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The Costs of Education, Longevity and the
Poverty of Nations

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Janeiro de 2003

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The Costs of Education, Longevity and the Poverty of Nations.[*]

Pedro Cavalcanti Ferreira[†]   Samuel de Abreu Pessôa

Abstract

This paper explores the distortions on the cost of education, associated with government policies and institutional factors, as an additional determinant of cross-country income differences. Agents are finitely lived and the model takes into account life-cycle features of human capital accumulation. There are two sectors, one producing goods and the other providing educational services. The model is calibrated and simulated for 89 economies. We find that human capital taxation has a relevant impact on incomes, which is amplified by its indirect effect on returns to physical capital. Life expectancy plays an important role in determining long-run output: the expansion of the population working life increases the present value of the flow of wages, which induces further human capital investment and raises incomes. Although in our simulations the largest gains are observed when productivity is equated across countries, changes in longevity and in the incentives to educational investment are too relevant to ignore.

Key Words: Distortions, Human Capital, Longevity, Income Diversity

JEL Classification: J24, O11, O17, O47, O57

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1 Introduction

This article studies the effects of distortions to factors accumulation, productivity and demography on cross-country income disparity. More specifically, we explore the distortions on the cost of education, associated with government policies and institutional factors, as an additional determinant of income differences. As the model takes into account life-cycle features of human capital accumulation, the the long run impact of life expectancy on per capita income is also investigated.

We posit a continuous time overlapping generation model of capital accumulation with exogenous technological change and two sectors, educational and goods. All economies in the world have access to both technologies but they differ in their total factor productivity (TFP). Moreover, human capital is such that the skill level of a worker with T_S years of schooling is $e^{\phi(T_S)}$ greater (where ϕ is an increasing and concave function) than that of a worker of the same cohort with no education at all. Life is finite in the model but average life span differs from country to country.

In this model there are two decisions made by individuals. First, at each instant of time they decide how much to consume or save out of their labor and capital incomes and public transfers. Second, they decide the optimal time to leave school. Following the labor-economics literature (e.g., Mincer (1974) and Willis (1986)), human capital investment is the time spent acquiring formal education plus the tuition cost. As usual, the longer people stay in school, the higher their stock of human capital is. At each moment, individuals weight the opportunity costs of being in school - the wages forsaken plus tuitions - against its benefit, which is the increase in the present value of wages due to higher human capital. One of the key variables to be considered in this decision is life expectancy, because the present value of the flow of wages, everything else being the same, increases with longevity.

Government taxes tuition and the return to physical capital. We think of these taxes in a broader sense, as distortions or incentives to factor accumulation. In the real word there are plenty of examples of such distortions. Specifically, we have taxation (or subsidy) of capital income, tariffs on capital goods imports, and many forms of corruption and rent-seeking activities which interfere on the decision to invest in physical capital. With respect to human capital accumulation, some distortions are labor income taxation, school tuition taxation, credit market imperfections, and public provision of schools (which is a subsidy). We interpret the taxes in the model as an edge between social and private value summarizing

the end result of these distortions.

The model is calibrated in two steps. In the first, we follow standard procedures and adjust the model to the US, estimating in the process productivity and the distortions to physical and human capital accumulation, among other variables. In the second step, a cross-section data set on schooling, investment ratio, life expectancy and labor force participation is employed, together with the technology and welfare parameters estimated previously for the US, to obtain the TFP, distortions and tuition costs for the remaining economies.

A first finding of the paper is the relative importance of distortions to human capital accumulation. For comparable values, its effect on long-run income is of the same order of magnitude as that of distortions to physical capital accumulation. This is somewhat surprising in a model where education has no impact on the long-run growth rate and, as opposed to Lucas (1988) and Uzawa (1965), is a bounded variable which cannot be accumulated indefinitely. Education in the model determines skill levels and so it directly effects labor services and output. It also has an indirect effect on the latter due to its impact on the return to physical capital, and so on investment, a channel that multiplies the total impact of the taxes on education investment. In contrast, the educational sector uses very little capital - its capital share according to the NIPA is only 6 percent - so that the distortion to physical capital has almost no impact on human capital investment.

An unexpected outcome, and one that has received little attention, is the importance of life expectancy in the determination of long-run output. Greater longevity allows for extension of the population working life and, consequently, an increase in the present value of the flow of wages of a given investment in education. Higher returns to education in turn induce individuals to stay in school longer, increasing average human capital and so long-run income. There is also an indirect effect on income prompted by physical capital accumulation, as the boost in human capital positively affects the return of the latter. We show that, everything else being equal, a country with life expectancy of 65 years instead of the 77 years of the benchmark case will have 23% less schooling, 26% less physical capital and its income will be 28% smaller in the long run.

A consequence of the above findings is that having more or less education does not imply that distortions or incentives to human capital accumulation are large or small. The key factor in this case is the relationship between years of education and working life span. Life expectancy in Angola is only 45 years and so distortions to investment in education were found to be very small, even with very little schooling. On the other hand, in some rich

countries such as France, were life expectancy is very high but schooling well below that of the US, those distortions were estimated as being higher.

The link between longevity and long-run incomes found in the model implies a channel from health policy to growth that has not been explored by the literature. Basic and cheap measures such as sanitation and preventive care are well known to have a huge impact on the welfare of populations. However, by increasing average life expectancy they indirectly effect the return to educational investment, which will induce further accumulation of human capital, boosting long-run income. Hence, the fight against common Third World epidemics such as malaria, and more recently AIDS, not only has a direct benefit in terms of lives saved but also an impact on the long-run prospects of these economies that may well surpass the static loss of product due to deaths and diseases. In other words, in countries where life expectancy is too low, health and sanitation measures are probably the most effective growth policy.

To the best of our knowledge there has not been much interest in investigating long-run level effects of distortion to human capital accumulation, especially using the Mincerian formulation of human capital. The macro literature has dedicated more effort to studying the growth impact of human capital taxation, as in Trostel (1993), Stokey and Rebelo (1995), and Hendricks (1999). These papers employ the two-sector endogenous growth framework of Uzawa (1965) and Lucas (1988). However, in the face of recent empirical evidence (Bils and Klenow (2000) and Krueger and Lindhal (2000)) it seems that the growth effects of incentives to human capital accumulation is either very low or nonexistent. Additionally, as documented by Krueger and Lindhal, there is not a compelling set of evidence favoring the existence of externality associated to human capital accumulation. Our environment seems to be a conservative one for assessing the long-run importance of education and most likely we are underestimating the importance of schooling.

Bils and Klenow (2000) and Mateus-Planas (2001) use a Mincerian formulation of schooling with a life-cycle decision regarding education. The former authors consider a version of the endogenous growth model to study econometrically the causality between education and growth. Mateus-Planas studies a vintage model of capital accumulation in order to asses the impact of distortion to capital accumulation on long-run income. Neither formulation considers a second sector that provides educational services as we do; they have no taxation and do not explore fully the general equilibrium impact of life-cycle features of human capital investment.

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Mankiw (1995) and Parent and Prescott (1995) investigate the impact of distortions on long-run income for a version of the neoclassical model with three factors of production: raw labor, physical capital, and human capital (or organizational capital). In contrast to our model, they consider human capital and physical capital symmetrically, as stocks of goods that can be accumulated without limit. Another formulation of the neoclassical model of capital accumulation and exogenous technological change is Parent and Prescott (2000, chapter 4). Their set up however does not incorporate the life cycle features of educational choice, making the correspondence between the aggregate model and the micro data less precise.

This paper is organized in four sections in addition to this introduction. In the next section, the model is presented and in Section 3 we discuss the calibration procedures. Section 4 presents the main results and Section 5 concludes.

2   The Model

2.1   Firms

There are two sectors in this economy, one that produces consumption and investment goods and another that produces educational services. Let output Y_1 in the Goods Sector be a function of physical capital services K_1 and skilled labor H_1 according to:

$$Y_1 = A_1 K_1^\alpha (e^{gt} H_1)^{1-\alpha},$$

where A_1 is the sector total factor productivity and e^{gt} is the exogenous technological progress. Skilled labor is given by:

$$H_1 = L_1 e^{\phi(T_S)}$$

where L_1 is raw labor. According to the equation above, the productivity of a worker with T_S years of schooling is $e^{\phi(T_S)}$ greater than that of a worker of the same cohort with no education at all. The function $\phi(T_S)$ is assumed to be increasing and to exhibit diminishing returns, and $\phi'(T_S)e^{\phi(T_S)}$ gives the increase in effective labor input from one extra year of schooling. This formulation follows the labor literature (e.g., Mincer (1974) and Willis (1986)), but has been used recently in the growth field by Jones (2002) and Bils and Klenow(2000)

Profit maximization of the firm gives

$$r_1 = \alpha A_1 k_1^{\alpha-1} \quad \text{and} \quad w_1 = e^{\phi(T_S)} e^{gt}(1-\alpha)A_1 k_1^\alpha,$$

where r_1 is the rental price of capital and w_1 is the wage rate, both in the first sector, and

$$k_1 \equiv \frac{K_1}{e^{gt}L_1 e^{\phi(T_S)}}, \tag{1}$$

is the stock of capital in efficiency units.

The proposed technology of the Educational Sector takes into account that the production of educational services is labor intensive. For instance, capital's share in income of educational services sector was only 6.2% in 1997, according to the Survey of Current Business, published by the U.S. Department of Commerce. In this sense it will be assumed that schools employ only labor and that there is no technological progress in the sector.[1] The production function of the sector is:

$$Y_2 = A_2 H_2 = A_2 L_2 e^{\phi(T_S)}$$

and wages are

$$w_2 = e^{\phi(T_S)} A_2.$$

2.2 Household

Suppose a household that is born at time s and faces a life span of T years. Life has three different periods: youth, T_Y, adulthood, T_W, when working, and old age, T_R, after retirement. Youth has two sub-periods: childhood, T_C, when staying at home, and T_S, when at school.

At each instant of time the household decides how much to consume or save out of labor and capital incomes and public transfers. A decision is also made on how much education to buy, which is equivalent in the model to deciding the optimal period of time T_S of staying in school. The utility function of an individual born at time s is:

$$\int_s^{s+T} e^{-\rho(t-s)} \frac{c(s,t)^{1-\frac{1}{\sigma}} - 1}{1 - \frac{1}{\sigma}} \mathrm{d}t, \tag{2}$$

where $c(s,t)$ is the consumption at t of an individual born in s, while ρ and σ are respectively the discount rate and the intertemporal elasticity of consumption.

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[1] This last assumption is necessary for a balanced growth path in which tuition increases at a rate equal to technological change. It simplifies calculations too. We also explore the case in which the school sector employs capital, but only report results when they differ from the benchmark case.

Individuals have 3 sources of income - wages from labor services, rents from capital and public transfer - which is used to pay for school tuition and consumption goods. In intertemporal format their budget constraint is given by:

$$\int_{s+T_Y}^{s+T_Y+T_W} e^{-r(t-s)}\mathrm{w}(s,T_S,t)\mathrm{dt} + \int_{s+T}^{s+T} e^{-r(t-s)}\chi(s,t)\mathrm{dt} \quad (3)$$
$$= \int_s^{s+T_Y} e^{-r(t-s)}c(s,t)\mathrm{dt} + (1+\tau_H)\int_{s+T_C}^{s+T_Y} e^{-r(t-s)}\eta q(t)\mathrm{dt},$$

where r is the interest rate, $\mathrm{w}(s,T_S,t)$ is the wage in time t of a worker born at s with T_S years of formal education and $\chi(s,t)$ is the government transfer at t toward a cohort-s individual. The last expression on the right hand side is the tuition costs, where τ_H is a tax (or subsidy) rate on education purchases, η the amount of education services that the student has to buy in order to be in school,[2] and $q(t)$ is the price of one unit of educational services in units of consumption goods. The above expression simply says that the present value of wages and government transfers should be equal to the present value of consumption and tuition costs. Note also that tuitions are not proportional to wages, a point we will elaborate later.

Individuals maximize (2) subject to (3). Solving for consumption, we obtain the individual's consumption profile:

$$c(s,t) = c(s,s)e^{\sigma(r-\rho)(t-s)}. \quad (4)$$

Let $\mathrm{w}(s,T_S,t) = \omega(t)e^{\phi(T_S)}$, where $\omega(t)$ are the wages for raw labor. Moreover, as we are interested in studying the model's solution at a balanced growth path in which income, transfers, and tuition grow at the same constant rate g, we will assume that $\omega(t) = \omega e^{gt}$, $q(t) = qe^{gt}$ and $\chi(s,t) = \chi e^{gt}$. With these simplifications we obtain an expression for initial consumption, after substituting (4) into (3):

$$\frac{c(s,s)}{v_a} = \frac{e^{gs}}{r-g}\left[\omega e^{\phi(T_S)}e^{-(r-g)T_Y}\left(1 - e^{-(r-g)T_W}\right) \right. \quad (5)$$
$$\left. -(1+\tau_H)e^{-(r-g)T_C}\left(1 - e^{-(r-g)T_S}\right)\eta q + \chi\left(1 - e^{-(r-g)T}\right) \right].$$

---

[2] We are assuming an indivisibility in the human capital accumulation process. In order to increase the education level, an individual has to buy η unites of educational services. In other words, to be at school means: not working and staying some hours at school daily, which corresponds to buying η unites of educational services.

The right-hand term is the individual's total wealth at the time of birth (i.e., labor income less tuition plus government transfers) and

$$\upsilon_a = \frac{(1-\sigma)r + \sigma\rho}{1 - e^{-((1-\sigma)r+\sigma\rho)T}}$$

is the propensity to consume out of initial wealth.

In this economy, the education decision is equivalent to choosing the optimal time to leave school. In the beginning of their lives, individuals pick the optimal quantity of education in order to maximize the present value of income:

$$\max_{T_S} \left[\int_{s+T_Y}^{s+T_Y+T_W} e^{-r(t-s)} w(s, T_S, t) dt - (1 + \tau_H) \int_{s+T_C}^{s+T_Y} e^{-r(t-s)} \eta q(t) dt \right].$$

In making this decision, individuals consider that the longer they stay in school, the shorter their productive life, T_W, as retirement age T_R is exogenous. Moreover, in addition to the foregone wages, there is the direct cost of school tuition. Using again $\omega(t) = \omega e^{gt}$, $q(t) = q e^{gt}$ and $\chi(s,t) = \chi e^{gt}$, and the fact that $T_Y + T_W = T - T_R$, we can write the optimal choice of education as:

$$\max_{T_S} \left[\omega e^{\phi(T_S)} \frac{e^{-(r-g)T_Y} - e^{-(r-g)(T-T_R)}}{r-g} - (1+\tau_H)\eta q \frac{e^{-(r-g)T_C} - e^{-(r-g)T_Y}}{r-g} \right].$$

Remember that agents born at s stay in school from $s + T_C$ to $s + T_Y$ $(= s + T_C + T_S)$ so the expression on the right gives the present value of total tuition costs, while the one to the left gives the present value of labor income.

From the first order condition of this problem at a balanced growth path we obtain:

$$\omega e^{\phi(T_S)} \phi'(T_S) \frac{1 - e^{-(r-g)T_W}}{r-g} = \omega e^{\phi(T_S)} + (1+\tau_H)\eta q. \tag{6}$$

The expression above equates the present value of staying in school one additional unit of time (the left-hand side) to the opportunity cost of not working plus the tuition cost at the stopping time (the right-hand time). Note that dividing both sides of equation (6) by $(1 + \tau_H)$ one can see that tax on tuition is equivalent to direct taxation on wage income. Note also that if it was not for the tuition term, human capital taxation or taxes on wages would have no impact at all. In the latter case, a tax term $(1 + \tau_H)$ would divide both the term on the left and $\omega e^{\phi(T_S)}$ in the above expression, so that, without tuition costs in the

model, the taxation term would be eliminated. Hence, the education decision would not be affected by taxation or distortions.

It is assumed that at each instant a cohort of size $\frac{1}{T}$ is born. Consequently, the total population is equal to 1. Let us call $N_C, N_S, N_W,$ and N_R respectively the population of children, students, workers, and retirees. It will be assumed that the student-population ratio is proportional to the ratio of years of education to life span:

$$\frac{N_S}{N} = N_S = \frac{T_S}{T}. \tag{7}$$

Likewise, we posit that:

$$N_C = \frac{T_C}{T}, \ N_W = \frac{T_W}{T} \text{ and } N_R = \frac{T_R}{T}. \tag{8}$$

2.3   Government Restriction

Government revenue is given by the sum of taxation of educational services and capital income, so that the government budget constraint is:

$$\tau_H \eta q(t) N_S + \tau_K r_1 K(t) = \chi(t).$$

2.4   Aggregate Consumption

Before presenting the equilibrium conditions of this economy, we need to derive an expression for aggregate consumption, which is done by adding the individual consumption over cohorts:

$$C(t) = \frac{1}{T} \int_{t-T}^{t} c(s, t) \mathrm{d}s. \tag{9}$$

Equation (4) provides the consumption profile for an individual. If initial consumption, due to technological change, increases at a rate g, so that $c(s, s) = xe^{gs}$, we obtain

$$
\begin{aligned}
C(t) &= x\frac{1}{T} \int_{t-T}^{t} e^{gs} e^{\sigma(r-\rho)(t-s)} \mathrm{d}s \\
&= \frac{xe^{gt}}{T} \frac{1 - e^{-(g-\sigma r+\sigma\rho)T}}{g - \sigma r + \sigma\rho}.
\end{aligned} \tag{10}
$$

From (5) and (10) it follows that:

$$c \equiv \frac{C(t)}{e^{gt}} = \frac{v_c}{T(r-g)} \left(\omega e^{\phi(T_S)} e^{-(r-g)T_Y} \left[1 - e^{-(r-g)T_W} \right] \right.$$
$$\left. -(1+\tau_H)\eta q e^{-(r-g)T_C} \left[1 - e^{-(r-g)T_S} \right] + \chi \left[1 - e^{-(r-g)T} \right]^a \right). \tag{11}$$

where v_c is a positive constant that depends on v_a and other parameters.[3] This expression simply says that aggregate consumption in each period is a fraction of the permanent income of the representative agent.

2.5 Long-Run General Equilibrium

The following equations describe the long-run equilibrium of this economy along the balanced growth path.

The equilibrium in the market for educational services is:

$$A_2(1-l_1)N_W e^{\phi(T_S)} = \eta N_S, \tag{12}$$

where l_1 is the fraction of the total labor force employed in sector one.

The equilibrium in the assets market implies that

$$r = (1-\tau_K)r_1 - \delta = (1-\tau_K)\alpha A_1 k_1^{\alpha-1} - \delta, \tag{13}$$

where τ_K is a tax rate on capital income. From the above expression we obtain the following equation that will be useful later:

$$k_1 = \left(\frac{1}{\alpha A_1} \frac{r+\delta}{1-\tau_K} \right)^{\frac{1}{\alpha-1}}. \tag{14}$$

Free labor mobility across sectors implies equality of wages in sectors one and two, both in units of good one:

$$w_1 = e^{gt}\omega = e^{gt+\phi(T_S)}(1-\alpha)A_1 k_1^\alpha = q e^{gt+\phi(T_S)}A_2 = q(t)w_2.$$

Under a balanced growth path, this last equation simplifies to

$$\omega \equiv \frac{\omega(t)}{e^{gt}} = (1-\alpha)A_1 k_1^\alpha = qA_2. \tag{15}$$

The government budget constraint, in which revenue is given by the sum of taxation of educational services and capital income:

$$\tau_H \eta q(t) N_S + \tau_K \frac{r+\delta}{1-\tau_K} K(t) = e^{gt} \left[\tau_H \eta q N_S + \tau_K \frac{r+\delta}{1-\tau_K} k \right] = e^{gt} \chi, \qquad (16)$$

where $(r+\delta)/(1-\tau_K) = r_1$ is the rental price of capital and follows from (13), and $k \equiv K/e^{gt}$.

The goods market equilibrium is:

$$c = A_1 l_1 N_W e^{\phi(T_S)} k_1^\alpha - (\delta + g)k, \qquad (17)$$

where c is given optimally by equation (11), after the expression for government transfers above is plugged in.

Finally, after substituting $\omega = A_2 q$, the equilibrium conditions with respect to the educational choice are:

$$\left[\frac{A_2}{\eta} e^{\phi(T_S)} \right]^{1/2} \left[\phi'(T_S) \frac{1 - e^{-(r-g)T_W}}{r-g} - 1 \right]^{3/4} = 1 + \tau_H. \qquad (18)$$

An important result that will be useful later can be seen from the equation above. The only channel between the distortion to capital accumulation (or the productivity of the goods sector) and the educational choice is through the interest rate, net of distortion, r. If the economy is open, such that r is given internationally, the educational choice will not be affected by changes in τ_K. The same is true if the economy is closed but the long-run solution for r is not very sensitive to the distortion to capital accumulation (nor to the productivity of the goods sector). In both cases the education choice, in general equilibrium, depends mainly on τ_H. The same does not happen with the capital decision: changes in τ_H have a considerable impact on k through their effect on $e^{\phi(T_S)}$.

3   Quantitative Methodology

The calibration of the model is carried out in two steps. First, the model is calibrated to the US. In the second step we assume that the economies in our data set share with the US the same values for preferences and technological parameters. Then, using some observable variables for each economy, we get the implied (or measured) values for the incentive parameters, τ_K and τ_H, and for productivity, A_1. We use the calibrated model to asses the sensitivity of the endogenous variables to changes in parameter values.

3.1 Calibration

The function $\phi(T_S)$ is taken from Bils and Klenow (2000):

$$\phi(T_S) = \frac{\theta}{1-\psi}T_S^{1-\psi}. \tag{19}$$

According to their calibration, we have $\psi = 0.58$ and $\theta = 0.32$. Hence, instead of the more usual linear return to education assumed in most of the literature, we posit diminishing returns because this seems to be the case when comparing micro estimates across countries.[4]

We will also consider the following parameters as observable:

$$l_2, T_C, T_S, T_W, T, g, \alpha, r, \delta, \sigma.$$

The share of labor in the educational sector, l_2, was obtained from the NIPA and is the average from 1987-1997 of the ratio of Full-Time Equivalent Employees in Educational Services to the Total Full-Time Equivalent Employees and was found to be 1.6%. For T we used the life expectancy in 1995, obtained for all countries in World Bank (1990). However, as the relevant educational decision is taken not at birth but some years later, we constructed an adjusted life expectancy series, conditional on survival to the age of five.[5] T_W was found using equation (8). In this case N_W was constructed using labor force and population data from World Bank (1990).

The capital share in the goods sector was set equal to one-third, which is the number found in the NIPA. The interest rate was set at 4.5%, depreciation at 6.6%,[6] the exogenous growth rate g equal to 1.36% a year[7] and the investment-output ratio to 0.18, the average value for the variable in the Summers and Heston database from 1975-1995. T_S for all economies corresponds to data on years of schooling attained by the working-age population from the Barro and Lee (2000) database.

There are six parameters left to be found:

$$A_1, \frac{A_2}{\eta}, \eta q, \tau_K, \tau_H \text{ and } \rho,$$

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[4]In addition, the value 0.58 for ψ provides 'enough' concavity of $\phi(T_S)$. See the discussion in Appendix B.

[5]We used the World Bank series Infant Mortality Rates (for children under one year old), Under-5 Mortality Rates and Life Expectancy at Birth to construct the adjusted life expectancy series.

[6]This is a long-run average for the investment/capital ratio, as given by NIPA, both evaluated at market prices.

[7]We estimated a trend line for the variable RGDPW of the Summers and Heston database from 1960-1992.

which will be estimated solving equations (12), (15), (17) and (18), the model's value for output

$$y = N_W e^{\phi(T_S)}(A_1 l_1 k_1^\alpha + q\eta\frac{A_2}{\eta}l_2), \tag{20}$$

and the investment-output ratio

$$\frac{i}{y} = \frac{(\delta + g)k}{N_W e^{\phi(T_S)}(A_1 l_1 k_1^\alpha + q\eta\frac{A_2}{\eta}l_2)}, \tag{21}$$

considering y and i/y as observable. Both were obtained using updated Penn World Table Mark 6.0 data for the year of 1995. Finally, we assume logarithmic preferences, so that σ is set equal to 1.

3.2   Cross-Country Incentive and Productivity Measurement

In order to get the implied values of τ_K, τ_H, A_1 for the remaining economies in our data set, we assumed that the economies share with the US the same preference, technology and return to education parameters. Hence, the values for the following exogenous parameters:

$$\{\theta, \psi, \rho, \sigma, \alpha, \delta\},$$

are those calibrated for the US. Moreover, g, r and A_2 are also equal across economies.[8]

Finally, with the help of cross-section data from the same sources for T, y, and $\frac{i}{y}$, we solve (12), (14), (17), (18), (20), and (21), for $\{A_1, \eta q, \tau_K, \tau_H, l_2, k\}$.

We are left with the calibration of the time spent in the job market, T_W, which, given the assumption of exogenous retirement life, is equivalent to the calibration of T_R. We use population and labor force data from the World Development Report (World Bank 1990) to calibrate T_R such that the model's value for

$$\frac{N_W}{N} = \frac{T_W}{T}$$

reproduces the data.[9] In other words, in this model the ratio of working time to life span is equal to the ratio of labor force to total population. We use data on N_W/N and T to obtain T_W and T_R.

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[8]Given that the educational sector almost only employs labor, $e^{\phi(T_S)}$ already controls for TFP differences in this sector.

[9]We are assuming that the daily shift does not vary across economies.

In this subsection, in order to identify τ_K we assumed that the the interest rate, free of distortion and risk, is the same across economies. Consequently, we are assuming capital mobility. Given that we do not have data for the difference between internal output and domestic income, we are implicitly assuming, when employing (17), that the net external debt is zero.

3.3 Simulation of the Model

We will later perform an experiment to evaluate the sensitivity of the endogenous variables to modifications in the parameter values. In particular we are interested in evaluating the relative impact on long-run per capita income of changes in

$$\{A_1, \tau_H, \tau_K, T\}, \tag{22}$$

keeping fixed all other parameters (in particular, when we change T we hold $\frac{T_R}{T}$ constant).

In this exercise we assume that the economy is open, so that we consider $r = \log(1.045)$ as given for every combination of (22). We then solve (18) to get T_S, and, consecutively: (12) for l_1, (14) for k, (15) for q, and (20) for per capita income. Finally, the difference between internal output and domestic income is given by the solution of (17), which is not necessarily zero now.[10]

4 Results

4.1 Measurement of productivity and distortions to factor accumulation

We are interested in understanding how differences in distortions to factors accumulation and productivity affect long-run income disparity across countries. In our model, everything else being the same, large τ_K and/or τ_H and small A_1 imply smaller per capita income. As in the long run all countries grow at the same rate g, these differences are permanent.

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[10]The fact that in the open economy solution of the model equation (17) is a residual equation used to get the implied service account means that, for a given value of r, the solution does not change with the preference parameters ρ and σ.

In estimating of τ_K, τ_H, and A_1 in the 89 countries in our sample, we found wide variations of these variables. Taking the US as the benchmark economy, so that we set $\{q_{\text{US}}, A_{1\text{US}}\} = \{1, 1\}$ and $\{\tau_{H\text{US}}, \tau_{K\text{US}}\} = \{0, 0\}$, τ_H in Mozambique and Niger, for instance, was found to be 0.88 and τ_K in Rwanda and Haiti 0.85, while being -0.17 in Argentina and -0.74 in Japan, respectively (hence, a relative subsidy in both countries). More interesting, the estimated correlations among τ_K, τ_H, A_1 are relatively small: it is 0.22, between τ_K and τ_H; -0.40, between τ_K and A_1; and -0.33, between τ_H and A_1. The low correlation between τ_K and τ_H, for instance, implies that an economy with good incentives to capital accumulation, and hence with high investment ratio, may also have very low observed schooling levels due to high taxation of education.

We estimated five countries as being marginally more productive than the US: Italy, France, Singapore, Belgium and Mauritius. On the other hand, there are countries such as Tanzania (the least productive in our sample), China and Togo where Total Factor Productivity (TFP) is one quarter or less of US productivity. The TFP ratio of the most productive to the least productive country is 6.1. These results are similar to those in Hall and Jones (1999), among others.

Table 1 below presents the estimated levels of τ_K, τ_H and A_1, relative to the US for a sub-group of countries. Adjusted life expectancy and relative income are also presented.

Table 1: Productivity, Distortions, Life
Expectancy and Relative Income

	A_1	τ_H	τ_K	T	y
Argentina	0.74	-0.17	-0.03	76.34	0.37
Belgium	1.04	-0.10	-0.22	78.62	0.76
Botswana	0,53	0.00	-0.09	57.17	0.20
Brazil	0.65	0.20	-0.21	73.79	0.25
China	0.27	0.39	-0.06	75.03	0.10
France	1.02	0.07	-0.42	78.96	0.73
Guatemala	0.81	0,01	0.54	70.6	0.14
India	0.35	0.14	0.32	74.09	0.07
Korea Rep.	0.52	-0.11	-0.98	73.49	0.50
Malawi	0.17	0.35	0.29	66.56	0.02
Portugal	0.88	0.26	-0.20	76.20	0.49
USA	1.00	0.00	0.00	76.9	1
Thailand	0,41	0,37	-0.85	74.5	0.25
sample mean	0.60	0.04	0.10	72.70	0.31

Before performing a systematic analysis of the impact of incentives and productivity on cross-country income differences, some comments on the parameters estimation may be illustrative. India, China and Guatemala are relatively poor or very poor countries. However, the reasons vary. Guatemala, among other reasons, is relatively rich in natural resources and hence its estimated productivity is very large. Its incentives to physical capital accumulation, however, are extremely low, among the worst in the sample. The estimated productivity in India and China, on the other hand, is well below the sample mean and in both cases distortions to human capital investment are high and above the sample mean. However, τ_K in China is very low. Malawi fares very badly in every possible aspect and there is no wonder it is one of the poorest countries in the world.

South Korea's strength is capital accumulation and education, but it has below-average productivity for world standards. Similar stories could be told with respect to Malaysia and to a lesser extent Japan (where estimated A_1 is above average but only 80% of the US level). Productivity in Thailand is also very poor, and also education incentives, but the country is

very good at setting the right incentives to physical capital accumulation and its estimated τ_K is the second smallest in the sample, after Singapore.[11]

For our purposes, the case of Portugal is of great interest. Portugal is a middle income country as its GDP per capita is only 49% of the US figure. Its estimated productivity is 12% below the leaders but well above average. Its incentives for physical capital accumulation are estimated as being better than American incentives. However, the distortions to human capital investment are very high, being the 16th. worst in the sample: Portugal has the same life expectancy as the US but only 46 percent of its educational attainments. A similar case can be made for France, which is much richer than Portugal but also has above average τ_H. In this case both productivity and τ_K are better than in the US, but due mostly to τ_H, France is only 75 percent as rich as the US. Again, low schooling is the explanation[12].

Schooling in Botswana, in contrast, is low, less than 6 years, but its estimated incentives for the accumulation of human capital are better than average, superior to many rich and more educated countries. Note, however, that life expectancy in Botswana is very low, 57 years, almost 20 years less than the sample median. The next section explores the link between longevity, education and development.

4.2   The Impact of Life Expectancy

One unexpected outcome of the simulation of the model is that in a group of poor or relatively poor countries with little education, the estimated values of τ_H are not very high. Indeed, not only for Botswana, but for countries such as Zambia, Lesotho and Zimbabwe, the estimated value of this variable was below average and even below those of many rich economies. However, schooling in all four cases is below average.

The apparent contradiction between little observed education and good estimated incen-

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[11]In Belgium, τ_K and τ_H are both smaller than in the US and productivity is larger. Income, however, is 30% smaller. The reason for this apparent puzzle is labor-force participation, which is 49% of the working-age population in the USA, while only 40% in Belgium. Hence, part of the income per capita difference is due simply to a larger proportion of workers in the population in the US, which in the model simulation is an exogenous parameter that varies across countries. In our calibration, T_W is proportional to labor-force participation. This is also an important factor explaining the relative income of France, Argentina and Brazil, among other countries.

[12]Recall that in our framework τ_H is equivalent to high payroll taxation. Hence, in the case of France, the estimated distortion may be capturing the high levels of labor taxation in this country.

tives is explained mostly by longevity. In a country in which agents do not expect to live long, the optimal decision is to stay in school for very few years. Remember that in this model, while in school agents are out of the labor market. Hence, the shorter the number of years that an agent expects to benefit from investing in education, the sooner is the optimal time to leave school. In the case of Lesotho, for instance, schooling is only 4 years but life expectancy is also very short, 52 years, so that the estimated τ_H is very small. With such a short life, 4 years of education is not a bad record[13]. On the other hand, rich countries with high life expectancy but relatively less education than the leaders have large estimated τ_H. As we just saw, in France the estimated value of this variable was 0.07, above the sample average, while life expectancy in 1995 was the same as in the US. Educational attainment of the French working age population in 1995, however, was only 62% of that of the American working age population (but 23% above the average level in our sample), an indication that distortions to human capital investment in France are comparatively large. Hence, the best performers in this case are not necessarily the ones with the highest schooling levels, but those with relatively high schooling with respect to life expectancy.

Once we control for longevity, this result no longer holds. If we keep education level constant in Botswana, but give the US life expectancy to its population (holding T_R/T constant), its estimated τ_H jumps to 0.10. In Lesotho it goes from -0.028 to 0.15. Hence, the correlation between τ_H and education, given observed life expectancy, is -0.50. However, this correlation is considerably higher in absolute value, -0.65, when we set each economy to US life expectancy. This result indicates that policies that increase longevity may have a considerable effect on output, as they raise the incentives to the acquisition of education.

In order to better understand the relationship between long-run income and longevity, in Table 2 below we present the result of the simulations of the model holding all parameters constant at the values estimated and calibrated for the US, at the same time that we vary life expectancy numbers:[14]

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[13]Had we not adjusted life expectancy and used life expectancy at birth for T, we would get $\tau_H = -0.06$ for Angola, a country with only 2.4 years of average education. In this case, life expectancy is only 45 years, so that productive life is extremely short, as is the return of a given investment in education. The observed education level, although small in absolute terms, is too high with respect to the expected return, which explains the negative τ_H.

[14]In this exercise we adjusted the retirement time in order to keep $\frac{T_R}{T}$ constant. See subsection 3.3 for the methodology.

Table 2: Long-Run Impact
of Life Expectancy

T	T_S	K	y
45	3.01	0.41	0.39
50	4.03	0.48	0.45
55	5.22	0.23	0.53
60	6.57	0.65	0.62
65	8.05	0.74	0.72
70	9.62	0.85	0.83
76.9	11.89	1	1
80	12.89	1.07	1.08

As life expectancy decreases, the number of years of education decreases monotonically. If instead of 76.9 years, life expectancy in the US was only 65 years (in line with South Africa and Lesotho, for instance), the equilibrium amount of education would decrease from 11.9 years to 8.05. With life expectancy as low as in Rwanda, schooling would drop to only 3.15 years in the US. This fall in education has a direct effect in output per worker, through the $e^{\phi(T_S)}$ component of the production functions of both sectors. However, it also has a considerable impact on physical capital. In the case of $T = 55$, optimal k would be only 43% of the benchmark case. The explanation is straightforward: the decrease in education reduces the return to physical capital, consequently decreasing investment and its long-run stock.

The total effect on output per worker is considerable: the model predicts that a country equal to the US in everything but with seven fewer years of longevity in the long run would be 17% poorer. In fact, we estimated that the output elasticity to life expectancy is quite high, around 1.7. The elasticity of schooling with respect to the same variable is even higher, 2.5. In other words, the model predicts that a country currently with $T = 60$ and $T_S = 5$, that for some reason increased its life expectancy to 66 years would end up with 6.25 years of education and 17% higher output per worker.

4.3 The Impact of Distortions to Education and Physical Capital Accumulation

In this section we study the sensitivity of the model to modifications in the two distortion parameters. Additionally, we are also interested in comparing their relative impact on long-run income. On the one hand, capital is an unbounded variable, but subject to decreasing returns; on the other hand, due to a finite life-span, human capital is bounded, but this counteracts the concavity of the production function. Finally, to some extent, the distortion to human-capital accumulation is tax-neutral (wage taxation also reduces the opportunity cost of being in school rather than in the labor market). Consequently, it is not clear which distortion is more harmful to long-run income or if their order of magnitude is even comparable. In order to asses this we have to make τ_H and τ_K comparable. We define

$$\tau_H^{\mathrm{E}} \equiv \frac{\tau_H}{1 + \tau_H},$$

where τ_H^{E} stands for 'equivalent.' It is the flow-equivalent taxation on labor.[15]

Table 3 below presents the results of an exercise in which τ_H^{E} varies and everything else is kept constant at the benchmark values:

Table 3: Long-Run Impact of
Human Capital Taxation

τ_H^{E}	T_S	K	y
-0.3	14,97	1,14	1,24
-0,15	13,67	1,09	1,14
0	11.89	1	1
0,15	9,28	0,86	0,81
0,30	5.65	0,65	0,56
0,50	1.80	0,39	0,31
0,65	0,64	0,28	0,22

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[15]If instead of considering taxation on tuition we had considered taxation on wages, τ_H^{E} would be the tax rate that would reproduce the same economic incentive to human capital accumulation. In other words, in equation (6) instead of $(1 + \tau_H)$ multiplying the ηq term, we would have $(1 - \tau_H^{\mathrm{E}})$ multiplying the 2 other terms (those proportional to wages). See Appendix A for a further elaboration on distortion to human capital accumulation.

As already said, distortions were normalized to zero in the US. In addition to the direct impact on education, τ_H^E also affects physical capital accumulation through the negative impact on its return. Hence, an economy with $\tau_H^E = 0.30$ will have less than half the education and 65 percent of the physical capital of the US, even with the same productivity, τ_K and longevity. Its income per worker will be 44 percent smaller. There are 12 countries with estimated τ_H^E around or larger than 0.30 (13 percent of the sample). With distortions such as that estimated for Niger and Mozambique ($\tau_H^E \approx 0.50$) there is practically no incentive to education investments: agents would accumulate less than two years of education and consequently income per capita would be less than a third of the US income. On the other hand, negative τ_H^E, "subsidy," induces agents to accumulate more education than the US, but the final effect on income is proportionally smaller: an economy with $\tau_H^E = -0.30$, everything else the same, would be only 24% richer.

The qualitative impact of τ_K on long-run output is similar to τ_H, as it impatcs income negativelly. There are, however, important differences. In our model, there is no physical capital in the production function of the educational sector. Hence, T_S does not change with τ_K, since the first order condition with respect to educational choice is not affected by it. For comparable values, the impact of distortions to investment in education on income per capita and per worker is of the same order of magnitude but marginally larger than that of distortions to physical capital accumulation, as is clear from Figure 1.

This quantitative result is not robust to modifications to the production function of the educational sector. We repeated the steps of Sections 2 and 3 for a version of the model with physical capital in both sectors, but without technology progress (otherwise the price of education would approach zero assymptotically). The capital share in the educational sector was set to 0.065, which is the average figure in the NIPA for the last ten years. All other parameters were those of Section 3 with minor adaptations.[16] The overall simulated effect of τ_K over the long-run income is now marginally larger than that of τ_H, as shown by Figure 2 below.

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[16] Actually, calculations are more complicated in this case. This is the main reason we opted to work mostly with the simpler model without capital in the educational sector.
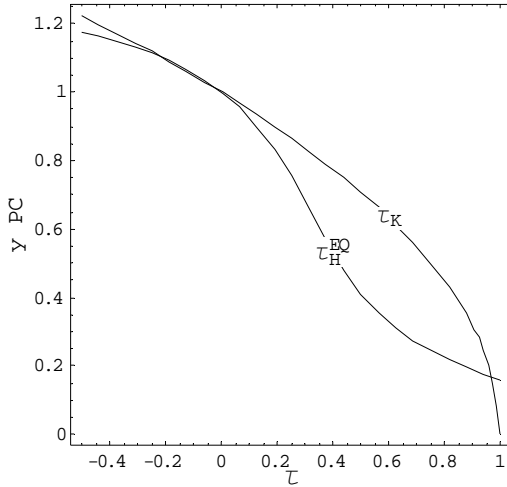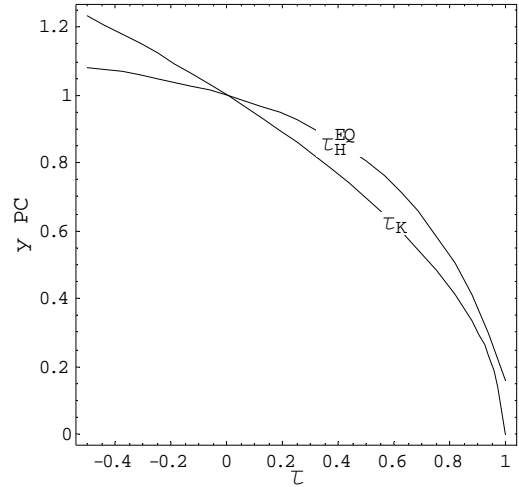
Figure 1: Schools without capital   Figure 2: Schools with capital

Distortions to the accumulation of physical capital now have a direct effect on both sectors and an indirect effect on the returns to educational investment and, for this particular parametrization, its impact on income is larger than that of τ_H. However, magnitudes are similar and the impact of distortions to human capital investment on long-run income is still sizable. The relevant result is that in an economy in which there are other costs to education than foregone wages, distortions to investment in human capital have a large impact on long-run output and relative incomes, comparable to that of distortions to physical capital accumulation. Moreover, as shown in the case of Portugal in Table 1, the measured $\tau_H\prime s$ are such that they may explain a large fraction of the distance of poor economies to the leading countries.[17]

Results concerning productivity differences are as expected. An economy equal in every aspect to the US but with only 50% of its productivity would have only 30% of the income per capita of the latter. If the country TFP was just 20% of that of the US, the smallest estimation in our sample, this economy's income per capita would be 9% of the American income. Hence, in this model productivity can explain a large part of the income disparity across countries. In fact, the elasticity of output per capita with respect to A_1 is 1.5. This result is exactly what the standard neoclassical model of capital accumulation - infinite horizon and exogenous technological change - delivers[18] and the same as those in Jones

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[17]An estimated τ_H of 0.43 corresponds to $\tau_H^E = 0.30$. From Table 2 we can conclude that educational distortions alone in Portugal explain almost half the gap with the US income.

[18]Our model delivers the same result of the infinity horizon model because we are assuming an open

(1997) and Hall and Jones (1999).

4.4   Counter-factual exercises

In a group of simulations we substituted in all economies, one at a time, τ_K, τ_H^{E}, A_1 and T (life expectancy) with the 9th-best estimated value of each parameter, which divides the first from the second best decile. We did this to avoid outliers that would occur if we had used the best estimated parameter.[19] In each exercise we held labor force participation (and the ratio T_R/T) constant. Table 4 below presents the results.

Table 4: Counter-factual exercises on relative

income per worker

	original	substitute by the 9th best value:			
		τ_k	τ_h	A_1	T
Mean	0,328	0,388	0,420	0,504	0,351
Variance	0,085	0,089	0,145	0,081	0,087
Coef. of Variation	0,259	0,228	0,345	0,160	0,247

We observed the largest gains in per worker income when substituting the 9th-best productivity in all economies. In this case, mean output per worker goes from 33 percent to 50.4 percent of the US per worker income. Although smaller, the average change obtained from the simulations with τ_H is significant: mean output per worker increases by 28 percent if instead of their own incentives for human capital accumulation, all countries had the 9th-best τ_H. The same exercise with τ_K delivered an average gain of 18 percent in long-run output per worker. The highest fall in dispersion (as measured by the variance-mean ratio) is obtained when A_1 is normalized.

Although it is true that policies aimed at increasing productivity apparently have the potential to deliver the highest average payoffs, better incentives to the acquisition of education also have a high return. This is even more apparent when we look at individual countries.

economy (cross-country equalization of the interest rate net of risk and distortion), and also because the share of the educational service in total output is very low.

[19]We did not use American parameter values because its estimated τ_H is close to the mean, while productivity and life expectancy are among the highest observed in their classes. When examining individual countries, however, we use the US as a benchmark to keep exercises comparable.

It has been shown previously that schooling in France is considerably less than in the US, but that life expectancy is equal and output per worker not too different (73% of the US level, according to the Summers and Heston database). Hence, the estimated τ_H was relatively high (0.07), while its performance in terms of A_1, and τ_K was good. If France were given the same incentives to human capital accumulation as that of the US, the model predicts that its output per worker would jump to 90% of the American GDP per worker, given the new schooling and capital levels implied by the new τ_H. Notice that in a model with exogenous human capital accumulation, this fact would not be noted, as education level in France is relatively high by world standards.

The impact on Portugal is even more dramatic: its GDP per capita would jump from 44 percent of the US GDP to 69 percent if it were given American incentives to invest in education. In this case, schooling would jump from 5.47 years to 8.68 years. Of course, most poor countries would also benefit from better educational incentives, and in some cases like Mozambique and Bangladesh GDP per capita would be twice as large as observed.

Given the life-cycle structure of our model, drastic modifications in longevity have a potentially large impact on long-run income. Average adjusted life expectancy in Sub-Sahara Africa is 64.7 years in our sample. The model predicts that GDP per worker would be 42 percent higher, on average, if African countries had American longevity (77 years). In the case of Zimbabwe, relative output per worker would increase from 10.8 percent to 18.7 percent of the US output, while schooling would go from 5.4 to 10.9 years, which is expected given the low estimated τ_H of this country. Similar results are observed in countries such as Botswana, Rwanda, Kenya and many others. In this group, the output gains are higher or close to those that would be obtained if their estimated TFP was substituted with American TFP. Although on average the largest gains are observed when TFP is substituted in (African countries in general are not too productive), changes in longevity and also in the incentives to educational investment are too relevant to ignore.

5   Conclusion

In this paper we have studied a finite life economy where distortions to factor accumulation and productivity differences explain cross-country income disparities. Human capital was modeled following the tradition of the labor field (e.g., Mincer (1974)) recently incorporated

into the growth literature as well, e.g., Bils and Klenow (2000). In this formulation, the skill level of workers is an increasing function of schooling and the accumulation of skills is mostly done at school, outside the labor market.

This framework contrasts with the usual Uzawa-Lucas formulation where there is no bound on the accumulation of human capital, which is continuously acquired during the worker's infinite life. Moreover, in general in the usual Uzawa-Lucas models there are no other costs of investing in human capital, such as tuition, than the forgone wages.

Investigation of the general equilibrium effects of distortions to human capital accumulation showed that they have a multiplicative impact through their effect on savings and physical capital. As investment in education falls because of taxation (or due to any other distortion), and with it the long-run stock of human capital, the return to physical capital also decreases, inducing individuals to reduce their investment. Our simulations showed that for reasonable parameters values, human capital taxation may be more detrimental to long-run income than taxation of physical capital. The literature on the latter, however, is much more extensive than that on the former, although there are important exceptions, most of them using endogenous growth models. One possible reason is that taxation on human capital in many models is neutral, as it decreases the return to human capital but also the cost of being out of the labor market. However, our results show that if there are any other costs imposed on the acquisition of education which are not proportional to wages (e.g., tuition), the long-run impact of taxation on human capital is relevant.

In our model longevity plays an important role in the determination of long-run incomes. This role could only arise because of the hypothesis of finite life and the Mincerian formulation of human capital, which seem to us the most realistic assumptions. A caveat here is that, especially in rich capitalist economies, increases in life expectancy may be followed by more than proportional increases in retired life, in which case this result does not apply. However, as poor economies move from 50 or less years of life expectancy to figures close to those of rich economies, productive life span most probably will expand and so will the return to educational investment and long-run income.

A Appendix: A Note on the Return to Education

In this paper, education modeling derives from the human capital literature of Schultz, Becker and Mincer. A very important concept in this tradition is the Social Marginal Internal Rate of Return (SMIRR) of T_S years of education, which is defined as the discount rate R such that the present value (PV) of wages minus the PV of tuition is equal to the PV of wages minus the PV of tuition when the individual stays $T_S + \Delta t$ years in school (Willis, 1986. p. 531). Formally,

$$
\omega e^{-(r-g)T_S} e^{\phi(T_S)} \frac{1 - e^{-(R-g)T_W}}{R - g} - \eta q \frac{1 - e^{-(R-g)T_S}}{R - g}
$$
$$
= \omega e^{-(r-g)(T_S+\Delta t)} e^{\phi(T_S+\Delta t)} \frac{1 - e^{-(R-g)(T_W-\Delta t)}}{R - g} - \eta q \frac{1 - e^{-(R-g)(T_S+\Delta t)}}{R - g}.
$$

After taking a Taylor expansion up to the first-order term and taking the limit for $\Delta t \to 0$ in this last expression we get (6) for $R = r$ if τ_H is zero. In other words, if there is no distortion to the acquisition of education, at the market equilibrium the SMIRR is equal to the market interest rate.[20]

With the help of the concept of SMIRR, we can calculate the difference between the private rate of return and the social rate of return. The SMIRR of T_S years of schooling for a given economy is the value of R that solves

$$
\omega e^{\phi(T_S)} \phi'(T_S) \frac{1 - e^{-(R-g)T_W}}{R - g} = \omega e^{\phi(T_S)} + \eta q.
$$

The private rate is the market interest rate. Consequently, the distortion to the human capital accumulation decision is

$$
\tau_H^I = \frac{R - r}{R},
$$

or, rearranging terms, it is the implicit tax rate that solves

$$
r = (1 - \tau_H^I)R,
$$

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[20] According to Mincer: "Investments in people are time consuming. Each additional period of schooling or job training postpones the time of the individual's receipt of earnings and reduces the span of working life, if he retires at a fixed age. The deferral of earnings and the possible reduction of earning life are costly. These time costs plus direct money outlays make up the total cost of investment. Because of these costs investment is not undertaken unless it raises the level of the deferred income stream. Hence, at the time it is undertaken, the present value of real earnings streams with and without investment are equal only at a positive discount rate. This rate is the internal rate of return on the investment." (1974, pg.7).

where τ_H^I stands for 'internal.' Figure 3 presents the relationship between τ_H^E and τ_H^I and Figure 4 presents the behavior of the two endogenous variables, SMIRR and education.
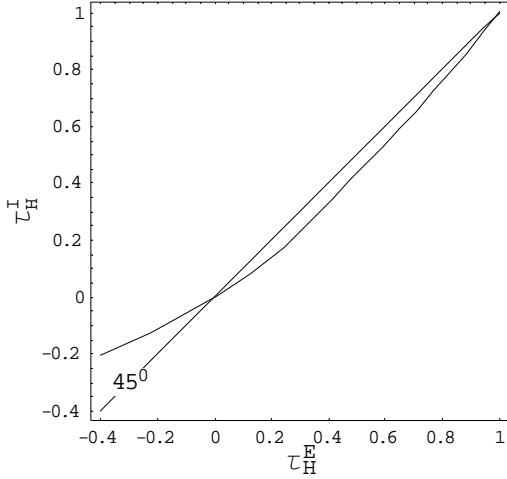

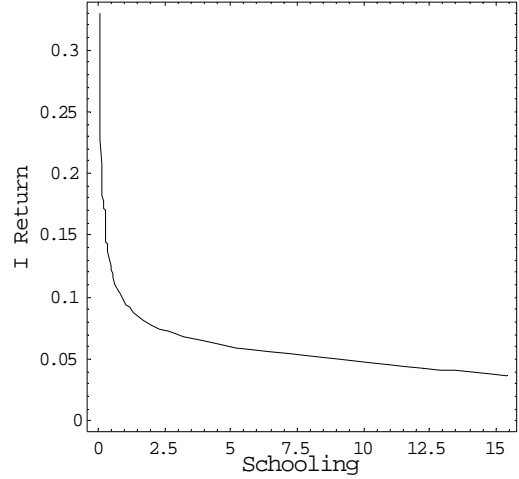Figure 3: τ_H^E and τ_H^I

Figure 4: SMIRR and Schooling

Both exercises used the benchmark configuration (i.e., the US parameters) and took τ_H^E as the exogenous variable. From Figure 3 we can see that the distortion concept used in this paper is quantitatively very close to the distortion constructed using the SMIRR notion employed by the labor literature. Although Figure 4 represents a general equilibrium outcome, due to the fact that physical capital does not affect the optimum educational decision, it can be considered a partial equilibrium relationship. From this point of view, Figure 4 is a clear representation of the capital view of education: we obtained a decreasing and strongly convex behavior of the marginal productivity of education as a function of years of education. We can say that T_S fulfills the role of a capital stock.

B   Appendix: A Note on Existence and Uniqueness

In this paper we solved three different systems of equations: (1) the calibration of the model for the benchmark economy; (2) the measurement of distortions across countries; and (3) the solution of the open-economy version of the model. In this appendix we discuss uniqueness for the calibration and distortion measurement procedures. Existence and uniqueness of the open economy version solution of the model follows directly from the equations if (18) is well behaved. We start by studying this equation.

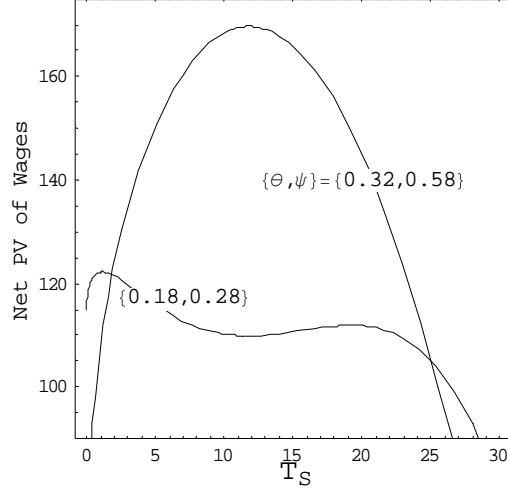## B.1   A Note on the educational choice

Figure 5: Net present value of wages as a function of T_S for two sets of values of $\{\theta, \psi\}$

In other to calibrate the $\phi(T_S)$ function we employed the specification for $\{\theta, \psi\}$ in Bils and Klenow (1999). Actually, in their work there are three possible sets of parameters, and although they produce the same average return of education on wages, they differ in concavity. We employed the most concave specification. One of the reasons is that it seems to be consistent with cross-section studies of return to education. The second reason is uniqueness. The first order condition with respect to the education choice, equation (18), is:

$$\left[\frac{A_2}{\eta}e^{\phi(T_S)}\right]^{\frac{1}{2}} \left[\phi'(T_S)\frac{1-e^{-(r-g)T_W}}{r-g} - 1\right]^{\frac{3}{4}} = 1 + \tau_H.$$

Although $\phi(T_S)$ is concave, $e^{\phi(T_S)}$ is convex. If there is no tuition cost (as is the case in Bils and Klenow (1999)), the term $e^{\phi(T_S)}$ cancels out and we get local second order condition for the solution of the first order condition.[21] This is not the case in our formulation. In particular, if we considered a less concave specification for $\phi(T_S)$, the observed T_S for the US would be a minimum of the calibrated net present value function, as Figure 5 illustrates. Evidently, in the distortion measurement and simulation exercises we checked whether the solution for (18) is the global maximum of the net-present-value of wages function (which has a compact domain)

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[21] We thank Marcos Lisboa for this observation.

B.2 Uniqueness of the calibration procedure

The solution is as follows: (12) gives $\frac{A_2}{\eta}$; (15) and (20) give ηq; (21) gives k; and (14) (after recalling (1)) gives A_1; (18) gives τ_H; (14) and (21) give τ_K; and (17) gives ρ. It is not possible to solve (17) explicitly for ρ. In order to get uniqueness we have to show that (17) is monotonic in ρ. That is, we have to show that

$$\nu_c = f(s) \equiv \frac{1 - e^{-sT}}{s} \frac{s + r - g}{1 - e^{-(s+r-g)T}},$$

where $s \equiv g - \sigma(r - \rho)$. Calculating, we obtain

$$s\frac{f'(s)}{f(s)} = sT\left[g\left(sT\right) - g\left((s + r - g)T\right)\right],$$

in which

$$g(a) \equiv \frac{e^{-a}(1 + a) - 1}{a(1 - e^{-a})} \text{ and } g'(a) > 0.$$

Given that $r - g > 0$, we have that

$$f'(s) < 0,$$

which guarantees uniqueness.

B.3 Incentive Measurement

The solution is as follows. It is possible to express $\{\tau_K, \tau_H, l_2, k, \eta q\}$ as a function of A_1: (21) gives k, (12) gives l_2, (18) gives τ_H, (14) gives τ_K, and (15) and (20) give ηq. Then we substitute for τ_K into (17), and recalling (1), we solve explicitly for A_1.

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