Land Abundance, Risk and Return:
A Heckscher-Ohlin Linear Programming Approach to FDI[1]

Peter K. Schott[2]
Ph.D. Candidate in Business Economics
Anderson Graduate School of Management, UCLA
pschott@ucla.edu

May 30, 1998
Comments Welcome.

Abstract

Why is investment in human and physical capital in Latin America lower than in the faster growing economies of East Asia? Is this phenomenon and Latin America's generally higher income inequality an important consequence of the input requirements and price variability of the regions' products. To help answer these questions, this paper explores a Heckscher-Ohlin linear program incorporating real-world information on input intensities and product prices. It demonstrates: (1) that land abundance may deter skill accumulation and raise income inequality; (2) that insufficiently diversified production may create unfavorable capital risk-return profiles for resource rich countries, deterring investment; and (3) that the effect of such unfavorable profiles may be mitigated by international investors' desire for a balanced portfolio of diversification cone assets. More generally, the paper provides an nice example of how a multi-sector, multi-factor linear program can be used to gain insight into a variety of pressing problems in international trade and development.

Key words: Heckscher-Ohlin; Investment; Factor Price Risk; Linear Programming Simulation
JEL classification: F1.

[1]Many thanks to Ed Leamer. Thanks as well to Hugo Maul, Sergio Rodriguez and participants of the 1998 Workshop for Empirical Research on International Trade and Investment Conference.
[2]Anderson Graduate School of Management at UCLA, 110 Westwood Plaza, Suite C501, Los Angeles, CA 90095-1481; tel: (310) 825-8207; fax: (310) 206-2002; email: pschott@ucla.edu; website: http//:www.personal.anderson.ucla.edu/~peter.schott.

Land Abundance, Risk and Return: A Heckscher-Ohlin Linear Programming Approach to FDI

1 Issues

Do land abundant countries have riskier capital rewards, and does this prevent them from attracting global investment? Does land abundance delay the emergence of skills, further delaying the development of manufacturing sectors integral to reducing income inequality? This paper seeks an answer to these questions by pushing the well-worn Heckscher Ohlin (HO) model in a new direction to provide insights about capital risk and return. It accomplishes this task by constructing a HO linear program employing real world data on factor inputs, endowments, product prices and price uncertainty. This linear program provides a simple framework, based upon fundamentals, for understanding the investment-inhibiting effects of insufficient manufacturing diversity. In addition, thought experiments based upon its output demonstrate that global investors' desire for a balanced portfolio of diversification cone assets may mitigate the investment-deterring effects of agricultural dependence, depending upon the covariance of capital returns by cone. More generally, the discussion of the modeling process provides a nice example of how a multi-sector, multi-factor linear program can be used to gain insight into a variety of pressing problems in international trade and development.

Though many previous studies have researched the effects of macroeconomic volatility on investment, growth and other performance measures (see, for example, the review in Sevren (1996)), few have investigated its root causes. An exception is IADB (1995), which, like the research below, points to the importance of primary product export concentration in addition to external shocks, government policy and inadequate financial institutions. Even in that study, however, the explicit link between factor endowments, input intensities and price variability – the consideration of which is so natural for a trade economist – has been ignored. In the theory and evidence sections to follow, we hope to make this relationship clear.

The remainder of the paper is organized as follows: section 2 illustrates how price risk translates into factor risk within the factor proportions model; section 3 illustrates how these concepts can be brought to life by a Heckscher-Ohlin linear program; and section 4 concludes.

2 Theory

2.1 How Does Price Risk Affect Factor Rewards? [1]

How does price variability affect reward volatility, and how might diversification out of agriculture and into manufacturing mitigate the risk to capital? Figures 2.1.1 and 2.1.2 help provide some intuition for this question by illustrating graphically the link between product price and factor reward uncertainty within the context of a Leamer (1987) triangle. Recall that this "endowment triangle" is the simplex formed by intersecting the positive orthant of a three-dimensional factor space with a plane so that the coordinate axes are represented by the corners of the simplex and industry-input and country-endowment vectors are represented by points within it.

[1] The theory in this section is developed more fully in Leamer, Maul, Rodriguez and Schott (1998).

Figure 2.1.1: The Affect of Price Risk on Rewards in a 3x*N* Model

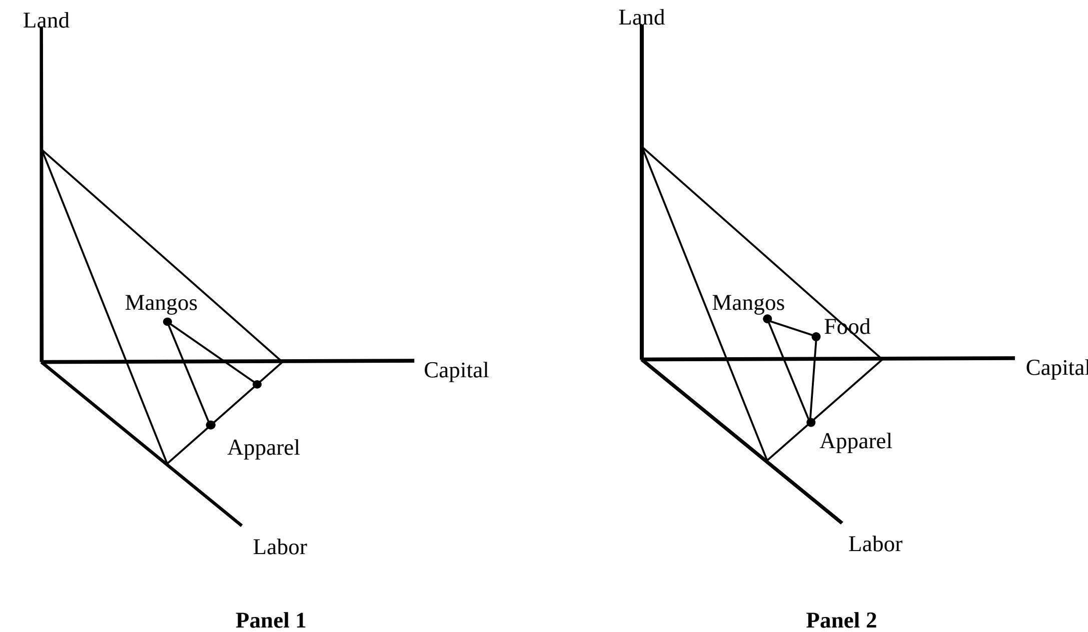
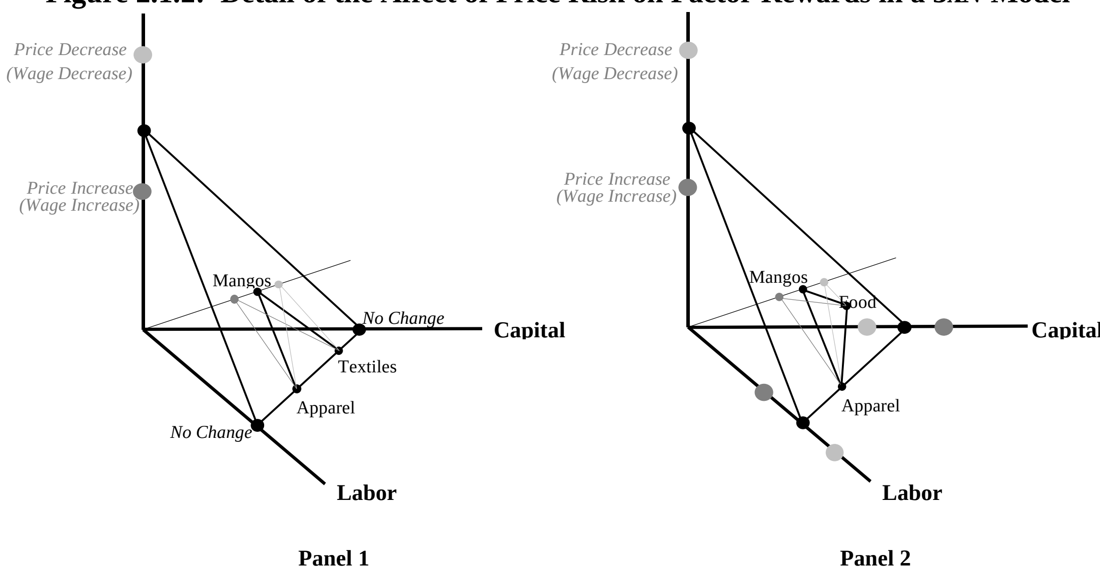


Figure 2.1.2: Detail of the Affect of Price Risk on Factor Rewards in a 3x*N* Model



Assume we have three factors – land, labor and capital -- and three sectors. In the first panel of figure 2.1.1, the three sectors are mangos, apparel and textiles, while in the second panel they are mangos, processed food and textiles. Careful inspection of the figure reveals that the production of apparel and textiles requires only physical capital and labor, while the cropping of mangos and food processing involve the use all three factors. Recall that the particular simplexes drawn (and anchored by the appropriate factor rewards) in each panel of the figure have been determined uniquely by each triplet of black dots. These dots represent tangency points between the simplexes and industry "iso-bowls", akin to the tangency of price lines and isoquants in the 2xN case.[2] Since approaching a corner of the endowment simplex along a ray emanating from that corner represents an increase in the use of that factor, holding the concentration of other factors constant, inspection of the figure also reveals that textiles use more physical capital than apparel, and both use the same ratio of land to labor, which is zero. Thus, the industries in panel 1 are more manufacturing-diversified than those in panel 2 because fewer products depend upon land.

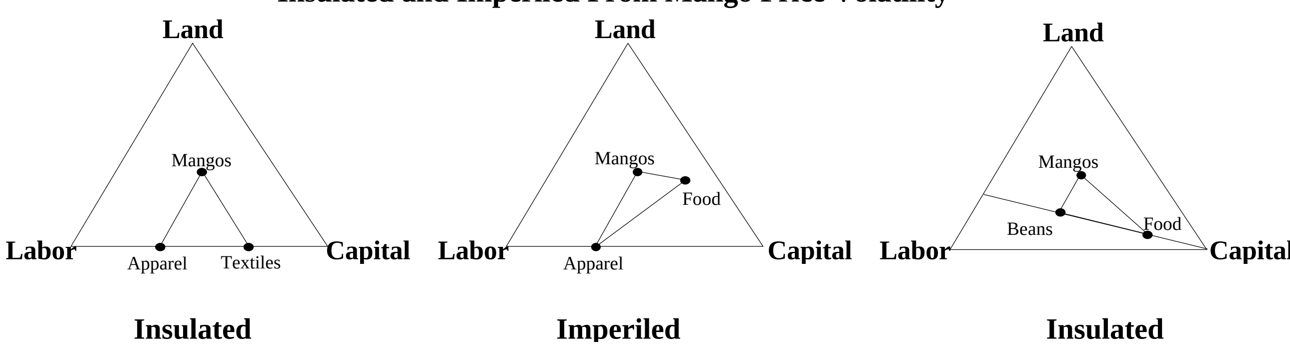
Now suppose that the price of mangos varies but that the prices of apparel and textiles remain constant. We can represent this price movement graphically in figure 2.1.2 by sliding the Mangos industry input dot along a ray emanating from the origin. Movement toward the origin represents a price increase (i.e. fewer factors for the same dollar output) and *vice versa*. What happens to factor rewards? As illustrated in the first panel, mango price movement stimulates fluctuations in the reward to land, which drops when the price of mangos falls (light gray circle) and increases when the price of mangos rises (dark gray circle), but the rewards to capital and labor do not change because the mangos-apparel-textiles cone of diversification merely pivots on the bottom edge of the simplex. Note that though this discussion has focused on the *nominal* rewards, this is equivalent here and below to focusing on *real* rewards if we normalize by the price of apparel, which is assumed to be constant.

If a country's production is not sufficiently diversified into land-independent manufacturing, as in the second panel of figure 2.1.2, the return to capital is "imperiled" by mango price volatility. Thus, as

[2] Actually, for simplicity of exposition, the particular Leamer triangle exhibited here relies upon fixed input technologies (i.e. "iso-corners" rather than "iso-bowls"). Though the mathematics becomes more complicated with non-Leontiff technology, general substantive conclusions should hold.

shown, fluctuations in the price of mangos tilt the high capital risk mangos-apparel-food processing cone of diversification in such a way as to shift the wages of all three factors. These shifts in factor rewards are indicated by the light and dark gray circles along each factor's vertex, where as above light gray means mango price decrease and dark gray means mango price increase. Indeed, as illustrated in figure 2.1.3, the reward to capital is insulated from product price variability so long as the sectors without volatility have identical land to labor input requirements. Geometrically, this is tantamount to lining up along a ray emanating from the capital vertex. This type of diversification occurs most intuitively in the first panel of figure 2.1.3, where manufactured goods all have zero land to labor requirements, but can occur with three natural resource commodities as well, as illustrated in the third panel. Of course, the insulation of capital in the third panel can be overturned if more than one commodity price is highly volatile.

Figure 2.1.3: Conditions Under Which Capital Returns are Insulated and Imperiled From Mango Price Volatility

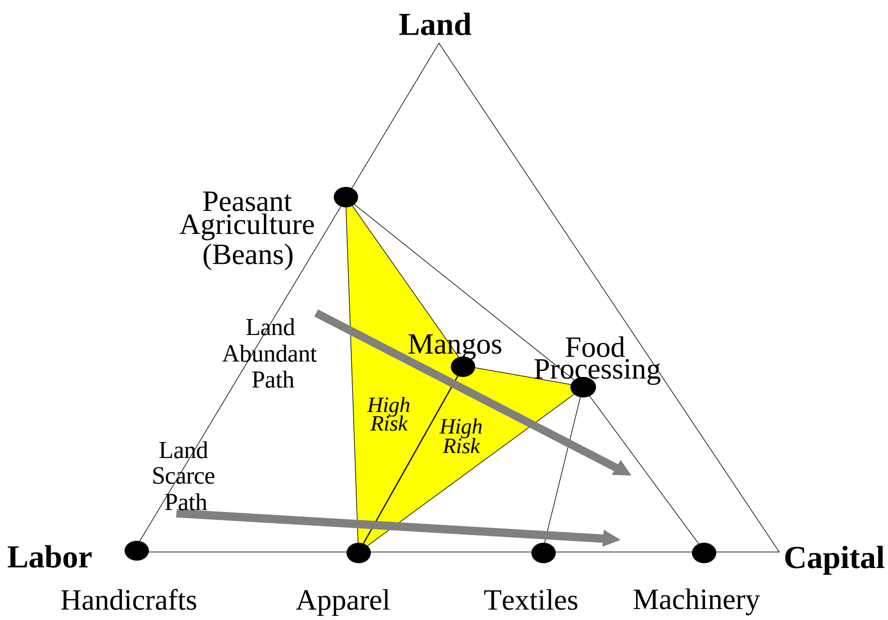


What are the implications of high capital risk cones for development? Figure 2.1.4 plots possible development, or capital accumulation paths of two types of countries, land abundant and land scarce, in an *n*-good world.[3] The upper arrow in the figure represents the land abundant development path, while

[3] Note that the manner in which the 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 2.1.3, for example, apparel and food are assumed to be relatively dear due to the large swaths of the simplex in which they are produced. With n goods, a simplex can be filled with many cones of diversification, each

the lower arrow traces out the land scarce path. Though both countries must pass through the two high risk cones, which are shaded in the figure, these cones comprise a much larger portion of the land abundant country's development path. To the extent that international investors avoid allocating capital to countries in high risk cones, land abundant countries may become "trapped" in the cones proceeding them. Land scarce countries, able to skirt through high risk cones relatively quickly by relying on domestic savings, on the other hand, may face no such obstacle to their development. As a result, whereas land scarce countries will move from handicrafts and apparel on to textiles and machinery, land abundant countries may remain undeveloped, producing handicrafts, apparel and beans indefinitely. This intuition provides the motivation for the simulation scenarios below. One of the implications of the linear program is that land abundance does indeed delay industrialization.

Figure 2.1.4: The Affect of High Risk Cones on Development

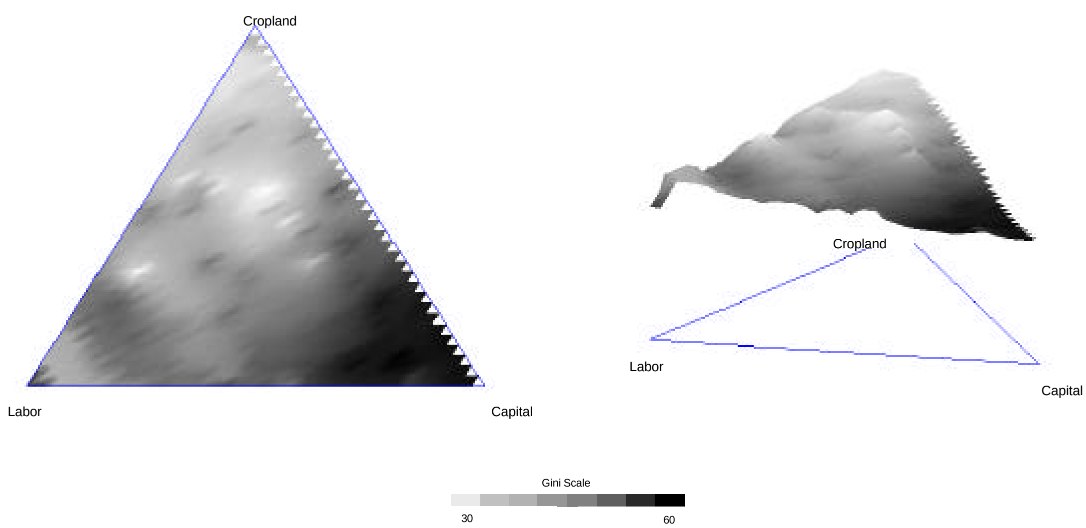


---

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, if there are no factor intensity reversals, the Factor Price Equalization theorem can be generalized to higher dimensions. With respect to risk, the diagrams above and calculations in section 3 below make clear that factor risk equalization holds as well.

To highlight a possible implication of this delay, figure 2.1.5 plots an estimated 1990 Gini coefficient surface over a Leamer (1987) endowment triangle anchored by labor, cropland and capital. This surface is estimated by first plotting each sample country in the endowment triangle and then taking factor-space weighted averages for each point on the simplex. In the figure, both shading and elevation (in the three dimensional view) are used to represent income inequality. Low Gini's are represented by dark gray and low elevation, while the highest Gini's are represented by light gray and peaks. One reason for the persistently high income inequality in Latin America, for example, may be its inability to attract enough capital to move towards the capital vertex of the simplex.

Figure 2.1.5: Income Inequality and Endowments



We can tell the same story about price uncertainty and capital risk algebraically. The Stolper-Samuelson mapping of goods prices into factor prices is built from zero profit conditions equating production costs to product prices:

$$A'w = p$$

where A is the matrix of inputs per unit of output, w is the vector of factor rewards and p is the vector of product prices. If the number of factors equals the number of products (i.e. A is square), and if there are no linear dependencies among the columns of A, then this system can be inverted to solve for the factor rewards as a function of factor prices:

$$w = (A')^{-1} p.$$

From these equations and from the mean $E(p)$ and covariance matrix $Var(p)$ of prices, we can solve for the corresponding mean and covariance matrix of the factor returns:

$$E(w)= (A')^{-1} E(p)$$

$$Var(w) = (A')^{-1} Var(p) (A)^{-1}$$

From this system of equations we seek conditions under which the mean return to capital is high and the variance is low. More generally, we want to determine the optimal global allocation of capital across a set of "diversification cones" when the cones differ in terms of economic structures A and price uncertainty $Var(p)$. In particular, we would like to answer the question: how should global capital be allocated across natural resource rich and natural resource poor countries? The answer might be "not much to resource rich countries" either because the high returns they offer do not compensate for the greater risk or because their risk-return profiles do not offer diversification incentives. This would be a force for keeping the natural resource rich countries in a permanent state of underdevelopment.

The equation for solving for means and covariances is easy to write down, but not so easy to understand. A first step toward understanding comes from a careful examination of the two-dimensional case with the inputs being capital and labor. Then the vector of factor rewards as a function of product prices is:

$$\begin{bmatrix} w_K \\ w_L \end{bmatrix} = \begin{bmatrix} A_{K1} & A_{L1} \\ A_{K2} & A_{L2} \end{bmatrix}^{-1} \begin{bmatrix} p_1 \\ p_2 \end{bmatrix} = (A_{K1}A_{L2} - A_{K2}A_{L1})^{-1} \begin{bmatrix} A_{L2} & -A_{L1} \\ -A_{K2} & A_{K1} \end{bmatrix} \begin{bmatrix} p_1 \\ p_2 \end{bmatrix}$$

Since it is only relative prices that affect real rewards, we might as well normalize by the second price and solve for

$$Var(w_K / p_2) = (A_{K1}A_{L2} - A_{K2}A_{L1})^{-2} A_{L2}^2 Var(p_1 / p_2) = \left(\frac{1 / A_{L1}}{\frac{A_{K1}}{A_{L1}} - \frac{A_{K2}}{A_{L2}}} \right)^2 Var(p_1 / p_2)$$

The message of this equation is conveyed by the denominator: diversity of capital intensities is a source of stability for capital returns. Countries that produce goods that are very similar in capital intensities have capital returns that are very sensitive to relative prices.[4]

2.2 Assessing Actual Product Price Variability

By focusing on mango price volatility, the previous section implied that natural resource-based commodities have greater price volatility than manufactured items. One method of discerning this differential volatility is to estimate and compare price forecasting standard errors for a variety of products. The use of forecasting standard errors rather than sample standard errors is designed to mimic the behavior of entrepreneurs who use historical time series data to predict future prices. They are calculated in two stages. The first stage is to run an Ordinary Least Squares regression of the log of each price index (US PPI deflated) of the form

---

[4] Although the labor-intensity of the first good enters the equation, that number and also the price variance depends on the units. It seems best to choose units of the products such that the labor input is one in both sectors.

$$p_t = a + bp_{t-1} + e_t$$

where p_t is the log of the deflated price index of a given commodity at year t. The second stage is to use the estimated coefficient, b, and regression standard error, s, from this regression to calculate the forecasting standard error,

$$f_s = s^2\left(1 + \sum_{n=1}^{s-1} b^{2n}\right)$$

where s is the number of years in the future to be forecast. This measure of volatility would equal the sampling standard error if b =0, that is if prices behave like a random sample out of a distribution, without trend and without serial correlation. But with a trend or with serial correlation, the simple standard error can give a very misleading idea of the real uncertainty.

Table 2.2.1 provides a summary of 5 year forecasting standard errors, estimated on price indexes from 1970 through 1994 (1970=1), for representative goods from each of 10 aggregate product groupings outlined in Leamer (1984). These groupings are:

Abreviation	Description
PET	petroleum products
MAT	raw materials
TRP	tropical products
ANL	animal products
CER	cereals and grains
FOR	forest products
LAB	labor intensive manufactures
CAP	capital intensive manufactures
MCH	machinery
CHM	chemicals

Most of these categories are broken down further in the table to provide a sense of how uncertainty varies within aggregates (note that TRP and FOR provide examples of both crop and manufactured products). For each of the categories except PET and FOR-crop, the highest and lowest standard errors for each group are reported along with a representative commodity. The representative commodities had forecasting standard errors either equal or very close to the average standard error of the group. High, low and representative manufactured products are at the four digit US SIC level of aggregation.

Table 2.2.1: Five Year Forecasting Standard Errors for Each of Ten Aggregates

Group	SubGroup	Hightest Std Error		Lowest Std Error		Representative Good	
PET		-	-	-	-	1.58	Crude Petroleum
MAT		0.44	Lead (US)	0.10	Manganese	0.27	Tin (London)
TRP	Crop	1.24	Sugar	0.08	Bananas	0.51	Coffee (Cent Amer)
	Manufactured	0.38	Sugar Processing	0.03	Canned Fruit	0.25	Roasted Coffee
ANL		0.84	Wool	0.18	Beef	0.39	Fish
CER		0.68	Lindseed	0.26	Maize	0.40	Wheat
FOR	Crop	-	-	-	-	0.38	Tropical Timber
	Manufactured	0.32	Specialty Sawmill	0.02	Paper	0.09	Hardwood Flooring
LAB	Furniture	0.06	Metal Office Furn	0.03	Mattresses	0.05	Wood House Furn
	Apparel	0.18	Leather Goods	0.02	Male Neckwear	0.04	Male Underwear
CAP	Rubber	0.06	Rubber Footwear	0.03	Rubber Products	0.04	Reclaimed Rubber
	Textiles	0.14	Yarn	0.03	Tufted Carpet	0.07	Warp Knit
	Iron/Steel	0.24	Primary Smelting	0.05	Brass	0.10	Copper Rolling
	Metal Manuf	0.11	Ornamental Work	0.02	Boilers	0.07	Metal Cans
MCH	Non-Electrical	0.09	Mining Equipment	0.03	Compressors	0.06	Hoists
	Electrical	0.09	TV Receivers	0.03	Fans	0.05	Refrigerators
	Transportation	0.25	Tanks	0.03	Trailors	0.07	Motor Vehicle Parts
	Professional	0.07	Measurment Devices	0.03	Surgical Equipment	0.05	Othrapedic Equipment
CHM		0.18	Carbon Black	0.04	Synthetic Fibers	0.11	Resins

[1] Forecasting standard errors for commodity groups based upon annual spot market prices, 1970-1993.

[2] Forecasting standard errors for manufactured goods errors based on U.S. shipment deflators in Bartelsman, Becker and Gray (1997).

[3] Price indexes for shaded commodities graphed in figure 5.

As indicated in the table, two trends stand out. The first is that natural resource prices are in general more uncertain than those of manufactured commodities, with crude oil and sugar being exceptionally volatile. The second trend is that manufactured commodities tend to be more volatile the more closely they are associated with raw materials. Thus, for example Sugar Processing, Leather Goods and Primary Smelting stand out within their respective aggregates. Both trends motivate our focus on the contribution of natural resource commodity price uncertainty on capital reward risk.

For a graphical view of the same data, figure 2.2.1 traces the deflated price indexes of the shaded representative goods in table 2.2.1 from 1970 to 1994 (1970=1). This figure highlights the relative stability of manufactures as well what appears to be a general decline in non-petroleum natural resource commodities since 1980. Note that the lower panel of the figure zooms in on the non-petroleum series for a better view of relative movements. Figure 2.2.2, which plots the same indexes for seven of the ten indexes 1950 to 1970 time period, indicates that both CER and TRP experienced similar declines earlier during the 1950s, while MAT seemed to experience a rise during the 1960s, perhaps due to the US military buildup associated with the Vietnam War.

3 A Numerical Simulation (Linear Programming) Model

Though Leamer's triangles are a very useful device for gaining intuition, they do not offer the kind of quantitative detail we'd like for answering the sorts of questions posed in the introduction. As a result, we turn here to the linear programming problem that lies behind these triangles, and report solutions to specific numerical programming problems using as inputs real world data on input intensities, product prices and their volatility. More specifically, the linear programming problem that underlies the figures is:

> Choose output mix q to maximize the value of output = GDP = $p'q$, subject to the resource constraint $Aq \le v$,

where q is the vector of outputs, v is the vector of factor supplies, A is the matrix of input/output coefficients and p is the vector of world prices. The corresponding dual program is:

> Choose factor costs w to minimize total costs = GDP = $w'v$, subject to the non-positive profit constraint $A'w \ge p$.

We will use this framework to study what happens to differentially endowed economies as they accumulate capital. Before discussing results in section 3.2, the next section will discuss how the data used by the simulation was gathered and refined.

3.1 Simulation Assumptions

Table 3.1.1 summarizes data gathered on manufacturing industry factor requirements and prices, all normalized by a unit of labor. Capital per worker (*k/l*) and value added per worker (*va/l*) for each three digit ISIC sector are calculated as the labor-weighted average of the cross section of countries for which data is available in 1990, with the sixth column of the table indicating the number of countries included in the averaging. The source of the data, including the gross fixed capital formation series from which a real capital stock per sector was computed, is the UNIDO INDSTAT3 database from the United Nations. Because the type of countries for which information is available through this database tends to correlate with capital intensity, we expect the capital and value added figures to be more representative of developed than developing countries.

Table 3.1.1: Factor Content of Manufacturing Sectors, Sorted by Tertiary Education Input, 1990

isic	industry	k/l	va/l	av workers	n	none/l	pri/l	sec/l	ter/l	US CPS industry code (education only)
353	Pet	60,348	317,074	10,683	25	0%	0%	40%	60%	200
351	IndCh	22,865	96,088	55,485	33	0%	1%	42%	57%	192
385	Prof	5,273	66,788	57,736	28	0%	7%	38%	55%	371,372,380,381,382
342	Print	5,804	61,637	125,194	29	0%	1%	47%	53%	171,172
352	OthCh	10,459	107,010	64,983	26	0%	2%	48%	50%	181,182,190,191
314	Tob	2,955	132,305	16,141	23	0%	0%	51%	49%	130
383	Elec	7,963	55,824	236,591	27	0%	1%	51%	48%	340,341,342,350
384	Trans	9,367	63,129	199,365	29	0%	1%	53%	46%	351,352,360,361,362,370
382	Mach	5,590	57,026	253,195	27	0%	2%	55%	43%	310,311,312,320,321,322,331,332
313	Bev	11,406	85,836	22,515	30	1%	3%	54%	42%	120
355	Rub	7,507	41,602	42,153	27	0%	3%	59%	38%	210,211
356	Plas	7,262	52,135	87,219	24	1%	3%	58%	38%	180
362	Glass	8,765	49,415	24,139	24	0%	3%	63%	34%	250
354	PetCoa	8,309	72,277	6,478	19	0%	0%	68%	32%	201
341	Paper	18,225	70,077	58,694	33	0%	2%	66%	32%	160,161,162
311	Food	5,923	47,859	195,250	33	1%	5%	63%	31%	100,101,102,110,111,112
381	Metal	5,402	45,405	143,469	32	0%	4%	66%	30%	281,282,290,291,292,300,301
361	Pott	5,180	25,133	17,595	31	0%	6%	64%	30%	261,251,252
372	Nfeff	14,473	64,013	31,723	24	0%	4%	68%	29%	272,280
369	Nmet	7,842	54,272	63,753	24	0%	5%	66%	29%	262
371	Iron	12,577	58,887	72,092	31	1%	2%	69%	28%	270,271
390	Oth	2,767	40,413	37,101	28	8%	8%	57%	27%	390,391,392
331	Wood	4,077	30,263	57,289	33	1%	5%	68%	25%	230,231,232,241
321	Tex	3,712	23,932	142,610	34	1%	4%	74%	22%	132,140,141,142,150
324	Foot	1,201	18,640	21,080	28	1%	3%	74%	22%	221
332	Furn	2,801	36,671	49,863	27	0%	7%	73%	20%	242
322	App	904	18,516	119,383	28	2%	13%	69%	16%	151
323	Lea	2,067	20,917	16,488	26	1%	8%	77%	15%	220,222

Notes:
[1] Capital, value added and worker data is from UNIDO database, based on n countries; k/l and va/l are labor weighted averages of the n countries avaiable.
[2] Education input requirements extrapolated from from US Current Population Survey Data, 1989-1991.
[3] Real capital stock is 15 year accumulated, depreciated (13.3%) and deflated (US PPI) gross fixed capital formation by sector.
[4] Education input requirements are based upon averages of indicated three digit sub sectors. Obvious outliers to these averages are shown in table 3.2.
[5] k=capital; l=worker; none=no education; pri=primary education; sec=secondary education; and ter=tertiary education.

Educational inputs are extrapolated from responses to the 1989-1991 US Current Population Survey (CPS). Respondents to these surveys indicated both their educational background and the industry within which they work (at the three digit, CPS level of aggregation). The proportion of respondents in each of the following years-of-schooling categories is used to approximate the educational requirements of a given three digit sector. These are clearly representative of advanced developed countries, not developing ones. We will say more about how we deal with this aspect of the data when we report the results.

Years of School	Level	Abbrev
<1	no education	none
1-6	primary	pri
7-12	secondary	sec
>12	tertiary	ter

Three digit CPS sectors are averaged as indicated in the table to estimate the educational requirement for a given three digit ISIC category. Note that Petroleum, Industrial Chemicals and Professional goods require the greatest proportion of tertiary educated workers, while Leather goods, Apparel and Furniture require the least. In some cases, there were obvious outliers within the set of three digit CPS sectors corresponding to a given ISIC sector. One of the CPS sectors used for the Machinery industry (ISIC 382), for example, is Computers (CPS 322). While average tertiary requirement for Machinery is 43%, that for computers is 74%. Thus, to complement table 3.1.1, several outliers are noted in table 3.1.2.

Table 3.1.2: Obvious Outliers to Education Input Requirements in Table 3.1

isic	industry	sub-industry	sic	none/l	pri/l	sec/l	ter/l
385	Prof	Photo	380	0%	1%	34%	64%
383	Elec	Radio,TV	341	0%	1%	40%	58%
383	Elec	House Appl	340	0%	2%	67%	31%
384	Trans	Space, etc	362	0%	0%	29%	70%
384	Trans	Aircraft	352	1%	1%	44%	53%
382	Mach	Office Mach	321	0%	2%	46%	52%
382	Mach	Computers	322	0%	1%	26%	73%
355	Rubber	Tires	210	0%	1%	54%	46%
381	Metal	Ordnance	292	0%	2%	53%	46%
361	Pott	Pottery	261	0%	5%	60%	35%
331	Wood	Wood Bldg	232	0%	1%	62%	36%

An interesting feature of table 3.1.1 is that the manufacturing industries allied most closely with natural resources (i.e. Wood, Furniture, Food, Beverages and Tobacco) have relatively low tertiary education requirements. This characteristic is consistent with the notion that the types of manufactured goods resource abundant countries produce during the earlier stages of industrialization do not demand high levels of education. This point will be underscored in the simulation results below.

Table 3.1.3 summarizes assumptions about agricultural input requirements gathered from field research in Guatemala. A noteworthy feature of this data is the relatively high per worker capital intensity of some of the perennial crops. Because many perennials require several years of waiting before harvesting can take place, much of the capital in perennial crop abundant countries can be absorbed by land, delaying the emergence of manufacturing. For more detail on this effect or how the agricultural data were calculated, see Leamer, Maul, Rodriguez and Schott (1998).

Table 3.1.3: Factor Content of Agricultural Industries

All figures are in $1990	Beans	Sugar	Corn	Rubber	Mangos	Cotton	Coffee	Cashew	Citrus	Rice	Bananas
Yields (tons/ha)	0.59	3.90	4.55	1.25	59.98	1.19	1.62	6.85	413.05	5.20	39.00
Average Price 1970-1980	415	420	126	1171	77	1729	3312	385	17	467	657
Value of Production	243	1637	572	1464	13303	2056	5365	2633	7221	2429	25637
Waiting Capital	0	564	0	6320	3190	0	6535	6348	17411	0	21217
Machinery Capital	20	243	670	0	229	1660	0	0	71	1681	845
Labor Requirements (man-days)	51	116	32	273	119	56	200	153	253	12	117
Labor Requirements (man-years)	0.17	0.39	0.11	0.91	0.40	0.19	0.67	0.51	0.84	0.04	0.39
SUMMARY DATA											
Waiting Capital (r=.1) / Worker	0	1459	0	6942	8064	0	9783	12446	20637	0	54273
Machinery Capital / Worker	119	628	6254	0	580	8863	0	0	84	43326	2163
Total Capital / Worker	119	2087	6254	6942	8644	8863	9783	12446	20721	43326	56436
Production / Worker	1432	4235	5343	1608	33624	10979	8032	5162	8559	62624	65578
Hectares / Worker	5.88	2.59	9.34	1.10	2.53	5.34	1.50	1.96	1.19	25.78	2.56
Capital / Hectare	20	807	670	6320	3420	1660	6535	6348	17482	1681	22063
Production / Capital	15.87	2.68	1.12	0.30	5.13	1.64	1.08	0.54	0.54	1.91	1.53

3.2 Simulation Results

As a first pass, rather than attempting to model several different educational factors (e.g.. primary, secondary and tertiary education), we model workers as possessing either high or low skill. With respect to the input intensities described in table 3.1.1, high skill corresponds to tertiary educated workers while low skill refers to any schooling less than that. One reason for selecting this categorization is to mitigate the effect of using US data on education inputs for what is essentially a developing country simulation: it seems reasonable to assume that developing country input requirements are split between high and low skill in roughly the same manner that US requirements are split between college and no college. A second reason for choosing to work with only two skill categories at this point is to ease interpretation of results.

Because the story of how skill accumulation varies with resource abundance is one of the questions motivating this study, the linear programming problem described above is modified to allow for the endogeneity of human capital accumulation. As a result, concomitant with determining output and wages, the program also chooses the optimal mix of high and low skill workers at any given level of capital abundance. We assume that the schooling required to turn a low skilled worker into a high skilled worker absorbs about 20% of a worker's productive life[5]. Except for this lost work time, low-skilled workers are allowed costlessly to be turned into high skilled workers. Thus we write the labor constraint as:

$$1.2H + L = v_{\bar{L}} \,,$$

where $v_{\bar{L}}$ is the total number of worker-years in the economy and L and H are the (endogenously determined) number of low-skilled and high-skilled worker-years, respectively. A community that opts for all H ends up with 20% fewer worker-years than a community with all L. We simply add this constraint to our four factor linear programming problem as follows:

<u>Primal Constraints</u>

$$\boldsymbol{Aq} \le \boldsymbol{v}$$

$$\begin{bmatrix} \boldsymbol{A_C} & 0 & 0 \\ \boldsymbol{A_K} & 0 & 0 \\ \boldsymbol{A_L} & 0 & -1 \\ \boldsymbol{A_H} & -1 & 0 \\ \boldsymbol{0} & 1.2 & 1 \end{bmatrix} \begin{bmatrix} \boldsymbol{q} \\ H \\ L \end{bmatrix} \le \begin{bmatrix} v_C \\ v_K \\ 0 \\ 0 \\ v_{\bar{L}} \end{bmatrix}$$

<u>Dual Constraints</u>

---

[5] Attaining a college education in the United States takes approximately 16 years, roughly one fifth of a 70 to 80 year work life. Qualitative implications of the simulation are not sensitive to variations in this assumption.

$$\boldsymbol{A'w} \le \boldsymbol{p}$$

$$\begin{bmatrix} \boldsymbol{A_C} & \boldsymbol{A_K} & \boldsymbol{A_L} & \boldsymbol{A_H} & \boldsymbol{0} \\ 0 & 0 & 0 & -1 & 1.2 \\ 0 & 0 & -1 & 0 & 1 \end{bmatrix} \begin{bmatrix} w_C \\ w_K \\ w_H \\ w_L \\ w_{\bar{L}} \end{bmatrix} \le \begin{bmatrix} \boldsymbol{p} \\ 0 \\ 0 \end{bmatrix},$$

where $\boldsymbol{A_i}$ are the input vectors for factor i, C and K represent cropland and capital, respectively, and $\boldsymbol{0}$ is a vector of zeros of the same length as $\boldsymbol{p}$ and $\boldsymbol{q}$.

This represents what looks like a rather minor change in the linear program, but it makes the solution change in an important way. With cropland, physical capital, high-skilled workers and low-skilled workers, the number of factors of production is four and the solution will usually involve the output of four products. But the fungibility of H and L supports the movement of the endowment point to the edge of a cone of diversification, and the number of products reduces to three. To put it differently, there are really only three inputs: capital, land and labor. The economy then divides labor into high and low skill categories as part of the maximization problem.[6]

Not all of the aggregates listed in tables 3.1.1 and 3.1.3 are included in the simulation because, unless input combinations and prices are *just* right (which is not too likely with aggregate data), not all goods will be selected by the linear program for production. The sectors that are included are listed in table 3.2.1.[7] Three differences between table 3.2.1 and the data listed in earlier tables deserve comment

---

[6] An alternate approach is to run the linear program with a fixed level of human capital for each country. Though this has the benefit of allowing the ratio of high to low skill workers to vary endogenously, it seems more satisfying to allow the number or workers to adjust. We are currently working on an alternative between these two extremes.

[7] How do we choose which sectors to include in the simulation? First, we exclude tobacco; as an extremely high value added to capital sector, it generally is produced to the exclusion of virtually all other sectors. Second, we exclude any remaining *dominated* sectors, defined as sectors that will not be produced even if a country's

before continuing. First, because of differences in product mix as well as other factors, the applicable price (i.e. value added) for a given manufacturing sector is likely to be higher in developed versus developing countries. Experimentation using both the value added per worker figures listed in table 3.1.1, which are based on the labor-weighted world averages, as well as those for several agriculturally intense developing countries, such as Colombia, Guatemala and Mexico, indicated that the latter provide more realistic results in terms of what is produced at given levels of capital intensity, and are therefore included in the simulation. If the price of industrial chemicals is very high, for example, countries produce it immediately, rather than moving through a ladder of development. Thus, developing country prices are selected to allow for such development.

Figure 3.2.1: Simulation Assumptions (All Quantities are Per Worker)

	Beans	**Mangos**	**Food**	**Beverage**	**Apparel**	**Textiles**	**Trans**	**Chemicals**
CropLand (Hectares)	5.00	2.53	2.59	1.50	0.00	0.00	0.00	0.00
Capital (US $)	119	8,644	14,566	13,493	904	3,712	9,367	22,865
Low Skill	1.00	1.00	0.69	0.58	0.84	0.79	0.54	0.43
High Skill	0.00	0.00	0.31	0.42	0.16	0.22	0.46	0.57
Price (US $)	1,432	33,624	50,095	43,028	3,161	12,000	29,589	39,661
Price/Capital	12.1	3.9	3.4	3.2	3.5	3.2	3.2	1.7

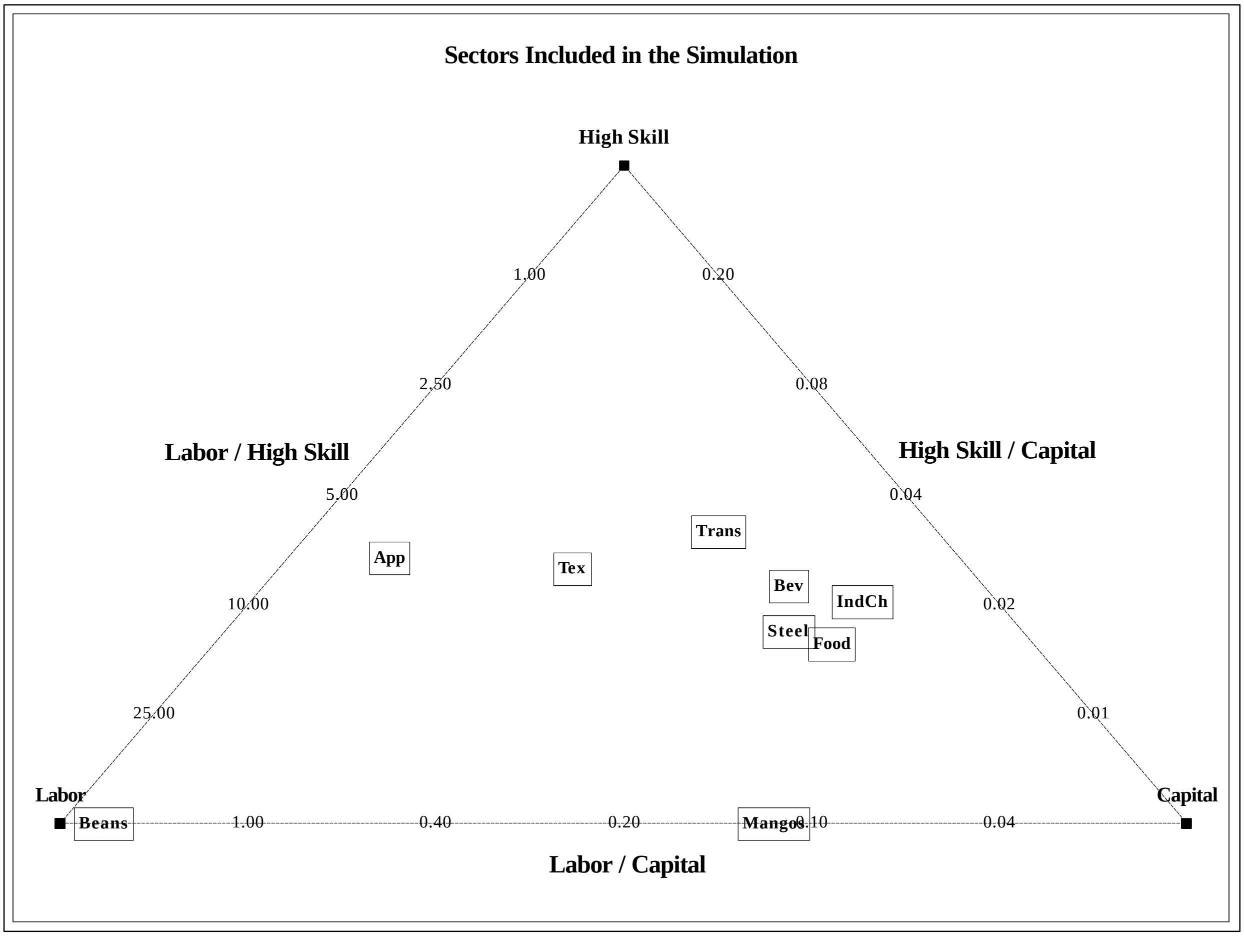
Second, the input requirements for the food processing and beverage sectors included in the simulation are derived by adding the capital and cropland requirements for sugar and coffee to that of the food (ISIC 311) and beverage (ISIC 314) figures given in table 3.1.1. This adjustment should be interpreted as compressing into food processing both the raising of a crop and the processing and

endowments match exactly the input requirements of the sector. (Thus, being dominated indicates that some linear combination of other sectors will always be superior to the dominated sector.) Non-dominated sectors are reported in table 2.3.4. Note that not all of the sectors in this table are actually produced in the simulation because, with endogenous human capital formation, there is no guarantee that country endowments will match a given sector's input requirements closely enough to make its production optimal.

packaging of it. Our motivation for this adjustment is to create a linkage between food processing and agriculture, thereby rendering land abundant country development paths more realistic. Finally, note that we use the input and price data from Beans in table 3.1.3 to represent a peasant agriculture sector in the development stories presented below.

To provide a visual context for comparing the simulation sectors, figure 3.2.1 plots them on an endowment simplex anchored by labor, high skill and capital. You can see that mangoes are moderately capital intensive but use no skill at all. Food processing has a skill intensity that is greater than apparel and textiles but less than chemicals and transportation. As our simulated countries accumulate capital, they will pick a path between these industry points. We consider three types of countries to help us understand the differential effects of natural resource abundance: Super Abundant, Abundant and No Land, with cropland per worker ratios of 6, 1.67 and 0 hectares, respectively. A cropland per worker ratio of 6 hectares is quite large: only one country in our sample, Australia, has an intensity this high, and it is almost twice as large as the next highest country in the sample, Canada.

Figure 3.2.2



Figures 3.2.2 and 3.2.3 provide a summary of two of the key implications of the simulation, both of which mirror reality. Figure 3.2.2, which plots the ratio of high skill to total workers as capital per worker accumulates, indicates that natural resource abundance leads to a greater delay in the emergence of skilled workers. Of course, this result is due to the assumption that agriculture requires very low levels of skill; since only resource abundant countries choose to produce agricultural goods because of their natural advantage in land, the associated lower demand for skill deters workers from seeking an education. As indicated in the figure, while the skilled jump to 20% of the population at the outset in the No Land country, they remain 0% of the population until $4,000 and $6,000 capital per worker in the Abundant and Super Abundant countries, respectively.

Figure 3.2.3: Ratio of High to Low Skill Workers vs Capital per Worker ($000)

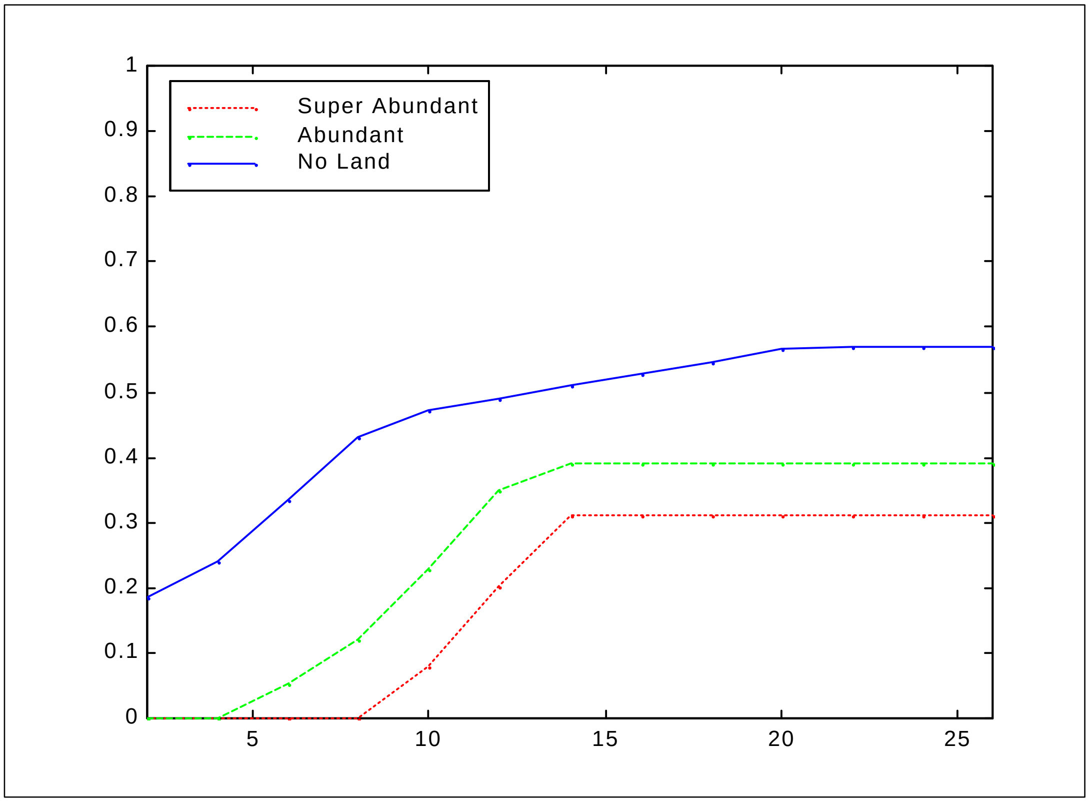


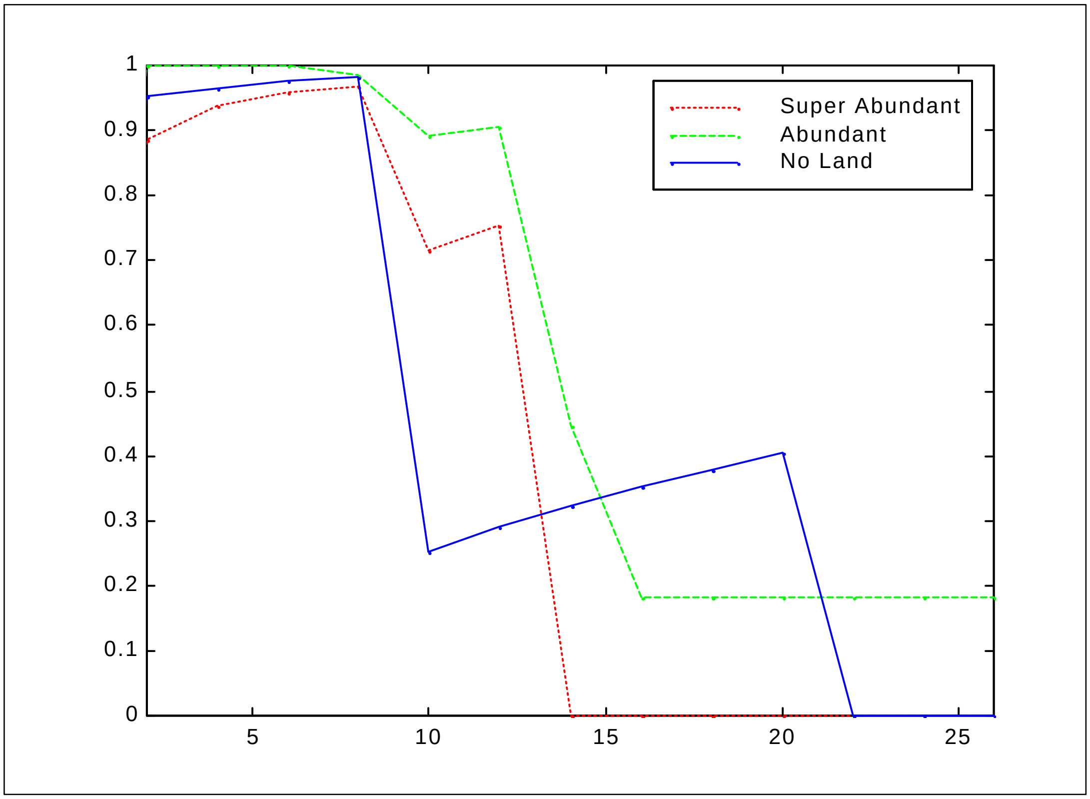
Figure 3.2.3 plots the evolution of income inequality, here measured as unity less the ratio of low skill worker GDP share to low skill worker population share. Thus, a measure of zero indicates perfect equality.[8] Our assumption in using this definition is that low skill workers own neither capital nor land, and therefore do not receive any of the GDP earned by these factors. The figure has several interesting features. First, income inequality declines with capital accumulation, though not monotonically, suggesting that periods of rising inequality, such as those currently being experienced by some countries, are not ruled out by theory. What causes the ups and downs in each series? As will become clearer below, these movements are due to the interaction between workers' salaries and the steady accumulation

---

[8] Recall that the ratio of high to low skill wages cannot be used here as a measure of inequality because it is fixed at 1.2 by assumption. By using the ratio of low skill workers to total possible workers, $v_{\bar{L}}$, in the denominator, this measure "corrects" for the 20% wage inequality built into the model by assumption.

of capital built into the model. Large drops in inequality are the result of jumps in salary associated with increased worker scarcity as countries transition to cones requiring more labor. Slow rises in inequality after these transitions are due to the incremental increases in per worker capital: within a cone, rewards are fixed, so as capital accumulates, it's share will rise. Each up-down cycle is interestingly reminiscent of the Kuznets curve.

Figure 3.2.4: Income Inequality versus Capital Per Worker ($000)



The second interesting feature of the figure is that income inequality decreases more rapidly in the No Land country than in either of the land endowed economies. As we will see in a moment, this result is a feature of more rapid industrialization: No Land sectors render labor more scarce earlier in terms of capital accumulation than either of the land abundant countries, driving up wages and therefore reducing the GDP share of land and capital.

Finally, note that Super Abundant has the lowest income inequality at both very low and very high levels of capital per worker. In general, this is due to the fact that in Super Abundant, land is so plentiful that employing it has no cost.

Can we fit the current state of the world to these trends? Though the figure suggests that income inequality can be lower in land scarce than in land abundant countries at the same per worker capital intensity, it is perhaps more accurate to compare countries at different stages of development. Since the US, for example, has approximately four times the per worker capital of most Latin American countries, one should contrast the income inequality at the latter stages of the No Land with the income inequality at the early stages of Abundant. In this manner, the results do make sense: Brazil and other land abundant countries tend to have very high (and rising) measured income inequality, while Taiwan and other land scarce countries tend to have lower inequality.

Tables 3.2.2 and 3.2.3 detail the linear program's results by noting how product mix and wages evolve with capital accumulation. Each table contains three panels, one for each country type; the top row of each panel contain the per worker capital accumulation index, in $2000 increments. Development paths are outlined by the sequence of boxes outlining the cones of diversification through which each country type passes. Note that each box contains a different set of sectors (table 3.5) or factor rewards (table 3.6). Thus, for example, table 3.2.2 reveals that Super Abundant produces beans and mangos from $2000 to $8000 of per worker capital, while table 3.2.3 indicates that the rewards to cropland, capital, high and low skilled workers in this cone are $0, 377%, $960 and $0, respectively.[9] In addition, the last

---

[9] Why are capital returns so high? This feature of the results is driven by the high price (valued added) to capital ratios in our underlying data. Another look at table 3.2.1, for example, indicates that this ratio ranges from 12.05 for beans to 1.73 for chemicals. If capital is scarce and labor and land are so abundant that their rewards are driven to zero, it is no surprise that capital returns can be 300% or more. Such ratios are a feature of the Guatemalan agricultural and UNIDO manufacturing data used in this simulation: very rarely does the capital requirement exceed value added, which is what one might expect for interest rates on the order of 10%-20%. Interestingly, similar value

two rows of each panel in table 3.2.2 exhibit the endogenous choice of high and low skill workers, while the last row of each panel of table 3.2.3 shows the path of income inequality.

Table 3.2.1: Output Mix versus Capital Abundance

Super Abundant

K/L	**2,000**	**4,000**	**6,000**	**8,000**	**10,000**	**12,000**	**14,000**	**16,000**	**18,000**	**20,000**	**22,000**	**24,000**	**26,000**
Beans	78	54	31	8									
Mangos	22	46	69	92	73	34							
Food Proc					25	62	94	94	94	94	94	94	94
Beverage													
Apparel													
Textile													
Transport													
Chemicals													
High Skill					*8*	*19*	*29*	*29*	*29*	*29*	*29*	*29*	*29*
Low Skill	*100*	*100*	*100*	*100*	*91*	*77*	*65*	*65*	*65*	*65*	*65*	*65*	*65*

Abundant

K/L	**2,000**	**4,000**	**6,000**	**8,000**	**10,000**	**12,000**	**14,000**	**16,000**	**18,000**	**20,000**	**22,000**	**24,000**	**26,000**
Beans	22	10											
Mangos	23	46	66	66	40	2							
Food Proc					26	63	41	64	64	64	64	64	64
Beverage							41						
Apparel			32										
Textile				12									
Transport				20	30	29							
Chemicals							11	28	28	28	28	28	28
High Skill			*5*	*12*	*22*	*33*	*36*	*36*	*36*	*36*	*36*	*36*	*36*
Low Skill	*45*	*56*	*93*	*86*	*74*	*61*	*57*	*57*	*57*	*57*	*57*	*57*	*57*

No Land

K/L	**2,000**	**4,000**	**6,000**	**8,000**	**10,000**	**12,000**	**14,000**	**16,000**	**18,000**	**20,000**	**22,000**	**24,000**	**26,000**
Beans													
Mangos													
Food Proc													
Beverage													
Apparel	56												
Textile	40	86	48	11									
Transport		9	45	81	81	65	50	35	19	4			
Chemicals					11	26	41	56	71	86	90	90	90
High Skill	*18*	*23*	*31*	*40*	*43*	*45*	*46*	*48*	*49*	*51*	*51*	*51*	*51*
Low Skill	*79*	*73*	*62*	*52*	*48*	*46*	*45*	*43*	*41*	*39*	*39*	*39*	*39*

High risk cones are shaded.

---

added to capital ratios are evident in the US data contained in the NBER Productivity Database. Thus, it appears as though the high capital returns are likely due to a combination of underestimated capital stocks and incomplete refinement of value added. Thus, though it is possible to "artfully" scale down interest rates to acceptable levels by arbitrarily adjusting these numbers, it seems more palatable to let the numbers stand as a reminder of the vagaries of data analysis.

Table 3.2.2: Factor Rewards versus Capital Abundance

Super Abundant

K/L	2,000	4,000	6,000	8,000	10,000	12,000	14,000	16,000	18,000	20,000	22,000	24,000	26,000
Crop Wage	0				0		0						
Capital Wage	3.77				2.68		0						
Low Skill Wage	960				10,420		47,170						
High Skill Wage	0				12,505		56,604						

Abundant

K/L	2,000	4,000	6,000	8,000	10,000	12,000	14,000	16,000	18,000	20,000	22,000	24,000	26,000
Crop Wage	191		1,315	2,485	2,495		6,363	4,528					
Capital Wage	3.83		3.50	3.11	2.72		0.66	0					
Low Skill Wage	0		0	432	3,734		22,635	36,127					
High Skill Wage	0		0	519	4,480		27,162	43,352					

No Land

K/L	2,000	4,000	6,000	8,000	10,000	12,000	14,000	16,000	18,000	20,000	22,000	24,000	26,000
Crop Wage													
Capital Wage	3.14				0.76						0		
Low Skill Wage	314				20,607						36,127		
High Skill Wage	377				24,728						43,352		

High risk cones are shaded.

To aid in interpreting the large amount of information conveyed in each of these tables, we provide a short development story for each country type:

Super Abundant

In Super Abundant countries, land is so plentiful that it's free, allowing peasants to earn the relatively large income of about $1000 a year planting beans in the economy's earliest stages. As capital accumulates and becomes cheaper, inequality temporarily worsens as the country's few capitalists increase the size and output of their mango plantations, but drawing more and more peasants off their small plots in the process. With even more capital, plantation owners are able to diversify into food processing. This push into agribusiness creates a greater demand for low and high skill labor, causing wages to jump, income inequality to drop and more low skilled workers to enter school. Further capital accumulation causes a temporary increase in income equality, but the country's specialization in agribusiness soon raises wages even further, eliminating inequality altogether. Indeed, Super Abundant workers are so highly paid, and land is so cheap, that industrialization beyond food processing is not viable.

Abundant

Land Abundant peasants have the hardest time earning a living. At the economy's earliest stages, after renting land and the few tools needed to work it, virtually no money is left. Fortunes increase and inequality declines as more capital stimulates first mango plantations and then the emergence of manufacturing, including apparel, textiles and transportation. With little demand for skill, few workers send their children to school.

Further capital accumulation drives down its return, improves inequality and opens up further opportunities in food processing, beverages and transportation. After a brief period where the returns to landowners spike as agricultural activity peaks, wages jump, inequality declines further and manufacturers' demand for skill lures even more young to attend school. Eventually, skill levels and capital are high enough to encourage entry into industrial chemicals, a premier industry, causing additional salary gains and inequality declines. However, the presence of wealthy landowners precludes Abundant low skill workers from achieving the same level of equality as their Super Abundant counterparts.

No Land

In No Land, the soil is not suitable for farming, so peasants are immediately employed in the producing of apparel and textiles. The people are poor relative to the inhabitants of Super Abundant (they earn just one third the income), but are better off than their counterparts in Abundant. Wages respond slowly to increasing activity in textiles and transportation, but the skill needed in these sectors encourages many low skilled workers to attend school. The great demand for low and high skill workers in the chemicals sector at per worker capital of $10,000 finally causes wages to spike and inequality to decline sharply, though inequality thereafter increases for a time as owners of capital expand their businesses. The specialization in chemicals that coincides with elimination of capital's reward results in another jump in wages, eliminating income inequality altogether.

The main theme of all three stories is that the demand labor associated with industrialization benefits low skill workers by raising their salaries and driving down the return to capital. The next section discusses how risk may inhibit the investment upon which this industrialization depends.

3.3 Agriculture Concentration and Capital Risk

Though illuminating, running the simulation as if the accumulation of capital in each country were inevitable contradicts an important aspect of reality, which is that product price uncertainty can increase a cone's capital risk and thereby inhibit capital accumulation. Recall that these high-risk cones can occur where insufficient diversification into manufacturing allows the return to capital to be imperiled by natural resource product price uncertainty.

Table 3.2.2 uses shading to identify potential high risk cones, signaled here by the production of a greater number of agricultural commodities than manufactured commodities. Because Super Abundant never moves into non-resource manufacturing, its entire development path is high risk. The same is almost true for Abundant, which has just two cones, at \$6,000 and \$8,000 capital per worker, with sufficient diversification.

To estimate whether the risk-return tradeoff in high risk cones might be less attractive to domestic and global investors than in diversified cones, we can use Stolper-Samuelson relationships presented earlier to calculate the expected reward and variance of each factor along each country's path of development:

$$\text{Expected Return:} \qquad E(w) = (A')^{-1} E(p)$$

Variance: $Var(w) = (A')^{-1}\, Var(p)\, (A)^{-1}$

The first step in performing these calculations is to associate each of the sectors in the simulation with the price series of an actual commodity.[10] Then, like above, we calculate *s* year ahead price forecasts and forecast standard errors by running an Ordinary Least Squares regression for each price index (US PPI deflated) of the form

$$p_t = a + bp_{t-1} + e \qquad (3.3.1)$$

where p_t is the deflated price index of a given commodity at year *t*. For any given price index, the forecast and forecast standard error are

$$m + b^5 (p_T - m) \qquad (3.3.2)$$

and

$$s^2 \left(1 + \sum_{n=1}^{s-1} b^{2n}\right), \qquad (3.3.3)$$

respectively, where *s* is the number of years in the future to be forecast, m is the average price over price series, p_T is last observation in the series, and b and s are coefficient and regression standard error of the autoregressive forecast. To calculate the covariance matrix *Var*(*p*), hereafter referred to as S, a hybrid

[10] Agricultural prices are gathered from various world spot market indexes, while manufactured goods prices are based upon US shipment deflators in Bartelsman, Becker and Gray (1994). Both sources contain annual observations for 1970 to 1993.

forecasting-seemingly unrelated regression framework is employed. Diagonal elements of S contain the forecasting variance for the particular commodity, calculated as above. Off-diagonal elements, on the other hand, are equal to the appropriate product of residual vectors from equation (2.1) divided by degrees of freedom, *df*. Thus, the (*m*,*n*) elements of S are:

$$\frac{e_m{}'e_n}{df}$$

for $m \neq n$.

Table 3.3.1 details the particular proxy good chosen to represent each of the simulation sectors, as well as their forecasted price (in terms of value added per worker) and forecasting error[11].

Table 3.3.1
Proxy Goods Used for Calculating Risk and Return by Cone

Sector	Proxy Good	Forecast Price	Forecast Error
Beans	-	1,409	309
Mangos	-	33,580	7,083
Food Processing	Processed Sugar	50,095	2,651
Beverage	Roasted Coffee	42,951	5,405
Apparel	Underwear	3,163	86
Textiles	Warp Knit	11,993	195
Transportation	Motor Vehicle Parts	29,586	732
Chemcials	Industrial Gases	40,246	1,780

Table 3.3.2 provides a breakdown of the expected return and standard deviation of the capital reward for each cone in each of the three countries' paths of development using these price indexes. Each cell in the table depicts the expected capital wage as well as its forecasting error. In addition, the vertical

[11] The forecasted price and error result from combining the value added per worker data from tables 2.3.1 and 2.3.3 with the respective price indexes.

length of each cell indicates the range of capital per worker for which it remains operative. Thus, for example, the Beans-Mangos cone of Super Abundant has an expected return and standard error of 377% and 614%, respectively, and it remains operative from $2,000 to $8,000 capital per worker. The total vertical length of each country's cones indicate the amount of capital per worker necessary to drive the expected return of capital to zero. Thus, a zero expected return occurs at $14,000, $16,000 and $24,000 for Super Abundant, Abundant and No Land, respectively.

Table 3.3.2: Risk-Return Profile by Cone of Diversification

	Super Abundant			Abundant			No Land		
K/L	**Sectors**	**Return**	**Risk**	**Sectors**	**Return**	**Risk**	**Sectors**	**Return**	**Risk**
2,000	Beans Mangos	3.77	3.28	Beans Mangos	3.83	3.28	Apparel Textiles	3.14	0.47
4,000							Textiles Transportation	3.11	0.37
6,000				Mangos Apparel	3.50	0.16			
8,000				Mangos Textiles Transportation	3.11	0.37			
10,000	Mangos Food	3.13	1.65	Mangos Food Transportation	2.72	1.98	Transportation Chemicals	0.76	0.28
12,000									
14,000				Food Beverages Chemicals	0.66	3.11			
16,000									
18,000									
20,000									
22,000									

High risk cones are shaded.

Two trends in the table stand out. The first is that the non-diversified cones of the land endowed countries, which have been shaded, are indeed riskier than the manufacturing-diversified cones. Second, risk-adjusted returns are higher in diversified cones. All else equal, this suggests that countries in these cones are more likely to have higher investment. The most attractive cones in this dimension are the Mangos-Apparel cone of Abundant and the Textiles-Transportation / Mangos-Textiles-Transportation cones Abundant and No Land, which are equivalent. These latter two cones are the same even though Abundant also produces Mangos because neither Textiles nor Transportation require land. As a result, the risk and return to capital are completely insulated from Mango price volatility in the manner suggested by theory in section 2.

Of course, investors care about diversification across assets as well as the risk-return characteristics of any individual investment. Thus, the allocation of world investment across cones of diversification also depends upon how the returns of different cones co-vary. Investors, for example, might seek investment in high risk, land abundant cones if the capital rewards in these cones are negatively correlated with rewards in lower risk, land scarce cones. Indeed, we know from basic finance that given Ω, the covariance matrix of cone returns, we can determine the share of investment that will flow to each of the non-redundant cones above for any desired level of risk or return. This is done by computing optimal portfolio weights to minimize risk subject to two constraints: first, that the portfolio return is equal to some target return, r^*; and second, that the vector of weights, s, which represent the share of investment flowing to each cone, sum to unity. More formally, the global investor’s problem is to

$$\min_{w} s'\Omega s \text{ st } s'r \geq r^* \text{ and } s'i = 1,$$

where r is the vector of cone returns and i is a vector of ones. The solution to this problem for a range of r^* traces out the efficient risk-return portfolio frontier:

$$s = -\tfrac{1}{2}\Omega^{-1}(r\,l_1 - i\,l_2)$$

where i is a vector of ones of the appropriate length and l_1 and l_2 are solved via the system:

$$\begin{bmatrix} l_1 \\ l_2 \end{bmatrix} = \begin{bmatrix} -r'\Omega^{-1}r & r'\Omega^{-1}i \\ -i'\Omega^{-1}r & i'\Omega^{-1}i \end{bmatrix}^{-1} \begin{bmatrix} r^* \\ 1 \end{bmatrix}.$$

In our case, the covariance matrix of cone returns, Ω, is equal to

$$\begin{bmatrix} v_{11} & . & . & v_{1c} \\ . & . & & \\ . & & . & \\ v_{j1} & & & v_{jc} \end{bmatrix}' \Sigma \begin{bmatrix} v_{11} & . & . & v_{1c} \\ . & . & & \\ . & & . & \\ v_{j1} & & & v_{jc} \end{bmatrix}$$

where v_{jc} is the appropriate capital element for good *j* of the inverted *A* matrix if good *j* is produced in cone *c* and zero otherwise.[12] Thus, just as factor rewards are insensitive to output within a particular cone, so is factor risk.

Figure 3.3.1 presents the results of these calculations, plotting the efficient portfolio frontier as well as each of the non-redundant cones from the simulation. Table 3.3.3 provides the cone covariance matrix, Ω, used to calculate this frontier. With this information, we are now able to examine how global investors might allocate investment among cones. We employ to two different thought experiments.

---

[12] Note that a distinct W matrix can be computed for each factor.

Figure 3.3.1: Efficient Frontier of Cone of Diversification Assets

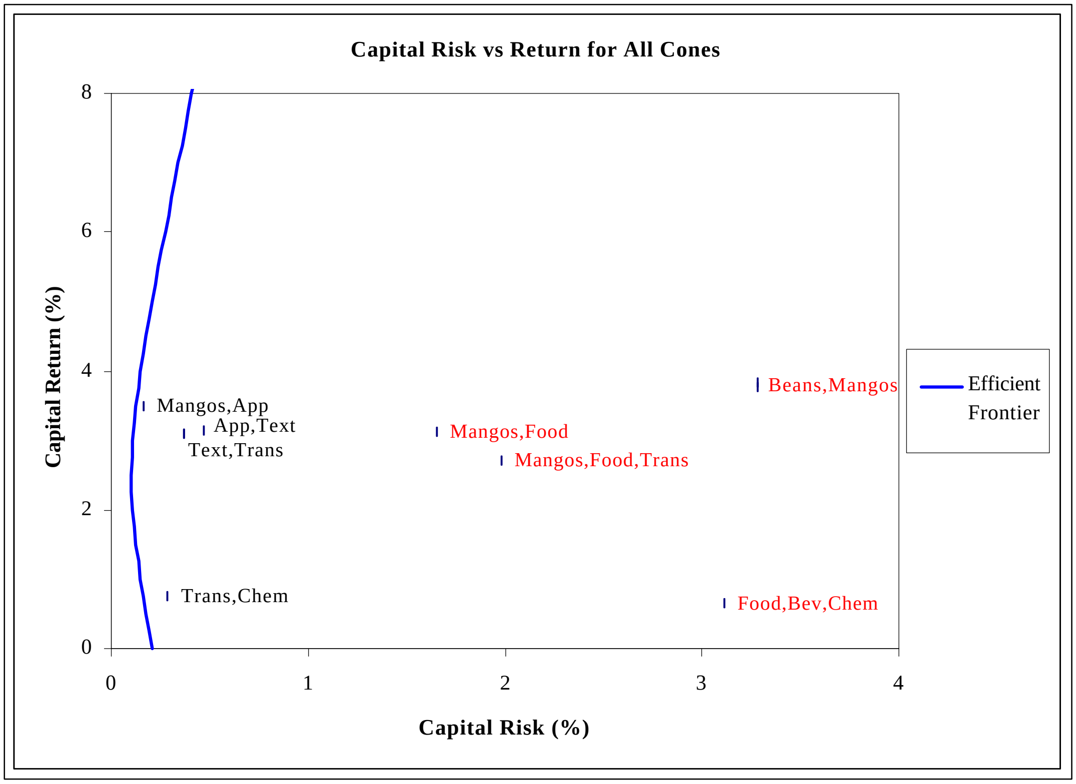


Table 3.3.3: Cone Covariance Matrix

	mangos,food	*beans,mangos*	*mangos,food,trans*	*food,bev,chm*	mangos,apparel	app,text	text,trans	trans,chm
mangos,food	2.74							
beans,mangos	-4.20	10.73						
mangos,food,trans	-0.02	0.05	0.02					
food,bev,chm	3.15	-5.93	-0.03	3.92				
mangos,apparel	-0.03	4.53	-0.06	-1.19	9.69			
app,text	-0.12	0.42	0.01	-0.20	0.26	0.22		
text,trans	0.17	-0.41	0.00	0.27	-0.16	-0.08	0.14	
trans,chm	-0.03	0.26	0.00	-0.10	0.26	0.01	-0.04	0.08

High risk cones are shaded.

First, assume that the world consists of many countries and that they are spread throughout all the cones generated by the simulation. Table 3.3.4 details how new investment would be allocated among these cones. The two header-rows of the table trace out the efficient portfolio frontier (return in the first row, risk in the second) while the next eight rows indicate the share of investment that would flow to each cone given a particular frontier risk-return combination. For example, if investors desired a return of 250%, they would place 90% of their investment into the non-diversified Mangos-Food-Transportation cone and 67% into the non-agriculture Textiles-Transportation cone. Note that several cones have negative allocation shares, which, for equities, is interpreted as selling short. In this context, the appropriate interpretation of short selling is hiring capital in one market and letting it in another, which reverses payment streams in the same manner as selling a stock short.[13] Thus, investors seeking a return of 250% would like to hire capital in the Beans-Mangos and Food-Beverages-Chemicals cones and let it elsewhere. The sub-totals at the bottom of the table summarize the share of investment flowing to high risk and diversified cones. As expected, higher returns necessitate greater investment in high-risk cones.

Table 3.3.4: Optimal Portfolio of Diversification Cone Assets

	2.500	**2.750**	**3.000**	**3.250**	**3.500**	**3.750**
Cone	**0.102**	**0.104**	**0.108**	**0.116**	**0.125**	**0.137**
mangos,food	***0.90***	***-0.10***	***-1.10***	***-2.10***	***-3.09***	***-4.09***
beans,mangos	***-0.32***	***0.02***	***0.36***	***0.70***	***1.04***	***1.37***
mangos,food,trans	***0.47***	***0.48***	***0.49***	***0.50***	***0.51***	***0.52***
food,bev,chm	***-1.22***	***0.12***	***1.46***	***2.80***	***4.14***	***5.48***
mangos,apparel	0.00	0.00	0.00	0.00	0.00	0.00
app,text	0.22	0.08	-0.06	-0.21	-0.35	-0.49
text,trans	0.67	0.16	-0.34	-0.85	-1.35	-1.86
trans,chm	0.28	0.24	0.20	0.16	0.11	0.07
~~**Summary**~~						
High Risk Cones	-0.17	0.52	1.21	1.90	2.59	3.28
Diversified Cones	1.17	0.48	-0.21	-0.90	-1.59	-2.28
Total	1.00	1.00	1.00	1.00	1.00	1.00

High risk cones are shaded.

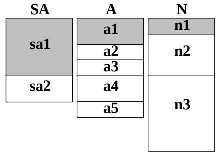
[13] If all investors wish to allocate investment in the same way, how will the market function? Though we cannot answer such questions given the implicit assumption of agent homogeneity in our model, we nevertheless use its outcomes as a signal of what investors would like to do.

The high allocation toward high-risk cones even at low returns is somewhat puzzling. *A priori*, we expected to see all diversified cone allocations positive and most high risk cones negative. The main message of the table appears to be that investors' taste for a diversified cone portfolio can mitigate capital inhibition in resource intense economies, though, even so, the fate of super abundance is dire: due to short-selling, their development process may not proceed beyond the first cone. An interesting feature of the efficient frontier is the relatively low tradeoff between risk and return.

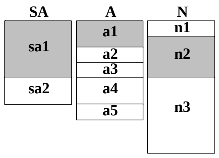
A second thought experiment seeks to understand how rest-of-world capital allocation affects development in three types of emerging markets. That is, assume the existence of a set of rest-of-world countries, spread throughout the cones, and that investors in this rest-of-world have, in some earlier stage of their decision process, determined how to split their investment between mature and emerging markets. How might this emerging market investment be allocated among our three countries? Here, too, we must impose the strong assumption that a sufficiently large rest of world exists so that product prices are not sensitive to investment.[14] On the other hand, given the relatively large number of countries which have recently embraced free markets and sought to attract capital from the developed world, this method of setting up the problem is nicely suggestive.

[14] Both of these thought experiments are quite dependent upon exogenous demand. One method of circumventing such a strong assumption, unexplored as of yet, is to consider maximizing world GDP at each iteration of the simulation by reallocating world capital among the three countries, subject to the constraint that at least the same level of each commodity is produced as in the first run of our simulation above.

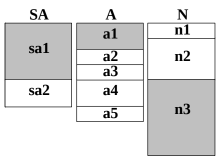
Table 3.3.5: Optimal Allocation of Investment Among Emerging Markets



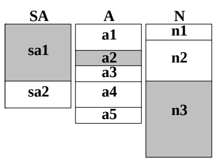
	Cone Allocations Along Portfolio Frontier						
	3.200	**3.300**	**3.400**	**3.500**	**3.600**	**3.700**	<- Return
~~**Cone**~~	~~**0.571**~~	~~**0.921**~~	~~**1.341**~~	~~**1.783**~~	~~**2.232**~~	~~**2.686**~~	<--Risk
beans,mangos	*0.08*	*0.23*	*0.38*	*0.52*	*0.67*	*0.81*	
app,text	0.92	0.77	0.62	0.48	0.33	0.19	



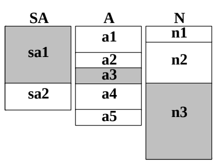
	Cone Allocations Along Portfolio Frontier						
	3.100	**3.200**	**3.300**	**3.400**	**3.500**	**3.600**	<- Return
~~**Cone**~~	~~**0.390**~~	~~**0.435**~~	~~**0.822**~~	~~**1.270**~~	~~**1.731**~~	~~**2.198**~~	<--Risk
beans,mangos	*-0.01*	*0.13*	*0.27*	*0.40*	*0.54*	*0.68*	
text, trans	1.01	0.87	0.73	0.60	0.46	0.32	



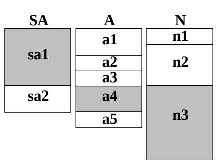
	Cone Allocations Along Portfolio Frontier						
	0.700	**0.800**	**0.900**	**1.000**	**1.100**	**1.200**	<- Return
~~**Cone**~~	~~**0.270**~~	~~**0.289**~~	~~**0.340**~~	~~**0.412**~~	~~**0.496**~~	~~**0.586**~~	<--Risk
beans,mangos	*-0.02*	*0.01*	*0.05*	*0.08*	*0.11*	*0.14*	
text,chm	1.02	0.99	0.95	0.92	0.89	0.86	



	Cone Allocations Along Portfolio Frontier						
	2.800	**2.900**	**3.000**	**3.100**	**3.200**	**3.300**	<- Return
~~**Cone**~~	~~**0.131**~~	~~**0.132**~~	~~**0.134**~~	~~**0.137**~~	~~**0.141**~~	~~**0.146**~~	<--Risk
beans,mangos	*-0.01*	*-0.01*	*-0.01*	*-0.01*	*0.00*	*0.00*	
mangos,app	0.75	0.79	0.82	0.86	0.90	0.93	
trans, chem	0.25	0.22	0.18	0.15	0.11	0.07	



	Cone Allocations Along Portfolio Frontier						
	1.700	**1.800**	**1.900**	**2.000**	**2.100**	**2.200**	<- Return
~~**Cone**~~	~~**0.171**~~	~~**0.172**~~	~~**0.176**~~	~~**0.181**~~	~~**0.188**~~	~~**0.198**~~	<--Risk
beans,mangos	*0.00*	*0.01*	*0.01*	*0.01*	*0.02*	*0.02*	
mangos,tx,tr	0.40	0.44	0.47	0.51	0.55	0.59	
trans, chem	0.60	0.56	0.52	0.47	0.43	0.39	



	Cone Allocations Along Portfolio Frontier						
	1.200	**1.300**	**1.400**	**1.500**	**1.600**	**1.700**	<- Return
~~**Cone**~~	~~**0.258**~~	~~**0.261**~~	~~**0.266**~~	~~**0.272**~~	~~**0.280**~~	~~**0.290**~~	<--Risk
mangos,food	*0.06*	*0.08*	*0.09*	*0.11*	*0.13*	*0.14*	
mangos,food,trans	0.13	0.16	0.18	0.21	0.24	0.26	
trans, chem	0.81	0.76	0.72	0.68	0.64	0.60	

Table 3.3.5 traces out the endogenous allocation of capital to our three countries assuming investors seek minimum risk along the efficient portfolio frontier. (Minimum risk allocations are boxed.) The table is broken into six panels, each of which contains a different frontier and associated allocation shares depending upon which cone each of the three countries inhabits. This frontier and these shares are computed using the appropriate rows of the cone covariance matrix, Ω, given above. Movement by each country through cones is portrayed in an icon to the left of each panel that is designed to mimic the shape of table 3.3.2. Note that only two investment opportunities are available if cones are redundant,[15] and that as one moves down the table, each successive panel indicates greater cumulative investment by rest-of-world in the three country-types. The following paragraphs provide descriptive words for each panel to ease interpretation:

Panel 1 In the beginning, low risk seeking investors put most of their investment into No Land. Due to the negative correlation between Manufacturing and Agriculture returns (a function of prices), however, Abundant and Super Abundant get some capital as investors seek to diversify. The result is that No Land gets accumulates capital more quickly.

Panel 2 Due to its receipt of most of rest of world investment, No Land moves into its second cone while Super and Abundant remain in their first. No Land is now even more attractive than before: capital inflows to the land abundant countries cease. Indeed, investors even seem willing to remove capital from land abundant countries and place it in No Land.

Panel 3 As a result all the previous investment, No Land moves into its third cone. Rest of world diversification into the resource rich economies decreases because returns from No

[15] If cones are redundant, the experiment assumes allocated capital is split evenly among countries.

Land's sophisticated manufacturing sector are almost independent of agriculture. Development of the land abundant countries will cease unless investors are willing to accept higher levels of risk.

Panel 4 If investors are willing to seek more risk, Abundant eventually will receive enough capital to move into a diversified manufacturing-agriculture cone. The higher return and lower risk associated with this cone makes it attractive to investors, who now split most of their investment between Abundant and No Land. The negative correlation of Abundant's manufacturing *vis a vis* Super's agriculture prices provides investors with an incentive to allocate a small level of investment in Super Abundant. Nevertheless, it remains mired in its first cone.

Panel 5 Abundant soon moves into its third cone, which is also manufacturing-agriculture diversified. It now attracts the bulk of investment.

Panel 6 Once Abundant acquires sufficient capital, however, its movement into capital intensive agriculture (Mangos and Food) sets up a trap: the return to capital declines and its risk shoots up. As a result, investors favor the much more stable, and mature, No Land, and seek diversification in Super Abundant.

The big message in this experiment is that, absent demand changes, resource rich economies may become trapped in a state of permanent underdevelopment, and the more resource rich a country is, the earlier it gets trapped.[16] To the extent that these results capture real world dynamics, they indicate an important problem for resource abundant economies seeking to industrialize by attracting outside capital.

4 Conclusions

This paper explores theoretically and via a Heckscher-Ohlin linear program whether the emergence of manufacturing can be hampered by land abundance. It demonstrates that land abundance may deter skill accumulation and raise income inequality, and that insufficiently diversified production may create unfavorable capital risk-return profiles for resource rich countries, deterring investment. In addition, it illustrates that the effect of such unfavorable profiles may be mitigated by international investors' desire for a balanced portfolio of diversification cone assets. More generally, the paper provides an nice example of how a multi-sector, multi-factor linear program can be used to gain insight into a variety of pressing problems in international trade and development.

[16] Changes in demand can affect this outcome by driving up the prices of goods produced by resource rich economies to the point that the risk adjusted return is internationally competitive.

Appendix A: Data Description

Data Sources

Net Exports	Statistics Canada World Trade Database
Labor force	World Bank CD ROM
Education	Barro and Lee (1994)
Capital	Maskus (1991), Song (1993) and Penn World Tables
Crop and forest land	Maskus (1991)
Investment	World Bank CD ROM
Terms of trade	World Bank CD ROM
Manufacturing inputs and value added	INDSTAT3 database from UNIDO and US Current Population Survey
Manufacturing prices	Bartelsman, Becker and Gray (1994)
Agriculture inputs	Leamer, Maul, Rodriguez and Schott (1998)
Agriculture prices	Various world spot market figures

Table A1

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

References

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

Bartelsman, Eric J., Randy A. Becker and Wayne B. Gray. 1994. NBER Productivity Database.

Inter-American Development Bank. 1995. Overcoming Volatility in Latin America.

Jones, Charles I. and Robert E. Hall. 1997. Fundamental Determinants of Output per Worker across Countries. Mimeo.

Leamer, Edward E. 1984. Sources of International Comparative Advantage. Cambridge: MIT Press.

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

Leamer, Edward E. 1997. Access to Western Markets and Eastern Effort, in Salvatore Zecchini, ed., Lessons from the Economic Transition, Central and Eastern Europe in the 1990s (Kluwer Academic Publishers, Dordrecht).

Leamer, E.E., H. Maul, S. Rodriquez and P.K. Schott, 1998, Natural resources as a source of Latin American income inequality, Unpublished manuscript.

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.

Sevren, Luis. 1996. Irreversibility, Uncertainty and Private Investment: Analytical Issues and Some Lessons for Africa. Mimeo.