Barriers to Capital Accumulation in a Model of Technology Adoption and Schooling

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Abstract

Standard growth models require large differences in barriers to capital accumulation to produce the observed disparities in the wealth of nations. I introduce technology adoption and schooling decisions into a standard growth model and show that the required differences in barriers implied by this model are much smaller. In particular, a calibrated version of the model implies income differences 3 times larger than a standard model. The amplification effect in income is generated by two reinforcing effects: schooling capital differences and aggregate total factor productivity differences. This suggests caution in interpreting the role of factor inputs in standard income accounting exercises. I show that a straightforward development policy to subsidize education is not optimal in the presence of barriers to capital accumulation. Removing barriers can replicate educational outcomes and generate higher income levels by several orders of magnitude.

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1 Introduction

Why does a typical worker in a rich country earn twenty to thirty times more than a typical worker in a poor country? In this paper, I argue that the complementarity between schooling and technology adoption decisions is important for understanding these income differences. While there is abundant empirical evidence supporting this complementarity, it has been neglected in studies of international income differences.

Standard growth models require large differences in barriers to capital accumulation to produce the observed disparities in the wealth of nations. I introduce technology adoption and schooling decisions into a standard growth model and show that the required barriers are much smaller. The amplification effect of barriers on income is given by the endogenous aggregate total factor productivity differences generated by the model and by schooling capital differences. Therefore, ignoring the complementarity of technology adoption and schooling decisions has important implications for the role of factor inputs in standard income accounting exercises. To illustrate the strength of this amplification result, I calibrate a version of the model with reasonable barriers and show that the model implies income differences 3 times larger than a standard model.[1] The model suggests an important role of human capital in development. However, subsidies to education are not optimal in the face of barriers to capital accumulation in this environment.

I consider a model where a single good can be produced with either a modern or a traditional technology. An important distinction between these technologies is that schooling is a productive input in the modern technology but not in the traditional technology. In this environment, technology adoption refers to the adoption of the modern technology, and technology adoption and schooling decisions are related since the adoption of the modern technology requires schooling investments in equilibrium.

There is strong evidence that the complementarity between technology adoption and schooling decisions is quantitatively important. A large fraction of the adult population has zero years of completed formal schooling in poor countries, while a negligible fraction has zero schooling in rich countries. Table 1 reports the fraction of the adult population that has

[1] An alternative way of presenting the result would be to show the required barriers needed to reproduce international income differences for a reasonable capital share. I prefer not to present quantitative results in this way since the relationship between income and barriers is highly non linear in these models, i.e., for high income differences, barriers needed are enormously large, while for reasonable barriers the implied income differences are not as large.

not completed a year of formal schooling, the fraction that has completed at least one year, and the average years of schooling for different groups of countries. There are remarkable differences across these groups. Even more striking differences emerge when considering individual countries. Figure 1 reports the fraction of the adult population with zero years of formal schooling: in rich countries virtually all the adult population has some schooling, while in poor countries up to 90% of the adult population has zero schooling. If the no schooling population roughly measures the usage intensity for traditional technologies, then explicitly allowing for this possibility in the model is crucial for understanding the data, in particular for poor countries.

The complementarity between technology adoption and schooling has received a great deal of attention in the early development literature. Welch (1970) and Shultz (1975, 1980) show that incentives to undertake educational investments are higher in environments where more advanced technologies are being adopted. More recently, Dunne and Schmitz (1995) and Doms, Dunne, and Troske (1997) show that plants using more advanced technologies have more educated workers. Rosenzweig (1995) summarizes empirical evidence regarding the relationship between education and technology. He argues that investments in education are not optimal everywhere, but investments in education are productive in environments with substantial technical change or with changing market and political institutions. A rough approximation of the connection between technology adoption and education is presented in Figure 2. It documents the positive relationship between average years of schooling in the adult population and a measure of total factor productivity from Hall and Jones (1998).

A central element in the recent economic growth literature is to develop quantitative models that are consistent with the large differences in per-capita income across countries. One approach is to consider broader notions of capital as in Mankiw, Romer, and Weil (1992) and Chari, Kehoe, and McGrattan (1996). Another approach is to consider other features of the standard model that can amplify the effects of barriers to capital accumulation on income disparity. Recent research in this direction includes Parente and Prescott (1994), Zeira (1998), Jovanovic and Rob (1998), Parente, Rogerson, and Wright (2000), and Parente and Prescott (1999).

Parente, Rogerson, and Wright (2000) introduce home-production into a standard growth model, obtaining important amplification income effects for the case with highly substitutable market and non-market goods, and a low capital intensity home technology. An implication of their model is that a large portion of the amplification effect is due to unmeasured non-market consumption. I find that introducing technology adoption and schooling into a standard growth model generates a large amplification income effect without unmeasured output. The reason is that, contrary to the home production story, my model generates aggregate total factor productivity differences.

The need for theories of total factor productivity differences across countries has been emphasized by Prescott (1998) and Parente and Prescott (2000). Parente and Prescott (1999) develop a model of monopoly rights to the use of technologies capable of generating quantitatively relevant TFP differences across countries. An important distinction with Parente and Prescott's model is that in my model aggregate TFP differences are tied to educational investments and barriers to capital accumulation. In a numerical example below I show that my model can generate aggregate TFP differences similar to Parente and Prescott's.

The paper is organized as follows. Section 2 describes the model economy and characterizes the stationary equilibrium. Section 3 presents a calibrated example and results. In the last section, I conclude with some discussion for future research.

2 Economic Environment

In this section I construct a simple model to study the role of the technology adoption and schooling complementarity for understanding international income differences. In what follows I restrict attention to stationary states and therefore I omit the time subscript in all variables. I consider an environment where there is only one good and firms have access to two production technologies: modern and traditional. The modern technology is a standard constant returns to scale neoclassical production function described by

$$Y_m = AK_m^{\alpha}H^{1-\alpha}$$

where K_m is the input of physical capital services, H is the input of productive labor services, and A is a technology-specific parameter. As in Lucas (1988), the skill level of an individual is measured by schooling capital h, and workers are perfect substitutes in production.

I assume that schooling capital is not productive in the traditional technology. More specifically, this technology is described by

$$Y_t = C K_t^{\psi} N^{\eta} L^{1-\psi-\eta}$$

where K_t is the input of physical capital services, L is the input of land, N is the input of (raw) labor services, and C is a technology-specific parameter. I assume there is a fixed supply of land.

Three properties of the technologies are worth emphasizing. The first property is the stark distinction in human capital intensity between technologies. In particular, schooling is not a productive input in the traditional technology. This assumption together with perfect credit markets for schooling investments imply that the equilibrium distribution of human capital in each economy has mass in only two points: educated and uneducated individuals. It also implies a one-to-one mapping in the model between the fraction of uneducated individuals and the employment share in the traditional technology. Table 1 and Figure 1 documented the important differences in non-schooling population across countries. I exploit this mapping by using the non-schooling data as a rough measure of employment in the traditional technology, a procedure that I describe in more detail in section 3. The second property is the presence of a fixed factor input in the traditional technology. This assumption guarantees that the traditional technology is always used in equilibrium.[2] The third property is that the technology specification allows for the possibility of differences in total factor productivity and physical capital intensity.[3] In the model, aggregate TFP and the aggregate physical capital income share are a weighted average of the respective parameters in each technology, where the weight is given by the output share of each technology. A key result of this paper is that the output share of each technology varies in a systematic way with barriers to capital accumulation.

Technology adoption in this environment refers to the adoption of the modern technology. A central element of the paper is the interaction between technology adoption and

[2]Similar qualitative results would be obtained under a more general specification of technologies requiring physical and human capital (without the fixed factor) with different degrees of capital-skill complementarity and heterogeneous individuals regarding the cost of acquiring education. The choice is made for expositional simplicity.

[3]An additional implication of the fixed factor in the traditional technology is that the capital share can vary across technologies without implying different labor shares.

schooling decisions, as documented by Welch (1970), Schultz (1974), Foster and Rosenzweig (1996), among others. Technology adoption and schooling decisions are related in the model because the adoption of the modern technology involves schooling investments in equilibrium.[4]

The process of education acquisition in the model is simple. At the beginning of the period individuals decide whether to obtain education or not and of which quality. Education only requires resources and there are perfect credit markets.[5] The schooling technology is described by

$$h = G(e)$$

where h is schooling capital of the individual and e represents expenditures in education measured in terms of the output good. G is strictly increasing and concave in e.

There is a large number of non-overlapping generations organized into dynasties. Individuals are ex-ante homogeneous and live for one period. Population is constant, normalized to mass one each period. Individual preferences are described by

$$U_t^i = u(c_t) + \beta U_{t+1}^i$$

where U_t^i is the utility of an individual of dynasty i of generation-date t, $u(c_t)$ is the per-period utility, and β is the discount factor. The dynastic assumption with complete markets makes the environment similar to a representative-agent structure where the return to assets is determined by the discount factor β.

Output can be allocated to consumption, investment in physical capital, and expenditures in education. The capital accumulation equation is given by

$$K' = (1-\delta)K + X_k$$

[4]Considering two types of technologies is an abstraction of the more general setting where technology adoption from an array of technologies with different skill intensities generates a distribution of individuals across skill levels. Allowing for this possibility would reinforce the results of the paper. Moreover, average years of schooling of the adult population with some schooling does not vary much across countries as documented in the last column of Table 1. Therefore, concentrating on a discrete education decision seems a reasonable abstraction.

[5]Expenditures in education include foregone earnings of time in school, parent's and teachers's time costs, and other resources. A more general technology specification in the face of perfect capital markets delivers the same results. See a previous version of this paper in Restuccia (1998) for a technology that explicitly distinguishes between these features.

where K' represents next period's physical capital stock and X_k is gross investment. At each date, the capital stock can be allocated to any sector

$$K = K_t + K_m$$

There is only one dimension in which economies differ in this environment: there are barriers to *physical* capital accumulation. I emphasize that barriers directly affect the accumulation of physical capital only. For simplicity, I assume that barriers are represented by a tax to investment in physical capital θ and that tax revenues are distributed back to consumers as a lump-sum transfer T.[6]

At the beginning of the period, the state of the individual is described by physical capital and land holdings. The individual makes consumption and saving decisions and the allocation of savings into the different alternatives: physical capital, land, and educational investments. Define a as total assets at the beginning of the period measured in terms of the output good,

$$a = (1 + \theta)k + ql$$

where $(1 + \theta)$ is the relative price of physical capital (determined by the tax on investment θ) and q the relative price of land. A simple arbitrage condition between assets implies that their real return must be equalized in equilibrium,

$$i = \frac{r_k}{(1 + \theta)} - \delta = \frac{r_l}{q}$$

where i is the return to assets a, and r_l is the return from land services. Also, since the individual has the option to allocate physical capital to either sector, their returns must also be equalized in equilibrium,

$$r_{k,m} = r_{k,t}$$

[6] Parente and Prescott (1994) and Parente, Rogerson, and Wright (2000) consider barriers $(1+\theta)$ as a technological parameter as follows, $k' = (1 - \delta)k + \frac{x_k}{(1+\theta)}$. An implication of this approach is that barriers not only distort the consumption/saving margin, but also affect the amount of actual goods allocated to consumption and capital, since investment implies a waste of resources in the amount of θx_k. This latter effect is captured by the difference in the price of output across economies. Therefore, this approach generates larger income differences for given barriers than the tax with transfers approach. I choose the tax with transfers approach because the model results are easier to describe (no need to calculate relative output prices) and represent a lower bound on income differences that can be generated by given barriers. For a more detailed discussion of the different implications of the two approaches see Restuccia and Urrutia (2001).

where $r_{k,i}$ is the return to physical capital services in each sector $i \in \{m, t\}$. Therefore the state of an individual at the beginning of the period is summarized by assets a. I consider a stationary equilibrium where prices and allocations are constant over time. Given prices and transfers, individuals solve the dynamic problem represented by the functional equation:

$$v(a) = \max_{\{c,h,e,\phi,a'\}} \{u(c) + \beta v(a')\}$$

subject to

$$c + a' = (1 + i)a + (1 - \phi)w_t + \phi(w_m h - e) + T$$

$$h = G(e)$$

$$\phi \in \{0, 1\}$$

where c is consumption, a' is asset holdings at the end of the period, e is expenditures on education, and ϕ is a discrete educational choice, where $\phi = 1$ means an agent acquires education. The income side of the budget constraint includes capital and labor income and government transfers.

There is a large number of competitive firms. Because of constant returns to scale in each technology, profit maximization implies zero profits and generates rates of return in equilibrium that are given by the marginal productivity of inputs in each technology.

A stationary equilibrium of this environment can be easily characterized. It amounts to finding the employment share in the traditional technology N^* such that: given prices, households and firms make optimal decisions, and prices clear all markets.

For an economy with a given barrier level θ, the distribution of human capital has mass in two points: educated individuals with schooling capital h and uneducated individuals. This is a result of the definition of technologies and perfect capital markets for educational investments. Individuals working in firms operating the traditional technology do not invest in education. Individuals working in firms operating the modern technology invest an amount e in education regardless of their asset position at the beginning of the period. This is because individuals can borrow and lend at the given market interest rate. Assuming a schooling technology $G(e) = Be^{\xi}$, schooling investment is given by

$$e = (B\xi w_m)^{\frac{1}{1-\xi}}$$

which depends on the modern wage. The modern wage is decreasing in barriers (due to the lower accumulation of capital and the complementarity between physical and schooling capital in the modern technology), and therefore educational investments are decreasing in barriers. In this setting, aggregate schooling capital is given by

$$H = (1 - N)h$$

The return to assets is equal in all economies and given by

$$i = \frac{1}{\beta} - 1$$

Because real rates of return among different investment alternatives are equalized in equilibrium and tied to the return to assets, the return to education is also constant across economies.[7] The gross return in physical capital differs across economies because of differences in barriers to investment and this determines the incentives for capital accumulation.

Mobility of labor across technologies implies an arbitrage condition on wages that determines the share of employment in each technology. This condition states that individuals must be at least indifferent between working in firms operating the modern or the traditional technology,

$$w_t \geq w_m h - e$$

The inequality arises in the case that the net wage in the modern technology is too low compared with the traditional wage, in which case the employment share in the traditional technology is equal to one. More generally, this condition determines the employment share in the traditional technology N^*. This share corresponds to the fraction of individuals that do not invest in school, a mapping that is exploited in the numerical exercise below.

[7] This is contrary to the evidence in Psacharapoulos (1994) that returns to education are higher in poor countries. Introducing a capital market imperfection to finance human capital investments would reconcile the predictions of the model with data in this dimension and would make the results of the paper stronger at the expense of substantially more complexity.

It is straightforward to show that the modern wage (net of educational expenditures) is determined by the rate of time preference and barriers to investment. Moreover, the modern wage is decreasing in barriers and independent of the fraction of individuals in the traditional technology N. The wage in the traditional sector is strictly decreasing in N; therefore, for each barrier level θ there is a unique stationary equilibrium with the property that $0 < N^* \leq 1$. An example of this situation is illustrated in Figure 3. Because both $(w_m h - e)$ and w_t decrease with barriers, it is not generally true that N^* increases with barriers. However, for reasonable parameters the employment share of the traditional technology N^* is increasing in θ.[8]

To illustrate some analytical implications of the model, consider the following extreme example of two countries. Country i has only educated individuals working in firms operating the modern technology and country j has only uneducated individuals working in firms operating the traditional technology. Relative per worker income between the two economies is given by,

$$\frac{y_i}{y_j} = \frac{(K_i/Y_i)^{\frac{\alpha}{1-\alpha}}}{(K_j/Y_j)^{\frac{\psi}{\eta}}} \times h_i \times \frac{A^{\frac{1}{1-\alpha}}}{C^{\frac{1}{\eta}}}$$

where the first term is the the familiar capital-output ratio effect for income differences implied by a standard one-technology model (with $\alpha = \psi$ and $1 - \alpha = \eta$). The second term is the effect of differences in a broader notion of capital that includes schooling capital. The third factor is what is absent from augmented growth models. It relates to the total factor productivity difference between the two countries. In a more general case where the distribution of education is not as extreme as in this example, the aggregate total factor productivity factor would be given by a weighted average between modern and traditional TFP parameters, where the weight is the output share of each technology in the stationary equilibrium of the model. Because the equilibrium output share is endogenously determined by the parameters of the model, in the next section I present a calibrated example that illustrates the quantitative properties of the model and the strength of the technology adoption and schooling complementarity for understanding international income differences.

[8] N^* is increasing in barriers if the modern wage reacts more to changes in barriers than the traditional wage. A sufficient condition is that the modern technology is more physical capital intensive than the traditional technology.

3 Quantitative Example

3.1 Calibration

I use the relative price of investment over consumption reported in Restuccia and Urrutia (2001) as a measure of barriers to physical capital investment.[9] I consider a baseline economy with no barriers ($\theta = 0$) and calibrate this economy to U.S. observations.

The parameters to calibrate and their targets are summarized in Table 2. Parameters are chosen to match relevant observations from the data, in many cases using equilibrium conditions implied by the model.

The model period is the equivalent to 60 real life years. Using the capital accumulation equation in steady state for the baseline economy, the depreciation rate is given by

$$\delta = \frac{x/y}{k/y}$$

Hence, depreciation is 8% annually to match an investment rate of 20% in the U.S. economy and a capital-output ratio of 2.5.[10] This is a reasonable value compared with calibrated models without population growth and exogenous technical progress. The corresponding depreciation rate for a 60 year period is 99%.

For the U.S. economy in 1985 the fraction of adult population with no schooling is less than 1%. Since in the model the share of traditional employment corresponds to the size of the no schooling population, I can calculate the value of the modern capital share by using the aggregate capital income share in the U.S. economy. This implies $\alpha = 0.35$. In steady state of the baseline economy, the euler equation for capital accumulation implies that the discount factor must satisfy

$$\beta = \frac{1}{\frac{\alpha}{k/y} + (1 - \delta)}$$

Given α and δ, the discount factor is chosen to reproduce a capital-output ratio of 2.5 using this equation. The fixed supply of land input L, the modern technology parameter A, and the schooling technology parameter B, are all normalized to 1.

[9] Similar results are obtained if instead I consider differences in total factor productivity, reported for example in Hall and Jones (1998), as a measure of productivity differences in the modern sector.

[10] Summers and Heston's (1991) definition of investment does not include consumer durables and net exports. I exclude these from the calculations in Cooley and Prescott (1995) to obtain a capital-output ratio of 2.5.

Gollin (1998) shows that aggregate labor income share is roughly constant in a cross section of countries when self-employment income is properly included. The aggregate labor income share in the model is given by

$$\frac{Y_t}{Y_t + Y_m}\eta + \frac{Y_m}{Y_t + Y_m}(1 - \alpha)$$

This implies that the labor elasticity parameter in the traditional technology η must be equal to 0.65 in order that the aggregate labor income share in the model be constant across economies (independent of the output share in each technology).

The elasticity of educational resources on human capital ξ is calculated to match estimated returns to schooling from a standard Mincer-type regression. In particular, a return to schooling of 6% in the U.S. implies, under the Mincer specification, that the wage gap between a worker with average schooling level and another with zero schooling of around 2. In the model the wage gap between an educated and uneducated worker is given by

$$\frac{w_m h}{w_t} = \frac{1}{1 - \xi}$$

therefore it implies $\xi = 0.5$. Microeconomic studies on the schooling technology have estimated a similar elasticity when several inputs in the schooling technology are taken into account (Haley, 1976). A lower return to schooling of 4% would yield a lower elasticity of 0.35. Card and Krueger (1996) estimate the elasticity of resources not including foregone wages and parents time to be close to 0.2. Therefore, I perform sensitivity analysis by presenting the results on income differences with lower values for the elasticity parameter in the schooling technology.

There are two parameters remaining, C and ψ. Their values are chosen to reproduce a fraction of no schooling population of 0.0085 for the baseline economy and of 0.85 for an economy with the highest barriers, as observed in the data. The procedure here exploits the fact that the ratio between the traditional employment share in the two economies is independent of C, and therefore ψ is chosen to match this ratio. Then C is chosen to match the employment share level in one of the technologies. An implication of this calibration is that for a given schooling parameter ξ, the traditional technology must be less efficient and less capital intensive than the modern technology for the model to reproduce the schooling attainment data.

3.2 International Income Differences

3.2.1 The Amplifier Income Effect

I define a barrier ratio to be the relative price of investment of the economy with the highest barrier relative to the baseline economy. Since the price of investment is 1 for the baseline economy, the barrier ratio amounts to $(1 + \theta)$. I describe the results of the model by systematically comparing two economies with a barrier ratio of 4.[11] I define the income ratio to be the output of the richest economy relative to the poorest.

Table 3 presents the results of the model for several key variables for the baseline economy and an economy with barriers of 4. Table 4 summarizes the income disparity results of the model with an elasticity in the schooling technology of $\xi = 0.5$ and selected lower values. The income ratio generated by the model with a barrier ratio of 4 is 7.7. This is more than three times larger than the income ratio generated by a standard growth model with the same barriers and physical capital income share. The table also illustrates the importance of the elasticity parameter of the schooling technology for generating sizable income differences.

A key result is that not only output is lower in the economy with barriers relative to the baseline economy, but also that the fraction of output produced with the traditional technology is substantially larger in the economy with barriers. This distinction is important since not all output produced with the traditional technology might be measured in the national income accounts (for instance household production and informal activities). Young (1995) reports large changes in labor force participation rates in East Asia during a period of very rapid growth providing evidence of unmeasured output in developing economies, since a large portion of these changes must be associated with a reallocation of labor from traditional (unreported) activities to modern activities. If no traditional output is measured, then income ratios in the model can be as large as in the data. Table 5 illustrates the implications of the model in terms of income ratios assuming some of the traditional output is not measured in the income accounts. If no traditional output is measured, income ratios

[11] This is the value of the highest relative price of investment relative to the lowest in my sample of countries as described in the data sources section.

are about 30. However, as a fraction of measured output, unmeasured output appears too large. Blades (1974) reports estimates of unmeasured output relative to measured output to be as large as 40% in poor countries. This would imply that 30 to 50% of traditional output might not be measured in the income accounts and therefore income ratios might be between 10 and 12.

Where is the amplification effect in income coming from? The amplification effect has two components as illustrated in the analytical example in the last section. One component of the amplification effect corresponds to the introduction of more capital, in this case, schooling capital. The other component relates to the endogenous aggregate TFP differences generated by the model. Most importantly these components reinforce each other and therefore the amplification effect is larger than each component in isolation. The quantitative impact of these components are evaluated in Table 6, where I report the results of the model by adding one component at a time. The model with no schooling is the baseline model with $\xi = 0$ and the model with no technology adoption is the baseline model with the modern technology as the only technology available. Therefore, the model with no schooling and no technology adoption is the standard growth model. With a capital share of 0.35 and a barrier ratio of 4, the standard growth model produces an income ratio of 2.1.

In the standard growth model rich countries appear poorer than in the data because the model does not capture the high schooling investments in these countries and poor countries appear richer than in the data because the model does not capture the more intensive use of inefficient technologies in these countries.

When schooling is introduced into the standard model, the income ratio increases by a factor of 2. This number is directly related to the calibration of the schooling technology to Mincer returns to schooling, as it would be implied in a standard income accounting exercise with an augmented model. If instead technology adoption is introduced, the income ratio does not vary with respect to the standard model unless traditional output is not measured.[12] When both features are introduced, income ratios are much larger than in the standard model. As indicated above the model with technology adoption and schooling captures two important properties of the data, rich countries are rich because incentives are

[12]This result is a consequence of the particular schooling technology specification. Under a more general specification with time and resource inputs, the technology adoption case with no schooling quality would imply income differences. See Restuccia (1998) for a version with this specification.

in place for the use of modern technologies and undertaking educational investments, and poor countries are poor because barriers to capital accumulation make modern technologies and investment in education less attractive and therefore traditional technologies are used more intensively.

To place the results of this paper in perspective with the literature, I consider two important papers that are closely related to mine: Parente, Rogerson, and Wright (2000) and Parente and Prescott (1999). Parente, Rogerson, and Wright (2000) introduce home production into a standard growth model. For reasonable barriers and market capital income share, their model generates income differences of 3. Because their model does not have schooling, I isolate the effect of schooling and show that my model generates a similar income ratio of 3.6. An important distinction is that their income difference is in measured output, if non-market output is included in the definition of income, differences are much smaller.[13] Parente and Prescott (1999) develop a model of total factor productivity where monopoly rights act as a barrier to the adoption and efficient use of technologies. In a numerical example, they show that the model produces total factor productivity (TFP) differences as large as 2.7. Their model abstracts from physical and schooling capital. Isolating for differences in physical and schooling capital, my model implies aggregate TFP differences of 1.7 or more depending on whether traditional output is measured or not. A key distinction is that aggregate TFP differences in my model are directly linked to barriers to capital accumulation and schooling investments.

The amplification effect of the technology adoption and schooling complementarity suggests caution in interpreting the role of factor inputs in standard income accounting exercises. The role of human capital in development is important when viewed together with technology adoption. However, a better understanding of the interaction between technology adoption and schooling is needed.

[13] In terms of aggregate output (measured and unmeasured) the home production model generates slightly higher or lower income ratios than the standard growth model with similar barriers and capital share. The reason is that home production allows individuals to avoid barriers by substituting market time by non-market time. However, this substitution effect additionally distorts the incentives for capital accumulation; therefore its net impact on income depends on the relative magnitude of these two opposing effects.

3.2.2 Policy Experiment: A Subsidy to Education

Evidence of an important role of human capital in development might suggest subsidies to education as a reasonable development policy. I show this is not the case in this environment, and understanding why is relevant since subsidies to education are common practice in developing countries.

I evaluate a subsidy policy to education in the context of my model. I find that subsidies to education are not optimal in the presence of barriers to capital accumulation. Eliminating barriers generates the same educational outcomes and higher income levels by several orders of magnitude. Table 7 summarizes the quantitative results of two subsidy experiments in an economy with a barrier ratio of 4. The first experiment, Policy A, consists of a flat subsidy to individuals acquiring education financed through lump-sum taxation. The objective of the subsidy is to achieve the school attainment of the baseline economy. The subsidy policy achieves a non-schooling population of 0.0085 as in the baseline economy, but generates a steady state output 4 times lower than the steady state output of the baseline economy with no barriers. The second experiment, Policy B, considers an education subsidy financed instead through distortionary taxation. If only revenues from the investment tax are used for the education subsidy, then steady state income differences are even larger. The intuition for these results is clear. A subsidy policy to education in the presence of barriers does not eliminate the negative incentives that barriers have on capital accumulation, and therefore both the physical capital stock and schooling quality investments remain low.

Subsidies to education would have a more important role in an environment with a credit market imperfection to finance educational investments. However, I argue this would be a second order effect compared with the negative incentives provided by high barriers to capital accumulation as suggested by the previous experiments.

4 Conclusions

I develop a simple environment that incorporates the complementarity of technology adoption and schooling decisions and use it to study the role of barriers to capital accumulation in accounting for international income differences. I find that a model with these features generates a larger income difference than a standard growth model. I show that the complementarity between technology adoption and schooling decisions generates aggregate total factor productivity differences in the model and these account for a large portion of the amplifier income effect, suggesting caution in interpreting income accounting conclusions on the role of factor inputs. Moreover, despite the more important role of human capital in development in this model, a subsidy policy to education is not optimal in the presence of barriers to capital accumulation. Removing barriers would generate the same educational outcome and an increase in income by several orders of magnitude.

I emphasize that these results do not depend crucially on the interpretation of barriers as tax to investment and on the particular modeling of technologies. Similar versions of the model with differences in modern-technology productivity and technologies with different degrees of capital-skill complementarity would yield similar qualitative results. The model does not shed light on the source of barriers to investment, although it suggest a reason for why they might remain in place. In economies with very unequal income distribution, in particular in economies where the capital stock is owned by a small fraction of individuals, implementing a policy of reducing barriers might be politically infeasible since the benefits of reform would be concentrated heavily on the capital owners.

Prescott (1998) has emphasized the need for a theory of total factor productivity. My model provides a candidate theory by relating TFP differences to schooling investments and barriers to capital accumulation. Moreover, a caveat to Prescott's conclusion is that the quantitative TFP differences needed to understand the current income differences might be smaller than previously thought, given the complementarity between technology adoption and schooling decisions. The results of this paper emphasize the importance of the technology adoption and schooling interaction and suggest the need for a better theory of this interaction in general equilibrium as an area for future research.

5 Data Sources and Sample

Data is from Summers and Heston (1991), Barro and Lee (1993), Hall and Jones (1998), and Restuccia and Urrutia (2001). The sample is restricted to all 1985 benchmark countries from Summers and Heston that have schooling data available from Barro and Lee for the same year. The result is a cross-section sample of 47 countries.

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Table 1: Fraction of Adult Population by Category and Average Years of Schooling for 1985

Region (# of Countries)	No Schooling	Some Schooling	AYS	AYS2
Developing Countries (73)	49.7	50.3	3.6	7.2
OECD Countries (23)	3.3	96.7	8.9	9.2
Middle Eastern Countries (12)	52.8	47.2	3.5	7.4
Latin American Countries (23)	22.4	77.6	4.5	5.8

Source: Barro and Lee (1993), Table 6, pages 383-4. Regional averages are weighted by each country's population aged 25 and over. No Schooling refers to adults that have not completed one year of formal education. AYS is average years of schooling of the entire adult population and AYS2 is average years of schooling of the adult population with some schooling.

Table 2: Baseline Parameter Values

Parameter	Value	Target
P	60	
θ	0	Baseline Economy
δ	0.9933	$i/y = 0.2$ and $k/y = 2.5$
α	0.35	Physical Capital Income Share
η	0.65	Constant cross-section Labor Share
L, A, B	1	Normalization
β	0.119	$k/y = 2.5$
ξ	0.5	Implied Mincer Wage Gap
C	0.002	Non-schooling Population Baseline Economy (0.0085)
ψ	0.04	Non-schooling Population Barrier 4 (0.85)

Table 3: Model's Results for Key Variables

	Baseline Economy	Barrier Economy $(1+\theta) = 4$
Y_m	0.0105	0.0004
$\frac{Y_t}{Y_t+Y_m}$	0.0045	0.74
w_t	0.0037	0.0008
w_m	0.1174	0.0557
$w_m h$	0.0069	0.0015
$\frac{r_k K}{Y_t+Y_m}$	0.35	0.12

Table 4: Model's Income Differences and the Amplifier Effect

	$\xi = 0.2$	$\xi = 0.3$	$\xi = 0.4$	$\xi = 0.5$
Income Ratio	3.1	3.9	5.2	7.7
(Amplifier Effect)	(1.5)	(1.9)	(2.5)	(3.7)

The amplifier effect measures the income ratio of the model against the income ratio generated by a standard growth model with the same barrier ratio and a capital share of 0.35. Using these numbers the standard model generates an income ratio of 2.11. For each value of ξ the calibration algorithm is re-run so that all economies are consistent with the same set of data targets. For each case, the implied values for C and ψ are given by: for $\xi = 0.2$, $C = 0.187$ and $\psi = 0.25$; for $\xi = 0.3$, $C = 0.06$ and $\psi = 0.19$; for $\xi = 0.4$, $C = 0.02$ and $\psi = 0.12$; and for $\xi = 0.5$, $C = 0.002$ and $\psi = 0.04$.

Table 5: Unmeasured Output and Measured Income Disparity

	$\lambda = 0$	$\lambda = 0.3$	$\lambda = 0.5$	$\lambda = 1.0$
Income Ratio	7.7	9.9	12.2	29.4
Unmeasured/Measured Output (%)*	0	29	59	284

λ - Fraction of traditional output not measured
* for the country with the highest barriers to investment

Table 6: Model's Income Disparity (Amplifier Effect)

	No Technology Adoption	Technology Adoption
No Schooling $\xi = 0$	2.11 -	2.11 (1.0)
Schooling $\xi = 0.5$	4.45 (2.1)	7.7 (3.7)

No Technology Adoption refers to the model without the traditional technology, and Technology Adoption refers to the case where both technologies are available.

Table 7: Subsidy to Education: Steady State Analysis

	Policy A	Policy B
$\frac{y_{\theta=0}}{y^s_{\theta=3}}$	4.4	7.3
$N^s_{\theta=3}$	0.0085	0.80

$y^s(\theta)$ and $y(\theta)$ are the steady state output for an economy with barrier θ, with and without the education subsidy and N^s is the steady state fraction of the no schooling population for an economy with the subsidy. Policy A refers to the education subsidy (financed through lump-sum taxation) necessary to achieve the fraction of non schooling population of an economy with no barriers. Policy B is an education subsidy (financed through distortionary taxation) equal in magnitude to the resources generated by barriers.

Figure 1: No Schooling Population and Relative Incomes

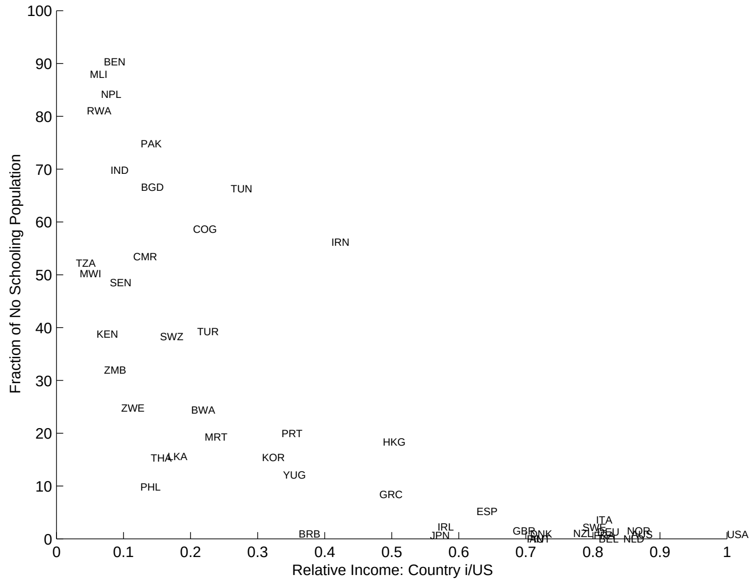

Figure 2: Total Factor Productivity and Average Years of Schooling

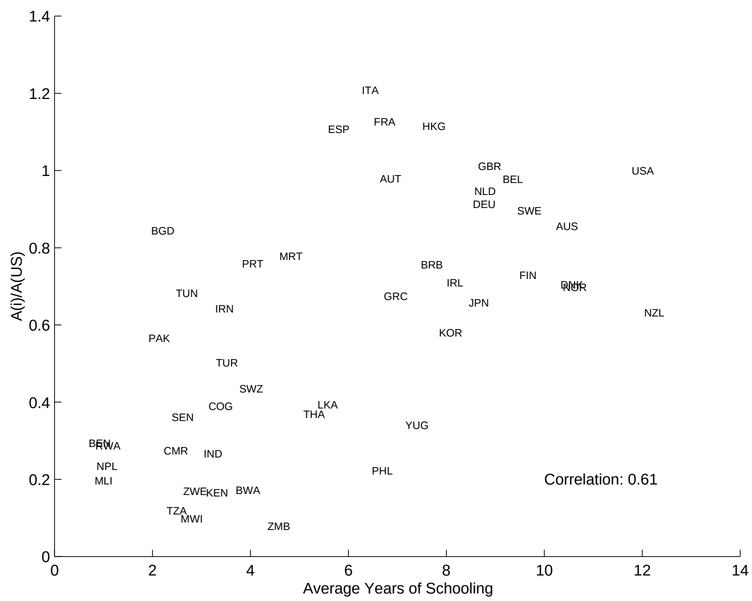

Figure 3: Stationary Equilibrium Traditional Employment Share