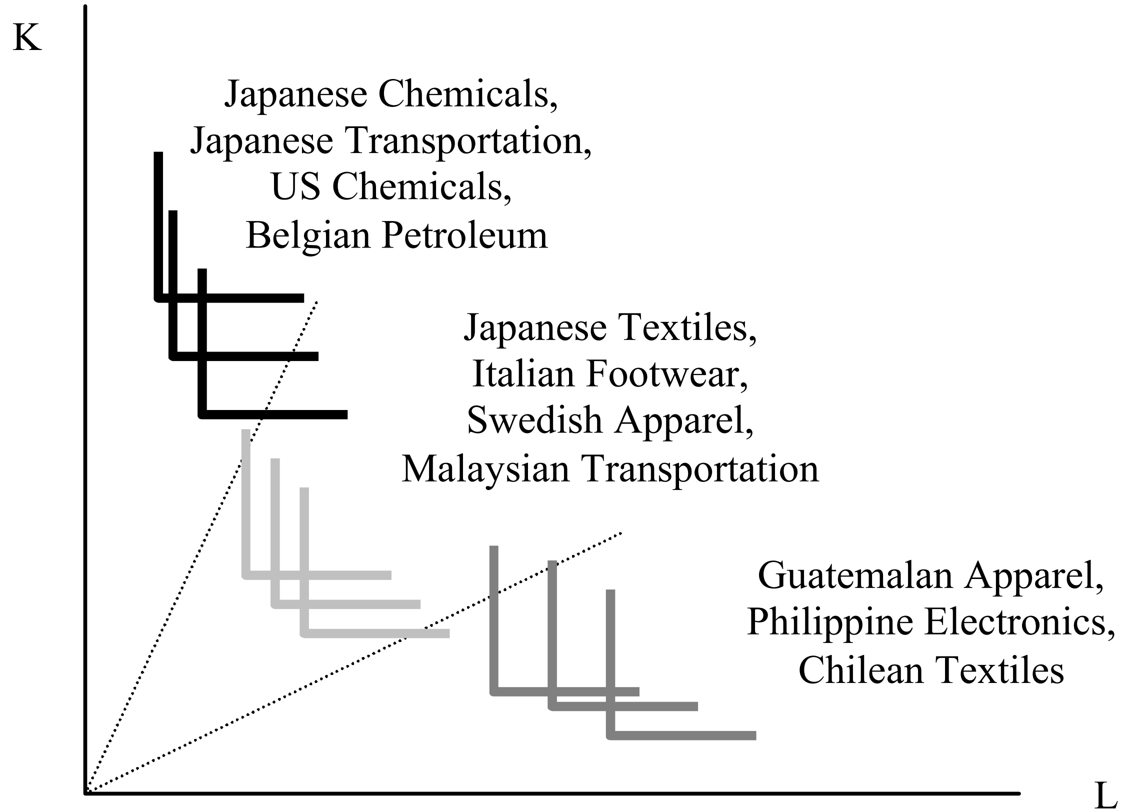


Table 1: Evidence of Multiple Cones

Cones	P-Value of LR Test	Posterior Odds Ratio (Alt vs Null)
1	-	-
2	<1%	2.1E+08
3	<1%	8.3E+10
4	<1%	7.7E+16
5	<1%	3.0E+10

Table 2: Sectoral Evidence for the Four-cone Alternate Hypothesis

ISIC	Aggregate	Posterior Odds Ratio (Alt vs Null)	ISIC	Aggregate	Posterior Odds Ratio (Alt vs Null)
341	Paper	15396335.46	381	Metal Products	0.56
331	Wood	4494.97	361	Pottery	0.45
369	Nonmetal Products	103.01	314	Tobacco	0.33
321	Textiles	85.77	311	Food	0.30
332	Furniture	64.38	385	Professional Equip	0.29
342	Printing	56.87	324	Footwear	0.27
352	Other Chemicals	32.04	351	Industrial Chemicals	0.27
355	Rubber	29.54	390	Other	0.12
382	Machinery	21.93	322	Apparel	0.04
313	Beverage	12.87	353	Petroleum Refining	0.04
362	Glass	12.21	371	Iron	0.03
383	Electrical Mach	3.75	372	Nonferrous Metals	0.02
384	Transportation	1.96			
323	Leather	1.19			
354	Petroleum	1.01			
356	Plastics	1.01			

Table 3: Summary of International Sectoral K/L Ratios ($US)

Sector	Min	Median	Max	Std/Mean	(Max-Min) /Std
Elec Mach	562	5,085	11,391	0.57	19
Nonmetal Prod	1,494	8,457	20,972	0.59	13
Plastics	616	6,229	14,895	0.63	23
Apparel	470	5,273	14,786	0.69	30
Metal Products	238	3,815	10,356	0.69	43
Other	93	2,850	9,313	0.71	99
Machinery	32	3,521	9,809	0.72	308
Tobacco	545	4,009	11,897	0.72	21
Food	500	10,653	27,398	0.72	54
Professional Equip	328	4,093	14,968	0.73	45
Glass	223	8,005	24,326	0.74	108
Printing	242	4,376	16,875	0.75	69
Other Chem	869	5,808	20,897	0.77	23
Textiles	138	1,136	4,905	0.79	34
Transportation Equip	145	4,376	19,007	0.82	130
Leather	157	2,112	9,438	0.83	59
Ind Chem	102	14,037	55,547	0.86	545
Nonferrous Metals	681	8,610	47,091	0.88	68
Wood	68	3,576	14,965	0.88	220
Paper	391	9,150	46,002	0.89	117
Pottery	422	3,127	16,962	0.90	39
Rubber	43	4,464	25,075	0.91	578
Petro-Coal Products	508	8,477	27,464	0.93	53
Iron	1,557	9,920	62,302	0.96	39
Petro Refining	393	36,655	218,219	1.00	555
Beverage	83	5,348	36,594	1.05	442
Furniture	48	2,270	16,360	1.15	339
Footwear	34	1,008	9,844	1.16	285

Table 4: Correlation of Country K/L Abundance with Machinery Value Added Shares

ISIC4	Sector	Corr
3829	Other, Non-Electrical Machinery	-0.70
3822	Agricultural Machinery	-0.12
3821	Engines	0.21
3823	Metal and Wood Working Machinery	0.48
3825	Office Computing and Accounting Mach	0.50
3824	Other, Special Industrial Machinery	0.73

Table 5: Single Cone Equilibrium versus Two and Three Cones, Via Bootstrapping

Model	Bootstrap P-Value
3 HO Aggregates / 2 Cones	<1%
4 HO Aggregates / 3 Cones	90%

Table 6: Sample Countries

OECD Code	Country	Abbrev	OECD Code	Country	Abbrev	OECD Code	Country	Abbrev
5850	Argentina	arg	1700	Greece	grc	2200	Norway	nor
700	Australia	aus	5230	Guatemala	gtm	5510	Panama	pan
1000	Austria	aut	6550	India	ind	6830	Philippines	phl
1100	Belgium	bel	1900	Ireland	irl	2300	Portugal	prt
5790	Bolivia	bol	6150	Israel	isr	4950	South Africa	zaf
5770	Brazil	bra	2000	Italy	ita	2400	Spain	esp
100	Canada	can	500	Japan	jpn	6570	Sri Lanka	lka
5830	Chile	chl	6170	Jordan	jor	2500	Sweden	swe
5630	Colombia	col	4650	Kenya	ken	6630	Thailand	tha
5490	Costa Rica	cri	6910	Korea	kor	2700	Turkey	tur
1300	Denmark	dnk	6750	Malaysia	mys	2800	UK	gbr
5730	Ecuador	ecu	4830	Mauritius	mus	5870	Uruguay	ury
1400	Finland	fin	5130	Mexico	mex	200	USA	usa
1500	France	fra	2100	Netherlands	nld	5650	Venezuela	ven
1600	Germany	deu	800	New Zealand	nzl	4730	Zimbabwe	zwe

Table 7: Three-digit ISIC Manufacturing Industries

ISIC	Industry	Abbreviation	Sample Products
311	Food	Fod	Slaughtering, Canning, Baking, Dairy
313	Beverage	Bev	Wines, Malts, Soft Drinks
314	Tobacco	Tob	Tobacco Products
321	Textiles	Tex	Spinning, Weaving, Knitted Fabrics
322	Apparel	App	Clothes, Furs Accessories
323	Leather	Lea	Leather Products
324	Footwear	Fot	Footwear Products Except Rubber
331	Wood	Wod	Sawmills, Planing, Veneers, Boxes
332	Furniture	Fur	Furniture Products
341	Paper	Pap	Pulp, Paper, Paperboard
342	Printing	Pri	Printing, Publishing, Photos
351	Industrial Chemicals	Ich	Chemicals, Fertilizers, Synthetic Resins, Plastics, Man Made Fibers
352	Other Chemicals	Och	Paints, Varnishes, Drugs, Soap
353	Petroleum Refining	Pet	Petroleum Refining
354	Petroleum, Coal Products	Coa	Briquettes, Coke
355	Rubber	Rub	Tires, Rubber Footwear
356	Plastics	Pla	Plastic Footwear, Dinnerware
361	Pottery	Pot	Ceramics
362	Glass	Gla	Glass Products
369	Nonmetal Products	Nme	Structural Clay Products, Cement, Lime, Stone
371	Iron	Iro	Basic Iron and Steel Products
372	Nonferrous Metals	Nfe	Precious and Primary Casting, Forging
381	Metal Products	Met	Cutlery, Hardware, Medical Fixtures, Pipes, Stoves
382	Machinery	Mch	Metal and Woodworking Machinery, Computers, Furnaces
383	Electrical Machinery	Ele	Electric Motors, Radios, TVs, Fuses, Batteries
384	Transportation Equipment	Tra	Autos, Planes, Ships, Bicycles
385	Professional Equipment	Pro	Surgical Dressings, Accelerators, Photographic, Optical, Clocks
390	Other	Oth	Jewelry, Toys