One Size Fits All? Heckscher-Ohlin Specialization in Global Production[*]

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This paper introduces a new technique for testing the Heckscher-Ohlin model that allows for the possibility that countries with sufficiently disparate endowments specialize in unique subsets of goods. Results based upon industry-level data reject one-size-fits-all homogeneity in favor of Heckscher-Ohlin specialization. Results also reveal that industry-level data hide substantial intra-industry heterogeneity, violating the assumptions of the model and complicating the interpretation of results from earlier research. A methodology for adjusting industry output to reflect underlying product variation is introduced. Re-estimation of the model using adjusted aggregates in place of ISIC industries provides strong support for Heckscher-Ohlin specialization. (JEL F11, F14, F2, C21)

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Existing attempts to find support for the idea that a country's endowments determine its production and trade have traditionally focused on the overly restrictive, “one size fits all” equilibrium of Heckscher-Ohlin (HO) trade theory.[1] This single-cone 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 electronics and apparel goods using the same techniques. But a second, far richer equilibrium is possible within the framework. This multiple-cone 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 satellites. Ignoring such specialization undermines efforts to find support for the HO model and can cloud our thinking about the response of wages to globalization. It also interferes with our ability to identify other determinants of global production, including cross-country differences in technology, factor efficiency and demand.

This paper introduces an empirical technique for testing the production implications of the factor proportions framework that can be used to differentiate single- from multiple-cone equilibria. This approach permits the effect of factor accumulation on a given sector’s output to vary with a country's endowments, allowing countries to move in

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[1] Exceptions include Edward E. Leamer (1987), Richard A. Brecher and Ehsan U. Choudhri (1993), Peter Debaere and Ufuk Demiroglu (2002) and Donald R. Davis and David E. Weinstein (2001), discussed further below.

and out of sectors as they develop. 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. By estimating the capital per labor cutoffs where changes in the derivative of output with respect to relative endowments take place, this technique can group countries according to the subset of goods they produce.

The first set of results, using a cross section of countries and ISIC industries, rejects the single-cone equilibrium in favor of the nested multiple-cone equilibrium. More importantly, it highlights the inadequacies of using coarse, industry-level data to test trade theory. In widely used classifications such as the ISIC, SITC and SIC, industries are defined as collections of goods sharing a similar end use. However, testing the key insight of Heckscher-Ohlin trade theory – that the factor intensity of goods produced by a country be similar to that country's relative endowments – requires grouping together products that are both close substitutes and manufactured with identical techniques. Traditional aggregates can fail on both counts. The three-digit ISIC aggregate Electrical Machinery, for example, includes both low-end portable radios and high-tech communications satellites. I show that three-digit ISIC manufacturing industries exhibit significant intra-industry variation in terms of both input intensity and price across countries. I interpret this variation as a signal of intra-industry product heterogeneity.

The presence of within-industry heterogeneity motivates introduction of an empirical methodology for recasting industry-level data into more theoretically appropriate “Heckscher-Ohlin aggregates”. When the model is re-estimated using these HO aggregates in place of actual ISIC industries, support for the idea that output is a function of endowments – that countries exhibit Heckscher-Ohlin specialization – is strong. Results indicate that the sample of developed and developing countries I examine are distributed across two cones of diversification in 1990, each producing a subset of manufactures.

In testing the production implications of the Heckscher-Ohlin model, this paper is most closely related to work by Leamer (1987), James Harrigan (1995, 1997), Harrigan and Egon Zakrajšek (2000), Jeffrey R. Bernstein and Weinstein (2002) and Stephen Redding (2002). It extends those efforts by focusing on the multiple-cone equilibrium and highlighting the role that industry-level data can play in obscuring production patterns. My emphasis on aggregation bias contrasts with Harrigan's (1997) focus on estimated industry-country technology differences, which may themselves be influenced by within-industry product heterogeneity. In this paper, deviations between raw and fitted data provide intuition for how factor efficiency may vary across countries and industries.

This paper's search for evidence of multiple cones of diversification also relates to tests of factor price equality, both across countries (Andrea Repetto and Jaime Ventura 1997) and across regions within countries (Gordon Hanson and Matthew Slaughter 2002; Andrew Bernard and Peter K. Schott 2001). The evidence I find in favor of Heckscher-Ohlin specialization is consistent with Repetto and Ventura's finding that relative wages vary inversely with capital abundance across countries.

This paper is also related to factor content tests of the Heckscher-Ohlin model (e.g. Harry P. Bowen et al 1987). A principal conclusion of these tests is that observed trade flows are small relative to the disparity in countries' endowments. Though these studies do not in principle rely upon a single-cone equilibrium, their typical use of the US input-output matrix as a proxy for all countries' production techniques works to suppress evidence of specialization: if labor-abundant countries produce labor-intensive goods within industries rather than the capital-intensive goods upon which US techniques are based, the true labor embodied in their trade will be underestimated.

Davis and Weinstein (2001) perform a less restrictive factor content test by allowing country-industry production techniques to vary with country endowments. Their results, which also allow for cross-country variation in demand, provide much stronger support for the factor proportions framework. One interpretation of their approach is that technique variation captures technology differences (Daniel Trefler 1995). An alternate interpretation from the perspective of this paper is that technique variation reflects intra-industry specialization.

Determining whether or not countries specialize is an important factor in gauging the current and future effects of globalization. In an open world economy, if high- and low-wage countries produce the same mix of (homogenous) goods, their workers compete directly: wage-price arbitrage mandates that a decline in the (world) price of labor-intensive goods – due to the reduction of trade barriers or the emergence of previously closed economies – forces wages down in all countries. However, if developed and developing countries specialize in distinct products, the link between wages in the two types of countries may be dampened depending upon the products' elasticity of substitution.

The paper proceeds as follows: Section I outlines the basics of the factor proportions framework and introduces the empirical specification designed to estimate it; Section II tests the model on traditional ISIC industries, highlights the inadequacy of those industries and develops an alternate "Heckscher-Ohlin" aggregation scheme; Section III re-estimates the model using the new aggregates; and Section IV concludes. Detailed descriptions of econometrics and data sources are reserved for appendixes.

I. Theory

A. Single versus Multiple-cone Equilibrium

A core implication of the Heckscher-Ohlin framework is that countries produce a mix of goods most suited 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 focuses on a single-cone equilibrium, where the word cone refers to the set of endowment vectors that select a particular mix of products. In this version of the model (e.g. two goods and two factors), 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

1 $$\mathbf{Aq} \leq \mathbf{v}\,,$$

where **A** is the (*F*x*I*) inputs per unit of output technology matrix, **q** is the (*I*x1) output vector, **v** is the (*F*x1) 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

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

where the elements of $\mathbf{A}^{-1}$ (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 multiple-cone equilibrium there are more goods than factors and countries specialize in 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.[3]

Framing the country's problem in terms of its dual, the (*F*x1) vector of factor rewards (**w**) can be found by minimizing the cost of GDP (**w′v**) subject to the zero profit condition

3 $$\mathbf{A}'\mathbf{w} \leq \mathbf{p}\,,$$

where **p** is the (*I*x1) vector of world prices. The wages associated with each mix of products (i.e. each cone of diversification) are then

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

Note that within a cone of diversification, factor rewards do not respond to changes in endowments, a condition referred to as factor price equalization or factor price insensitivity (Leamer 1995). Though partial equilibrium analysis suggests 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. Relative wages do adjust if factor accumulation moves a country from one cone to another.

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[2] As noted by Davis and Weinstein (2001), **q** can be interpreted as value added if we recognize that the resulting Rybczynski coefficients are net of intermediate inputs.

[3] The allocation of production across sectors within a cone may be indeterminate if prices are such that more goods than factors are tangent to a cone's isocost line. This "unevenness" is discussed further below.

With an additional assumption about demand,

A4 All individuals in all countries share identical homothetic preferences,

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

5 $$\mathbf{AN_c} = \mathbf{v_c} - s_c\mathbf{v_w}.$$

where $\mathbf{N_c}$ is the (Ix1) vector of country c's net exports, s_c is country c's share of global output and $\mathbf{v_w}$ is the (Fx1) 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 standard approach to testing the trade implications of the model (e.g. Bowen et al 1987) is to examine the strength of the equality in equation (5). 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 an Abba P. Lerner (1952) diagram of a two-factor, four-industry 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. 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 per 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 (Alan V. Deardorff 1974; Leamer 1984).[4] 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 segments where country c does not produce industry i (e.g. where the derivative of output with respect to endowments is zero).

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

Figure 1 also indicates that capital accumulation moves countries 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 isocost lines under perfect competition (assumption A2). One such isocost line, tangent to Machinery and Textiles, is present in the diagram. 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 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 a decline in world price of apparel. Indeed, their real wages rise. If the US and labor-abundant countries were to occupy the same cone, however, declines in the world price of labor-intensive goods adversely affect US workers' wages.

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 can be used to evaluate model performance.

B. Estimating Two-Factor Development Paths

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),

$$\frac{Q_{ic}}{L_c} = \alpha_{1i} + \alpha_{2i}\frac{K_{ic}}{L_c} + \varepsilon_{ic}. \tag{6}$$

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 (e.g. Harrigan 1995).

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,

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

where $\tau_t \in (1, T-1)$ represents the capital-labor ratio of the t^{th} estimated interior knot and $\mathrm{I}\{.\}$ 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 (i.e. a spline for each industry's development path).[5]

In the first estimation below I estimate equation (7) on a cross section of forty-five countries and twenty-eight three-digit ISIC industries 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 $\left(\tau_{it} = \tau_t \forall t \in \left(1, T-1\right)\right)$. Estimation also constraints the line segments of each development path to meet at the knots. In practice, I estimate the location of interior knots by gridding over all possible combinations of T knots for a given interval size, using a grid interval of \$500.[6]

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. As noted in the Statistical Appendix, these hypotheses can also be evaluated via posterior odds ratios, or Bayes Factors. Conceptually equivalent to Gideon Schwarz (1978) and Hirotugu Akaike (1981) criteria, odds ratios have a natural degrees of freedom correction that accounts for the increase in parameters in moving from a null hypothesis with $2I$ parameters to an alternate hypothesis with $2IT+T$ parameters. An odds ratio 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.

An advantage of the empirical specification developed in this section is that it tests a well-defined alternative hypothesis against a well-defined and nested null hypothesis.

C. What if There Are More than Two Factors or Cones are "Uneven"?

With three or more factors of 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 ratio than land-scarce countries. In a three-factor model that includes land (Z), the correct specification of equation (7) is

8 $$\frac{Q_{ic}}{L_c} = \sum_{t=1}^{T+1} \beta_{1it} \mathrm{I}_t \left\{ \frac{K_c}{L_c}\left(\frac{Z_c}{L_c}\right) > \tau_t\left(\frac{Z_c}{L_c}\right) \right\} + \beta_{2it} \frac{K_c}{L_c} \mathrm{I}_t \left\{ \frac{K_c}{L_c}\left(\frac{Z_c}{L_c}\right) > \tau_t\left(\frac{Z_c}{L_c}\right) \right\} + \varepsilon_{ic},$$

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[5] In the estimations below, τ_0 is assumed to be zero while τ_T is assumed to be \$67,000, the upper range of the sample countries' observed capital-labor ratios.

[6] Sensitivity analysis using grid values ranging from \$100 to \$2000 does not change results substantially. Note that a narrower grid can only increase evidence against the null of a single-cone model.

where both the location of knots and industry slopes are functions of land abundance (Z_c/L_c).

Though existing empirical research has demonstrated the importance of factors beyond capital and labor in influencing countries' production patterns (Leamer 1984), estimation of equation (8) is quite difficult and not pursued here. Instead, in Section III I follow Leamer (1987) and rely upon a shortcut that splits countries according to a third endowment, either land or education per worker, and estimate separate splines for each cohort.[7] In that procedure, the splines' knots as well as their derivatives of output with respect to the capital-labor endowment ratio vary with a third endowment.

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 (e.g. two factors with three isoquants tangent to the cone's isocost line). In that case, countries in the same cone may nevertheless arbitrarily produce a different subset of goods, and specialization is therefore not a violation of the single-cone equilibrium. 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 and be produced using the same techniques. Evidence presented below suggests that both conditions are violated by traditional aggregation schemes.

D. What is an Industry?

Before proceeding with the estimation it is useful to consider the manner in which industries are defined. Though aggregation bias has been a concern since Bela Balassa (1966), surprisingly little attention has focused on the appropriateness of industry classifications for testing trade theory.[8]

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 in the factor proportions framework. Reconciling the two requires two additional assumptions:

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

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

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[7] Employing this technique for ISIC industry data in Section II is impractical given the large number of estimated knots. It is also less desirable given the need to correct for the coarseness of ISIC industries.

[8] Attempts to surmount the problems of industry coarseness do exist. Leamer (1984), for example, groups two-digit SIC industries into factor-use groups and shows that relative net exports among these groups respond to country-factor accumulation over a fifteen-year time period. That effort is in the spirit of earlier work by Balassa (1966), J. Michael Finger (1975) and Antonio Aquino (1978), who attempt to devise alternate output aggregation schemes to unravel the determinants of intra-industry trade. In related work, David Dollar et al (1988) note the wide disparity of industry capital intensities across countries.

The virtue of aggregating goods according to end use rather than input intensity, of course, is that they are more likely to be substitutes (e.g. white cotton tube socks made by hand versus white cotton tube socks made by machine). Estimations in Section II rely upon assumptions A6 and A7. These assumptions are relaxed in Section III.

II. Estimating the Multiple-Cone Model using ISIC Industries

A. Data

Estimations rely upon value added, capital stock and employment data for up to forty-five countries across twenty-eight three-digit ISIC manufacturing industries in 1990. Country capital-labor ratios are from Keith E. Maskus (1991) while economy-wide labor statistics are from the World Bank. As indicated in Table 1, the country sample incorporates both developed and developing countries; as noted above, this diversity is important for identifying specialization.

Industry data are from the United Nations Industrial Development Organization (UNIDO 1995). One drawback of focusing on manufacturing is that it precludes testing whether disparities in skill or natural resource endowments lead to specialization across broader areas of an economy, such as services, mining and agriculture (Leamer 1984). On the other hand, manufacturing aggregates may contain fewer non-tradables than these other sectors, so that their actual development paths may more closely resemble the theoretical archetypes described above. Table 2 summarizes 1990 industry value added per total labor force (Q_{ic}/L_c) for each country by three-digit ISIC industry. This table documents large variation in production across countries within industries and across industries within countries. These data are displayed in Figure 3 and discussed further below.

As noted above, the estimations in Section III also control for additional endowments. Data on cropland and forestland endowments are from the World Bank, while data on skill (i.e. education attainment) are from Robert J. Barro and Jong-Wa Lee (1994). Skilled workers are defined as those attaining at least a secondary education.

B. Estimation Using ISIC Industries

Table 3 reports the results of estimating equation (7) using the sample of countries and industries described in the previous section. The table summarizes the relative fit of the single-cone hypothesis versus nested alternative hypotheses of up to five cones of diversification.[9] Because estimation of the alternative hypothesis for each model involves computing parameter estimates for all possible combinations of T knots, computational constraints prevent estimating more than five cones in any reasonable amount of time. This limitation is not too important given that estimation of the five-cone model is

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[9] Coefficient estimates and standard errors are not reported to conserve space but are available from the author upon request. The estimation in this section does not control for endowments other than capital and labor.

sufficient for rejecting the single-cone model for both of measures of fit (classical p-values and posterior odds ratios).

The results in Table 3 indicate rejection of the single-cone model. The first column reports p-values for a classical likelihood ratio (LR) test of single versus multiple cones. The single-cone equilibrium is rejected at the 99% level of significance for all alternate hypotheses. The posterior odds ratios reported in the third column favor the five-cone model. These odds ratios assess the relative fit of alternate hypotheses after correcting for the increase in parameters associated with adding cones of diversification (see Statistical Appendix for more detail). While the single-cone model has 2I parameters, a multiple-cone model (i.e. $T>0$) has $2IT+T$ parameters.

Figure 3 plots the favored five-cone development path for each industry over the underlying output (Q_{ic}/L_c) versus capital abundance (K_c/L_c) data for each industry. Information in the upper right-hand corner of each plot identifies the industry. Industries are ordered in terms of increasing capital intensity from left to right, and down, according to maximum observed capital per worker.[10] 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 across and down the matrix.

Figure 3 reveals that estimated development paths deviate substantially from the theoretical archetypes of Figure 2. Many sectors, including Apparel (2,4) and Footwear (1,3), exhibit positive value added per worker in more than two cones. As a result, re-estimating the model on "super-industries" formed by summing industries with similar factor intensity – in an effort to reduce the number of industries and non-parametrically control for arbitrary production – is unlikely to bring estimates closer to theory because output will remain positive for all countries.

On the other hand, estimated development paths do contain hints of underlying specialization. Labor-abundant countries produce relatively little of the most capital-intensive sectors. In addition, the oft-changing relationship between output and endowments in most industries is suggestive of the sort of movement in and out of sectors implied by the multiple-cone model. In particular, the twin-peaked development paths of the Transportation, Food, Electrical Machinery and Machinery industries, all of which lie along the lowest row of the matrix, appear to separate 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), Textiles (4,1), Plastics (4,2) and Industrial Chemicals (6,1).

Figure 4 demonstrates theoretically how twin-peaked development paths can result from grouping goods with different capital intensities into the same ISIC aggregate, a violation of assumption A7. The left panel of this figure traces out an Electronics development path where just two goods – portable radios and satellites – are combined into a single industry. The right panel illustrates the more general point that combining a

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[10] Details on the computation of industry-country capital-labor ratios are provided in the Data Appendix.

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. This insight, combined with the results of the simple estimation in this section, motivates an inquiry into the appropriateness of industry-level data for testing trade theory.

C. Evidence of Cross-Country, Intra-Industry Heterogeneity

The extent to which input intensity varies by industry across countries is illustrated in Figure 5. The height of each bar in the plot represents the capital intensity (K_{ic}/L_c) of a given industry for a given country. The country-industry capital stocks used to construct these intensities are computed using the perpetual inventory method on UNIDO (1995) gross fixed capital formation data (see Data Appendix for more detail).

Countries in the figure are sorted in order of increasing capital abundance from Sri Lanka (LKA) to Belgium (BEL), while ISIC industries are ordered in terms of average capital intensity from Apparel (322) to Petroleum (353). The vertical scale of the plot is censored at \$60,000 to provide a clearer view of all sectors.

If countries produced identical goods, 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 (across industries) capital intensity rankings are not uniform. Second, within-industry (across countries) capital intensity rankings vary substantially: Germany's Apparel sector, for example, is almost 13 times as capital-intensive as Colombia's.

An alternate view of this dispersion is provided by Table 4, which reports the minimum, median and maximum capital intensity for each industry in US dollars along with two measures of dispersion,

$$\frac{\text{Std}(k_{ic})}{\text{Mean}(k_{ic})} \text{ and } \frac{\text{Max}(k_{ic}) - \text{Min}(k_{ic})}{\text{Min}(k_{ic})}, \tag{9}$$

where $k_{ic} = K_{ic}/L_c$ is the capital intensity of country c in ISIC 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.

Examination of output across four-digit ISIC industries also confirms the existence of product mix heterogeneity. Table 5, for example, lists the correlation of country capital abundance and four-digit ISIC production shares within the three-digit ISIC Machinery aggregate.[11] 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

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[11] The four-digit data originates from the same source as the three-digit data (i.e. UNIDO 1995) but cannot be used in the estimations in the previous section because country coverage is too sparse. 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.

machinery and agricultural machinery) while capital-abundant economies tend to manufacture the rest.

Heterogeneity is also evident in alternate datasets. Perhaps the most useful in this regard is the product-level NBER Trade Database collected by the US Census and packaged by Robert C. Feenstra (1996). These data identify the origin, value and quantity of roughly 16,000 US import products from 1972 through 1994, thereby allowing the calculation of unit values. Schott (2001) reports a strong correlation between unit value and source country endowments within manufacturing products. In 1994, for example, the US imported men's cotton shirts from half of its 162 trading partners. The unit values of these shirts range from \$56 (Japan) to \$1 (Senegal). The correlation of unit value with country capital abundance is 0.56 and is significant at the 99% confidence level. The difference in the US price of goods emanating from capital-abundant versus capital-scarce countries is strong evidence that the two groups of countries produce different goods. As a result, they likely define distinct isoquants.

In addition to pointing out the need for moving beyond industry-level data to test international specialization, the heterogeneity documented in this section highlights the potential problems of using industry-level data to explore other violations of HO 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). Indeed, part of observed cross-country variation in total factor productivity or factor efficiency may be driven by differences in intra-industry product mix.

III. Estimating the Multiple-Cone Model using "HO Aggregates"

To overcome the limitations of ISIC industry data noted in the previous section I now introduce a procedure to recast the data into more theoretically appropriate "Heckscher-Ohlin aggregates". Using HO aggregates in place of ISIC industries complicates estimation of the model but yields strong support for Heckscher-Ohlin specialization.

A. Constructing "HO Aggregates"

Relax assumption *A7* and use instead

A7' The further apart country capital intensities are within an ISIC industry, the more likely the countries are to be producing different goods.

To form more theoretically appropriate HO aggregates out of ISIC industries, I rank the *CI* country-industry capital intensities displayed in Figure 5 in ascending order and split them into groups. Let X_{nc} denote value added of HO aggregate *n* in country *c* and k_{ic} represent the capital intensity of ISIC aggregate *i* in country *c*. X_{nc} is the sum of *n*'s value added in all its ISIC aggregates with capital intensity between the maximum and minimum capital intensity for that aggregate, or

10 $$X_{nc} = \sum_{k_{ic} \in (k_{n-1}, k_n]} Q_{ic} \, ,$$

where k_{n-1} and k_n are the capital intensity cutoffs for aggregate n. Because we can create as many aggregates as we like, this technique is used below to preserve evenness within cones, i.e. $T=N-1$.

Forming aggregates in this way 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.

This assumption guarantees that the relationship between derived aggregates and country endowments remains as described in Section I. 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 less stringent than the assumption about prices underlying every estimation using ISIC industries. Thus, the HO aggregates described here are superior to three-digit ISIC industries in terms of similarity of input intensity and no worse in terms of price heterogeneity.

It is important to note that there is nothing about the procedure for forming HO aggregates that renders verification of the multiple-cone model a foregone conclusion. Assuming full employment, country c's capital-labor ratio is by definition a labor-weighted average of the capital per labor ratios in each of its I industries, or

$$\frac{K_c}{L_c} \equiv \frac{\sum_{i \in I} L_i \frac{K_i}{L_i}}{\sum_{i \in I} L_i}, \tag{10}$$

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. The estimation undertaken in the next section is a structurally-motivated, non-parametric assessment of this similarity.

B. Estimating Development Paths Using HO Aggregates

Use of HO aggregates complicates estimation of equation (7) in several ways. First, two sets of cutoffs must be estimated in addition to the slopes and intercepts of the development path. The first set of cutoffs, as in Section II, are the T knots defining cones. The second set of cutoffs are the $N=T+1$ boundaries defining the number of HO aggregates. A two-cone, three-HO aggregate development path, for example, requires estimating two capital-intensity cutoffs to define the three HO aggregates and one capital-intensity knot to define the two cones in addition to the slopes and intercepts defining the HO aggregates' development paths. Mechanically, the development paths are estimated by choosing slopes and intercepts via maximum likelihood for all combinations of knots and HO aggregate cutoffs.

Second, the shape of each development path is constrained as implied by theory in Figure 2. The first segment of the development path of the most labor-intensive HO aggregate, for example, must have a negative slope and hit the *x*-axis at the location of the first estimated knot; additional segment(s) of this development path are constrained to lie along the *x*-axis. These constraints on development path shape were not imposed in the estimation in Section II because of the large number of industries relative to the number of factors, and because of the suspicion of within-industry product heterogeneity.

Finally, allowing the number of HO aggregates to vary with the number of cones breaks the nesting of single- and multiple-cone models: 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, bootstrapping must be used to construct confidence intervals for comparing the single- and multiple-cone estimations (Bradley Effron and Robert J. Tibshirani 1993).[12]

Table 6 summarizes the fit of single- and multiple-cone models using HO aggregates. It reports Bootstrap p-values for the two- and three-cone equilibria versus the null hypothesis of a single-cone equilibrium. This estimation does not control for endowments other than capital and labor. As indicated in the table, there is strong evidence for the two-cone model but little evidence for three cones. These results imply that the product mixes of the most and least capital-abundant countries in the sample are different, but that all countries produce the moderately capital-intensive, middle HO Aggregate.

The intercepts, slopes, knots and HO aggregate cuttoffs of the optimal development path are reported in Table 7. This table also lists the theory-mandated constraints imposed on the shape of each development path. Maximum likelihood indicates that the three HO aggregates are defined by capital intensity cutoffs of \$500 and \$3000 and the knot between cones is \$18,000.[13]

Figure 6 plots the estimated development path for each HO aggregate under the favored two-cone equilibrium. In the figure, HO aggregates are ordered by increasing capital intensity from left to right, and each country observation with positive value added of an aggregate (i.e. $X_{nc}>0$) is identified by its corresponding three-letter World Bank code. Confidence intervals (95%) for positively- or negatively-sloped segments of each development path provide a sense of the precision with which they are estimated.

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[12] Mechanically, these confidence intervals are 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 is used to select bootstrap p-values for the relative fit of the two hypotheses using the original data. (See Statistical Appendix for a more detailed discussion of the algorithm used.)

[13] This estimation does not yield traditional standard errors for the HO aggregate cutoffs or the knots. Examination of the distribution of model fit across cutoffs reveals that it is fairly flat, indicating that they are relatively imprecisely estimated.

All OECD countries in the sample inhabit the more capital-intensive cone, a result which suggests that workers in capital-abundant countries may be somewhat insulated from price declines of the world's most labor-intensive manufacturing products. This result is consistent with research by Harrigan (2000) showing that US producer prices did not fall substantially as a result of the Asian financial crisis, which lowered the world price of many labor-intensive goods.

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 6 reveals that very few of the most capital-abundant countries produce the first HO Aggregate. Finland, Ireland and Denmark stand out, predominantly because of Finland's relatively labor-intensive footwear sector and Ireland's and Denmark's relatively labor-intensive leather sector; these results may be driven by protectionism. The global Multifiber Arrangement, for example, places quantitative restrictions of developing country exports of apparel and textile products to developed countries.

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 jumping into capital- intensive sectors 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 estimations in this paper do not control for cross-country variation in technology. Nevertheless, the distribution of countries around the estimated development paths may provide an indication of how technology varies across HO aggregates and countries. Germany, for example, has higher-than-expected capital-intensive aggregate production, a result that is consistent with its reputation for efficiency as well as its relative abundance of skilled workers.

In the middle aggregate, the US, Australia and Canada are clear outliers. These three countries also have the highest land-labor ratios, which suggests that land may influence their development paths. To attempt to account for this influence, I estimate separate development paths for countries above and below the median of cropland and forestland per worker. As noted earlier, separate estimation of equation (7) for subsets of countries allows development paths knots as well as their slopes to vary with a third endowment.

Figure 7 plots the results of this estimation and indicates that countries with less than median land abundance exit the labor-intensive HO aggregate at a lower capital-labor ratio than land-abundant countries.[14] This outcome is consistent with the observation that land abundance retards growth (e.g. Charles I. Jones and Robert E. Hall 1999). Leamer et

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[14] Estimated coefficients are not reported to conserve space but are available from the author upon request. The capital per labor cutpoints defining HO aggregates are the same in the upper and lower panels of Figure 7 but different than the optimal cutpoints in Figure 6.

al (1999), for example, argue that the sectors associated with natural resource abundance absorb capital that might otherwise flow into manufacturing, depressing workers' incentives to accumulate skill and delaying industrialization.[15]

Finally, Figure 8 provides a feel for the country-ISIC industry pairs that make up each of the three HO aggregates in Figure 6. This figure reveals that a relatively labor-intensive ISIC industry for Sweden, like Apparel, is combined with a relatively capital-intensive ISIC industry for the Philippines, 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 country's choice between producing these sectors is arbitrary. This arbitrariness is almost certainly not the case in the real world, but imposing it is useful for gaining insight into the multiple-cone equilibrium.[16]

IV. Conclusion

Existing tests of the Heckscher-Ohlin model generally focus on the single-cone equilibrium in which all countries produce all goods using the same technique. This paper introduces a new empirical methodology for testing the much richer multiple-cone equilibrium in which countries specialize in subsets of goods depending upon their relative endowments.

Results based upon standard, industry-level data reject the single-cone model but highlight potential heterogeneity of output within industries across countries. Further analysis reveals that the capital intensity of three-digit ISIC manufacturing industries varies substantially across countries, which is interpreted as a signal of intra-industry product variation. I develop a technique to recast ISIC industries into more theoretically appropriate HO aggregates, and use these aggregates to test the model. Doing so provides strong support for international specialization.

Understanding the extent of international specialization is important for gauging the impact of international trade on high- and low-wage economies. If all countries inhabit a single cone of diversification, the wages of all workers are adversely affected by declines in the world price of labor-intensive goods. However, if high- and low-wage countries specialize in non-overlapping sets of goods, this price-wage arbitrage may be reduced, or broken, depending upon the substitutability of goods.

The techniques introduced in this paper are quite useful for gaining insight into international specialization, but they stretch industry-level data about as far as it can go.

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[15] A similar experiment with respect to education (not reported but available from the author) indicates that countries with higher skill intensity tend to enter capital-intensive sectors earlier than those with lower levels of education.

[16] Leamer (1998) finds that the prices of industries with similar input intensities tend to move together over time. This observation provides some justification for the grouping of different ISIC industries into HO aggregates pursued here.

Further progress is more likely to result by applying them to newly available, product-level international trade data.

A. Data Appendix

I. Country Information

Country capital per labor endowments are from Maskus (1991). Country labor and land endowments are from the World Bank (2000). Data on education attainment are from Barro and Lee (1994). I define skilled workers as those who have attained at least secondary education.

II. Industry Information

Value added, employment and gross fixed capital formation data by country and three-digit ISIC manufacturing industry are from the United Nations Industrial Development Organization (UNIDO 1995).

Three digit ISIC-country capital stocks are constructed using the perpetual inventory method. Due to missing information, it is not possible to compute capital stocks for all industries and countries in the sample. To compute the 1990 capital stock of industry 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 are estimated non-parametrically; results are in general not sensitive to the particular way in which this is done. A table of capital intensity by country corresponding to Figure 5 is available from the author upon request.

B. Statistical Appendix

I. Spline Estimation on Existing Three-Digit ISIC Aggregates

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

A1 $$[y_{1c}, \ldots, y_{Ic}] = \mathbf{x}'_{\mathbf{c}}[\pi_1, \ldots, \pi_I] + [\varepsilon_{1c}, \ldots, \varepsilon_{Ic}],$$

where $\mathbf{y}_c$ is 1xI vector of output, $\mathbf{x}_c$ is the (2+T)x1 vector of independent variables, $\boldsymbol{\pi}$ is the (2+T)xI vector of slopes and $\boldsymbol{\varepsilon}_c$ is the 1xI vector of output measurement errors. Note that there are $\kappa_c=2+T$ 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 $\mathbf{y_c}$ given $\mathbf{x_c}$ is

A2 $$f(\mathbf{y_c} \mid \mathbf{x_c}) = (2\pi\sigma^2)^{I/2} \exp^{-(\boldsymbol{\varepsilon}'_{\mathbf{c}}\boldsymbol{\varepsilon}_{\mathbf{c}})/2\sigma^2}.$$

The likelihood of output across all countries, $\mathbf{Y}$, given the set of explanatory variables $\mathbf{X}$, is

A3 $$f(\mathbf{Y} \mid \mathbf{X}) = \prod_{c \in C} f(\mathbf{y_c} \mid \mathbf{x_c}) = \prod_{c \in C} (2\pi\sigma^2)^{I/2} \exp^{-(\boldsymbol{\varepsilon}'_{\mathbf{c}}\boldsymbol{\varepsilon}_{\mathbf{c}})/2\sigma^2},$$

which yields the log likelihood (L)

A4 $$L = \log f(\mathbf{Y} \mid \mathbf{X}) = -\frac{IC}{2}\log(2\pi) - \frac{C}{2}\log|\boldsymbol{\Sigma}_{\mathbf{c}}| - \frac{1}{2}\sum_{c \in C} \boldsymbol{\varepsilon}'_{\mathbf{c}}\boldsymbol{\Sigma}_{\mathbf{c}}\boldsymbol{\varepsilon}_{\mathbf{c}},$$

where $\boldsymbol{\Sigma}_{\mathbf{c}}$ is $E(\boldsymbol{\varepsilon}'_{\mathbf{c}}\boldsymbol{\varepsilon}_{\mathbf{c}})$. As is well known, this expression can be reduced to the concentrated log likelihood

A5 $$L = -\frac{IC}{2}\log(2\pi) - \frac{C}{2}\log|\boldsymbol{\Psi}|,$$

where $\boldsymbol{\Psi} = \frac{\boldsymbol{\varepsilon}'_{\mathbf{c}}\boldsymbol{\varepsilon}_{\mathbf{c}}}{C}$. If industries are independent, then

A6 $$\log|\boldsymbol{\Psi}| = \sum_{i \varepsilon I} \log\frac{ESS_i}{C},$$

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

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 equations (A5) and (A6) reveals that this test statistic is equal to

A7
$$LR = C\left(\left(\sum_{i\varepsilon I}\log\frac{ESS_i}{C}\right)_{Null} - \left(\sum_{i\varepsilon I}\log\frac{ESS_i}{C}\right)_{Alternate}\right).$$

A more informative comparison of the alternate versus null models, however, accounts for the latter's increased number of parameters. This comparison is accomplished in a Bayesian framework via an odds ratio, or Bayes factor. For diffuse conjugate priors on all parameters

A8
$$\begin{gathered}\beta \sim N\left(b^*, \left(\sigma^2\right)^{-1} N^{*-1}\right) \\ \sigma^2 \sim \Gamma\left(s_1^2, \upsilon_1\right)\end{gathered},$$

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

A9
$$\begin{aligned} f(Y) &= \iint f\left(Y \mid \beta, \sigma^2\right) f\left(\beta, \sigma^2\right) d\beta d\sigma^2 \\ &= k(\upsilon_1, C)\left|\frac{M}{s_1^2}\right|^{1/2}\left(\upsilon_1 + \frac{Q}{s_1^2}\right)^{-(\upsilon_1 + C)/2}, \end{aligned}$$

where

A10
$$\begin{gathered} M = I_T - X\left(N^* + X'X\right)^{-1} X' \\ k(\upsilon_1, C) = \frac{\upsilon_1^{\upsilon_1/2}\left(\frac{\upsilon_1}{2} + \frac{C}{2} - 1\right)!}{\pi^{C/2}\left(\frac{\upsilon_1}{2} - 1\right)!} \end{gathered}.$$

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

A11
$$\frac{f\left(y \mid H_{Alt}\right)}{f\left(y \mid H_{Null}\right)} \cong A\frac{\left(\kappa_{Null} - \kappa_{Alt}\right)}{2}\log(C) + \frac{C}{2}\left(\log\left(ESS_{a,Null}\right) - \log\left(ESS_{a,Alt}\right)\right),$$

where κ is the number of parameters and *i* indexes industries. 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) that 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 (1973).

II. Estimating Development Paths Using HO Aggregates

A direct comparison of the single- versus multiple-cone equilibria involves comparing non-nested hypotheses where the dependent variable is formed from different subsets of the underlying country-ISIC industry value added 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 industry 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_c represents the regressors in equation (7).

3 Use the drawn country-HO aggregate outputs to compute an *ICx1* vector of country-ISIC sector outputs, Q_{ic}^{*}, where $Q_{ic}^{*} = s_{ic} X_{nc}^{*}$ and s_{ic} is recovered from the original data (i.e. $s_{ic} = Q_{ic} / X_{nc}$).

4 Use the Q_{ic}^{*} to compute output in N^{*} HO aggregates, denoted X_{nc}^{**}, where $X_{nc}^{**} = \sum_{k_{ic} \in (k_{n-1}, k_n]} Q_{ic}^{*}$.

5 Estimate the fit of the alternate hypothesis of N^{*} HO aggregates and N^{*}-*1* cones using the procedure outlined in Section III.

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, Four-Good Lerner Diagram

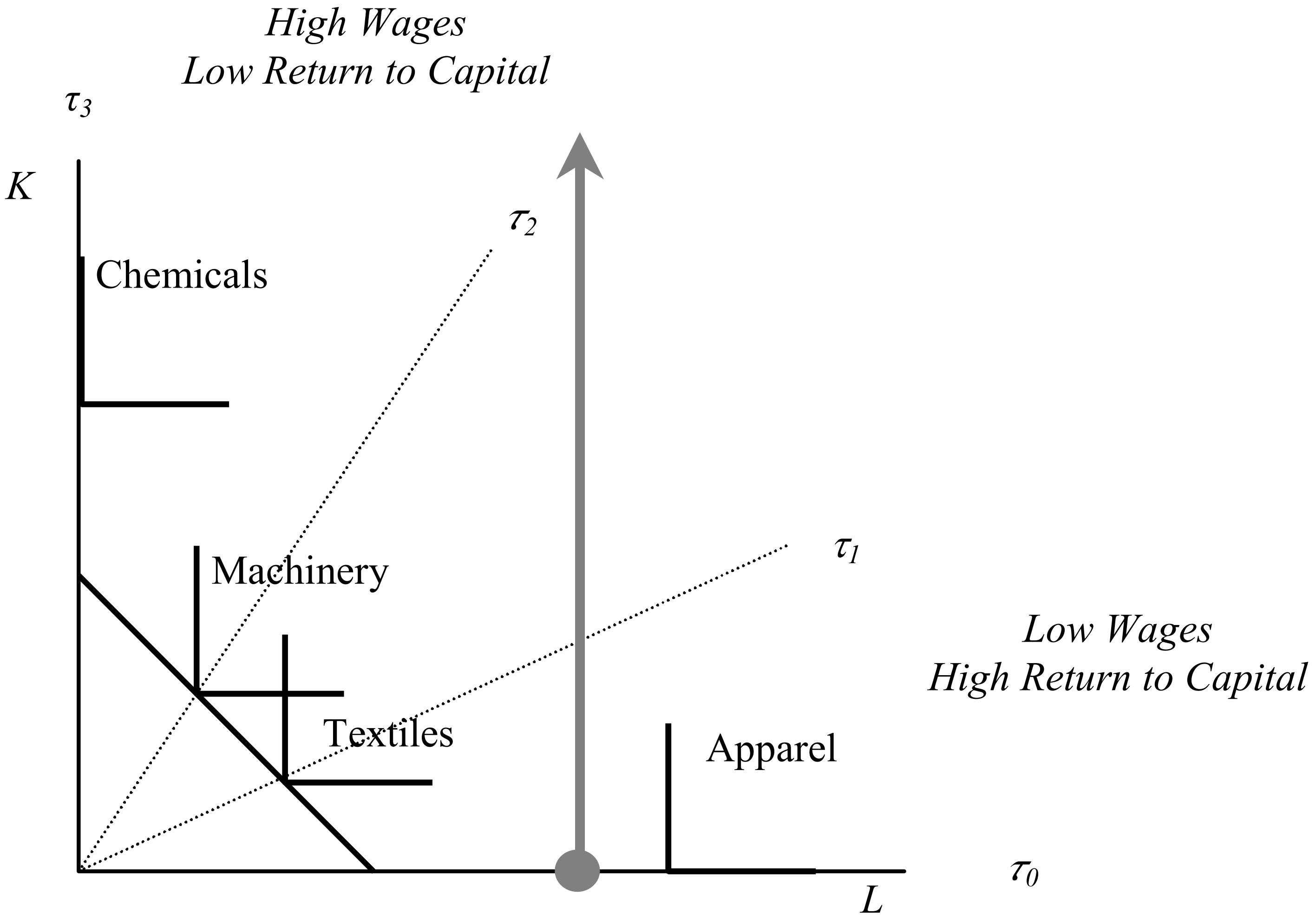
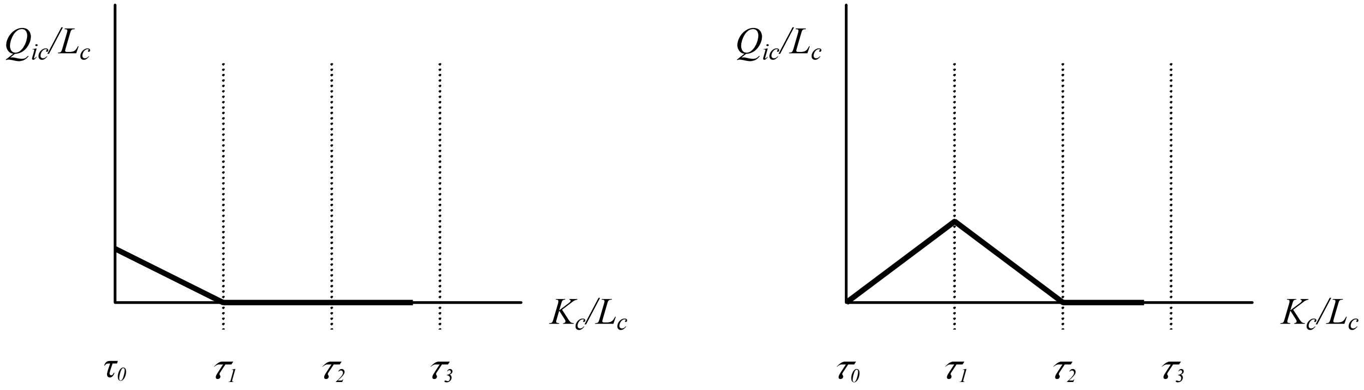
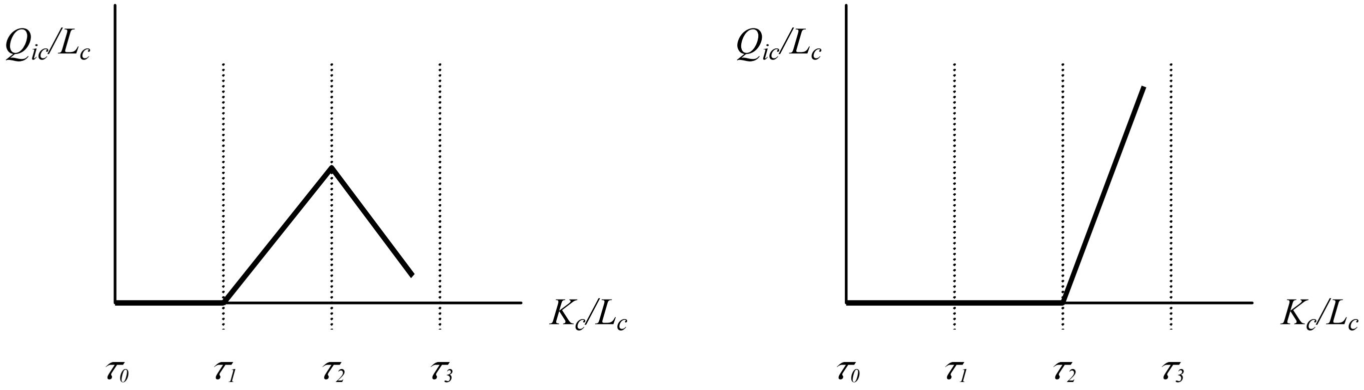


Figure 2: Industry Development Paths Implied by Figure 1



Panel A: Apparel Production

Panel B: Textile Production



Panel C: Machinery Production

Panel D: Chemical Production

Figure 3: Estimated Development Paths (Equation 7) Using 1990 ISIC Industry Data

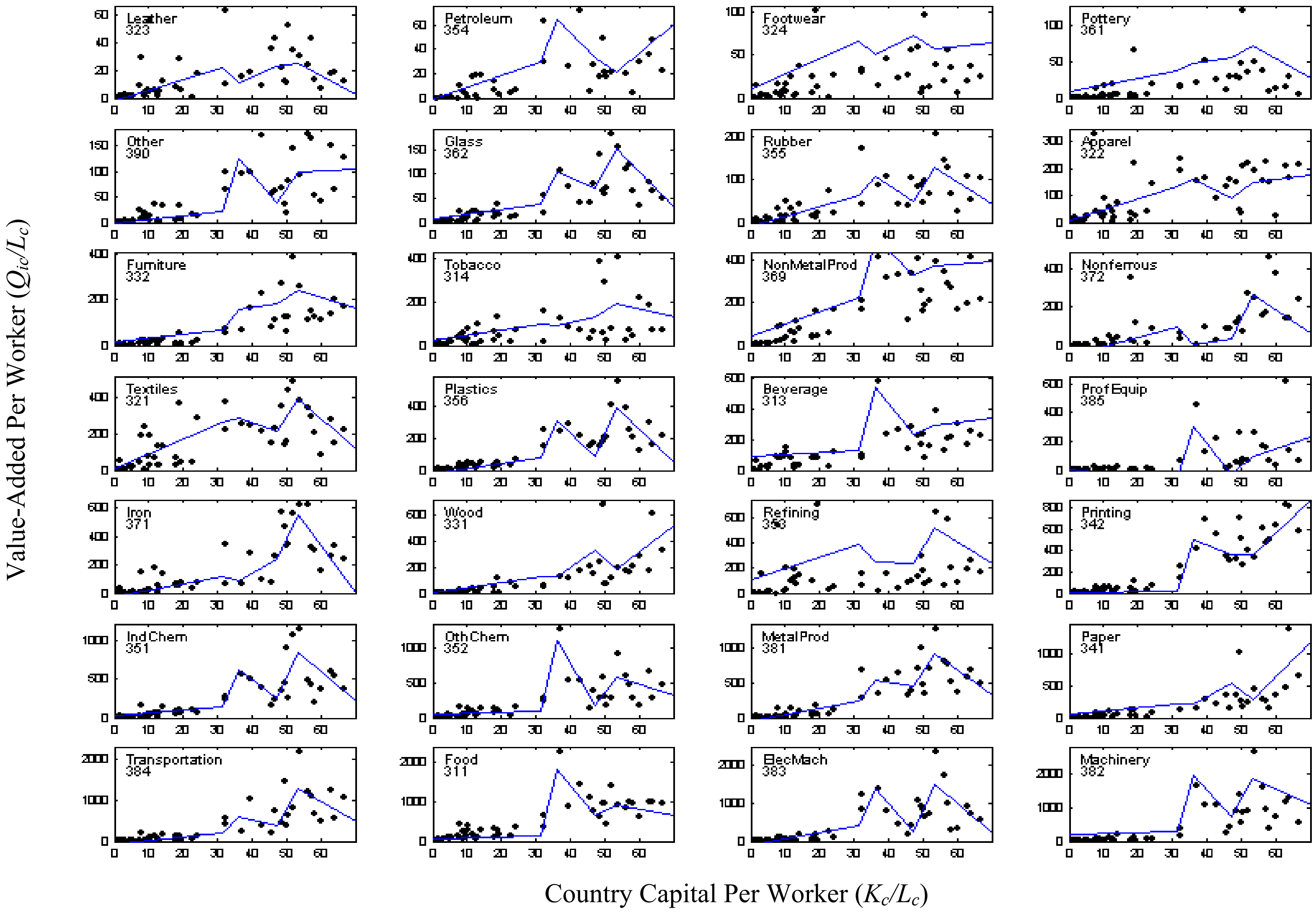


Figure 4: Potential Development Paths Under ISIC Aggregation

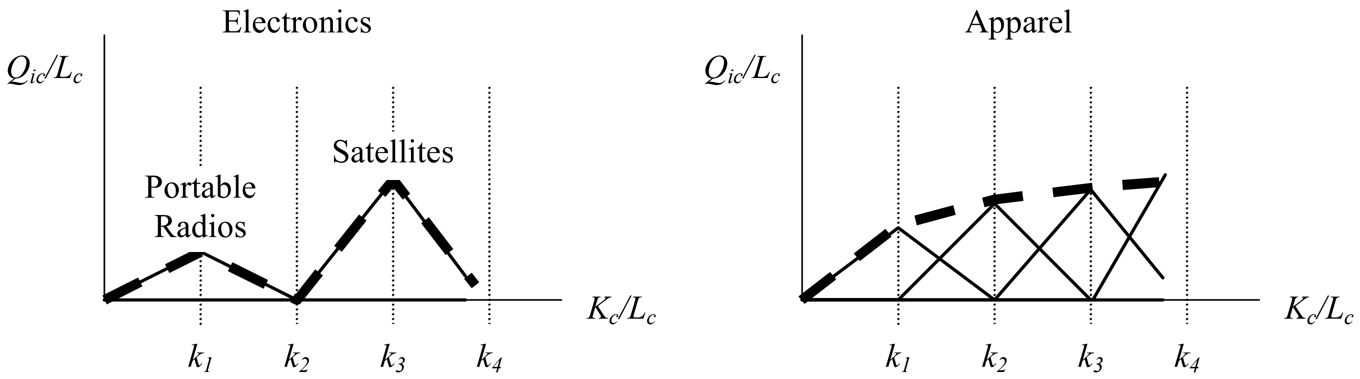
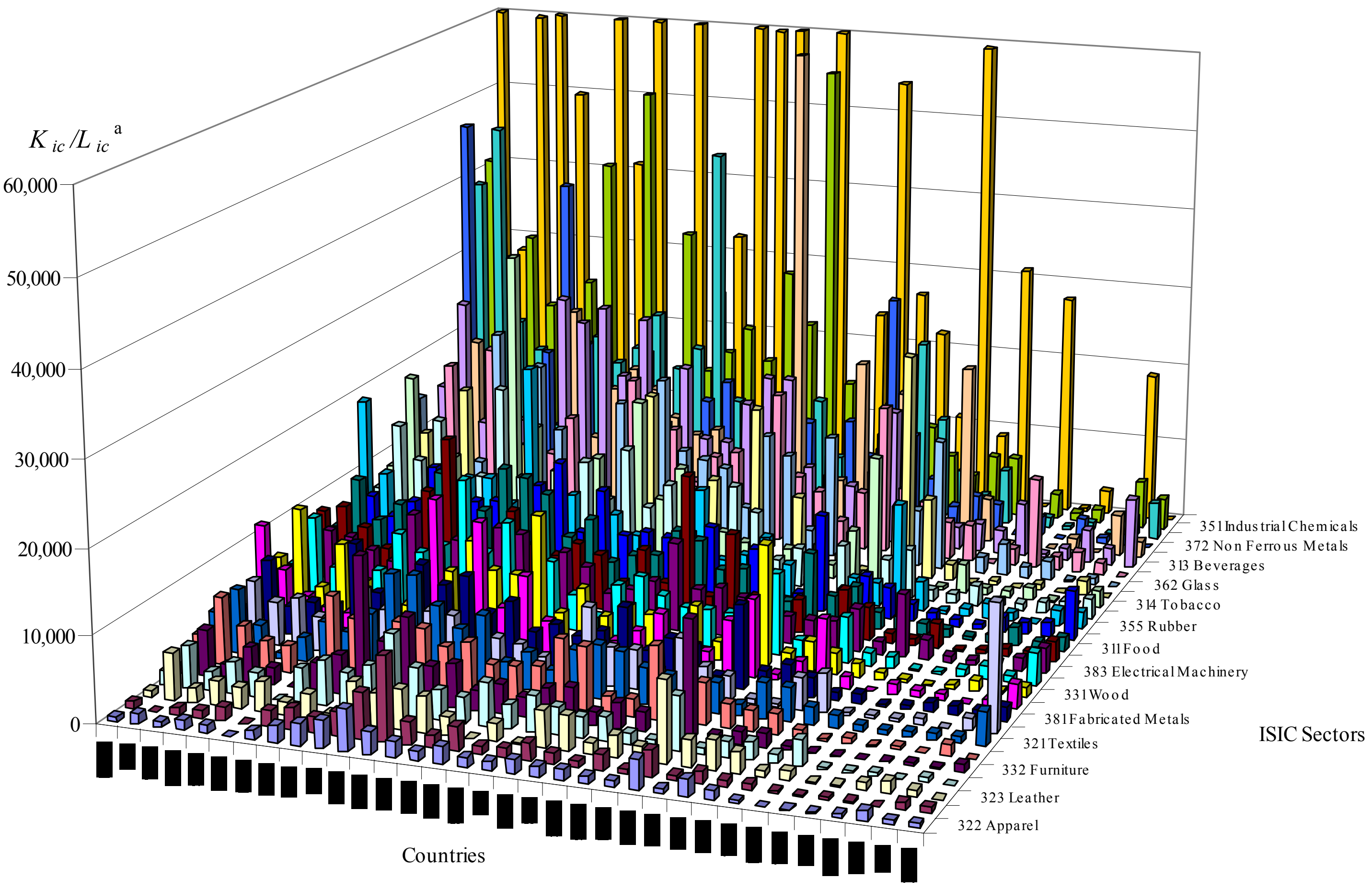
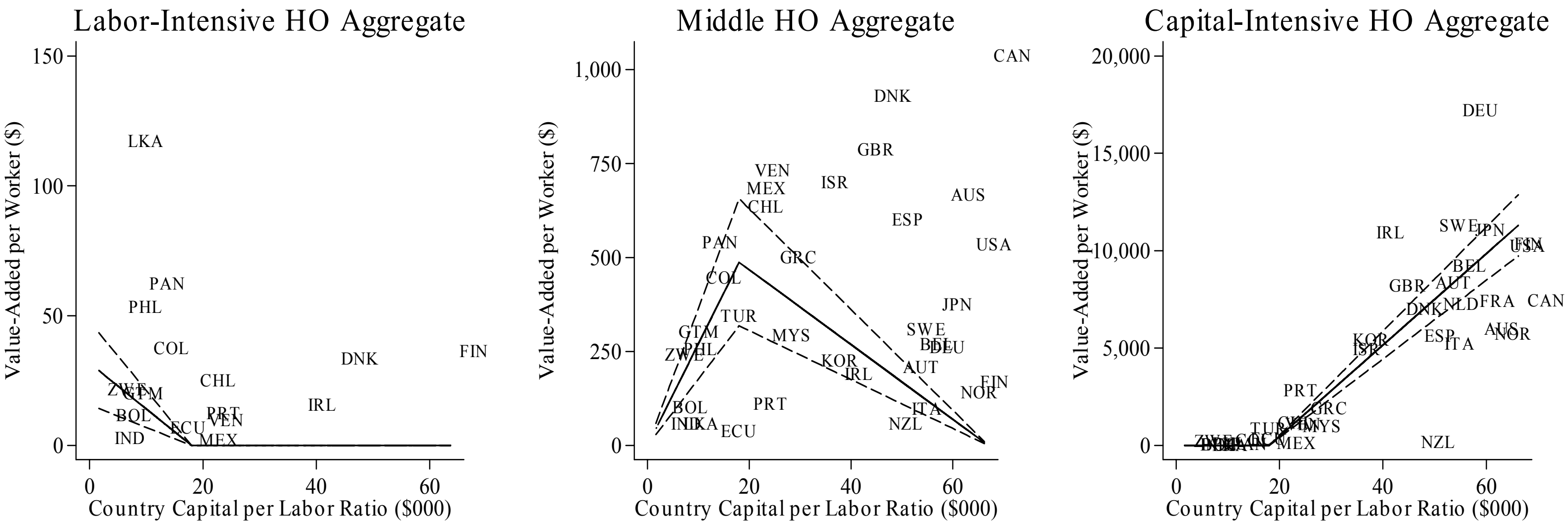


Figure 5: Country-ISIC Industry Capital Intensity, 1990



Notes: Labels for every second ISIC industry are suppressed to promote readability. [a]Vertical scale is censored at $60,000.

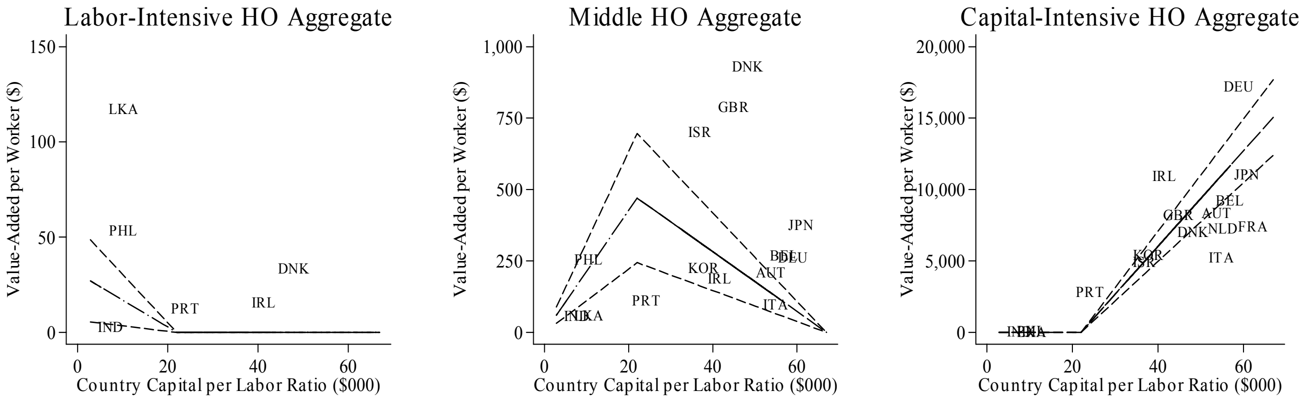
Figure 6: Estimated Development Paths Using HO Aggregates



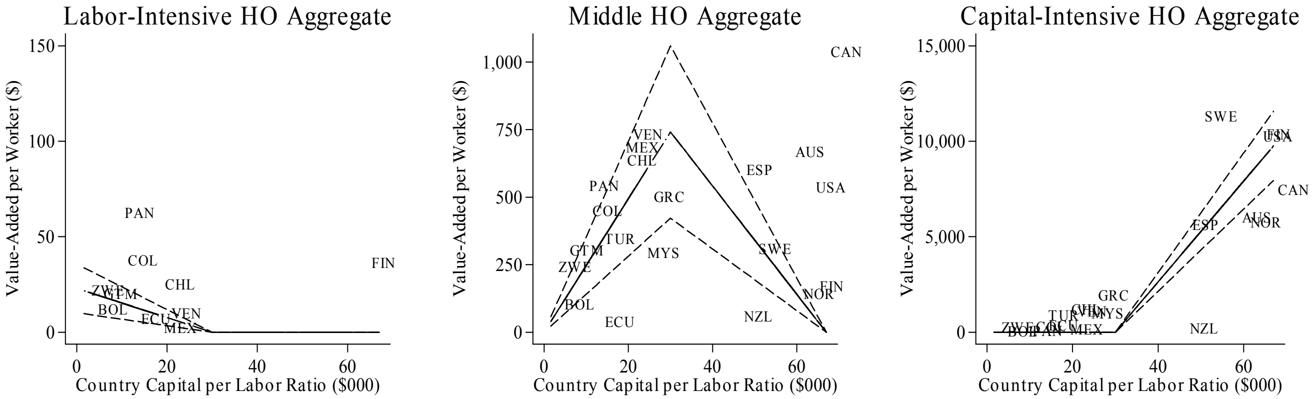
Notes: Panels report estimated development paths for the preferred three-HO-aggregate development path from Tables 6 and 7. Dashed lines represent the 95% confidence interval.

Figure 7: Separate HO Aggregate Development Paths for Land Scarce and Land Abundant Countries

Land-Scarce Countries (Below Median)



Land-Abundant Countries (Above Median)



Notes: Panels report estimated development paths separately for land-scarce and land-abundant countries under the preferred three-HO-aggregate development path from Table 6. Dashed lines represent the 95% confidence interval.

Figure 8: HO Aggregate Country-ISIC Industry Pairs in Preferred Three-HO-Aggregate Development Path (Figure 6)

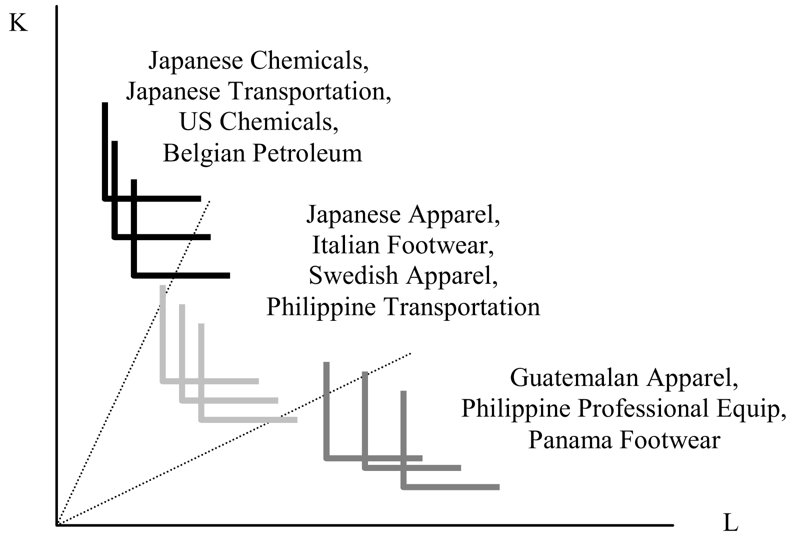


Table 1: 1990 Capital per Worker Endowments and World Bank Codes of Sample Countries

Country	Abbreviation	K_c/L_c (\$000)	Country	Abbreviation	K_c/L_c (\$000)	Country	Abbreviation	K_c/L_c (\$000)
Argentina	ARG	8	Greece	GRC	24	Norway	NOR	60
Australia	AUS	58	Guatemala	GTM	4	Panama	PAN	9
Austria	AUT	48	India	IND	3	Philippines	PHL	5
Belgium	BEL	52	Ireland	IRL	37	Portugal	PRT	19
Bolivia	BOL	3	Israel	ISR	32	South Africa	ZAF	12
Brazil	BRA	14	Italy	ITA	50	Spain	ESP	46
Canada	CAN	66	Japan	JPN	56	Sri Lanka	LKA	5
Chile	CHL	18	Jordan	JOR	13	Sweden	SWE	49
Colombia	COL	10	Kenya	KEN	1	Thailand	THA	9
Costa Rica	CRI	10	Korea	KOR	32	Turkey	TUR	13
Denmark	DNK	43	Malaysia	MYS	23	UK	GBR	39
Ecuador	ECU	13	Mauritius	MUS	7	Uruguay	URY	10
Finland	FIN	64	Mexico	MEX	18	USA	USA	63
France	FRA	57	Netherlands	NLD	50	Venezuela	VEN	19

Germany	DEU	54	New Zealand	NZL	46	Zimbabwe	ZWE	2

Notes: Data are in thousands of U.S. dollars. Capital per worker endowments are from Maskus (1991).

Table 2: Value Added per Worker (Q_{ic}/L_c) by Country and Industry, 1990

ISIC3 Industry	ARG	AUS	AUT	BEL	BOL	BRA	CAN	CHL	COL
311 Food	414	941	628	1401	46	274	958	320	124
313 Beverages	82	212	229	163	23	30	222	78	88
314 Tobacco	42	45	387	75	2	16	74	63	16
321 Textiles	195	206	352	497	8	135	224	69	77
322 Apparel	43	150	149	220	1	72	213	34	21
323 Leather	30	13	22	34	2	13	12	8	6
324 Footwear	17	34	58	13	4	37	25	25	9
331 Wood	23	213	240	121	5	35	337	56	5
332 Furniture	22	127	271	389	0	31	169	11	4
341 Paper	78	160	364	251	1	68	660	116	28
342 Printing	61	499	317	404	5	46	579	47	20
351 Industrial Chemicals	162	204	348	1080	1	143	363	51	49
352 Other Chemicals	158	282	292	289	7	144	472	128	57
353 Petroleum	535	204	133	93	150	139	171	100	14
354 Coal	11	4	18	21	na	19	22	14	3

355 Rubber	32	67	85	66	0	43	105	15	12
356 Plastic	38	209	149	413	3	54	219	37	21
361 Pottery	14	9	30	36	0	5	5	2	6
362 Glass	22	65	141	183	1	15	49	11	11
369 Mineral Products	82	267	402	210	13	77	211	45	32
371 Iron	145	299	570	555	0	141	244	59	27
372 Non Ferrous Metals	27	466	119	275	5	45	243	356	5
381 Fabricated Metals	142	518	691	712	2	88	487	76	26
382 Machinery	74	378	898	922	0	205	572	35	12
383 Electrical Machinery	90	303	1071	731	1	164	563	26	26
384 Transportion Equipment	189	662	451	802	1	147	1066	32	32
385 Professional Equipment	10	61	60	68	0	25	70	2	7
390 Misc Manufacturing	9	55	68	145	4	32	129	3	8

ISIC3 Industry	CRI	DEU	DNK	ECU	ESP	FIN	FRA	GBR	GRC
311 Food	280	931	1422	71	761	1006	984	886	349
313 Beverages	123	388	264	10	284	260	207	234	123

314 Tobacco	30	411	71	0	64	69	74	84	72
321 Textiles	31	386	213	29	234	151	295	248	287
322 Apparel	31	192	90	3	158	167	224	165	143
323 Leather	5	31	9	1	43	19	43	19	18
324 Footwear	7	38	23	2	55	36	55	45	26
331 Wood	21	201	170	5	153	616	161	113	45
332 Furniture	21	257	224	3	108	201	153	160	24
341 Paper	43	439	219	11	148	1406	263	283	70
342 Printing	32	334	556	8	311	825	481	692	75
351 Industrial Chemicals	32	1157	386	5	242	535	419	500	75
352 Other Chemicals	48	910	537	23	396	276	479	525	162
353 Petroleum	34	640	41	116	95	263	583	156	56
354 Coal	0	na	72	1	27	47	na	26	7
355 Rubber	16	209	43	5	105	52	129	106	22
356 Plastic	34	564	222	13	173	166	257	291	71
361 Pottery	3	51	25	2	31	29	na	52	19
362 Glass	11	156	40	3	80	63	119	74	13

369 Mineral Products	34	392	329	19	339	411	290	318	166
371 Iron	na	625	98	6	266	332	325	285	72
372 Non Ferrous Metals	1	252	25	1	90	142	175	98	90
381 Fabricated Metals	19	1276	642	14	384	687	774	529	116
382 Machinery	13	2688	1065	1	406	1310	956	1060	46
383 Electrical Machinery	32	2363	460	10	422	715	992	788	114
384 Transportion Equipment	16	2196	394	7	729	549	1102	1020	126
385 Professional Equipment	na	261	217	1	27	134	158	129	4
390 Misc Manufacturing	4	93	171	1	61	66	166	98	12

ISIC3 Industry	GTM	IND	IRL	ISR	ITA	JOR	JPN	KEN	KOR
311 Food	103	7	2275	671	411	77	853	21	339
313 Beverages	28	1	587	80	86	37	132	8	106
314 Tobacco	8	1	123	18	24	99	26	1	157
321 Textiles	20	10	259	222	442	26	346	5	383
322 Apparel	7	1	153	235	209	17	152	1	191
323 Leather	1	0	16	10	53	5	24	0	64

324 Footwear	3	0	14	30	95	4	19	1	33
331 Wood	3	0	126	64	69	5	179	1	49
332 Furniture	2	0	64	72	124	18	112	1	55
341 Paper	6	2	141	132	166	27	285	4	119
342 Printing	14	1	416	258	264	16	613	2	142
351 Industrial Chemicals	11	6	562	274	253	58	487	1	234
352 Other Chemicals	42	5	1274	231	170	56	598	6	276
353 Petroleum	2	3	23	63	73	72	62	1	161
354 Coal	0	0	na	63	17	0	20	0	29
355 Rubber	11	2	88	42	96	1	146	3	172
356 Plastic	9	1	246	257	205	22	394	2	153
361 Pottery	2	0	21	16	122	4	38	0	15
362 Glass	3	0	107	20	72	4	108	0	56
369 Mineral Products	13	3	415	168	184	112	341	4	207
371 Iron	9	8	68	62	347	32	621	1	347
372 Non Ferrous Metals	0	2	7	33	76	12	153	na	67

381 Fabricated Metals	9	2	348	675	343	31	805	5	288
382 Machinery	2	6	1658	153	870	12	1619	0	393
383 Electrical Machinery	7	6	1364	1208	641	15	1713	4	845
384 Transportion Equipment	2	7	229	408	622	1	1223	3	574
385 Professional Equipment	1	0	453	69	75	3	164	0	64
390 Misc Manufacturing	1	0	98	66	81	2	176	2	99

ISIC3 Industry	LKA	MEX	MUS	MYS	NLD	NOR	NZL	PAN	PHL
311 Food	39	78	130	119	969	604	1101	250	97
313 Beverages	19	79	93	28	241	305	142	79	36
314 Tobacco	25	24	36	18	297	221	29	31	19
321 Textiles	13	27	46	41	161	88	152	7	17
322 Apparel	23	8	331	39	38	27	133	35	22
323 Leather	0	na	9	1	11	7	36	3	1
324 Footwear	3	7	5	1	12	5	27	6	1
331 Wood	1	2	8	81	77	286	212	5	7
332 Furniture	0	2	7	10	58	109	83	7	5

341 Paper	3	25	6	21	260	364	363	55	8
342 Printing	2	6	20	37	516	638	353	33	6
351 Industrial Chemicals	2	81	19	103	897	375	163	7	12
352 Other Chemicals	5	66	17	32	296	182	139	48	34
353 Petroleum	17	na	0	27	176	90	90	na	22
354 Coal	na	6	0	4	21	29	6	5	0
355 Rubber	6	17	3	73	46	27	41	2	7
356 Plastic	1	14	11	36	209	129	150	27	5
361 Pottery	3	5	0	5	49	12	11	0	1
362 Glass	1	22	0	10	57	36	41	8	4
369 Mineral Products	4	35	17	61	163	167	117	22	11
371 Iron	1	64	7	40	338	160	74	2	10
372 Non Ferrous Metals	0	25	na	9	na	382	91	2	5
381 Fabricated Metals	2	34	23	44	466	362	315	19	7
382 Machinery	1	27	6	48	570	735	223	1	4
383 Electrical Machinery	1	55	8	268	848	347	171	3	34
384 Transportion Equipment	4	121	6	68	395	475	212	5	11

385 Professional Equipment	0	3	21	13	49	38	16	4	1
390 Misc Manufacturing	2	3	26	15	18	41	56	18	4

ISIC3 Industry	PRT	SWE	THA	TUR	URY	USA	VEN	ZAF	ZWE
311 Food	294	956	74	104	393	974	180	173	51
313 Beverages	77	167	93	37	150	172	87	82	64
314 Tobacco	133	58	55	48	75	183	41	6	16
321 Textiles	373	140	237	132	195	284	43	66	54
322 Apparel	222	45	35	39	92	207	24	55	21
323 Leather	28	12	2	2	56	18	6	6	2
324 Footwear	102	6	2	3	16	19	13	25	14
331 Wood	120	685	6	8	16	169	5	36	9
332 Furniture	52	124	22	3	11	137	10	24	7
341 Paper	130	1018	0	23	42	465	41	94	14
342 Printing	118	710	7	18	68	838	27	59	20
351 Industrial Chemicals	97	446	5	62	56	597	66	73	24
352 Other Chemicals	108	573	10	60	134	664	98	98	27

353 Petroleum	na	298	na	186	198	185	703	97	na
354 Coal	na	49	na	19	1	36	3	17	na
355 Rubber	12	87	16	19	48	109	21	31	8
356 Plastic	53	177	30	13	54	303	32	44	10
361 Pottery	66	28	2	19	17	15	3	3	1
362 Glass	39	66	3	22	17	82	16	23	2
369 Mineral Products	163	254	93	56	36	195	43	62	11
371 Iron	61	472	14	58	25	258	74	182	39
372 Non Ferrous Metals	18	144	0	24	3	142	117	50	3
381 Fabricated Metals	186	1001	20	37	60	572	50	132	28
382 Machinery	119	1401	65	58	18	1179	27	111	9
383 Electrical Machinery	188	905	85	61	58	913	36	75	18
384 Transportion Equipment	131	1453	29	72	107	1252	29	133	17
385 Professional Equipment	8	262	2	4	16	622	6	12	1
390 Misc Manufacturing	32	35	17	3	12	152	8	35	3

Notes: Data are in U.S. dollars and are computed using UNIDO (1995) data. *Na*=not available.

Table 3: Evidence of Multiple Cones Using Equation (7) and ISIC Industry Data

Cones	Likelihood Ratio Test P-Value	Posterior Odds Ratio
1	-	-
2	<1%	1.80E-08
3	<1%	1.05E-09
4	<1%	3.55E-03
5	<1%	1.05E+01

Notes: Table reports results of testing null hypothesis of a single-cone model against alternate multiple-cone hypotheses of up to five cones. Sample includes 45 countries and 28 three-digit ISIC manufacturing industries. Posterior odds ratios greater than unity indicate superior performance of the alternate hypothesis after accounting for changes in degrees of freedom. See text and Statistical Appendix for more detail. Estimated development paths for the favored five-cone model are plotted in Figure 3.

Table 4: Variation in Country-ISIC Industry Capital Intensity, 1990

Sector	Min	Median	Max	Std/Mean	(Max-Min) /Min
383 Electrical Machinery	562	5,085	11,391	0.57	19
369 Mineral Products	1,494	8,457	20,972	0.59	13
356 Plastic	616	6,229	14,895	0.63	23
322 Apparel	470	5,273	14,786	0.69	30
381 Fabricated Metals	238	3,815	10,356	0.69	43
390 Misc Manufacturing	93	2,850	9,313	0.71	99
382 Machinery	32	3,521	9,809	0.72	308
314 Tobacco	545	4,009	11,897	0.72	21
311 Food	500	10,653	27,398	0.72	54
385 Professional Equipment	328	4,093	14,968	0.73	45
362 Glass	223	8,005	24,326	0.74	108
342 Printing	242	4,376	16,875	0.75	69
352 Other Chemicals	869	5,808	20,897	0.77	23
321 Textiles	138	1,136	4,905	0.79	34
384 Transportation Equipment	145	4,376	19,007	0.82	130

323 Leather	157	2,112	9,438	0.83	59
351 Industrial Chemicals	102	14,037	55,547	0.86	545
372 Non Ferrous Metals	681	8,610	47,091	0.88	68
331 Wood	68	3,576	14,965	0.88	220
341 Paper	391	9,150	46,002	0.89	117
361 Pottery	422	3,127	16,962	0.90	39
355 Rubber	43	4,464	25,075	0.91	578
354 Coal	508	8,477	27,464	0.93	53
371 Iron	1,557	9,920	62,302	0.96	39
353 Petroleum	393	36,655	218,219	1.00	555
313 Beverages	83	5,348	36,594	1.05	442
332 Furniture	48	2,270	16,360	1.15	339
324 Footwear	34	1,008	9,844	1.16	285

Notes: Table reports variation in ISIC industry-country capital intensity (K_{ic}/L_{ic}) across countries in 1990. Columns two through four are in U.S. dollars. Industries are sorted according to column 5 in ascending order. Industry capital stocks are computed using the perpetual inventory method on industry gross fixed capital formation data available from UNIDO (1995). See text and Data Appendix for further detail.

Table 5: Correlation of 1990 Country Capital Abundance and Four-Digit ISIC Value Added Shares, Machinery

Four-Digit ISIC Industry	Correlation
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

Notes: Table reports correlation of country capital per worker ratio and country four-digit ISIC Machinery value added shares. Industry data are from UNIDO (1995); country capital per labor ratios are from Maskus (1991). Industries are sorted by correlation.

Table 6: Evidence of Multiple Cones Using Equation 7 and HO Aggregates

Model	Bootstrap P-Value
3 HO Aggregates / 2 Cones	<1%
4 HO Aggregates / 3 Cones	98%

Notes: Table reports results of testing null hypothesis of a single-cone model against non-nested alternate hypotheses of up to three cones of diversification using HO aggregates in place of ISIC industry data. Models are evaluated via bootstrap p-values. See text and Statistical Appendix for further detail on the construction of HO aggregates and bootstrap p-values.

Table 7: Coefficient Estimates for the Preferred Two-Cone, Three-HO-Aggregate Development Path

Coefficient	Labor Intensive HO Aggregate	Middle HO Aggregate	Capital Intensive HO Aggregate
β_{11}	29	-	-
	(7.2)		
β_{21}	-1.3	24.6	-
	(0.3)	(3.9)	
β_{12}	-	805.3	-5770.5
		(130.8)	(422.5)
β_{22}	-	-12	262.3
		(1.9)	(19.2)
Observations	45	45	45
Root Mean Squared Error	21	298	2553
Constraints	$\beta_{12}=0$	$\beta_{11}=0$	$\beta_{11}=0$
	$\beta_{22}=0$	$18\beta_{21} - \beta_{12} - 18\beta_{22} = 0$	$\beta_{21}=0$
	$-\beta_{11} - 18\beta_{22} + \beta_{12} = 0$	$\beta_{12} + 67\beta_{22} = 0$	$\beta_{12} + 18\beta_{22} = 0$

Notes: Table reports constrained OLS estimates of the favored two-cone, three-HO-aggregate development path displayed in Figure 6. Standard errors are in parentheses. Coefficient notation follows equation (7): β_{11} and β_{21} are the intercept and slope of the first segment of each development path, while β_{12} and β_{22} are the intercept and slope for the second segment. These estimates take capital intensity cutoffs of \$500 and \$3000 to define HO aggregates, and a capital abundance knot of \$18,000 to define cones, as given. Both sets of cutoffs are fit-optimizing according to the maximization procedure discussed in the text and the Statistical Appendix.