Education, the Distribution of Production and Trade: What's the Relationship?[1]

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Abstract

As world markets integrate, leaders around the world face heightened pressure to boost their countries' global performance. One policy almost always advocated for achieving this goal stands out, both because it seems to make so much sense and because it is offered to every country: increase worker education. This paper extends standard trade theory to incorporate education and determine its relationship to the distribution of production and trade. It demonstrates that increases in secondary and tertiary education pull countries out of "undesirable" industries and pushes them into "desirable" ones in the manner prescribed by theory.

Key words: Heckscher-Ohlin; Education; Factor accumulation; Distribution of production
JEL classification: F11; F14; F21; O10; I12

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1 Issues

As world markets integrate and international economics becomes an increasingly important component of domestic politics, leaders around the world face heightened pressure to boost their countries' global performance. One policy almost always advocated for achieving this goal -- pushing countries into desirable, or "good jobs at good wages" sectors -- stands out, both because it seems to make so much sense and because it is offered to every country: increase worker education. However, though previous research has examined both individual returns to education (e.g. Becker 1993) and the contribution of education to aggregate GDP growth (e.g. Denison 1985 and Young 1995), an inquiry into how education affects the distribution of goods produced – i.e. movement up the "ladder of development" -- has been neglected. The primary aim of this paper is to address this gap in the literature by drawing upon key insights of standard trade theory. Within this framework it is sensible to ask whether higher levels of education push countries into more "desirable" sectors and to think about what would happen if all countries were to pursue identical levels of education.

Attempts to understand how factor or wealth accumulation impact the pattern of industrial growth have a long history in economics. Kuznets (1957) and Chenery (1960), for example, studied the effects of increases in per capita income on production profiles and found that more wealth coincided with more manufacturing at the expense of agriculture. More recently, Leamer (1987) investigated the influence of land on development paths by generalizing the standard two factor Hechscher-Ohlin model to encompass a third factor. The contribution of the present paper lies in employing Leamer's framework to incorporate education as a third factor and in demonstrating that its prescriptions are evident internationally. In doing so, it also provides further evidence for the usefulness of the Heckscher-Ohlin model (e.g. Bowen *et al* 1987).

The remainder of the paper will proceed in three steps: first, to describe the theoretical link between factor accumulation, production and trade; second, to examine cross-national data to determine whether the theory can be mapped to reality; and third, to conclude.

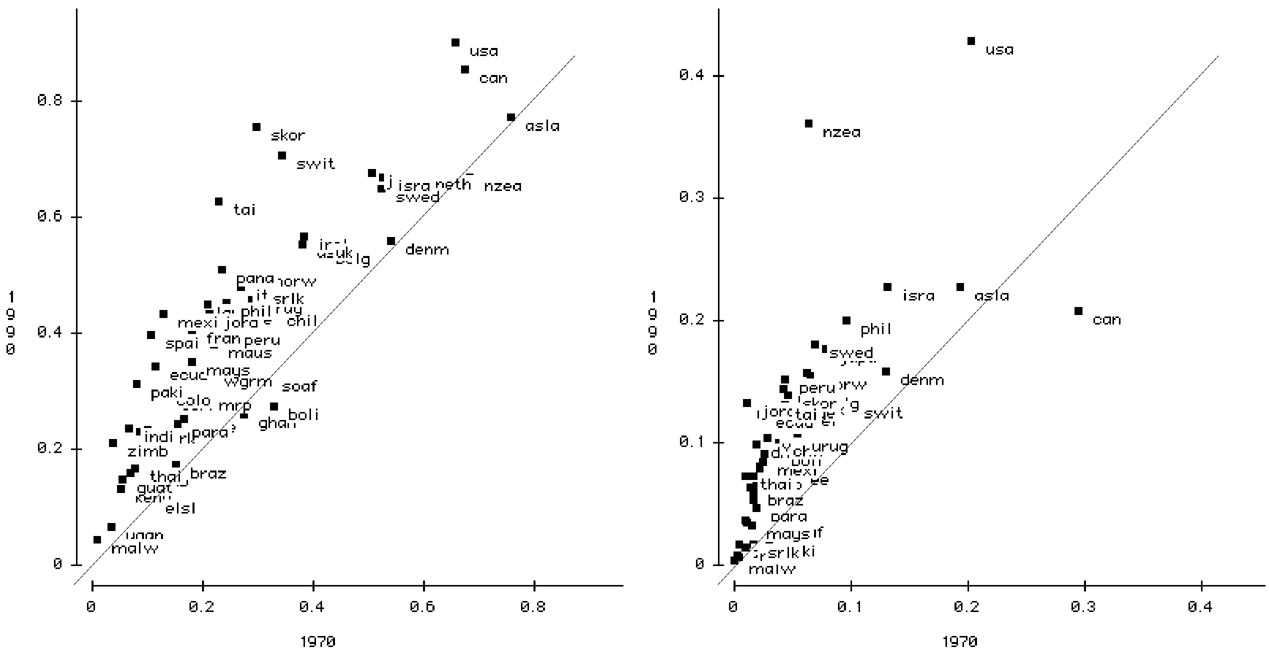
2 Linking Education, Production and Trade

Countries and their citizens certainly act as if education is important. Figure 1, for example, plots the percent of workers that had attained secondary and tertiary education in 1990 versus the same percent for 1970 for a sample of 57 countries described in Appendix A.[1] (This same dataset will be used throughout the paper.) A cursory glance at the two panels of the figure indicates that higher education levels have risen dramatically in 20 years (evidenced by points above the 45 degree line), particularly for Latin American and Asian countries. Among developed countries, the United States and New Zealand are clear outliers in tertiary education.

[1] Note that the portion of workers attaining tertiary education includes those who have attained secondary education.

Figure 1
Secondary and Tertiary Education Attainment as Percent of Population, 1990 vs 1970

Secondary+Tertiary **Tertiary Only**



Blanket recommendations to boost education, however, often ignore (or leave unspoken) the most important insight of standard trade theory, which is that a given country's production and trade depend directly upon its position relative to its peers. Just as a firm might weigh the actions of its rivals in positioning itself in a new market, for example, so might a country consider the relative factor endowments of its peers – and the benefits of differentiating itself -- in deciding upon public policy incentives for factor accumulation. In a global environment, all such incentives – from the tax-deductibility of physical capital depreciation to the subsidization of schooling -- are "trade policy".

2.1 A 2xN Versus a 3xN HO Model

Trade theory offers three basic perspectives – Ricardian, Heckscher-Ohlin (HO) and Increasing Returns -- for understanding the link between factor accumulation and production profiles. Each offers a different insight into the causes of trade and the effects of policy; the proper framework to employ for any given issue depends upon the particular problem being addressed. Since my focus is on the effects of long term changes in factor endowments, as opposed to differences in production technology, factor specificity, imperfect competition or increasing returns to scale, and since the HO model has been shown to be a useful benchmark for thinking about production and trade in this respect (e.g. Leamer 1984, Song 1993 and Trefler 1993), it is a reasonable starting point. Nevertheless, it is important to keep the other frameworks in mind when considering alternate assumptions and interpreting empirical results.

A simple two factor HO model, as outlined in Leamer (1984), is grounded on several standard abstractions.[2] These assumptions lead to well-known and quite powerful conclusions, including: the Factor Price Equalization Theorem, which states that factor rewards will be equal for all countries within the same cone of diversification; the Rybzinski Theorem, which argues that at constant commodity prices, an increase in the supply of one factor will increase the output of the good which uses that factor intensively, and reduce the output of the other good; the Stolper-Samuelson Theorem, which asserts that an increase in the price of the imported good increases the return of the scarce factor and reduces the return of the abundant factor; and the Heckscher-Ohlin Theorem, which offers that countries will export the good employing intensively the relatively abundant factor, and import the good using intensively the scarce factor. I will focus on the intuition of the first three of these theorems throughout the main body of the paper; see Leamer (1984) for formal proofs and generalizations.

If the two factors in this model are capital (K) and labor (L), development can be thought of as an increase in the capital-labor ratio as countries accumulate capital.[3] As illustrated in panel *a* of figure 2, a Lerner (1952) diagram containing dollar isoquants for textiles (a capital intensive good) and apparel (a

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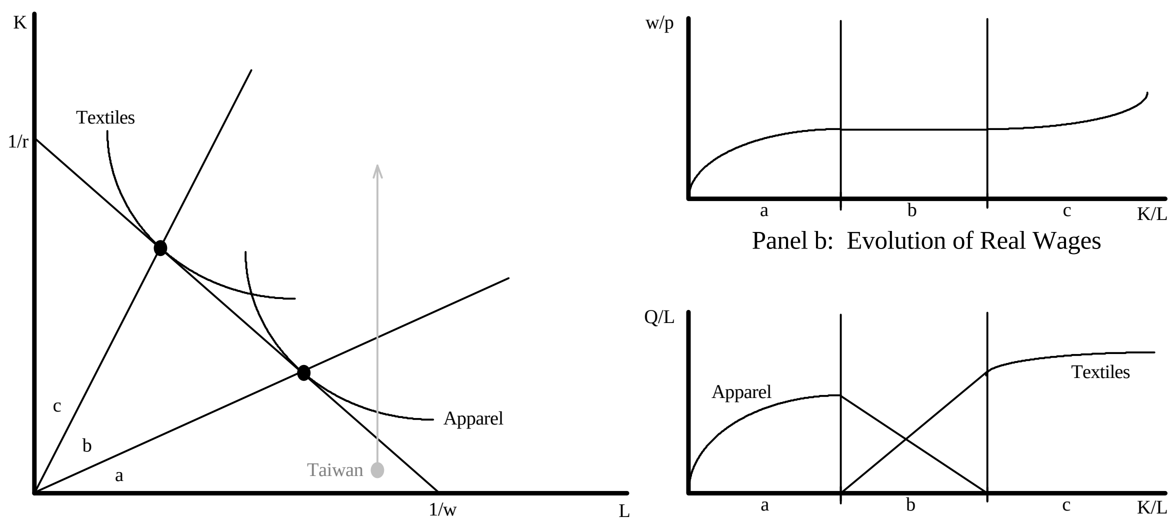
[2] They are factor immobility, sufficient endowment similarity, perfect competition, universal technology, universal and homothetic demand, and the existence of "world prices".

[3] It seems reasonable to assume that the state has more immediate control over capital accumulation than labor accumulation, though Mainland China's ambitious efforts to reduce its birth rate are an apt exception.

labor intensive good), as a labor intensive country, say Taiwan during the 1950s, accumulates capital, it moves from a cone where it specializes in apparel (cone *a*) to one where it produces both apparel and textiles (cone *b*). If it were to accumulate sufficient capital, it then would move into cone *c* and specialize in textiles.

In this example, as Taiwan accumulates capital, the real return to workers (*w/p*) and the output per worker (*Q/L*) of each good follow the paths prescribed by the theorems listed above and illustrated in panels *b* and *c*. Real wages are flat in cone *b*, for example, due to factor price equalization, but rise in cones *a* and *c* as workers become more scarce.

Figure 2
A 2x2 Heckscher-Ohlin Model



Panel a: Lerner (1952) Diagram

Panel b: Evolution of Real Wages

Panel c: Deardorff (1974) Diagram

Though instructive, the 2x2 context is too simple to capture the richness of realistic development paths because it abstracts both from worker skill and from the very real choice countries face between investing in productive capacity versus the education of citizens.[4] A better approach is to add a third factor, human capital, to the framework.

Human capital can be thought of broadly as knowledge that resides in workers' minds.[5] It is economically productive in at least two ways. First, as an input to production: certain jobs require specific skills. Second, combined with time, as a facilitator of technological diffusion and innovation: human capital-endowed individuals "speak the same language" (perhaps math or economics) and can exploit each others' innovations, or discover new ones, to increase their personal output. In this paper I will focus on the former.

Operationalizing human capital is a matter of selecting an index of knowledge broad enough to be applicable across sectors, but not so coarse as to be vacuous. In that respect, neither the number of PhD's in solid state physics nor the proportion of literate workers feels quite right. Some researchers, including Bowen *et al* (1987) have used job categories to separate workers into skill categories (e.g. professional, managerial, clerical, sales, service and agricultural) and determine their effect on trade. An alternate approach, and the one employed here, is to use primary, secondary and tertiary education attainment, as measured by Barro and Lee (1994). This categorization has two benefits: first, to the extent that it is less sector specific than skill categories, it is more consistent with the spirit of the HO model. Second, results incorporating it provide a clearer mapping of theory to policy, which is aimed more at subsidizing levels of basic education than career selection. On the other hand, educational attainment neglects the important contribution to human capital of on the job training. An additional problem with the use of attainment is

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[4] Recent debates in the U.S. Congress over extending education tax credits (citizens) versus decreasing the capital gains tax (capacity), are demonstrative.

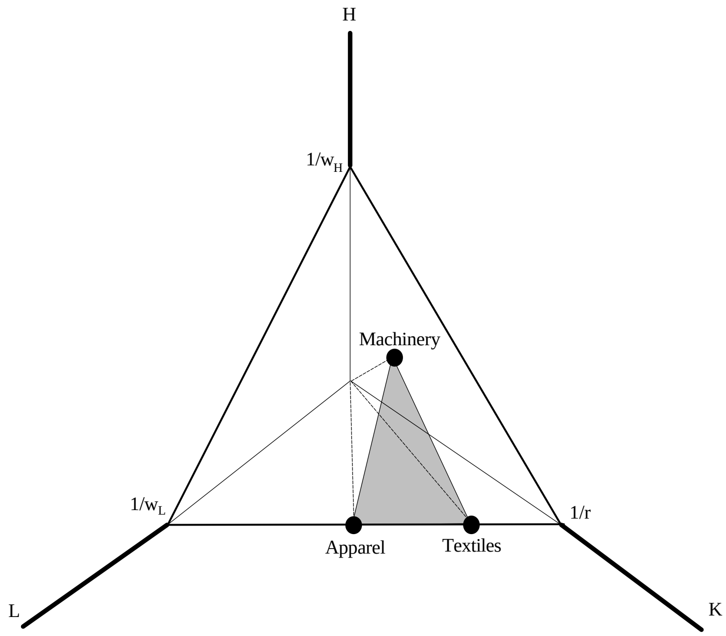
[5] Human capital encompasses other factors besides formal education, such as health, on the job training and understanding of the political process, which may increase productivity but which are difficult to measure and compare cross-nationally. I focus here on formal education attainment as a first step towards understanding the role of human capital more generally in production.

that it, like similar measures, does not account for quality, focus (e.g. creativity versus memorization), or technique (e.g. group versus individual learning).

Figure 3 illustrates the mechanics of generalizing a two factor HO model to three dimensions so that interesting issues associated with development can be illustrated in a simple diagram. Whereas Leamer (1987) developed the framework to investigate the influence of land as a third factor, we will focus here on employing it to study human capital accumulation. The trick is to construct an endowment simplex by reducing a three dimensional factor space of capital (K), labor (L) and human capital (H) to a two dimensional simplex. This simplex is formed by intersecting the positive orthant of the factor space with a plane so that the coordinate axes in the three-dimensional factor space are represented by the corners of the endowment triangle, while the industry-input and country-endowment vectors in three dimensions can be represented by points on the simplex. In this case, however, industry "iso-corners[6]" rather than isoquants uniquely determine factor rewards by choosing the equilibrium plane at given goods prices. Thus, the black dots in figure 3 are analogous to those of the first panel of figure 2: the former represent the two points necessary to select the line defining labor and physical capital rewards (w,r) while the latter represent the three points necessary to select the plane defining labor, physical and human capital rewards (w_L, r, w_H).

[6] For simplicity of exposition, Leamer's triangles rely upon Leontiff technology rather than the Cobb-Douglas technology suggested in figure 2.

Figure 3
Building a 3xN Heckscher-Ohlin-Vanek Model



The three stylized industry input points depicted in figure 3 are for apparel, textiles and machinery. As drawn, the production of apparel and textiles requires only physical capital and labor, while the manufacture of machinery requires all three factors. Note that the dotted lines emanating from the origin represent equilibrium factor input combinations just as in figure 2, and that the particular simplex drawn (and anchored by the appropriate factor rewards) in the figure has been determined uniquely by the three black dots, which represent tangency points between the simplex and industry "iso-corners". Note as well that approaching a corner of the endowment simplex along a ray emanating from that corner represents an increase in the use (for an industry input vector) or concentration (for an endowment vector) of that factor, holding the concentration of other factors constant. Thus, textiles use more physical capital than apparel, and both use the same ratio of human capital to labor, which is zero.

I will call the triangles formed by connecting industry input points cones of diversification, just as in the standard two factor, two goods case. In figure 3, the single cone is shaded. The manner in which industry-input points are connected to form cones of diversification depends upon product prices: in general, the more expensive a commodity, the larger its region of production (Leamer 1987). In figure 4 below, for example, machinery is assumed to be relatively dear due to the large area in which it is produced. With *n* goods, each simplex will be filled with many cones of diversification, each of which, through zero profit conditions, has three unique factor rewards given the three product prices which anchor it, similar to the 2xN case. In this way, the Factor Price Equalization theorem can be generalized to higher dimensions.[7]

Since factors become relatively more abundant as a country moves closer to a given vertex associated factor rewards will decline as countries move through a world made up of several or many cones of diversification. In figure 4 below, for example, wages are lowest in cone *a* near the labor vertex, but increase in cones along any ray emanating from it.

Development paths under this 3xN model are far richer than those under the standard 2xN model or a 3xN model incorporating land because they highlight the tradeoff between investing in human and physical capital. To think about this choice, two additional simplifying assumptions are useful:

- A1 *Limited Information*: Countries know everything about the cone of diversification they are in, and nothing about the cones they will move to in the future.
- A2 *Capital Non-Fungibility*: Human and physical capital are not fungible once investment has occurred.

If countries do not anticipate the cones they will occupy in the future (A1), their preferences for accumulating either human or physical capital relative to labor will depend upon whichever of the two has the highest factor reward within their current cone. For the endowment simplex constructed above, a natural representation of physical capital is machinery. Human capital, on the other hand, can be thought

[7] This generalization ignores factor intensity reversals.

of as units foregone workdays in the sense that educated workers are a nontradeable good produced by combing raw labor with a portion skilled labor (Leamer 1988).[8] Whereas the price of machinery, p_M, is determined by world product markets, we can think of the "price" of an educated worker as the cost necessary to produce her. Assume this cost is

$$w_L + w_H a_H ,$$

where w_L and w_H represent the factor rewards of labor and human capital, respectively, and $a_H<1$ represents the of portion of human capital services that goes into education. That $a_H<1$ indicates that one teacher can teach many students at the same time.

Since, within any given cone of diversification, prices (p_M) and factor rewards (w_L,r, w_H) are constant under a generalization of the Factor Price Equalization theorem, countries will invest in one or the other of the two factors depending upon their relative returns. What is important for our purposes is that if

$$\frac{r}{p_M} > \frac{w_H - w_L}{w_L + w_H a_H}$$

in a particular cone, investment will be in physical capital exclusively and *vice versa*.

2.2 Understanding Development Paths

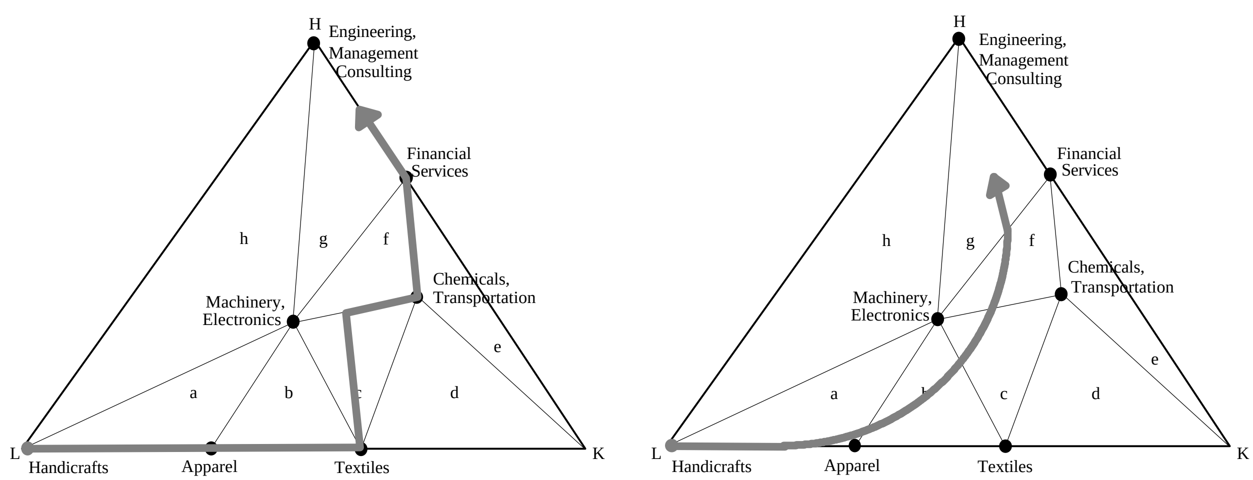
In order for a development path to be "realistic", it must be traveled in such a way as to assure that all goods are produced eventually. Countries moving along the *edge* of a cone of diversification will

[8] Classifying education as a non-tradeable allows it to be produced no matter which particular cone diversification a country inhabits.

produce only the two goods connected by that edge, while countries moving through the interior of a cone will produce all three goods (Leamer 1987). In addition, countries will produce less and less of the good(s) they leave behind, and more and more of the one(s) they move towards, under a generalization of the Rybczynski Theorem.

Panel *a* of figure 4 illustrates a possible development path as a country accumulates human and physical capital under all of the assumptions noted above. Along this path, countries decide which factor to accumulate without regard to their future development, a scenario I will refer to as "static" optimization since it is cone-specific. A story for this stylized path could proceed as outlined in table 1.

Figure 4
A 3xN HO Model with Two Types of Development Paths



Panel a: Static Optimization **Panel b: Dynamic Optimization**

Table 1
Possible Story for the Development Path Shown in Figure 4a

Cone *a*	At the outset, countries possess only labor. In this zone the returns to human and physical capital are both very high since both factors are extremely scarce. Over time, enough wealth is created to permit investment. If the salary of teachers is so high that the return to physical capital is greater than that of human capital, the country accumulates physical capital exclusively. (Note that if this were not the case, and all countries followed a path of human capital accumulation in cone *a* , textiles would never be produced.) As a result, the country moves along the bottom of the simplex, producing first handicrafts and then apparel.
Cone *b*	As the country crosses into cone *b*, the returns to human capital and labor increase, while that of physical capital (given a constant world price of machinery) falls. Education is now even more expensive than in cone *a* so assume physical capital accumulation continues. Thus, the country moves out of apparel and into textiles.
Cone *c*	The return to labor continues rising, while the returns to human and physical capital both fall. Assume product prices are such that the return to human capital falls far enough for the country to favor human over physical capital accumulation. As a result, the country moves out of textiles and into machinery and chemicals.
Cone *f*	The return to human capital falls, but wages and return to physical capital both rise. Withholding workers from production is now very expensive, so the country again favors physical capital accumulation, moving out of machinery and electronics and into chemicals and transportation.
Cone *g*	Wages and the return to human capital rise, while the return to physical capital falls. Human capital accumulation is favored and the country moves out of manufacturing and into the lucrative service and consulting sectors.

This path's associated "ladder of development", or sequence of goods produced as factors accumulate, is given in table 2. Over time, the country climbs up the ladder from handicrafts to services.

Table 2
Tawian's Ladder of Development

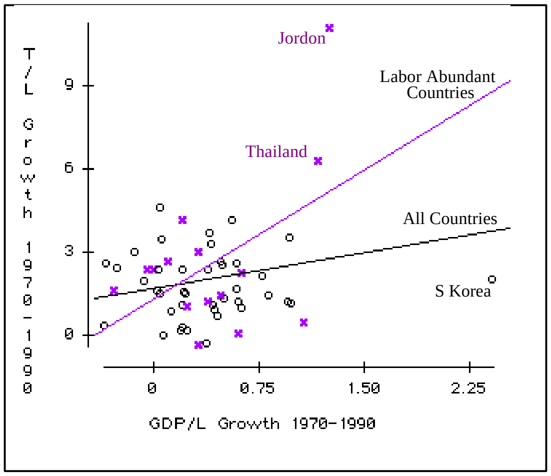
Engineering, Management Consulting
Financial Services
Chemicals, Transportation
Machinery, Electronics
Textiles
Apparel
Handicrafts

On the other hand, if we relax assumption A1 and allow for the country to anticipate its future development, investment in human capital may begin before it is optimal "statically" to do so. Such a "dynamic optimization" path is shown in panel *b* of figure 4. In general, the more certain our country is about its future needs (i.e. heading for the service cones), the earlier it is likely to invest in human capital. In this sense, the two panels lie at opposite ends of a continuum from uncertainty to certainty.

One characteristic of this intuition is that the faster a country adds physical capital, the more sensible it will be to invest in human capital earlier rather than later, since it will need to employ that human capital more rapidly. We can investigate this implication empirically by checking whether high-growth, labor intensive economies added to their education endowment faster than low-growth, labor intensive countries. The underlying assumption here is that, while both types of labor intensive economies are near the labor vertex in figure 4, high growth economies are heading up the ladder of development more quickly.

Figure 5 plots the growth in tertiary education per worker for 1970 to 1990 versus the growth in GDP per worker for the same period. The scatter contains two regression lines: one for the quartile of countries that were most labor abundant in 1970 and one for the entire sample. As indicated, labor abundant countries had a more positive relationship between tertiary education growth and GDP growth than did the sample overall, consistent with expectations, but this relationship is sensitive to two outliers, Thailand and Jordon.

Figure 5
Labor Abundant Countries Educate Faster



x = Labor Abundant o = Other

Of course, even if this consistency were supported by more observations we would still not have proof of our expectation: it is possible that the arrows of causality between education and growth flow in the opposite direction. Wood and Ridao-Cano (1996) and others, for example, argue that it is openness to trade that enhances the development of human capital, which allows these countries to grow faster.

3 Estimating Real World Ladders of Development

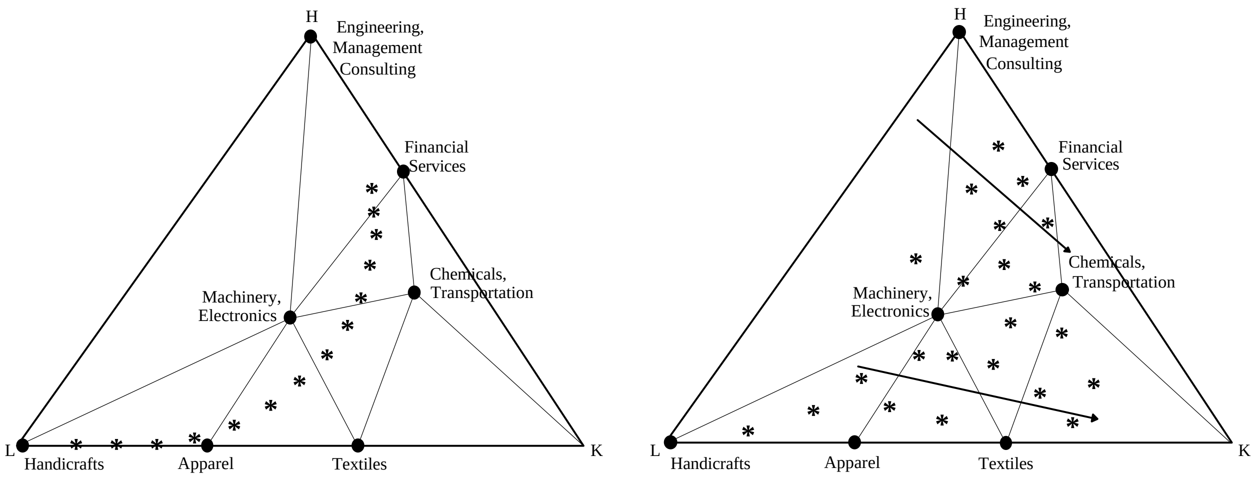
The theory outlined thus far provides us with an intuitively appealing framework for understanding the choices involved in factor accumulation. Nevertheless, defining real-world cones of diversification and the paths countries might travel through them over time is a far more daunting task. Not only are there many patterns of cones that could connect the same set of industry points in any given simplex, but changes in goods prices due to the actions of groups of peer countries over time can alter the prices which determine which pattern dominates at any moment. In addition, exogenous forces such as culture, domestic politics, war and international trade agreements can influence either *when* countries begin to develop or *how fast* they are able to accumulate factors, with the result that the ladder of development of one cohort of developing countries might differ substantially from the cohort(s) preceding it. In addition, some countries may become "stranded" along "out-dated" paths, particularly if the costs of converting one form of capital to another (assumption A2) are especially high.

This issue of how development paths change over time is particularly intriguing and the subject of much debate: is the best analogue for Taiwanese development in the 1970s the path followed by the UK during the industrial revolution or that followed by Japan in the 1950s? In the story given in table 1, for example, physical capital accumulation was favored over human capital accumulation during early development. But what if one country can access the teachers in another by sending its workers abroad for training, as surely seems to be the case with many developing countries today? Then the cost of human capital accumulation may drop sufficiently for it to be favored, perhaps inducing movement through cone *h* rather than through cone *a* in figure 4, allowing for earlier production of Machinery and Electronics. Though there may be some evidence of this occurring over time in East Asian economies, a deeper treatment of this issue is, unfortunately, beyond the scope of this paper.[9]

Given the complex interaction of these forces, the distribution of countries within an "actual" simplex at any given point in time is not likely to be ordered along a single development path. Thus, if we examine a cross section of countries in any given year, we should anticipate the data to look more like that of panel *b* of figure 6 than that of panel *a*.

[9] One avenue which might be worth exploring is embedding competition between countries facing factor accumulation decisions within a dynamic HO model. Given the enormous complexities involved, however, keeping such a model tractable is a great challenge.

Figure 6
Possible Distribution of a Cross Section of Countries in Year t



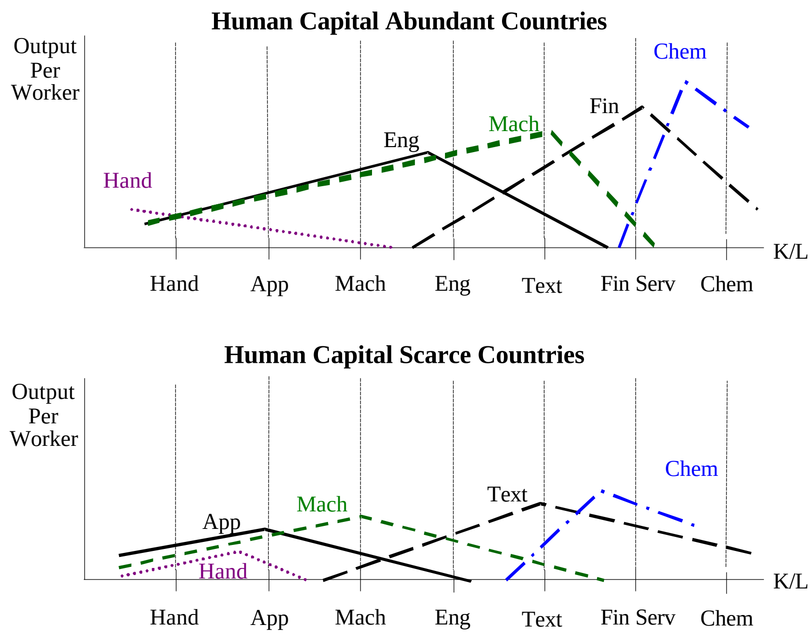
Panel a: All countries follow same path

Panel b: Paths change, countries get "stranded"

One way to estimate real-world ladders of development, suggested by panel *b*, is to use a cross section of countries in a given year and ask how production varies as countries accumulate physical capital (Leamer 1987). Figure 7 provides the theoretical answer to this question for the two types of countries, human capital abundant and human capital scarce, suggested by the two arrows in panel *b*.[10] In both cases, the production function of each good is concave and piece-wise linear, and curves according to the Rybzinski Theorem.

[10] Incidentally, a dynamic rather than cross-sectional interpretation of these arrows is that they represent the paths taken by Japan and West Germany after the destruction of much of their capital stock in World War II. Because of Germany's higher educational levels, its postwar production concentrated on more sophisticated goods such as chemicals and machinery while Japan's relatively education-scarce economy focused on apparel and light manufacturing.

Figure 7
Output per Worker in Two Types of Countries



A close examination of the figure reveals that differences in human capital endowment have four effects on production. First, output is generally higher for human capital intense countries because of the extra contribution of that factor. Second, differences in education affect which goods are produced. Third, peak output per worker increases with the capital intensity at which the peak occurs. Finally, the curvature of production functions changes with human capital intensity: maximum output per worker of Handicrafts, for example, occurs at higher capital per worker for human capital scarce countries, while the reverse is true for sectors such as Machinery and Chemicals. One interpretation of this effect is that more education pulls a country out of “undesirable” (i.e. labor intense) industries and pushes them into “desirable” (i.e. capital intense) ones. In the empirical investigation to follow, I will seek evidence of this particular prediction of the theory.

Ladders of development can be read off of figure 7. by considering the capital per labor ratio at which maximum output per worker occurs. These ladders, sorted from high down to low, are presented in table 3.

Table 3
Human Capital Development Paths

Human Capital Abundant	Human Capital Scarce
Chemicals	Chemicals
Financial Services	Textiles
Machinery	Machinery
Engineering	Apparel
Handicrafts	Handicrafts

3.1 The Effects of Capital Accumulation

To estimate real-world ladders and the effect of education upon them, I will proceed in two steps. The first is to estimate "development functions[11]" analogous to those depicted in figure 7 using the sample of 57 countries described in Appendix A.[12] The second is to determine whether adding education to these development functions is influential in the manner just described.

To approximate the piece-wise linear relationship between output per worker and capital per worker shown in figure 7, a functional form to simulate them must be chosen. A good candidate, consistent with both the raw data and the curvature suggested by the figure, will allow for little or no output at low levels of capital per worker, increases in output at medium levels of capital per worker, and declining output at higher levels of capital per worker. To mimic this contour I began with the specification

$$q_{ij} = a_i + b_{i0}k_j + b_{i1}k_j^2 + b_{i2}k_j^3, \qquad (1)$$

[11] Note that I cannot call them production functions because industry output depends upon country, not industry, factors.

[12] Note that, due to data availability, not all 57 countries in the sample are included in the estimation of each industry. The average number of industries included is 45.

where q_{ij} is output per worker in industry *i* for country *j* and k_j is the capital-labor ratio in country *j*.[13] Experimentation with alternate specifications, including piece-wise linear functions and the sequential removal of terms from equation 1, however, reveals that excluding the level capital per worker term from equation 1 provides the best results in terms of both overall fit and exhibiting maxima within the sample capital per worker range. When the level term is included in equation 1, for example, it is insignificant and the adjusted R^2s of the regression are lower for roughly 80% of the industries in each time period.[14] As a result, I adopt the following specification in the results that follow:

$$q_{ij} = a_i + b_{i1}k_j^2 + b_{i2}k_j^3 \qquad (2)$$

In general, the substantive conclusions to follow do not depend upon the exact specification employed.

Table 4 exhibits the results of estimating equation 2 using OLS for the years 1970 and 1990 on 28 manufacturing industries at the three digit International Standard Industrial Classification (ISIC) level. (Results for 1980 were similar to those for 1970 and were left out to conserve space.) Each row of each panel contains information about the cross-sectional regression run on that particular industry for the specified time period.

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[13] That is, country *j*'s output in sector *i* divided by the total number of workers in country *j*.

[14] The adjusted R^2 of Beverages (ISIC 313), Tobacco (ISIC 314), Plastics (ISIC 356), Non Ferrous Metals (ISIC 372) and Metal Products (ISIC 381) are generally higher across the three time periods when the level term is included.

Table 4
Estimation of Equation 2 for 1970 and 1990

1970					
ISIC	Industry	t(k2)	t(k3)	Adj R2	Max
372	Nonferrous Metals	0.90	0.07	0.49	na
331	Wood	1.48	-0.20	0.62	62.2
342	Printing	2.87	-0.75	0.82	31.8
311	Food	2.99	-1.29	0.75	19.2
384	Transportation Equipr	2.58	-1.28	0.64	16.7
341	Paper	2.04	-1.02	0.52	16.7
382	Machinery	3.23	-1.84	0.67	14.6
356	Plastics	4.51	-2.59	0.81	14.5
381	Metal Products	4.71	-2.71	0.81	14.4
322	Apparel	4.99	-3.08	0.80	13.4
383	Electrical Machinery	3.80	-2.38	0.69	13.3
351	Industrial Chemicals	3.62	-2.31	0.65	13.0
352	Other Chemicals	4.13	-2.67	0.70	12.8
369	Nonmetal Products	7.73	-5.00	0.89	12.8
355	Rubber	3.32	-2.17	0.59	12.7
332	Furniture	3.90	-2.58	0.66	12.5
371	Iron	3.22	-2.16	0.57	12.5
362	Glass	3.24	-2.31	0.50	11.7
354	Petroleum, Coal Produ	1.56	-1.15	0.18	11.5
385	Professional Equipme	2.29	-1.68	0.31	11.3
313	Beverage	4.02	-3.03	0.55	11.0
353	Petroleum Refining	2.48	-1.89	0.31	10.9
321	Textiles	6.02	-4.62	0.72	10.8
390	Other	3.54	-2.73	0.46	10.8
324	Footwear	3.82	-2.95	0.49	10.7
323	Leather	1.59	-1.25	0.11	10.6
361	Pottery	3.59	-3.06	0.36	9.8
314	Tobacco	3.09	-2.61	0.28	9.8
Capital per Labor range of sample is (0.2, 14.3)					

1990					
ISIC	Industry	t(k2)	t(k3)	Adj R2	Max
341	Paper	0.03	1.04	0.50	na
331	Wood	1.03	0.10	0.52	na
372	Nonferrous Metals	1.21	-0.17	0.51	298.3
353	Petroleum Refining	1.81	-0.73	0.55	100.8
384	Transportation Equipr	2.56	-1.03	0.68	100.5
342	Printing	4.38	-1.87	0.86	95.1
385	Professional Equipme	1.98	-1.17	0.38	68.5
382	Machinery	4.65	-3.18	0.69	59.1
371	Iron	4.55	-3.17	0.67	58.1
390	Other	3.30	-2.33	0.50	57.5
332	Furniture	3.93	-2.85	0.55	55.6
381	Metal Products	7.35	-5.38	0.82	55.4
351	Industrial Chemicals	4.41	-3.29	0.58	54.2
356	Plastics	5.82	-4.43	0.70	53.2
354	Petroleum, Coal Produ	2.36	-1.84	0.29	52.8
322	Apparel	2.04	-1.59	0.18	51.8
311	Food	5.10	-4.00	0.61	51.7
362	Glass	5.29	-4.15	0.63	51.6
355	Rubber	4.27	-3.37	0.51	51.4
314	Tobacco	3.59	-2.83	0.42	51.4
369	Nonmetal Products	7.74	-6.11	0.78	51.3
352	Other Chemicals	6.18	-4.89	0.68	51.1
383	Electrical Machinery	5.61	-4.48	0.62	50.6
313	Beverage	6.08	-4.88	0.66	50.4
321	Textiles	4.07	-3.47	0.38	47.6
324	Footwear	2.65	-2.36	0.14	45.3
361	Pottery	3.55	-3.20	0.24	44.8
323	Leather	3.62	-3.29	0.25	44.4
Capital per Labor range of sample is (0.5, 74.8)					

In each panel, the third and fourth columns provide t-statistics for the square and cube term coefficients (i.e. for b_{i1} and b_{i2}), while the fifth column lists the regression's adjusted R^2 and the sixth column reports the capital per labor value which maximizes the estimated industry function[15]. The industries are sorted according to these maxima, from highest down to lowest, to suggest ladders of development akin to those in table 3. Except for three industries – Nonferrous metals in 1970 and Paper

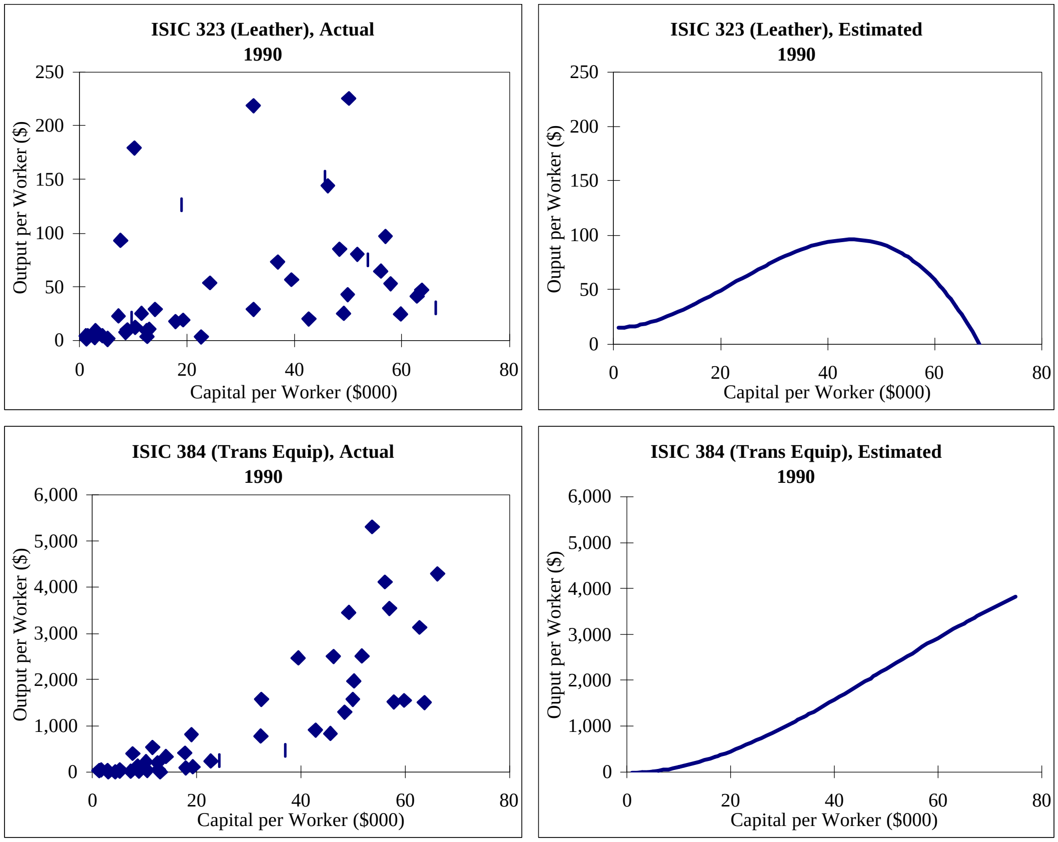
[15] From equation 2, this maximum is equal to $-\frac{2b_{i1}}{3b_{i2}}$ for each industry i.

and Wood in 1990 – all development functions contain a maximum, and for most industries this maximum is within the sample capital to labor ratio range given on the last row of each panel.

Visual inspection of curves with maxima beyond the sample range reveals that they are virtually linear within it. Figure 8, for example, provides a comparison between sample data and estimated curves for two industries in 1990: Leather, which is characteristic of low ladder goods, and Transportation Equipment, which is characteristic of high ladder goods. Both the raw data and the estimated curves are plotted on the same scale to facilitate comparison. A few of the 28 sectors in each year exhibited either individual or a small group of outliers, including the Leather industry. The upper panels of figure 8, for example, indicate that it might be reasonable to separate the Leather data into two groups depending upon whether output per worker is above or below $100.[16] Potential explanations for such outcomes include the exclusion of relevant productive factors, discrepancies in how physical capital is measured internationally and the possibility that true development functions vary either by country or by country groups.

[16] The higher output countries, from highest to lowest output per worker, are Italy, South Korea, Uruguay, New Zealand, Spain, Portugal and Argentina. Though re-estimation of the production function excluding these points increases the estimated maximum to 49.7 from 44.4, the industry remains at the bottom of the ladder.

Figure 8
Data versus Estimated Production Function, Select Industries, Same Scale



Given these potential pitfalls, the results in table 4 are encouraging and in line with those reported in Leamer (1987) on a similar but smaller dataset for 1978. T-statistics and adjusted R^2 terms are generally high, and the sorting of industries is generally consistent with intuition: sectors such as Chemicals, Professional Equipment (e.g. optics), Machinery (which includes computers) and Transportation Equipment are towards the high end of the ladder while Footwear and Leather group towards the low end. Paper and Wood seem rather high, but this is likely due to a positive correlation between physical capital and wood resources.[17]

[17] Re-estimating equation 2 with controls for agricultural and forest land also cause Wood, Furniture and Paper to drop to the middle of the ladder in each time period.

The relative height of Apparel in both time periods is also puzzling but may be an artifact of zealous developed country protectionism: international accords, particularly the Multifiber Agreement, may shield this sector's production in industrialized countries more than others, causing output to be "artificially" inflated in high capital per worker countries. On the other hand, it is also possible that the aggregation of goods into three digit ISIC categories, which in this case lumps t-shirts in with Vera Wang wedding gowns and Gortex jackets, may also influence this result.

Table 4 also highlights potentially interesting industry re-rankings between 1970 and 1990, including the decline of Electrical Machinery, which still exhibits a drop down the ladder even when the above regressions are re-run to control for land.[18] To the extent that this change is not caused by variations in either an excluded factor or the relative mix of goods within the ISIC category over time, they may be due to changes in development paths related to shifts of technique. It may be the case that by 1990, for example, production of many electronic machines, which required capital intense (i.e. high tech) production in 1970, was possible using low skill assembly workers in unsophisticated plants. This permitted relatively low capital countries, such as Thailand, Malaysia and South Korea, which have by far the largest growth in this sector from 1970 to 1990, to ramp up production, drive down prices, alter cones of diversification and pursue a different development path from their predecessors. Unfortunately, while brainstorming such explanations is thought provoking and suggestive, it is difficult to isolate all potential influences and provide more definitive evidence.

3.2 Is Education Influential?

To estimate whether education is influential in development functions across industries, equation 2 can be modified to include education and interactions of education and physical capital,

[18] The re-ranking of Electrical Machinery occurs even after controlling for land and education.

$$q_{ij} = a + b_{i1}k_j^2 + b_{i2}k_j^3 + d_{i1}t_j^2 + d_{i2}t_j^3 + g_{i1}k_j^2t_j^2 + g_{i2}k_j^3t_j^3, \qquad (3)$$

where t_j is tertiary education attainment per worker in country *j*. An F-test for $(g_{i1}, g_{i2}) = (0,0)$ can then be performed to determine if education is influential: coefficients significantly different from zero indicate that education affects the curvature of the development function, one of the affects prescribed by the HO model and illustrated in figure 7. Rejection of the null, therefore, is one gauge of the usefulness of incorporating education into the standard model. The more useful the model, the more interpretation of the estimated functions will provide insight into *how* education affects the distribution of production.

Table 5 contains the results of estimating equation 3 for 1970, 1980 and 1990 on the sample of 28 industries. The first column for each year lists the adjusted R^2 of the regression, while the second reports one minus the F-probability that $(g_{i1}, g_{i2}) \neq (0,0)$. The columns are sorted according to the 1990 ladder of development from table 4 to provide a visual cue as to whether high or low ladder goods are more affected. Shaded values in columns four through six indicate F-probabilities below 10%, and a given ISIC code and industry in columns 1 and 2 are shaded if education reaches this significance for at least two of the three time periods.

Table 5
Estimating the Influence of Tertiary Education, No Control for Land
(Equation 3)

		1970		1980		1990	
ISIC	**Industry**	**AdjR2**	**1-Fprob**	**AdjR2**	**1-Fprob**	**AdjR2**	**1-Fprob**
331	Wood	0.65	0.80	**0.50**	**0.90**	0.53	0.73
341	Paper	0.59	0.81	0.38	0.47	**0.55**	**0.95**
372	Nonferrous Metals	0.47	0.22	0.62	0.25	0.50	0.12
353	**Petroleum Refining**	0.27	0.07	**0.70**	**0.99**	**0.59**	**0.93**
384	Transportation Equipment	0.76	0.33	0.73	0.73	0.67	0.49
342	Printing	0.84	0.63	0.82	0.46	0.84	0.19
385	**Professional Equipment**	0.40	0.56	**0.64**	**1.00**	**0.65**	**1.00**
382	Machinery	0.64	0.06	0.80	0.86	**0.75**	**0.94**
371	Iron	**0.64**	**0.98**	0.69	0.71	0.73	0.56
390	Other	**0.65**	**0.92**	0.10	0.46	0.47	0.44
332	Furniture	0.64	0.06	0.67	0.82	0.56	0.62
381	Metal Products	0.83	0.04	0.84	0.34	0.81	0.46
351	Industrial Chemicals	0.62	0.24	0.67	0.70	0.57	0.64
356	Plastics	0.81	0.57	0.76	0.57	0.68	0.56
354	Petroleum, Coal Products	0.12	0.36	0.36	0.37	0.26	0.41
322	Apparel	0.82	0.47	0.65	0.50	0.13	0.21
311	Food	0.74	0.78	0.67	0.71	0.58	0.22
362	Glass	0.47	0.38	0.67	0.85	0.67	0.88
355	Rubber	0.65	0.80	0.52	0.56	0.51	0.36
314	Tobacco	0.25	0.65	**0.46**	**0.99**	0.47	0.79
369	Nonmetal Products	0.90	0.75	0.85	0.68	0.79	0.63
352	**Other Chemicals**	0.75	0.85	**0.75**	**0.91**	**0.69**	**0.91**
383	Electrical Machinery	0.67	0.29	0.72	0.88	0.64	0.82
313	Beverage	0.60	0.87	0.61	0.87	0.65	0.42
321	Textiles	0.71	0.75	0.52	0.49	0.37	0.44
324	Footwear	**0.55**	**0.98**	0.58	0.70	0.21	0.72
361	Pottery	0.37	0.08	0.41	0.54	**0.71**	**1.00**
323	Leather	0.04	0.31	0.30	0.53	0.23	0.70
Total Significant			*3*		*5*		*6*

As indicated by the last row of the table, tertiary education is influential in three industries in 1970, five in 1980, and six in 1990. Before discussing these results, however it is instructive to check their sensitivity to the exclusion of additional productive factors. To do so, equation 3 can be modified to control for agricultural (a) and forest land (f) as follows:

$$q_{ij} = a + b_{i1}k_j^2 + b_{i2}k_j^3 + d_{i1}t_j^2 + d_{i2}t_j^3 + g_{i1}k_j^2t_j^2 + g_{i2}k_j^3t_j^3 + g(a, f)\,. \qquad (4)$$

Table 6 reports the results of estimating equation 4 for

$$g(a, f) = w_{i1}a_j^2 + w_{i2}a_j^3 + w_{i3}k_j^2a_j^2 + w_{i4}k_j^3a_j^3 + w_{i5}f_j^2 + w_{i6}f_j^3 + w_{i7}k_j^2f_j^2 + w_{i8}k_j^3f_j^3,$$

which incorporates land in a manner consistent with the inclusion of education in equation 2.3. Results are similar for alternate specifications of $g(a,f)$.

Table 6
Estimating the Influence of Tertiary Education, Controlling for Land
(Equation 4)

ISIC	Industry	1970 AdjRsq	1970 1-Fprob	1980 AdjRsq	1980 1-Fprob	1990 AdjRsq	1990 1-Fprob
331	Wood	0.80	0.60	0.84	0.64	0.78	0.47
341	Paper	0.89	0.84	0.92	0.27	**0.95**	**0.93**
372	Nonferrous Metals	**0.49**	**0.93**	0.61	0.26	0.51	0.16
353*	Petroleum Refining	0.36	0.73	0.68	0.84	0.59	0.89
384	Transportation Equipment	**0.81**	**0.93**	0.69	0.34	0.68	0.21
342*	**Printing**	**0.92**	**1.00**	0.82	0.79	**0.92**	**0.99**
385*	**Professional Equipment**	**0.81**	**0.98**	0.68	0.70	**0.61**	**0.99**
382*	Machinery	0.72	0.82	0.79	0.67	**0.81**	**0.94**
371*	Iron	**0.71**	**0.93**	0.65	0.89	0.73	0.82
390*	Other	0.73	0.39	0.03	0.05	0.47	0.04
332*	Furniture	0.62	0.71	0.63	0.51	0.50	0.68
381	Metal Products	**0.89**	**0.97**	0.85	0.35	0.80	0.46
351*	Industrial Chemicals	**0.81**	**1.00**	0.72	0.81	0.59	0.85
356	Plastics	0.83	0.74	0.81	0.61	0.73	0.44
354	Petroleum, Coal Products	0.10	0.78	0.41	0.35	0.24	0.55
322	Apparel	0.91	0.82	0.65	0.84	0.07	0.51
311	Food	**0.82**	**1.00**	0.63	0.64	0.52	0.39
362*	Glass	**0.55**	**0.94**	0.68	0.84	0.66	0.86
355*	Rubber	0.70	0.71	0.49	0.75	0.54	0.83
314*	**Tobacco**	**0.31**	**0.93**	**0.57**	**1.00**	**0.58**	**0.97**
369	Nonmetal Products	0.90	0.28	0.85	0.80	0.78	0.59
352	Other Chemicals	**0.92**	**1.00**	0.76	0.87	0.66	0.39
383*	**Electrical Machinery**	**0.86**	**1.00**	**0.81**	**0.92**	**0.72**	**0.94**
313	Beverage	**0.64**	**0.98**	0.60	0.87	0.61	0.44
321*	Textiles	**0.80**	**0.99**	0.61	0.68	0.38	0.77
324*	**Footwear**	**0.80**	**0.96**	**0.78**	**1.00**	**0.18**	**0.95**
361*	Pottery	0.71	0.34	0.34	0.46	**0.69**	**1.00**
323*	Leather	**0.88**	**0.93**	0.38	0.89	0.18	0.82
Total Significant			*16*		*3*		*8*

** Denotes sectors for which the variance in Fprob is lower when controlling for land.*

A close comparison of table 6 with table 5 indicates that controlling for land alters the measured effect of tertiary education in several ways. First, the number of sectors influenced increases dramatically in 1970, less so in 1990, and falls in 1980. Second, the number of sectors influenced in at least two time periods nearly doubles. Of the three industries significantly affected in more than one time period without controlling for land (table 5), Professional Equipment is significant and Petroleum Refining and Other

Chemicals are close to 90% significance when controlling for it (table 6). Finally, controlling for land leads to more stable F-probabilities, a factor supporting the contention that tertiary education's influence be uniform from 1970 to 1990. Whereas the average variance in the three F-probabilities for each sector in table 5 is 0.067, it is 0.047 for those in table 6, a decrease of just under 30%. Table 6 indicates with an asterisk those industries with lower F-probability variance when controlling for land. They include all those for which tertiary education is significant in at least two time periods.

The changes induced by controlling for land urge caution in interpreting these results. To the extent that other major (non-traded) productive factors are excluded, our results may still be biased. However, the fact that tables 5 and 6 are not wholly inconsistent provides some hope that this implementation of the HO model is useful and that we are uncovering relatively robust relationships between education and production.

Do the sectors influenced by tertiary education make intuitive sense? I did expect *a priori* that college education would be significant in more sophisticated sectors such as Professional Equipment and Printing (which includes publishing). And the significance of tertiary education in other sectors is understandable in light of the complex dependencies inherent in the 3xN model and illustrated in figure 7. That Footwear is affected, for example, is consistent with the hypothesis that having more college graduates educates economies out of this sector.

The absence of tertiary influence in other perceived sophisticated industries, such as Industrial Chemicals, Machinery and Transportation Equipment, is somewhat puzzling. Note, however, the arbitrariness of a 90% significance level. If 80% were used instead, the number of shaded cells in both tables 5 and 6 would roughly double and the number of sectors exhibiting significance in at least two of the years would triple. In that case, both Machinery and Industrial Chemicals would be highlighted in table 6, though Transportation Equipment would not.

One reason why the influence of education may not be as strong in Chemicals, Machinery and Transportation is that the most education-intense sub-sectors comprise just a small component of overall output. Alternatively, it could be that the real influence of educated workers – the services and training they provide, for example, to design, organize and manage the shop floor – is dwarfed by lower skill manufacturing and assembly within each sub-sector.

To shed light on this second hypothesis we can examine the role of secondary education in production. Table 7, which contains the same results as table 6 but for the stock of secondary plus tertiary education rather than just tertiary education, indeed provides some evidence for it. As indicated, the number of sectors influenced (at 90% significance) by secondary education in at least two time periods is higher than the number affected by tertiary education. It is also interesting to note, for example, that whereas the influence of tertiary education on Transportation Equipment wanes over time (table 6), that of secondary education on this sector increases (table 7). This phenomenon may be related to changes in technique in a manner similar to that outlined for electrical machinery above: high school graduates are taking over sectors formerly populated by engineers. Suggestive in this respect as well is the relatively large number of industries affected by secondary education in 1980 versus the large number affected by tertiary education in 1970.

Table 7
Estimating the Influence of Secondary Education, Controlling for Land
(Equation 4)

		1970		1980		1990	
ISIC	**Industry**	**AdjRsq**	**1-Fprob**	**AdjRsq**	**1-Fprob**	**AdjRsq**	**1-Fprob**
331	Wood	0.82	0.81	0.82	0.50	0.78	0.65
341	Paper	0.93	0.87	0.92	0.42	0.95	0.66
372	Nonferrous Metals	0.51	0.22	0.64	0.62	0.52	0.10
353*	**Petroleum Refining**	**0.45**	**0.96**	**0.70**	**0.97**	**0.63**	**0.95**
384	**Transportation Equipment**	0.79	0.61	**0.75**	**0.94**	**0.74**	**0.91**
342	**Printing**	0.88	0.48	**0.86**	**0.98**	**0.91**	**0.96**
385*	Professional Equipment	0.72	0.60	0.68	0.81	0.56	0.85
382*	Machinery	0.71	0.63	0.79	0.66	0.77	0.73
371	Iron	0.62	0.06	**0.64**	**0.90**	0.64	0.02
390	Other	0.52	0.84	0.09	0.12	0.51	0.57
332	Furniture	0.64	0.67	0.60	0.05	0.48	0.27
381	Metal Products	0.86	0.60	0.85	0.25	0.81	0.58
351	Industrial Chemicals	0.71	0.55	**0.75**	**0.97**	0.54	0.31
356*	**Plastics**	**0.84**	**0.92**	**0.84**	**0.94**	0.74	0.66
354	Petroleum, Coal Products	0.14	0.73	0.35	0.07	0.18	0.43
322	Apparel	0.86	0.38	**0.64**	**0.90**	0.03	0.63
311*	Food	0.78	0.83	0.67	0.89	0.54	0.61
362*	Glass	0.44	0.11	0.61	0.43	0.61	0.34
355*	**Rubber**	0.59	0.36	**0.56**	**0.98**	**0.63**	**0.99**
314*	Tobacco	0.26	0.64	**0.48**	**0.96**	0.46	0.68
369*	Nonmetal Products	0.92	0.41	0.84	0.67	0.76	0.36
352*	**Other Chemicals**	**0.87**	**0.98**	**0.79**	**0.97**	0.69	0.82
383	Electrical Machinery	0.79	0.42	**0.81**	**0.91**	0.71	0.65
313	Beverage	0.54	0.49	0.59	0.85	0.63	0.15
321*	Textiles	0.71	0.19	0.59	0.60	0.35	0.41
324	Footwear	**0.75**	**0.97**	**0.51**	**0.91**	0.03	0.45
361	Pottery	0.74	0.07	0.30	0.61	0.07	0.54
323*	**Leather**	0.85	0.44	**0.34**	**0.91**	**0.20**	**0.91**
Total Significant			*4*		*10*		*5*

* *Denotes sectors for which the variance in Fprob is lower when controlling for land.*

3.3 How is Education Influential?

Determining *how* education affects ladders of development is more complicated. From the theory above, we note two general effects. First, some goods will be produced exclusively by human capital abundant countries, while others will be manufactured solely by human capital scarce countries. In figure 7, for example, Textiles and Handicrafts fall into the first group, while Financial Services and Consulting fall into the latter. In the real world, where all countries produce virtually all goods (at least at the three digit ISIC level), we can think of zero production as relatively little production. Second, peak capital per worker ratios for sectors produced by both types should in general be higher for human capital abundant countries than for human capital scarce countries, as they are in figure 7 for Machinery and Chemicals.

To probe the data for these effects, the curves estimated in table 6 were plotted for high and low values of tertiary education per worker that correspond to the 25th and 75th percentiles of the sample, respectively, for each year.[19] Visual inspection of the resulting plots indicates that they fall into two types. The first consists mainly of low ladder goods such as Footwear, where more education meant production that was generally lower and that peaked earlier. These sectors fit nicely with the first effect just mentioned: one would expect countries with more human capital to produce less of these goods and to begin exiting these sectors at lower levels of capital. The second group is comprised mainly of higher ladder goods such as Printing, where production is generally higher and peaks later with more education.

Table 8 summarizes these groupings. The first column of each panel specifies industries whose peak output per worker are larger with low education, while the second column details industries whose peak is larger with high education. The upper panel indicates industries for which these relationships held for all three time periods, while the lower one details those for which they held only for only two. (Industries are sorted by ISIC code within each grouping.) The placement of many of the sectors, including Apparel, Footwear, Industrial Chemicals and Machinery, is intuitive.

[19] These values were 0.02 and 0.06 for 1970, 0.03 and 0.10 for 1980 and 0.05 and 0.15 for 1990, respectively. Note that agricultural and forest land per worker are set to zero.

Table 8
Effect of More Tertiary Education

Panel a: Relationships Hold In All Three Time Periods

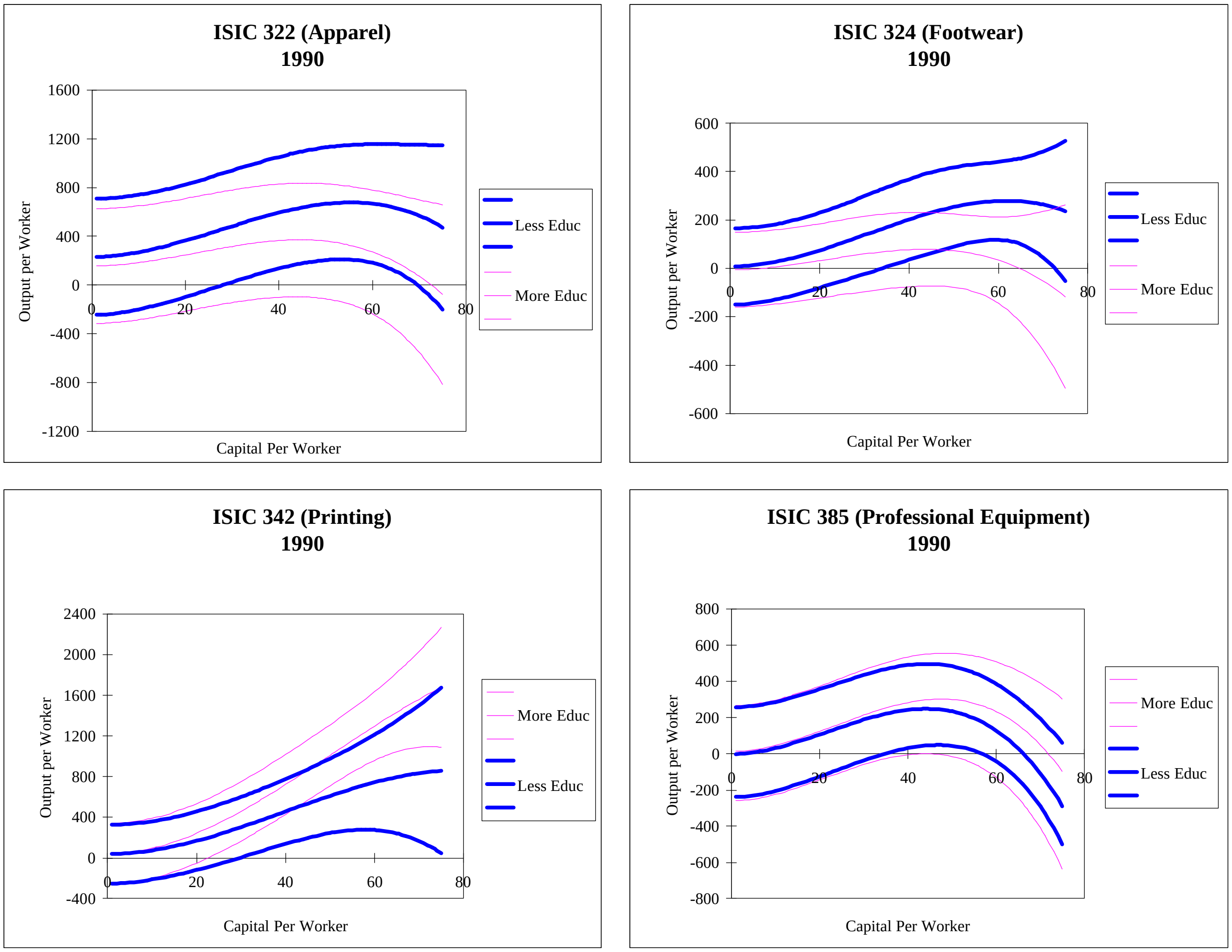
Earlier Exit	Later Exit
313 Beverage	331 Wood
314 Tobacco	341 Paper
322 Apparel	342 Printing
324 Footwear	351 Industrial Chemicals
352 Other Chemicals	354 Petroleum, Coal Refining
355 Rubber	372 Nonferrous Metals
361 Pottery	382 Machinery
371 Iron	384 Transportation

Panel b: Relationships Hold In Two of Three Time Periods

Earlier Exit	Later Exit
311 Food	353 Petroleum Refining
321 Textiles	356 Plastics
323 Leather	381 Metal Products
332 Furniture	383 Electrical Machinery
362 Glass	
369 Non-Metal Products	
385 Professional Equip	

Professional Equipment, one of the industries most consistently affected by tertiary education in the regressions run above, peaks higher with more education only in 1990 and therefore seems oddly positioned in the table. Examination of the estimated development function for this sector helps to uncover at least one of the reasons why: Figure 9 plots the development function and 95% confidence bounds for Footwear and Apparel (low ladder sectors) and Professional Equipment and Printing (high ladder sectors) at high and low levels of education. Note that whereas the more and less education curves for Footwear and Printing tend to separate at mid to high levels of capital, those for Apparel and Professional Equipment are virtually the same throughout.

Figure 9
Examples of Estimated Ouput per Worker at High and Low Levels of Tertiary Education
(With 95% Confidence Intervels)



The strong overlap of confidence intervals in some industries is not surprising given the concentration of capital and tertiary education observations at the low end of the scale. The data may simply not be rich enough to define strongly the development functions at high factor levels, a problem likely aggravated by aggregation. Unfortunately, two few countries report output at the four digit ISIC level to re-estimate the functions with more discriminating data.

Another difficulty in discerning tertiary education's effect on high ladder manufactures may be developed countries' movement out of manufacturing and into services. An interesting line of research in this regard would be to study sectors such as Engineering and Consulting. To the extent that they are more reliant on human capital, results might be more insightful. Unfortunately, international data on such disaggregate services is also not readily available.

Nevertheless, despite some uncertainty as to the exact effect of education on the production of high ladder goods, results indicate that the Heckscher-Ohlin model in general, and Leamer's triangles in particular, are a useful framework for understanding education and development. Secondary and tertiary education are influential in a number of sectors, and more education appears to push countries out of cones of diversification defined by low ladder goods and into cones comprised of high ladder goods.

4 Conclusion

This paper offers two results. First, theory and data suggest that more education pushes countries out of certain industries and pulls them into others in a manner consistent with intuition. Second, the nice match between theory and data provides additional support for the usefulness of the Heckscher-Ohlin framework for understanding and thinking through pressing issues of public policy.

But the inquiry raises many more interesting questions than it resolves. How might conclusions change with an explicitly dynamic formulation of the problem? Are some techniques of teaching secondary and tertiary students more helpful in moving countries up their ladder of development than others? What substantive and conceptual skills are most worth learning? How are education and the production of sophisticated services related? What role should firms, or how production is organized, play in Leamer's triangles? Is there feedback between the distribution of production and the quality of education offered?

Appendix
Description of Data and a Visualization of a 3xN World

Table A1 contains a list of the 57 countries encompasses by the dataset, and their abbreviations.

Table 9
Countries in Dataset

Country	Abbrev	Country	Abbrev	Country	Abbrev
argentina	arge	guatemala	guat	philippines	phil
australia	asla	india	indi	portugal	port
austria	astr	ireland	irel	south africa	soaf
belgium	belg	israel	isra	south korea	skor
bolivia	boli	italy	ital	spain	spai
brazil	braz	japan	japa	sri lanka	srlk
canada	can	jordan	jord	sweden	swed
chile	chil	kenya	keny	switzerland	swit
china	chin	malawi	malw	taiwan	tai
colombia	colo	malaysia	mays	thailand	thai
costa rica	cori	mauritius	maus	turkey	turk
denmark	denm	mexico	mexi	uganda	ugan
domincan republic	dmrp	netherlands	neth	united kingdom	uk
ecuador	ecud	new zealand	nzea	uruguay	urug
el salvador	elsl	norway	norw	usa	usa
finland	finl	pakistan	paki	venezuala	vene
france	fran	panama	pana	west germany	wgrm
ghana	ghan	paraguay	para	zambia	zamb
greece	gree	peru	peru	zimbabwe	zimb

The dataset contains observations for the following variables for 1970, 1980 and 1990[20]:

Manufacturing Production Data: Three digit ISIC production data is compiled from the 1996 INDSTAT3 database published by UNIDO. Data are in real (1985) U.S. dollar equivalents.

Educational Attainment: Data on the percent of population over age 15 which has attained no, primary, secondary or tertiary education are taken from the Barrow and Lee (1994) database.

[20] A complete dataset is available upon request. The figures and results presented in this paper were generated using DataDesk, Eviews, Excel, Gauss, Quattro and Word.

Data for Taiwan are taken from *Education Statistical Indicators, Republic of China, 1995* while those for mainland China are estimated from lagged World Bank gross enrollment rates.[21] Since separate data is not available for workforce education attainment, I assume that attainment of workers and of the general population are equal.

Capital Endowment: Capital endowment figures except for Taiwan are taken from Maskus (1991) and are calculated as the 15 year accumulated, depreciated (13.33%) and deflated (1985) series of gross fixed capital formation. Capital endowment figures for Taiwan were estimated in a similar fashion using raw data from *Taiwan Statistical Data Book, 1993.* Capital figures are measured in thousands of U.S. dollars.

Land Endowment: Data on two types of land endowment are taken from Maskus (1991): LAND1 refers to arable land and land under permanent crops or pasture, while LAND2 refers to the area of forests and woodlands. Both are measured in thousands of hectares.

GDP, Population, Workers: Real (1985) U.S. dollar GDP, population and worker data are drawn from the Penn World Table, Mark 5.6, from Summers and Heston (1991).

What does a 3xN world looks like? Figure 10 plots the 1990 endowment vectors for the set of countries noted above.[22] In this figure I define human capital as the portion of workers who have attained either a

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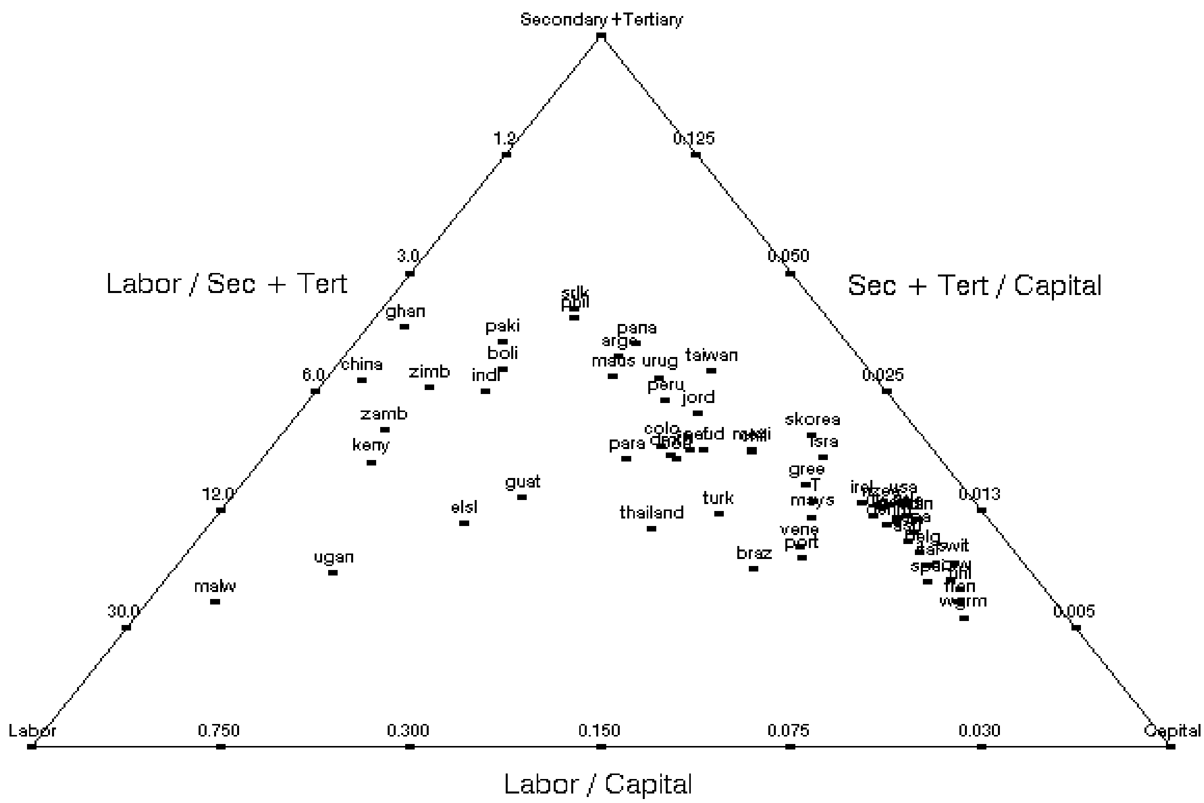
[21] As a rough approximation, 1990 education data for China is estimated using 1960 enrollment rates.

[22] Note that the specific plane used to generate figure 10 is arbitrary: units are chosen to achieve a “pleasant” spread of points throughout the triangle. Most planes, as you might imagine, result in the bunching of points near one of the three vertices. Note that the endowment point T in the figure represents the world, or total, endowment.

secondary or a tertiary education for two reasons. First, in light of the results in section 3, I assume both categories contribute skills necessary for manufacturing. Second, it seems to be a reasonable means of mitigating the discrepancies in individual educational systems, some of which succeed in teaching tertiary level skills to secondary students.[23]

Figure 10
1990 Endowment Simplex



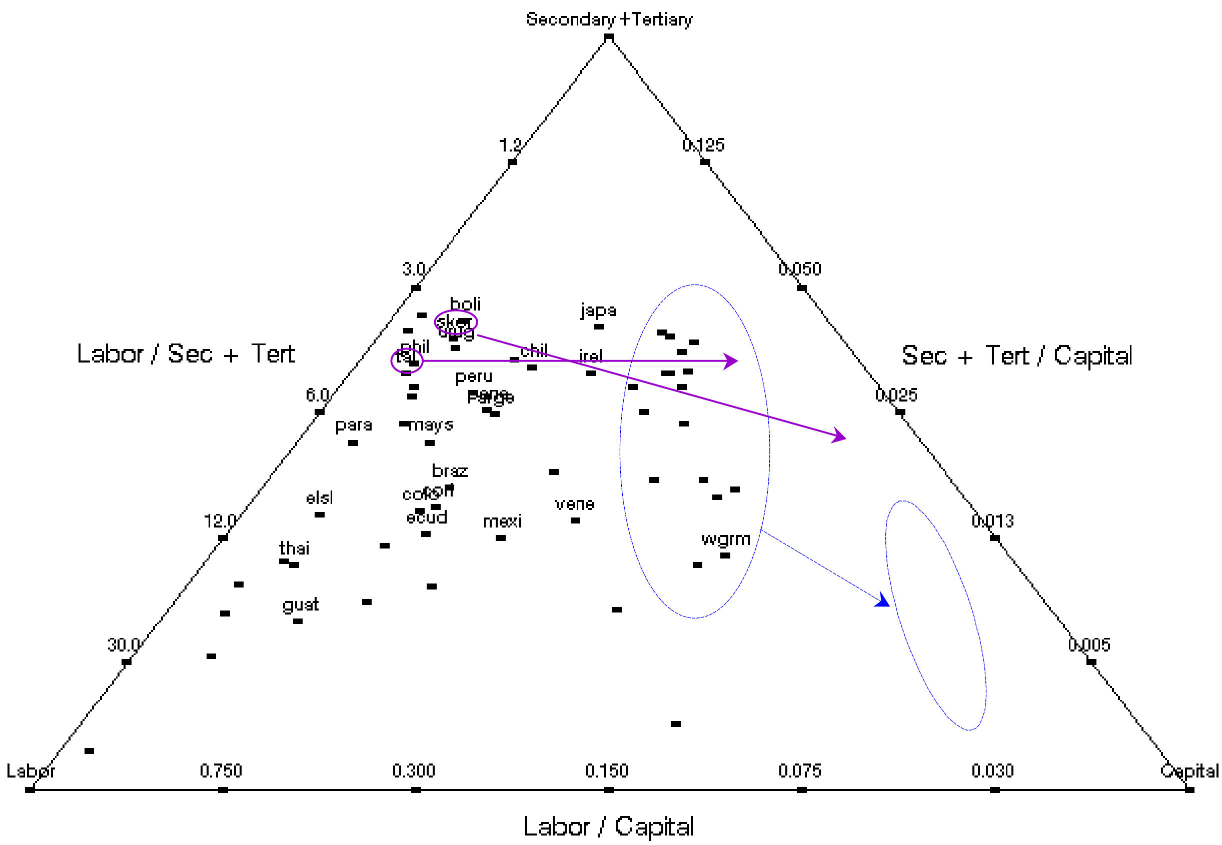
The most striking feature of figure 10 is the mass of developed countries in the high physical capital, high human capital portion of the triangle. Within this group, West Germany ("wgrm") is unique in terms of high physical capital per human capital (i.e. lots of tools per educated worker), a profile which likely contributes to its recognized advantage in the manufacture of high quality machinery and the benefits

[23] For more on the difficulties surrounding this issue, see Behrman and Rosenzweig (1994).

in terms of enviable living standards this confers. Studying the effects of integration with East Germany with more recent data would be an interesting exercise in this context.

Development over time over time can be discerned by comparing figure 10 with figure 11, an endowment simplex for 1970 plotted on the 1990 scales. The solid circles and arrows reveal, for example, that Taiwan ("tai) and South Korea ("skorea") were two of only a few developing countries to make significant enough gains in human and physical capital to move close to the developed country pack in the last two decades. This movement is highlighted by the solid circles and arrows. Indeed, South Korea in 1990 is similar to Japan in 1970.

Figure 11
1970 Endowment Simplex Using 1990 Scale



To increase readability, many European, North American and African country labels have been excluded

Interestingly, the dashed circles and arrows also record how the mass of developed countries has grown tighter over time, suggesting greater goods competition in 1990 than in 1970 due to greater similarity in factor endowments. Coupled with lower tariff barriers, this increased similarity dovetails neatly with growing trade contentiousness.

References

Barro, R.J. and J. Lee, 1994, International comparisons of educational attainment, NBER Dataset.

Becker, G.S., 1993, Human capital (University of Chicago, Chicago).

Behrman, J.R. and M.R. Rosenzweig, 1994, Caveat emptor: Cross country data on education and the labor force, Journal of Development Economics 44, 147-171.

Bowen, H.P., E.E. Leamer and L. Sveikauskas, 1987, Multicountry, multifactor tests of the factor abundance theory, American Economic Review 77, 791-809.

Chenery, H.B., 1960, Patterns of industrial growth, American Economic Review 50, 624-654.

Deardorff, A., 1974, A geometry of growth and trade, Canadian Journal of Economics 7, 295-306.

Denison, E.F., 1985, Trends in American economic growth 1929-1982 (Brookings Institute, Washington DC).

Education statistical indicators, Republic of China, 1995, Ministry of Education, Republic of China.

Kuznets, S., 1957, Quantitative aspects of the economic growth of nations, Part II: Industrial distribution of national product and labor force, Economic Development and Cultural Change 5.

Leamer, E.E., 1984, Sources of International comparative advantage (MIT Press, Cambridge).

Leamer, E.E., 1987, Paths of development in the three-factor, *n*-good general equilibrium model, Journal of Political Economy 95, 961-999.

Leamer, E.E., 1988, Theory and evidence of immigrant enclaves, Mimeo, University of California Los Angeles.

Lerner, A.P., 1952, Factor prices and international trade, Economica 19, 1-15.

Maskus, K.E., 1991, Comparing international trade data and product and national characteristics data for the analysis of trade models, in: P. Hooper and J.D. Richardson, eds., International economic transactions (University of Chicago, Chicago).

Song, L., 1993, Sources of international comparative advantage: Further evidence, Dissertation, Australian National University.

Summers, R. and A. Heston, 1991, The Penn World Table (mark 5) -- An expanded set of international comparisons, 1950-1988, Quarterly Journal of Economic 106, 327-368.

Taiwan Statistical Data Book, 1993, Council for Economic Planning and Development, Republic of China.

Trefler, D., 1993, International factor price differentials -- Leontiff was right, Journal of Political Economy 101, 961-987.

Wood, A. C. Ridao-Cano, 1996, Skill, trade and international inequality, Institute of Development Studies, Working Paper 47.

Young, A., 1995, The tyranny of numbers: Confronting the statistical realities of the East Asian growth experience, Quarterly Journal of Economics 110, 641-680.