Barriers to Capital Accumulation and Aggregate Total Factor Productivity

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August 2002

Abstract

I develop a growth model where output can be produced with a modern and a traditional technology. The traditional technology has a lower TFP and a lower share of reproducible capital than the modern technology. In this simple framework, barriers to capital accumulation affect the extent to which these technologies are used. Intuitively, barriers reduce the return to using the modern technology relative to the traditional technology because reproducible capital is a more important input in the modern technology. As a result, barriers to capital accumulation not only affect the capital to output ratio in the economy but also aggregate TFP. The theory thus connects two seemingly disparate research programs in the recent growth literature: models of factor accumulation and models of total factor productivity. The model economy is calibrated by interpreting the traditional technology as producing agricultural output and the non-reproducible factor as land. The theory implies that barriers to capital accumulation are associated with large agricultural shares. This novel implication of the theory is strongly supported by both cross-country data and time series evidence from a set of East Asian miracle countries. For a reasonable parameterization of the model, the required TFP differences needed to account for a reasonable disparity in the wealth of nations are reduced by a half relative to the standard growth model that abstracts from technology choice.

Keywords: income, technology choice, barriers, total factor productivity.
Journal of Economic Literature Classification Numbers: O1, O4.

† I am grateful to the editor (Randall Wright) and two anonymous referees for comments that substantially improved the quality of this paper. I am indebted to Andrés Erosa for extensive comments and discussions about this research. All remaining errors are my own. *Contact information*: diego.restuccia@utoronto.ca.

1 Introduction

I introduce technology choice in an otherwise standard neoclassical growth model with barriers to capital accumulation and show that it substantially amplifies the role of barriers in accounting for international income differences. The environment consists of a single good and two technologies, modern and traditional, that require capital and labor inputs. These technologies differ in total factor productivity and the share of reproducible capital. Barriers lower the return to factor allocation in the modern technology. Therefore, an implication of the theory is that barriers increase the share of resources allocated to the traditional technology and this allocation, in turn, generates lower aggregate TFP endogenously. I show that relative to the standard neoclassical growth model, the exogenous TFP differences required in this model to generate a reasonable disparity in the wealth of nations are reduced by a half for reasonable levels of barriers.

Standard neoclassical growth theory cannot account for the great disparity in the wealth of nations. Important extensions to the standard theory to include broader notions of capital such as schooling capital (Mankiw, Romer, and Weil, 1992), technological capital (Parente and Prescott, 1994), and human/organizational capital (Chari, Kehoe, and McGrattan, 1996); require either implausibly large schooling investments or large barriers and investment of unmeasured capital. Subsequent theories of total factor productivity (TFP), such as Parente and Prescott (1999), have neglected the potential role of barriers to capital accumulation in generating aggregate TFP differences across countries. The theory I propose in this paper nests these two seemingly disparate approaches in accounting for the wealth of nations.

In standard growth models, international income differences are entirely due to differences in capital to output ratios, while in this model, income differences are amplified through the allocation of factor inputs to less efficient technologies. There is substantial evidence supporting this implication of the theory.

2 Economic Environment

2.1 Technologies and Main Implications

At each date, there is a single good that can be produced according to two technologies, modern (m) and traditional (a),

$$Y_{m,t} = K_{m,t}^{\alpha}(B_0\gamma^t N_{m,t})^{1-\alpha},$$

$$Y_{a,t} = (K_{a,t}^{\psi}L^{1-\psi})^{\alpha}(A_0\eta^t N_{a,t})^{1-\alpha},$$

where K_i is the input of reproducible capital services and N_i is the input of labor services in technology $i \in (a, m)$, L is the input of non-reproducible capital services, and both technologies exhibit labor-augmenting productivity growth $(\gamma, \eta > 1)$. Notice that the output elasticity of capital and labor are the same across technologies consistent with the findings in Gollin (2002). In the analysis that follows, I interpret traditional output as agriculture and the non-repoducible factor in the traditional technology as land. Capital accumulation follows

$$K_{t+1} = (1-\delta)K_t + \frac{X_t}{\pi},$$

where X_t is gross investment and π is a technology parameter that determines the rate at which output goods are transformed into capital. In the next section, I consider the relative price of investment as a measure of barriers π. Following the lead of Parente and Prescott (1994) this modification of the capital accumulation equation has become standard in cross-country income level analysis.

The following simple example illustrates the main implications of the model. Suppose there are two countries: country i allocates all labor to the modern technology and country j allocates all labor to the traditional technology. Then, the relative per-worker income can be written as

$$\frac{y_i}{y_j} = \left[\frac{(K/Y)_i}{(K/Y)_j}\right]^{\frac{\alpha}{1-\alpha}} \left[\frac{1}{(K/Y)_j}\right]^{\frac{(\psi-1)\alpha}{1-\alpha}} \frac{B_0}{A_0}. \tag{1}$$

Equation (1) illustrates the mechanisms of relative income differences implied by barriers to capital accumulation across countries in this model. The first component consists of the standard tradeoff between consumption and saving summarized by differences in capital to output ratios. The second term corresponds to differences in the reproducible-capital intensity across technologies[1]. The third term consists of total factor productivity differences between the modern and traditional technologies.

The choice of technology in each country is extreme and arbitrary in this example, the intensity to which each technology is used in production is an endogenous outcome of the model. In the next subsection, I explicitly derive the conditions to factor allocation in each technology and show how in equilibrium these allocations are related with barriers to capital accumulation. The main finding is that barriers generate a misallocation of factor inputs to the less efficient technology, generating a negative effect in aggregate TFP. The factor allocation implication of the theory is strongly supported by cross-country and time series evidence.

[1]Notice that if the share of non-reproducible capital $(1-\psi)$ is small, then this factor would not be important quantitatively. Moreover, if the capital to output ratio in country j is below one, as it is the case in many poor countries, then the second term in this equation would imply *lower* income differences between the two countries.

2.2 Population and Equilibrium

I assume a representative (stand-in) infinitely-lived household with preferences over consumption sequences given by

$$\sum_{t=0}^{\infty} \beta^t \log(C_t/N_t)N_t,$$

where β is the time discount factor and the per-period utility of per-capita consumption is weighted by the household size N_t. Households are endowed with one unit of productive time each period, K_0 units of the capital stock at date 0, and L units of land. Households can allocate time to either sector. I assume exogenous and constant population growth, with the initial population size normalized to one

$$N_{t+1} = \phi N_t, \qquad \phi > 1.$$

An equilibrium in this economy consists of a sequence of allocations $\{K_{m,t}, K_{a,t}, N_{m,t}, N_{a,t}, K_{t+1}, C_t\}_{t=0}^{\infty}$, prices $\{w_t, r_t\}_{t=0}^{\infty}$, and land rents $\{\Pi_t\}_{t=0}^{\infty}$ such that: (*i*) given prices and land rents, allocations solve the household's problem, (*ii*) factor prices are competitive, and (*iii*) markets clear at each date: output $C_t + X_t = Y_t$, capital $K_t = K_{a,t} + K_{m,t}$, and labor $N_t = N_{a,t} + N_{m,t}$. A *balanced growth path equilibrium* is an equilibrium as defined above with the property that (K_a, K_m, K, C, Π) are growing at the rate $\gamma\phi$, (N_a, N_m, N) are growing at the rate ϕ, w is growing at the rate γ, and r is constant.

I focus on the cross-country implications of the model and therefore abstract from sectoral reallocation within a country over time. I assume that productivity growth differs across the modern and traditional technologies so that labor shares across sectors remain constant in the balanced growth path[2]. To illustrate the properties of the model in a simplified fashion, I transform all growing variables by dividing for exogenous growth. Abstracting from the time subscript, the two technologies can be written as

$$y_a = A k_a^{\psi\alpha} n_a^{1-\alpha}, \tag{2}$$

$$y_m = B k_m^{\alpha} n_m^{1-\alpha}, \tag{3}$$

where all inputs are divided by $\gamma^t N_t$, $n_i = N_i/N$ is the employment share in sector $i \in \{a, m\}$, $A = A_0^{1-\alpha} L^{(1-\psi)\alpha}$, and $B = B_0^{1-\alpha}$.

Finding an equilibrium in this model is simple. Factor mobility implies that wage and

[2]This requires $\eta = \gamma^{\frac{1-\psi\alpha}{1-\alpha}} \phi^{(1-\psi)\frac{\alpha}{1-\alpha}}$.

rental rates are equated across sectors, therefore, capital to labor ratios are proportional

$$\frac{k_a}{n_a} = \psi \frac{k_m}{n_m}. \tag{4}$$

The return to capital is determined by the euler equation from households, that in turn determines the capital to labor ratio in the modern technology

$$\frac{k_m}{n_m} = \left(\frac{B\alpha}{\pi[\gamma/\beta - (1-\delta)]} \right)^{\frac{1}{1-\alpha}}. \tag{5}$$

The capital to labor ratio in the modern sector in equation (5) depends on the same fundamental objects as in the standard theory. In particular, equation (5) and (4) illustrate that high barriers imply low capital to labor ratios. The capital to labor ratio in the modern sector determines the wage in this sector (see equation 3). Wage equalization across sectors determines the employment share in the traditional sector

$$n_a = \left(\frac{A}{B} \psi^{\psi\alpha} \right)^{\frac{1}{\alpha(1-\psi)}} \left(\frac{\pi[\gamma/\beta - (1-\delta)]}{B\alpha} \right)^{\frac{1}{1-\alpha}}. \tag{6}$$

From the employment shares and the capital to labor ratios across sectors, all other quantities can be readily obtained. Notice in equation (6) that barriers to capital accumulation affect the allocation of labor across sectors. The reason is that barriers affect the capital to labor ratio in the modern sector, diminishing the return of working in that sector. This triggers a movement of labor away from the modern sector that equalizes sectoral wages in equilibrium.

Manipulating equations (2), (3), and (4), it is straightforward to show that aggregate output in the model is given by

$$y = (k_m/n_m)^\alpha \left[A\psi^\alpha k_a^{\alpha\psi-\alpha} n_a + B(1-n_a) \right]. \tag{7}$$

Equation (7) illustrates that aggregate income depends on: (a) the capital to labor ratio in the modern sector that in turn is affected by barriers (see equation 5) and (b) aggregate TFP, which is a weighted average of sectoral TFP. This can be easily seen by letting $\psi \approx 1$ and noting that the term in brackets becomes $An_a + B(1-n_a)$, that is, aggregate TFP is roughly an average of sectoral TFP weighted by the employment share in each sector. A key result of the theory is the link between the employment share of the traditional sector n_a and barriers to capital accumulation π (see equation 6). Although there is abundant evidence of differences in technology use across countries, these differences may not all be related with barriers to capital accumulation, other factors such as unions and institutional regulations may be important. In this paper I explore a channel connecting factor accumulation and aggregate TFP that has been neglected by two important strands in the literature: one emphasizing the role of distortions to capital accumulation (such as Mankiw, Romer, and Weil, 1992 and Chari, Kehoe, and McGrattan, 1996) and another one emphasizing the role of barriers to technology adoption (such as Parente and Prescott, 1999, 2000; and Prescott, 1998).

2.3 Calibration

I assume that the benchmark economy faces no barriers $\pi = 1$ and calibrate this economy to U.S. data. The emphasis in this paper is on technology use applied to cross-country income differences, but could well be applied to labor productivity differences in agriculture and other sectors. However, technology use is difficult to measure in the data. To the extent that some sectors tend to systematically produce with less efficient technologies, such as agriculture in developing countries, I use the agricultural sector to impose restrictions on the parameters pertaining to the traditional technology. Another reason to use agriculture to restrict the traditional technology is that land is a natural candidate for the non-reproducible capital input featured in this technology.

There are 8 parameters to calibrate: β, γ, ϕ, δ, A, B, α, ψ. The growth of modern technology TFP γ and the growth rate of population ϕ are chosen to match long-run post-war U.S. productivity and working-age population growth. The capital income share in the U.S. economy determines α. The physical capital depreciation rate δ and the time discount factor β are chosen to match the investment to output ratio and capital to output ratio. The income elasticity of non-reproducible capital $(1-\psi)\alpha$ is reported in estimations of agricultural production functions, such as in Hayami and Ruttan (1985) and Mundlak (2001). The estimated values range between 0.1 and 0.4. I choose 0.1 as a benchmark. To the extent that high $(1-\psi)\alpha$ values imply low reproducible capital intensity in the traditional technology and low income levels in countries with a large traditional sector, using the low-end estimate is a conservative strategy for a study of relative income differences with barriers to capital accumulation. TFP in the modern sector B is chosen to generate a normalized aggregate income of 1 in the benchmark economy and TFP in the traditional sector A is chosen to match the employment share of agriculture[3]. Table 1 reports a summary of these parameter values and targets.

[3]Recall that the units of A include land.

Table 1: Calibration of Benchmark Economy

Parameter	Value	Target
γ	1.02	growth rate of aggregate productivity 1.02
ϕ	1.019	growth rate of working age population 1.019
α	0.35	capital income share 0.35
ψ	0.71	income elasticity of land 0.1
δ	0.04	investment to output ratio 0.2
β	0.94	capital to output ratio 2.5
B	0.72	normalization of aggregate output 1
A	0.58	employment share in agriculture 0.02

2.4 Cross-Country Income Differences

I consider a world of closed economies that are identical in all respects except on barriers to capital accumulation π. I emphasize that, unlike Mankiw, Romer, and Weil (1992) and Chari, Kehoe, and McGrattan (1996), barriers only affect the accumulation of physical capital since I abstract from human capital and other forms of intangible capital. In this dimension, my analysis also differs from Parente and Prescott (1994) since they consider barriers to technology adoption, that is essentially a barrier to unmeasured capital.

Table 2 documents the implications of the model regarding aggregate income, the share of employment in the traditional sector, and the capital to output ratio for different levels of barriers. To be consistent with the way the data is reported in Summers and Heston (1991), I use the output price of the benchmark economy to compute aggregate income in all other economies[4]. The empirical counterpart of barriers in the data is the relative price of investment. The evidence suggests that reasonable factor differences in the relative price of investment across countries lies between 4 and 6 (see Jones, 1994 and Restuccia and Urrutia, 2001). The results in Table 2 indicate that aggregate income of the distorted economy with barriers of 4 is 41% of the benchmark economy[5]. In addition, the share of employment in the traditional technology is 17% and the capital to output ratio is 4 times smaller than in the benchmark economy.

Two implications of the results are worth emphasizing. First, aggregate income differ-

[4]Actually, in Summers and Heston (1991) an international price (geometric average) is constructed, but the results are similar using the U.S. price, $\pi = 1$. The price adjustment of an economy with a barrier of 4 implies that aggregate international income is roughly 85% of the domestic measured income.

[5]This result is robust with respect to the value of the capital land share $(1 - \psi)$. I find that the capital land share has no impact on the labor allocation n_a as long as the traditional TFP parameter A is calibrated to match a fix target. It has a small impact on aggregate income, roughly given by the second term in equation (1). However, the capital land share has an important impact on capital/output differences across countries, in particular, small values of ψ generate implausibly large differences in capital to output ratios.

Table 2: Cross-Country Income Differences

π	$y_{\text{(B.E. price)}}$	n_a	K/Y
1	1.00	0.02	2.53
2	0.62	0.06	1.25
4	0.41	0.17	0.61
6	0.32	0.32	0.39
10	0.25	0.69	0.21
12	0.22	0.92	0.16

ences across countries are larger than in a model with one technology. Roughly speaking, a standard one-sector growth model with similar capital share implies that a country with a barrier of 4 has an aggregate income of 0.5. Therefore, allowing for technology choice substantially amplifies the role of barriers on income differences across countries. Second, the model generates small shares of labor allocated to the traditional technology. In the data, as Figure 1 illustrates, the share of agriculture in the labor force is as high as 90% in poor countries, roughly 45 times the agricultural labor allocation in rich countries. Therefore income (and aggregate TFP) differences would be larger if labor allocations implied by the model were closer to the data.

A way of improving the implications of the model in terms of employment shares and making the quantitative implications of the model readily comparable with alternative models is to relax the extreme assumption that all countries are using the same technologies (although in different proportions). There are important productivity differences across countries (for instance see the evidence in Hayami and Ruttan (1970) for agricultural productivity, Prescott (1998) for other industries, and Hall and Jones (1998) for the aggregate economy). In the following experiment I ask: what are the exogenous aggregate TFP differences required in order to reproduce a given income difference across countries? For this purpose, I consider a slight modification of the technologies in (2) and (3) to allow for exogenous aggregate TFP differences across countries, by multiplying them by a factor $\theta \in (0, 1]$. For a given country I ask, what is the θ required to generate a factor income difference of 10 with respect to the benchmark economy for different levels of barriers. The results of these computations are presented in Table 3 where the first row documents the benchmark economy.

The results are striking. First, for an economy with barriers of 4, the exogenous TFP differences required to match a factor income of 10 is 0.4. In the standard growth model, the required exogenous TFP differences to generate the same factor income is 0.2. That is, the model with technology choice reduces the requirement on TFP differences by half.

Table 3: Exogenous TFP Differences

π	$y_{\text{(B.E. price)}}$	θ	n_a
1	1.0	1.00	0.02
1	0.1	0.23	0.19
2	0.1	0.31	0.35
4	0.1	0.40	0.69
6	0.1	0.46	1.00

Exogenous factor differences in TFP of 2.5 is within the reasonable range argued by the evidence in Prescott (1998). Second, the model implies shares of traditional employment that are much closer to the agricultural shares in the data. For an economy with barriers of 4, the traditional employment share is much larger than the one implied by the model without exogenous TFP differences (69% and 17% respectively). Notice, however, that this result occurs even though the relative TFP across sectors has not changed.

A paper that is similar in spirit to mine is Parente, Rogerson, and Wright (2000). They introduce household production into the standard growth model. The household production model implies that barriers to capital accumulation produce a reallocation of hours of work from market activities to home activities. This substitution produces large amounts of unmeasured output in the distorted economy that accounts for all income differences (above and beyond the effect of barriers on capital accumulation in the standard growth model). That is, differences in *total* output and welfare, although still substantial, are equal or even smaller than in the neoclassical growth model. The theory proposed here implies no unmeasured output or investment. The main distinction of the results is that my model generates TFP differences endogenously. Without unmeasured output or investment my model is capable of generating similar income differences as in Parente, Rogerson and Wright (2000).

3 Some Evidence

The main implication of the model is that barriers determine the allocation of labor across technologies and hence aggregate income. This prediction of the model is strongly supported by cross-country data. Figure 1 documents a strong negative correlation between the share of agriculture in the labor force and relative income, while Figure 2 reports a strong positive correlation between the share of agriculture in the labor force and the relative price of investment as a measure of barriers in a cross-section of countries for 1985.

An implication of the model is that countries that reallocate capital and labor away from the traditional sector relative to the benchmark would catch-up in terms of steady state relative income levels. To check this implication of the model in the data, I look at the behavior of a set of miracle countries. Figure 3 reports the growth experience of a set of countries. Japan is an example of remarkable growth performance. Relative to the per-worker GDP of the U.S., Japan went from 1/6 to 2/3 of the U.S. from 1950 to 1990. As a measure of barriers in Japan, the relative price of investment went from 1.7 of the U.S. in 1960 to roughly 1 in 1985. This 70% fall in relative barriers is associated with an increase in the relative investment rate that almost doubled the U.S. level during the period. However, the key implication is whether the agricultural employment share fell. Indeed, Japan went from an agricultural share of 62% in 1950 to less than 10% in 1990 (reducing by half the factor difference in this statistic with respect to the U.S.).

Taiwan and Korea are also miracle countries and the same qualitative pattern described above for Japan holds for these countries. Following the example in Lucas (1993), I check that the Philippines conforms a different pattern than Korea during this period. This is indeed the case. Barriers stayed relatively high during the period, and the agricultural labor force share fell faster in the U.S. than in the Philippines, with Philippines still presenting more than 50% of the labor force in agriculture in 1990. Young (1995) documents the importance of rising labor force participation and intersectoral allocation of labor (from agriculture to manufacturing) in accounting for the growth performance in East Asian economies. Young also points to the rising levels of education and investment rates as important factors. An interpretation of Young's results is that, accounting for rising participation rates, intersectoral transfers of labor, and capital investments, the TFP growth rates needed to account for these growth miracles is much smaller. Young's results strongly support the implications of my model. Relative to Young's analysis, my theory offers an explanation for the movement of labor away from traditional activities in miracle economies.

Another piece of evidence comes from plant dynamics in U.S. manufacturing. Baily, Hulten, and Campbell (1992) document the sources of aggregate productivity growth in the U.S. manufacturing sector. They find that around half of the overall productivity growth is accounted for by shifts in employment from less productive plants to more productive plants. To the extent that labor allocation is crucial in accounting for productivity growth in a country with almost no distortions, country distortions in the allocation of resources to the most productive technologies may account for a sizable portion of labor productivity across countries. An interpretation of the exercise pursued in this paper is as a study of the role of labor allocation across technologies in accounting for income differences across countries.

4 Discussion

The available evidence suggest that labor allocation to the most productive technologies can account for an important portion of income differences across countries. I study this proposition in an otherwise standard neoclassical growth model with technology choice. The model substantially amplifies the role of barriers in accounting for income differences across countries.

Extending the analysis to consider other forms of capital (see an earlier version of this paper in Restuccia (2001) for an extension with human capital) would improve the predictions of the model in two important dimensions. First, it would reduce the exogenous TFP differences needed to generate a given income ratio (as in Mankiw, Romer, and Weil, 1992; Parente and Prescott, 1994; and Chari, Kehoe, and McGrattan, 1996). Second, as long as the modern technology is more intensive in this additional capital than the traditional technology, barriers would generate larger labor allocation differences across countries. As an example and starting from the benchmark economy, I calculate the difference in modern TFP needed to generate reasonable labor allocation differences across countries for a given level of barriers. For a country with barriers of 4, a 10% lower TFP in the modern sector is enough to generate a traditional employment share of almost 90% (compared to 17% for the same economy in the constant-B model). This effect further increases income differences from 0.41 in the constant-B model to 0.34.

The model can also be extended to study the transition of an economy to modern growth and the role of transitory income in accounting for current income differences across countries as proposed by Lucas (2000). Hansen and Prescott (1999) develop such an environment and Ngai (2000) uses their framework with barriers to capital accumulation to assess Lucas' proposition quantitatively. My model can be extended to embed Ngai's formulation, by allowing a third technology, similar to the traditional but with high initial TFP and slower TFP growth. In this extension, the model would feature a Malthusian period and a transition to modern growth where traditional technologies are used to a larger extent in poor countries (high barriers) relative to rich countries (low barriers). This characterization of modern growth is what distinguishes my analysis from Hansen and Prescott (1999) and Ngai (2000). Provided there are no large changes in barriers/policies, the cross-country income distribution at the end of the 21st century would provide a test of whether the income distribution converges to the one implied by the standard neoclassical model as suggested by Lucas (2000) and implied by the model in Ngai (2000) or to one that features larger steady state income differences as implied by my model.

This paper also relates to models of technology adoption that study income and growth differences across countries. Parente and Prescott (1994) study technology adoption as a form of capital, but in their formulation income differences steam from barriers to technology adoption directly, something that is difficult to measure in the data. Moreover, the theory requires large amounts of unmeasured investments. Nelson and Phelps (1966) consider a model of technology adoption with human capital requirements. Benhabib and Spiegel (1994) implement this model empirically and find support in the data. Differently than these two papers, I focus on income levels and on technology choice in production. Aggregate total factor productivity steam in their models from the adoption of more efficient technologies, while in my set up these aggregate technology differences steam from the allocation of labor to inefficient technologies.

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Figure 1: Labor Force in Agriculture and Per-Worker GDP 1985

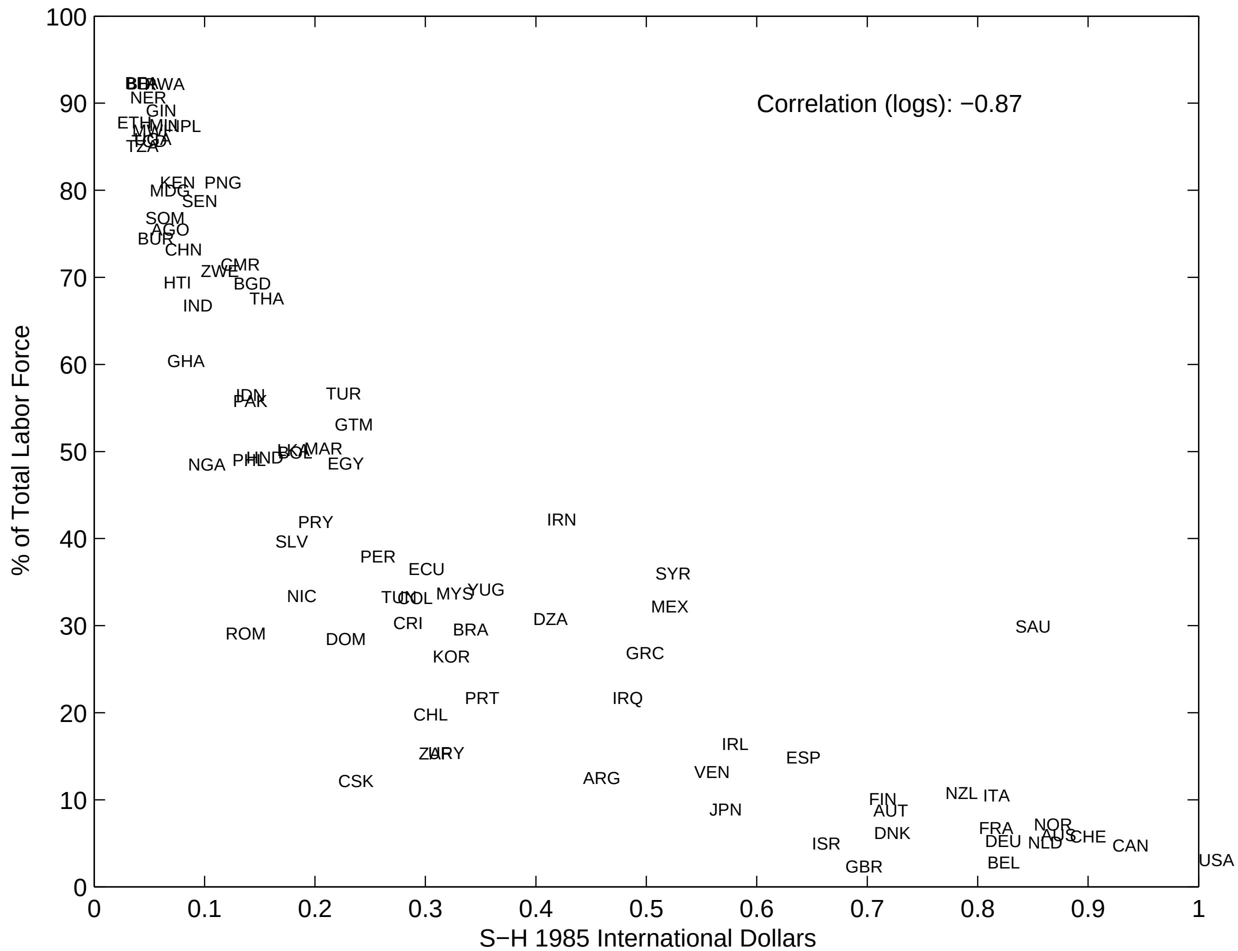

Figure 2: Labor Force in Agriculture and Relative Prices 1985

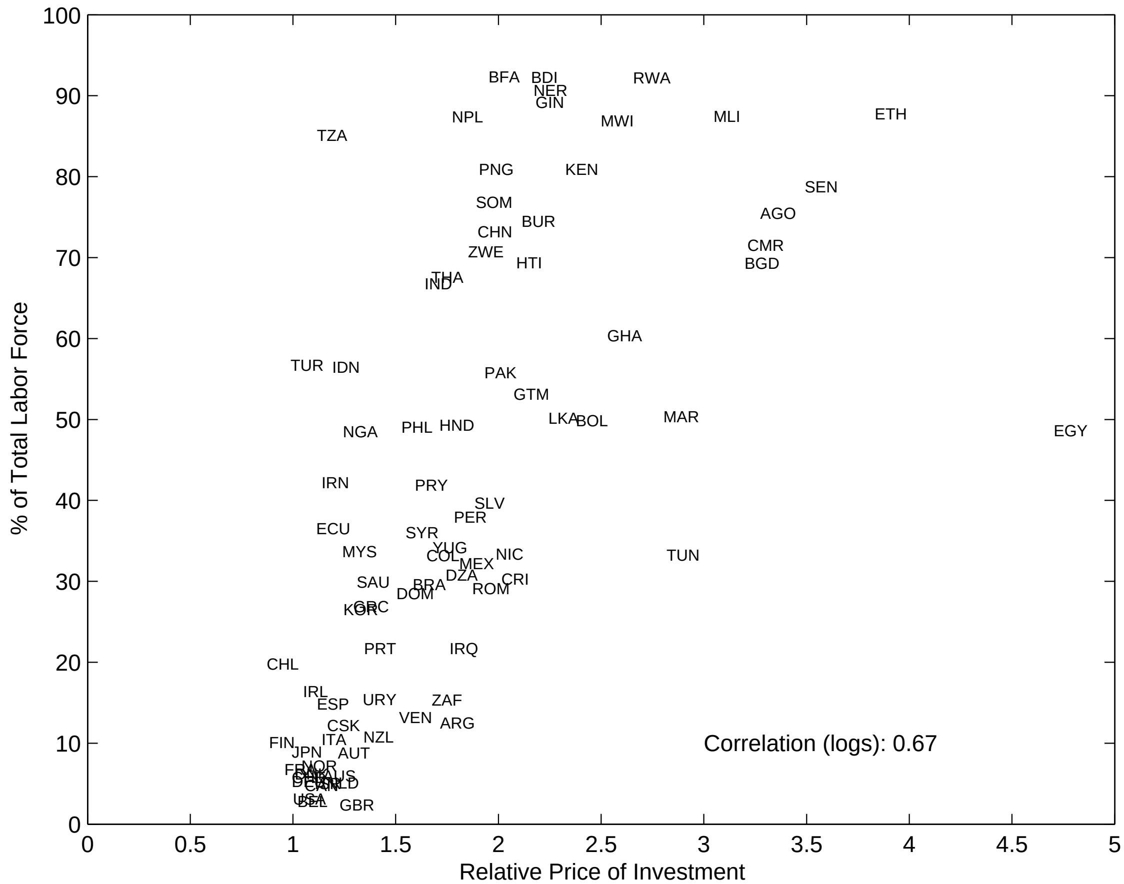

Figure 3: Country Experiences over Time