

# Human Capital Inequality, Life Expectancy and Economic Growth\*

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## Abstract

This paper provides a theoretical model in which inequality affects per capita income when individuals decide to invest in education depending on their life expectancy. The model assumes that life expectancy depends to a large extent on the environment in which individuals grow up, in particular, on the human capital of their parents. After calibrating the life expectancy function according to the international evidence for cross-section data, our results show the existence of multiple steady states depending on the initial distribution of education. In accordance with the evidence displayed by many developing countries, the low steady state is a poverty trap in which children are raised in poor families, have a low life expectancy and work as non-educated workers all their lives. The empirical evidence suggests that the life expectancy mechanism explains to a great extent the relationship between inequality and human capital investment rates.

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## 1. Introduction

Since the last decade an increasing body of literature has appeared that analyzes the influence that inequality in the distribution of income or wealth may exert on economic

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growth and income differentials across countries. The complexity of the relationship between inequality and growth has led theoretical models to look at this problem in different ways. Although these studies approach the relationship between inequality and growth from different perspectives, the greater part of the literature points out a discouraging effect of inequality on growth, that is, the implications of the models suggest that more inequality is associated with lower growth rates. Broadly, the literature has focused on two mechanisms through which inequality may influence growth.<sup>1</sup> The first mechanism can be called the fiscal policy approach and has been analyzed by Bertola (1993), Alesina and Rodrik (1994) or Persson and Tabellini (1994), among others. The main idea behind these models is that, in the political process, economies with greater inequality in the distribution of wealth will vote for greater redistributive policies than those with a more even distribution. If such redistributive policies are financed with distortionary taxes affecting investment rates, the more unequal societies will experience lower growth rates. The second kind of mechanism have the common assumption of incomplete credit markets, an approach started with the pioneer model of Galor and Zeira (1993).<sup>2</sup> In this model, the assumption of non-convexities in the accumulation of human capital jointly with imperfect credit markets means that individuals who inherit an amount lower than a threshold level do not invest in human capital and work as unskilled workers. Therefore, in this model initial distribution of wealth is crucial in determining long-term human capital and income levels, since the higher the number of individuals below the threshold level, the lower the average accumulation rate of the economy.

In addition to the traditional channels, there is a strong correlation between demographic variables and inequality measures. However, little attention has been devoted to channels that connect inequality and growth through fertility decisions or education decisions depending on individuals' life expectancy. An exception is the recent paper of De la Croix and Doepke (2003). In this paper the authors develop a model that analyses a new link between inequality and growth based on differences in fertility rates. In their model households with lower human capital chose to have a higher number of children and less education for them, which increases the weight of lower skilled individuals for the future and therefore lowers human capital and growth rates in the economy.

Besides the fertility decisions another important demographic variable that is related to inequality and growth is life expectancy. In fact, the absolute correlation between

<sup>1</sup> Benabou (1996) or Aghion, Caroli and García-Peñalosa (1999) survey this literature.

<sup>2</sup> Models that relate distribution and growth under the presence of imperfect credit markets include Banerjee and Newman (1993), Aghion and Bolton (1997) or Piketty (1997).

a human capital inequality index and life expectancy is even greater than the correlation between the human capital inequality index and fertility rates.<sup>3</sup> Nevertheless, no theoretical model has studied the connection between inequality and life expectancy, and how they influence growth and investment in human capital. Therefore, the main contribution of this paper is the analysis of an alternative channel through which inequality in the distribution of human capital may influence the process of human capital accumulation. This new mechanism is based on the relationship between human capital distribution, life expectancy and the time devoted to acquiring human capital.

The important role played by life expectancy in determining the optimal education decisions of individuals has already been pointed out by models that analyze the relationship between demographic variables and development. For example, Ehrlich and Lui (1991) focus on a theoretical model that links longevity, fertility and economic growth to explain the “demographic transition”. In their overlapping generation model, assuming that parents invest in children as insurance for old-age, a sufficient exogenous increase in longevity promotes economic growth as well as reduces fertility rates. In a more recent study, Blackburn and Cipriani (2002) endogenize life expectancy. As a result, their model generates multiple development regimes depending on initial conditions. Endogenizing life expectancy allows Blackburn and Cipriani (2002) to explain jointly the main changes that take place during the demographic transition of economies, such as greater life expectancy, higher levels of education, lower fertility and later timing of births. Cervellati and Sunde (2005) analyse a model in which human capital formation, technological progress and life expectancy are endogenously determined and reinforce each other. In a microfounded theory the authors show that the inclusion of endogenous life expectancy helps to explain the long-term development of economies and, in particular, the industrial revolution experienced by many countries as an endogenous result in the process of development. Chakraborty (2004) also endogenizes life expectancy and assumes that the survival probability depends on the public investment in health. In this model low life expectancy is detrimental for growth because on the one hand, low expectations of surviving make individuals less patient and willing to save and invest and, on the other hand, lower life expectancy also reduces the returns of investing in education.<sup>4</sup>

<sup>3</sup> For a pool of 100 countries for the period 1960-1985, the coefficient of correlation between the human capital Gini coefficient and fertility rates is 0.797 and the correlation between the human capital Gini coefficient and life expectancy is -0.866. For a cross-section of 92 countries the coefficient of correlation between the human capital Gini coefficient in 1960 and the average fertility rate for 1960-1985 is 0.829 and the correlation for the human capital Gini coefficient in 1960 and the average life expectancy for 1960-1985 is -0.868. This strong correlation holds when we control for the initial levels of the per capita income and the average years of education.

<sup>4</sup> De la Croix and Licandro (1999) and Kalmeli-Ozcan *et al.* (2000), among others, have developed

Nevertheless, in spite of the increasing interest the recent years in the relationship between demographic variables and the development of societies, no model has emphasized the important role that life expectancy can also play in explaining the relationship that connects inequality and growth. Differentials in the demographic variables among individuals that belong to different income groups matter because they influence the accumulation of human capital. For instance, De la Croix and Doepke (2003) develop a model in which increases in inequality reduce growth due to the fact that rich and poor individuals have different patterns of fertility. In particular, poor parents tend to have more children and provide less education than rich parents. Moav (2004) also points out the different patterns of fertility among rich and poor individuals. In this paper the dynamic system generates multiple steady states. Poor dynasties with income below a threshold level converge to a low steady state characterized by low levels of education and income and high fertility rates. As a result, the greater the number of individuals above the threshold level the greater the average income and education in the economy. However, although the evidence also shows that poor and rich individuals display differences in their life expectancy, no model has analysed the influence that differences in life expectancy can have on the accumulation of human capital among individuals and how this affects inequality.

This paper studies explicitly an additional channel that connects inequality and growth through differences in life expectancy among individuals that have a different socioeconomic status. We include endogenous life expectancy in a model populated by heterogeneous agents in which individuals live for two periods and differ in their second period survival probability. In particular, we consider that life expectancy is conditioned by the human capital of the families which individuals are born into, an assumption supported by the empirical evidence (see, among others, Case *et al.* (2002) or Currie and Stabile (2003)). Given their expected survival probability, individuals choose the optimal time devoted to becoming educated in order to maximize their intertemporal utility.

The survival probability function is calibrated according to the cross-section data and, as a result, the model shows multiple steady states.<sup>5</sup> In particular, the time in-

continuous time overlapping generations models in which optimal schooling investment decisions depend positively on life expectancy. In addition, the important role that life expectancy can play in models with endogenous fertility rates and human capital investment decisions is also revealed in the papers of Kalemli-Ozcan (2002), Soares (2001) or Tamura (2002).

<sup>5</sup> Other models with heterogeneous agents that generate multiple steady states, without assuming non-convexities in the production process, are the recent papers of Moav (2004) or Eicher and García-Peñalosa (2001). In Moav (2004), parents face a trade-off between child quality and child quantity. The endogenous fertility choice in this model results in multiple steady states. In Eicher and García-Peñalosa (2001), the key assumption for the existence of multiple steady states is the interdependence of supply and demand for skilled workers under skilled-biased technological

dividuals devote to human capital accumulation converges towards two steady states: poor individuals converge to a low steady state and rich individuals converge to a high steady state. Consequently, the initial distribution of wealth determines the long-term average human capital and the average income in the economy. The fewer the number of individuals with education lower than a threshold level, the greater the average human capital and average income in the economy.

The interesting result of this paper is that the policy implications we obtain are similar to those of Galor and Zeira (1993). However, the underlying assumptions of the models are quite different. In their model the assumptions of imperfect credit markets and indivisibilities in human capital investment are crucial for the results. In our model the results are mainly due to the assumption of differences in the survival probabilities between individuals. Hence, in Galor and Zeira's (1993) model, restricted poor individuals would invest more human capital if capital markets were perfect. In our model, where there is no problem in financing education, poor individuals invest optimally a low amount of human capital since their low life expectancy increases their opportunity cost of becoming educated.

We also analyse the implications of the model empirically using cross-country data and we find that the model is supported by the empirical evidence. In order to estimate the implications of the model, first we analyse the relationship between inequality and life expectancy and then, we study the influence that life expectancy can exert on the decision to invest in education. The results suggest that the strong negative relationship between human capital inequality and human capital accumulation is to a great extent driven through the life expectancy channel.

The structure of the paper is as follows. Section 2 reviews some of the empirical literature that studies the relationship between socioeconomic variables and life expectancy and displays the basic structure of the model. Section 3 calibrates the model and analyses the relationship between inequality and growth. Section 4 studies empirically the implications of the model. Finally, Section 5 presents the conclusions reached.

## 2. The model

In this section we present a very simple model to analyze the relationship between inequality, life expectancy and growth. For this purpose we consider an overlapping generation model in which individuals can live at most for two periods. The probability of living during the whole first period is one, whereas the probability of living until the end of the second period is  $\pi_{t+1}$ . At the end of the first period each individual

change. Azariadis (2001) offers an excellent survey of the literature about poverty traps.

gives birth to another such that all individuals have a descendent and the population growth rate is zero. In every period the economy produces a single good that is used for consumption.

### 2.1 Life expectancy

The economy is populated by individuals that differ in their family wealth but that are identical in their preferences and innate abilities. We assume that an individual's life expectancy will depend on the economic status of the family which the individual is born into.

The empirical evidence shows a negative association between socioeconomic status and mortality. Marmot *et al.* (1991) found in the Whitehall II study a positive association between the grade of employment of British civil servants and their health status, a result already obtained in the first Whitehall study initiated in 1967. More recently, using data for the United States, Deaton and Paxson (1999) have found that higher income is associated with lower mortality, whereas Lleras-Muney (2002) findings reveal that education has a large negative causal effect on mortality.

Some papers have also suggested that this relationship is not linear. Smith (1999) analyses the relation between individuals' health and their income or wealth using the Health and Retirement Survey (HRS) for 12,000 American individuals. He estimates an order probit model with self reported health status as the dependent variable.<sup>6</sup> The results show that the relationship between self reported health and income or wealth is non-linear, and that the positive and statistically significant effect of income and wealth on self reported health status decreases as socioeconomic status increases.

However, Case *et al.* (2002) suggest that the gradient, that is, the positive association between health and socioeconomic status, has its origins in childhood. Using data for the United States they provide evidence of a positive relationship between household income and children's health. In addition, they find that the positive relationship increases with the age of the children. Currie and Stabile (2003) use data on Canadian children and confirm these results. Moreover, the authors show that the health of the children born in low socioeconomic status families deteriorates with age because these children suffer from more health shocks. Likewise, Currie and Hyson (1999) find that being born into a low socioeconomic status family increases the probability of reporting poor health at the ages of 23 and 33. Other studies also show that parents' education has a positive impact on child height, which may be used as an indicator of long-run health status, even after controlling for parents' income (see, for example, Thomas *et al.* 1990

<sup>6</sup> Smith, Taylor and Sloan (2001), using the HRS, find that subjective perceptions of mortality are good predictors of observed mortality.

and 1991).

On this matter, there are medical studies that point out the important role that the environment plays during pregnancy and on newborn children in determining the future diseases and illnesses which an individual may suffer from.<sup>7</sup> For example, Ravelli *et al.* (1998) investigate glucose tolerance in people born around the time of famine in the Netherlands during 1944-1945. They found that prenatal exposure to famine, mainly during late gestation, was associated to decreased glucose tolerance in adults increasing the risk of diabetes. Barker (1997) focuses on the “fetal origins” hypothesis which states that human fetuses change their physiology and metabolisms in order to adapt to a limited supply of nutrients. These programmed changes may be the origins of a number of diseases in later life such as hypertension, coronary heart disease, strokes and diabetes.

The foregoing results suggest that it is realistic to assume that individuals born into rich families will have greater life expectancy than those born into poor families, who are more likely to be affected by undernourishment during the early stages of life and an unhealthier environment during childhood, for instance, lower standards of hygiene at home, an less healthier diet or less use of preventive and curative medical services. Moreover, we consider that the positive effect that family income may exert on an individual's life expectancy decreases as income increases and vanishes at high income levels. In particular, as human capital is one of the main determinants of income and wealth, we assume that parents' human capital will determine the survival probability of their children. Thus, we consider a positive but decreasing effect of parents' human capital on the life expectancy of their descendants. The probability of an individual  $i$  born in period  $t$  surviving to different periods ( $t + s$ ) is as follows:

$$\pi_{it+s}^t = \begin{cases} 1 & \text{for } s = 0 \\ \pi_{it+1}^t (h_{it}^{t-1}) & \text{for } s = 1 \\ 0 & \text{for } s \geq 2 \end{cases} \quad (1)$$

where  $h_{it}^{t-1}$  is the human capital of the parent. In the next section we use a specific equation for the survival probability according to the empirical evidence of the relationship between life expectancy and schooling years. Given that the evidence is only available for schooling years, throughout the paper we make the survival probability depend on parents' schooling years instead of a broad concept of human capital.

## 2.2 Technology

Since there are several mechanisms that connect inequality and growth, the aim of this

<sup>7</sup> Marmot and Wadsworth (1997) review some studies that link health in childhood with health in adulthood.

study is to make the model as simple as possible in order to isolate the role that life expectancy can play in explaining a connection between inequality and growth. To do so, on the technology side, we focus entirely on the effect that life expectancy has on the accumulation of human capital and we assume no physical capital accumulation in the model. This assumption is not too strong considering that this model will mainly be applied to poor countries where life expectancy is particularly low, their technologies are intensive in labor and, therefore, the per capita stock of physical capital is very low.

In the first period of life individuals are endowed with one unit of time. They allocate  $L_{it}^t$  units towards producing final goods with the following technology:

$$Y_{it}^t = A_t L_{it}^t \quad (2)$$

where  $A_t$  is a function of other production inputs and  $0 \leq L_{it}^t \leq 1$ . For simplicity, we consider that  $A_t$  grows at the constant rate  $g$ ,

$$A_t = A e^{gt} \quad (3)$$

which allows us to rewrite the production function in efficiency levels:

$$y_{it}^t = A L_{it}^t \quad (4)$$

Individuals allocate the remaining units of their time ( $1 - L_{it}^t$ ) towards acquiring formal education for the second period according to the function:

$$h_{it+1}^t = \theta(1 - L_{it}^t) \quad (5)$$

where  $\theta$  is the number of years of the first period and  $h_{it+1}^t$  the schooling years that individual  $i$  accumulates when young.

Other studies specify a broader technology of the production of human capital that includes the stock of human capital of parents as well as the average human capital in the economy (e.g Glomm and Ravikumar (1992) or De la Croix and Doepke (2003)). In these models, in order to achieve endogenous growth it is necessary to assume constant returns to scale in the accumulable factors, human capital of parents and average human capital. This implies that the production function of the human capital of individuals is a concave function of the human capital of the parents. Therefore, on aggregate average human capital will be lower the more unequal the distribution of human capital is. In such a case, the model would display a negative association between human capital distribution and economic growth even in the case where all individuals had the same life expectancy. Hence, we have opted for a much simpler specification of the human capital technology in order to isolate the effect of inequality on growth through differences in

the life expectancy of individuals.

In the second period of life, individuals allocate all their time endowment to the production sector such that,

$$y_{it+1}^t = AL_{it+1}^t e^{\alpha h_{it+1}^t} \quad (6)$$

where  $L_{it+1}^t = 1$ . Thus, the higher the human capital stock accumulated during the first period the higher the income produced in the second period. The specification of the production function in the second period relies on the work of Mincer (1974), since it relates the log of income to schooling years

$$\ln y_{it+1}^t = \ln A + \alpha h_{it+1}^t \quad (7)$$

Therefore, the coefficient  $\alpha$  can be interpreted as the return of education.

Equation (5) assumes that the stock of human capital in period  $t + 1$  is entirely the result of the years of education acquired in the first period of life. Even though years of education is an incomplete indicator of the stock of human capital, one of the main advantages of constructing a consistent model around years of education is that it can provide some quantitative results, given the existing data sets as, for example Barro and Lee (2001). In particular, the specification of the production function in the second period of life, displayed in equation (6), is a good approximation of individuals' income since the value of  $\alpha$ , the parameter that connects education with income, has been deeply estimated in the literature (see Krueger and Lindahl, 2001).

### 2.3 Preferences

The preferences of an individual born in  $t$  are represented by a log-linear utility function of the form:

$$u_i^t = \ln c_{it}^t + \gamma \pi_{it+1}^t (h_{it}^{t-1}) \ln c_{it+1}^t \quad (8)$$

The expected lifetime utility is defined over consumption when young ( $c_{it}^t$ ) and consumption when old ( $c_{it+1}^t$ ), where the second period utility is discounted for the endogenous survival probability  $\pi_{it+1}^t (h_{it}^{t-1})$  and for the rate of time preference  $\rho$ , where  $\gamma = 1/(1 + \rho)$ .

During the first period, agents can finance their consumption with two types of income. The first one is given by the production of goods ( $y_{it}^t$ ) which, as equation (2) states, is a function of the time devoted to production. In addition, during the time individuals invest in education, we assume they have access to a minimum income per schooling year financed by the government. Thus, the level of consumption in  $t$  is given

by

$$c_{it}^t = AL_{it}^t + \frac{\tau A}{(1 + r_t)}(1 - L_{it}^t) \quad (9)$$

where  $\tau$  is a transfer fixed for all individuals, such that  $0 \leq \tau \leq 1$ , which determines the revenue that covers consumption while this agent is attending school, net of all education costs.<sup>8</sup> For simplicity, we assume that  $\tau$  is exogenous and that this revenue increases with  $A$ , that is, consumption during education years is higher in economies with higher  $A$ . In addition, we will assume that the government balances its budget in every period. Hence, the transfers received by individuals will be endogenously determined in the model and will depend on the revenues collected by the government. At every period the government collects taxes from the older generation and provides transfers for the younger generation. The term  $r_t$  will guarantee that the government budget is balanced.

Many models separate the period when individuals acquire formal education from the period in which individuals work. Nonetheless, in our model we want to point out that in many developing countries many individuals start working in their childhood. Therefore, in addition to the income coming from labor in the production of goods, we need some additional funds to finance education and consumption in the first period, otherwise it would be quite costly to acquire formal education since future consumption is penalized by a common discount factor lower than one ( $\gamma < 1$ ) and, in order to maximize utility, individuals would choose a value of  $L_{it}^t$  close to its maximum value, that is,  $L_{it}^t = 1$ . In most economies, the revenue finances consumption, whereas attending school, which is thus proportional to  $(1 - L_{it}^t)$ , is jointly financed by parents and public policies such as grants. Theoretical models usually incorporate bequests as a basic resource for financing education years. However, as long as bequests are a function of parents' incomes, this constitutes an important channel through which the human capital of parents affects the human capital of their descendants. In fact, bequests play a crucial role in models that study the link between inequality and growth through imperfect credit markets since under credit constraints family wealth is the only source to finance an investment project. Hence, due to the fact that we are interested in analyzing these effects exclusively through the endogenous life expectancy, it is convenient to assume that it is the government who finances education fees and other expenses during the time individuals invest in education.

In particular, we assume that the government makes a transfer to the individual in the first period of life and the individual pays a tax in the second period. Most of the governments in developed countries provide grants that cover tuition fees, feeding

<sup>8</sup> The parameter  $\tau$  refers to the transfers received during the whole first period.

and some money for personal expenses, others finance individuals' education through loans. In developing countries the relative amount of the grant is not as big as the one in developed countries (as is represented in equation (9) by the term  $A$ ) but it still covers education costs and some consumption expenses. For example, the program Progresa run in some areas of Mexico does not only cover free education but also, conditioned to school attendance and some health care, includes cash transfers received by the mother to feed her children.

In order to get a government balanced budget in the model, we assume that in the second period of life individuals pay a tax proportional to the amount they received in the first period. Thus, in the second period, total income is used to finance private consumption and to pay a tax to the government. The budget constraint of the individual in the second period is:

$$c_{it+1}^t = y_{it+1}^t - \frac{\tau A}{\pi_{it+1}^t (h_{it}^{t-1})} (1 - L_{it}^t) \quad (10)$$

Equation (10) takes into account the fact that individuals may not live the whole second period. As  $\tau A(1 - L_{it}^t)$  appears in equation (10) divided by the endogenous survival probability, agents pay back all this income independently of the number of years they live in the second period. Note that when  $r_t > 0$  the taxes individuals pay in the second period are greater than the transfers they received in the first period to finance education.

The term  $(1 + r_t)$  in expression (9) guarantees that the government budget is balanced each period. In particular, at any period  $t$  the government collects money from the old generations to supply funds for the young generations such that in every period the government budget constraint is balanced:

$$\int \frac{\tau A}{(1 + r_t)} (1 - L_{it}^t) di = \int \tau A (1 - L_{it-1}^{t-1}) di \quad (11)$$

which after some simplifications is equal to

$$\frac{1}{(1 + r_t)} \int h_{it+1}^t dF_t(h_{it+1}^t) = \int h_{it}^{t-1} dF_{t-1}(h_{it}^{t-1}) \quad (12)$$

where  $F_t(\cdot)$  is the distribution function of the human capital of individuals born in period  $t$ . Thus,  $r_t$  is determined endogenously in the model in every period such that total transfers equal total revenues. Simplifying the above expression we find that  $r_t$  equals the average growth rate of human capital in the economy

$$(1 + r_t) = \frac{H_{t+1}^t}{H_t^{t-1}} \quad (13)$$

Note that in the steady state since in every household parents and children invest the same amount of resources in acquiring formal education,  $h_{it+1}^t = h_{it}^{t-1}$ , the total amount transferred to children coincides with the total amount taxed to parents, thus, in the steady state  $r_t = 0$ .

In addition to imperfect capital markets there may be other mechanisms through which inequality and growth can be connected, note that we can think of the government as institutions whose function is to reallocate the savings in the society. In particular, we might assume that the financial market is perfectly competitive and that zero profit companies reallocate all savings in the economy. In any period  $t$  the aim of these institutions is to collect money from the older generations and to supply funds for the younger generations such that every individual can get a loan in their first period of life and return the borrowed amount in the second period. The interest rate is then determined endogenously in the model in every period such that the total amount borrowed in the economy equals the total amount lent. The results of the model would be the same. This remark highlights that the results of the model will not be due to imperfections in the credit market since any individual in this economy, independently of her income, can obtain a transfer to finance education.

#### 2.4 Optimal education years

The optimal behavior of agents is to choose the amount of human capital that maximizes their intertemporal utility function. Thus, individual  $i$  chooses the time devoted to schooling  $(1 - L_{it}^t)$  that maximizes (8) subject to the production functions (4) and (6), the accumulation of human capital (5), the budget restrictions (9) and (10), and the non negativity and inequality restrictions  $(0 \leq L_{it}^t \leq 1)$ .

For  $0 \leq L_{it}^t \leq 1$ , the first order condition for this problem gives place to a non-linear function of  $L_{it}^t$  in terms of  $h_{it}^{t-1}$  and the different parameters of the model (see Appendix 1):

$$\begin{aligned} \left(1 - \frac{\tau}{(1 + r_t)}\right) \left(\exp\{\alpha\theta(1 - L_{it}^t)\} - \frac{\tau}{\pi_{it+1}^t(h_{it}^{t-1})}(1 - L_{it}^t)\right) &= \gamma\pi_{it+1}^t(h_{it}^{t-1}) \\ \left(\alpha\theta \exp\{\alpha\theta(1 - L_{it}^t)\} - \frac{\tau}{\pi_{it+1}^t(h_{it}^{t-1})}\right) \left(L_{it}^t + \frac{\tau}{(1 + r_t)}(1 - L_{it}^t)\right) & \quad (14) \end{aligned}$$

As we show below, the time individuals devote to accumulating human capital increases

with their second period survival probability, which is a function of parents' human capital. Since the income in the second period depends on the time agents devote to accumulating human capital, the longer they expect to live the greater their human capital investment. Agents with no probability of living during the second period, because the human capital of their parents is too low, will not allocate any fraction of their time to acquiring education. At the other extreme, if  $\pi_{it+1}^t(h_{it}^{t-1}) = 1$ , then  $(1 - L_{it}^t)$  will reach its maximum value.

In other words, the time individuals devote to education in this model will be a function of the schooling years of their parents, but exclusively through the endogenous life expectancy mechanism since intergenerational transfers from parent to children are nonexistent and transfers to finance education are assumed.

### 3. Inequality and Growth

In this section we analyze the relationship between inequality in the distribution of education, life expectancy, human capital accumulation and per capita income. Firstly, we calibrate the model. Then, we display the numerical results of the evolution of human capital over time. Finally, we explore how inequality may affect life expectancy, human capital and growth.

#### 3.1 Calibration

To analyze the influence that inequality in the distribution of human capital exerts on the process of development, following Blackburn and Cipriani (2002), we assume a specific function for the second period survival probability:

$$\pi_{it+1}^t(h_{it}^{t-1}) = \frac{\underline{\pi} + \bar{\pi}\varpi(h_{it}^{t-1})^\phi}{1 + \varpi(h_{it}^{t-1})^\phi} \quad \text{with } \varpi \text{ and } \phi > 0 \quad (15)$$

We choose this function due to its good properties. Thus, it is an increasing function of human capital

$$\frac{\partial \pi_{it+1}^t(h_{it}^{t-1})}{\partial h_{it}^{t-1}} > 0 \quad (16)$$

and it is bounded by  $\underline{\pi}$  and  $\bar{\pi}$  since

$$\pi_{it+1}^t(0) = \underline{\pi} \quad (17)$$

and

$$\lim_{h \rightarrow \infty} \pi_{it+1}^t(h_{it}^{t-1}) = \bar{\pi} \leq 1 \quad (18)$$

Apart from its theoretical properties, on an empirical level this function captures the relationship between life expectancy and human capital across countries very well, for appropriate values of its parameters. We rely on aggregate data since micro data relating parents' education with offspring life expectancy for a broad number of countries are not available. Figure 1 shows the dispersion between life expectancy at birth in 1985, taken from the World Bank, and the average schooling years for the population of 25 years old and over in 1960, from Barro and Lee (2001). The different reference years for these two variables try to capture our assumption that the survival probability in  $t + 1$  of the generation born in  $t$  is a function of the human capital of the generation born in  $t - 1$ .<sup>9</sup> This figure shows a clear concave relationship between the stock of human capital and life expectancy.<sup>10</sup> The fitted function in Figure 1 is obtained assuming that  $\theta = 40$ ,  $\underline{\pi} = 0$ ,  $\bar{\pi} = 1.0$ ,  $\varpi = 0.5$  and  $\phi = 1.4$ . Given these parameters, agents have a life expectancy of 40 years if their parents have no schooling. Since the model considers two equal periods we assume a duration of 40 years for every period.

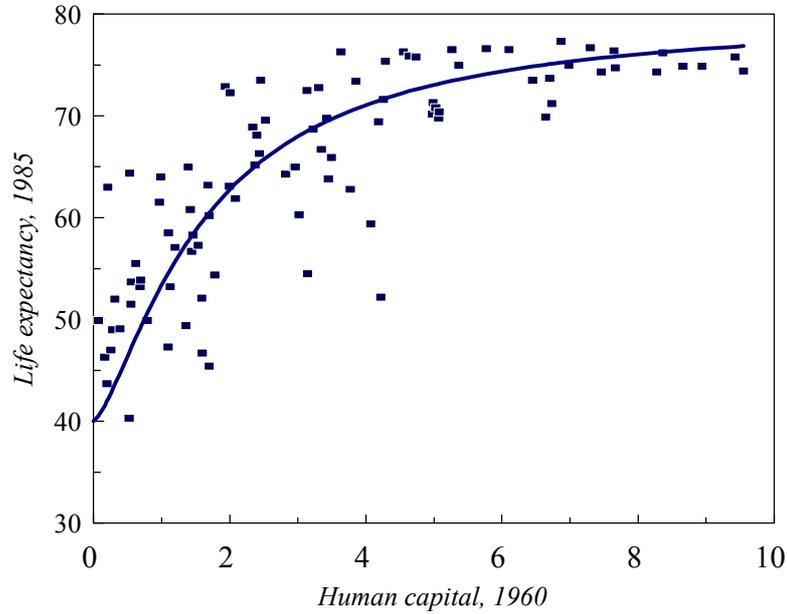
With regard to the production function a reasonable value for  $\alpha$  is 0.07, since its estimated values usually range from 0.05 to 0.15 depending on the sample (see Krueger and Lindahl, 2001). We also assume a standard value for the rate of time preference,  $\rho$ , equal to 0.02, which gives a value of 0.4529 for  $\gamma$ , since  $\theta = 40$ . Finally,  $\tau$  is calibrated to 0.18, in order to obtain a high steady state in which the years of education are equal to 16, that is, the average of the maximum number of years of formal education in OECD countries (see De la Fuente and Doménech, 2001). With these parameter values the model is capable of generating multiple steady states. Nevertheless, we also explore how the changes in these parameters affect the properties of the model.

### 3.2 The evolution of human capital

Equation (14) summarizes the dynamics of the model across generations and it is repre-

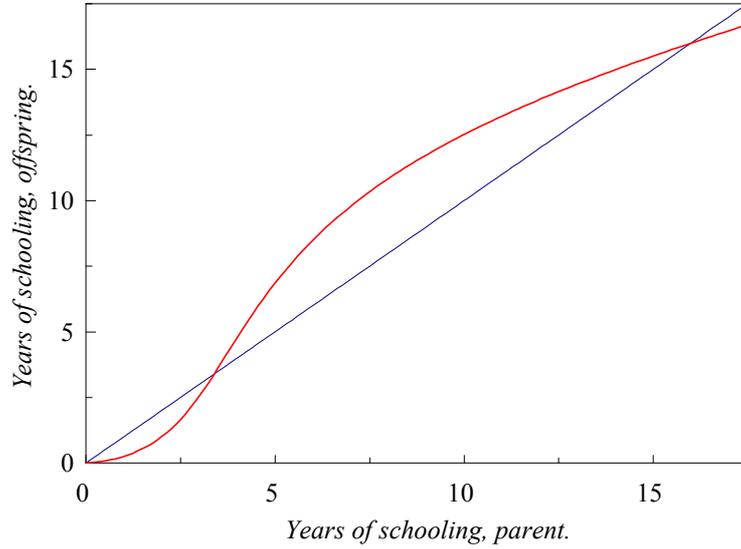
<sup>9</sup> Life expectancy at birth is defined as the number of years a newborn infant would live if prevailing patterns of mortality at the time of birth were to remain the same throughout its life. Since life expectancy has been increasing during recent decades, the prevailing patterns of mortality in 1960 changed in 1970 and so on. Therefore, life expectancy in 1985 also proxies the mortality patterns in 1985 of people born before this year.

<sup>10</sup> The concave shape holds with the different available years in the sample. In addition, infant mortality relates negatively at a decreasing rate with the stock of human capital. The relationship between infant mortality and the stock of human capital may proxy the relationship between the survival probability of one generation and the stock of human capital of the previous one.



**Figure 1:** Life expectancy in 1985 versus average years of schooling in 1960, 92 countries.

sented in Figure 2, given the values of the parameters discussed above and the properties of the first order condition (see Appendix 2). As we can observe, the number of years devoted to education increases with the human capital of the parents. The economy exhibits three different steady states: there are two low steady states with values of zero and around 3.5 years of schooling, and a high steady state of 16 years of schooling. However, since  $h_{it}^{t-1} = h_{it+1}^t = 3.5$  this is not a stable steady state, the dynamics of the model mean that individuals with parents having less than 3.5 years of education (that is, primary education not completed) will converge to the lowest steady state with no schooling. The fact that the steady state of 3.5 years of education is an unstable one can easily be seen by following the dynamics displayed in Figure 2. The picture shows that if the parents have 3.5 years of education their children will also have 3.5 years of education and the children of their children also. However, if the parents are placed in the neighborhood of 3.5 years of education their future generations will end up in a different steady state. In particular, if the parents have for example 3 years of education their future generations will end up in a steady-state without formal education. On the contrary, if the parents have more than 3.5 years of education their future generations will



**Figure 2:** Human capital dynamics.

achieve the highest steady state, 16 years of formal schooling.<sup>11</sup>

In Figure 3 we present the sensitivity of human capital steady states to changes in the different parameters of our model. As expected, an increase in the revenues to finance consumption in the first period (i.e., an increase in  $\tau$ ) results in an upward shift of the function relating human capital of the two generations. It can be shown that, given the calibrated values of the other parameters, when  $\tau = 0$  the model exhibits only one steady state in which  $h_{it}^{t-1} = h_{it+1}^t = 0$ , which can be interpreted as a credit market restriction for the whole economy. As we pointed out in subsection 2.3 this result is due to the fact that in the first period of life individuals study and work.

While  $\tau = 0$  for the whole economy is an unreal assumption, our model can be

<sup>11</sup> Some empirical papers give evidence in favour of multiple steady state models. For example, Quah (1993a, b, 1996) uses annual transitional matrix methodology to estimate long-run tendencies of incomes across countries. His findings suggest a polarization, instead of convergence, across world incomes. Kremer *et al.* (2001) estimate transition probabilities over five-year intervals rather than annual intervals. Their resulting ergodic distribution gives a mass of 72 per cent of countries in the richest income category. However, they obtain that the transition to this steady state is very slow. In addition, if recent trends in international income mobility continue, their results predict an increase in the coefficient of polarization and the standard deviation of log income over the years.

seen as a generalization of Galor and Zeira's (1993) one where  $\tau$  is allowed to vary among individuals. For example, individuals born into poor families with no education have no collateral and are restricted in the credit market, a situation which is equivalent to  $\tau = 0$ . However, in our model even if  $\tau > 0$  poor individuals do not invest in education because their low life expectancy increases their opportunity cost of becoming educated. Therefore, the model predicts multiple steady states even when individuals can finance their education.

An increase in the returns of education or in the life horizon ( $\alpha$  and  $\theta$ , respectively) and a reduction of the rate of time preference ( $\rho$ ) also produces an upward shift of the function since the investment in education is more profitable. Finally, an increase of the survival probability for any given level of  $h_{it}^{t-1}$ , through higher  $\phi$  or  $\omega$ , creates more education incentives.

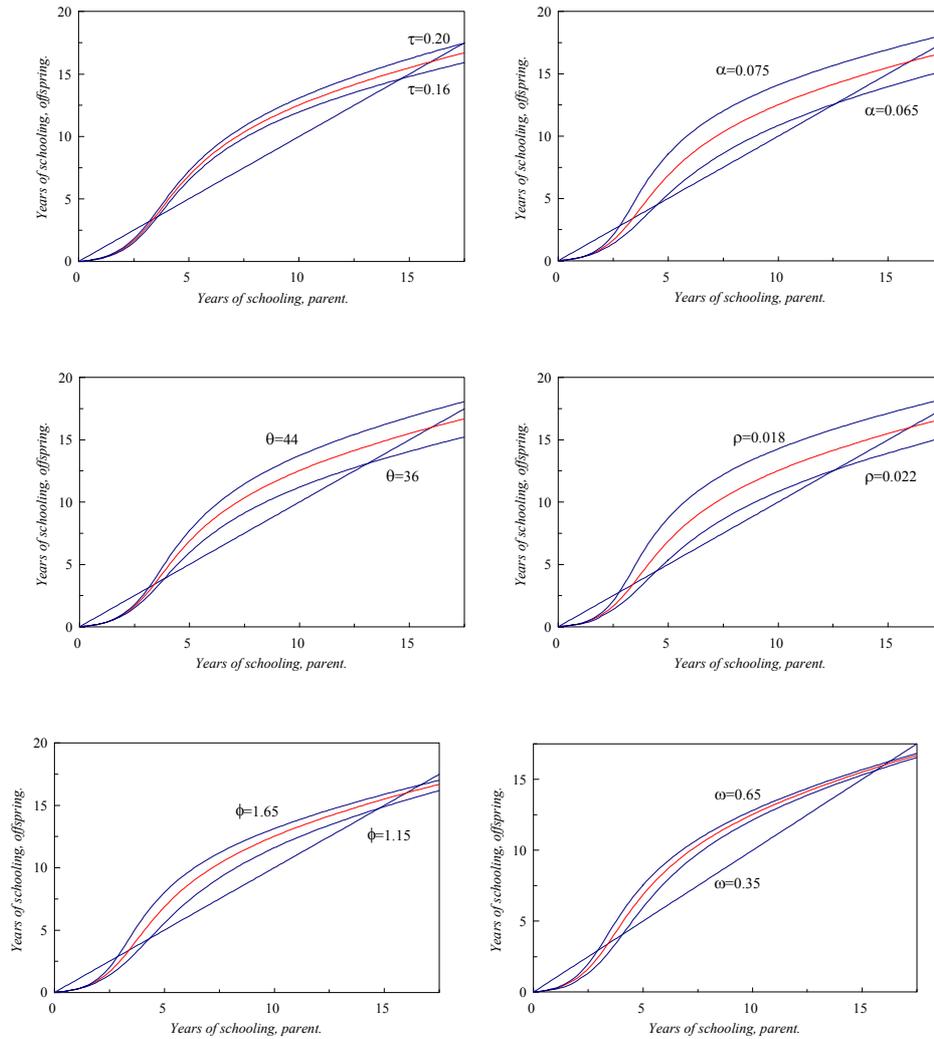
Figure 2 makes clear that individuals who are born into poor families with low levels of education ( $h_{it}^{t-1} \simeq 0$ ) will have a low survival probability ( $\pi_{t+1}^i(h_{it}^{t-1}) \simeq 0$ ) and, therefore, have no incentives to accumulate human capital ( $h_{it+1}^t \simeq 0$ ), devoting all their time to working in the production sector ( $L_t^i = 1$ ), with a low productivity. This low steady state is found in some Latin American, African or South Asian countries, in which many children born into poor families, with no education, live for a short period of time, have no access to education and work as unskilled workers from childhood, affecting a large share of the world population. Using Barro and Lee's (2001) data for the year 2000, at least 20 per cent of the population of 15 years old and over was illiterate in 50 out of the 108 countries in the sample. In 25 of these countries, at least 40 per cent of the population was illiterate. The share of the population with no education is 80 percent in Mali and Niger, where the life expectancy at birth is 43 and 46 years, respectively.

The dynamics of the model predict that governments could bring these families out of the no-schooling poverty trap if they guarantee access to a minimum level of education for some generations and increase life expectancy.

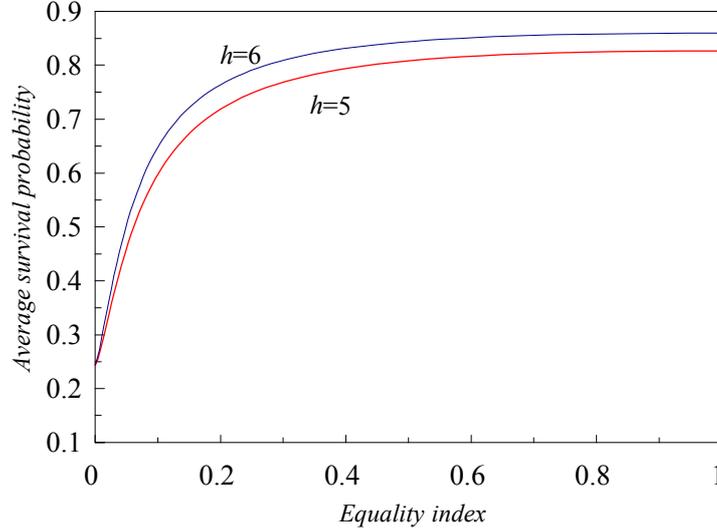
### 3.3 Human capital distribution, life expectancy and economic growth

In accordance with the previous results, in this model the initial distribution of wealth will determine the long-run average human capital and average income in the economy. Given the simplifying assumptions we have made the model does not exhibit endogenous growth in the steady states, but it is useful to explain one source of the per capita income differentials across countries. Thus, the fewer the number of individuals with education lower than the threshold level, the greater the average human capital and average income in the economy.

Under the assumption of imperfect credit markets and indivisibilities in human



**Figure 3:** Sensitivity analysis of human capital steady states to changes in the benchmark values of  $\tau$  (0.18),  $\alpha$  (0.07),  $\theta$  (40),  $\rho$  (0.02),  $\phi$  (1.4) and  $\omega$  (0.5).



**Figure 4:** Average survival probability and human capital equality index ( $h_{pt}^{t-1}/h_{rt}^{t-1}$ ).

capital investment, Galor and Zeira (1993) obtain similar results. In their model the initial distribution of wealth determines the share of the population with no education that works as unskilled workers. Likewise, their model also shows the possibility of two steady states, a low steady state with unskilled workers and a high one with skilled workers. However, the underlying assumptions of their model are quite different from ours. In Galor and Zeira's model, the assumption of imperfect credit markets causes that the distribution of wealth influences economic activity in the short term, and indivisibilities in human capital investment are crucial in order to preserve these results in the long run. In contrast, the results of our model are mainly due to the assumption that differences in the survival probabilities among individuals are a function of their parents' human capital.

The existence of multiple steady states depending on initial conditions makes clear that the initial distribution of education matters a great deal for the evolution of the average human capital in the economy. It can be easily shown that, given two countries with the same average human capital stock in one period, the country with the greater inequality will exhibit lower average survival probability and, therefore, a lower stock of human capital in the following period. Assuming that the economy is populated by a fraction  $\lambda = 0.25$  of rich individuals, denoted by  $r$ , and a fraction  $(1 - \lambda)$  of

**Table 1**  
Dynamics of human capital

Initial equality index	Initial human capital	Average human capital Generations				
		1	2	3	4	5
1.00	5.00	6.86	9.62	12.23	13.99	14.99
0.75	5.00	6.73	9.30	11.93	13.81	14.89
0.43	5.00	5.86	6.44	7.126	8.62	11.08
0.42	5.00	5.81	6.19	6.14	5.15	4.48
0.35	5.00	5.33	4.48	4.22	4.10	4.05

poor individuals, denoted by  $p$ , in Figure 4 we have represented the average survival probability, for two economies with averages of 5 and 6 schooling years, as a function of the equality index ( $e$ ), which is constructed as the ratio between the human capital of poor and rich individuals

$$e_t = \frac{h_{p,t}^{t-1}}{h_{r,t}^{t-1}} \quad (19)$$

As we can observe, for an equality index higher than 0.4 the average survival probability increases very slowly, but when the index is below 0.4, this probability decreases rapidly as the distribution of human capital becomes more unequal.

As the distribution of human capital affects the average life expectancy of the economy, inequality will also have a negative effect on the steady state level of average schooling years and, therefore, on the growth rate of the economy during the transition to the steady state. In Table 1 we have illustrated this implication of the model. Let us assume again that the economy is populated by a fraction  $\lambda = 0.25$  of rich individuals and a fraction  $(1 - \lambda)$  of poor individuals, such that the average human capital of the economy is given by

$$\bar{h}_t = \lambda h_{r,t}^{t-1} + (1 - \lambda) h_{p,t}^{t-1} \quad (20)$$

For a starting level of schooling  $\bar{h}_t$  there are different combinations  $h_{r,t}^{t-1}$  and  $h_{p,t}^{t-1}$  satisfying this condition, with important implications for the distribution of human capital. For example, if human capital is perfectly distributed then  $h_{r,t}^{t-1} = h_{p,t}^{t-1} = \bar{h}_t$  and  $e_t = 1$ . On the contrary, if the human capital of rich individuals is the high steady-state level,

such that  $h_{r,t}^{t-1} = 16$ , then

$$h_{p,t}^{t-1} = \frac{\bar{h}_t - \lambda 16}{1 - \lambda}. \quad (21)$$

In Table 1 we have assumed that  $\bar{h}_t$  is equal to 5 years, above the unstable steady state, and we have simulated the dynamics of the average human capital, using equation (14) for the two groups of individuals and different initial distributions, which are characterized by the equality index. Given the calibrated values of the parameters, the steady state is reached after more than five generations. Economies with a low inequality index reach a high steady state in which  $h_{r,t+j}^{t+j-1} = h_{p,t+j}^{t+j-1} = 16$  and the transition is more rapid, the higher the equality in the initial distribution of human capital. In contrast, when  $e_t < 0.43$  the average human capital reaches a low steady state in which  $h_{r,t+j}^{t+j-1} = 16$  and  $h_{p,t+j}^{t+j-1} = 0$ . An equality index below 0.43 implies that poor individuals start with an initial level of education that is lower than the unstable steady state. In this case, poor individuals converge to the low steady state with zero years of education, whereas rich individuals converge to the high steady state with 16 years of education. As a result, the average years of education in the economy will be lower than 5 years after some generations. The results imply that even two economies that start with the same level of education could end up in quite a different situation if one of them has high inequality levels. Therefore, these results highlight that the distribution of human capital could have outstanding effects upon the economic prospects of societies.

#### 4. Empirical Evidence

This section analyzes empirically the relationship between human capital inequality, life expectancy and human capital accumulation. In order to test the link between inequality and growth through the life expectancy channel we estimate some implications of the model. In the first place we study if more unequal societies have experienced lower life expectancy. Then, we analyze if greater life expectancy is related with more human capital accumulation.

In the analysis of the relationship between inequality and life expectancy we focus on a cross-section that includes 92 countries. Following the model we ask if the distribution of education in one generation is related with lower average life expectancy in the following generation. In particular, using the calibrated function for the survival probability, we have estimated the following equation:

$$LE_{i,1985} = \theta_{\min} + (\theta_{\max} - \theta_{\min})\pi_{i,1985}(h_{i,1960}) + \mu Gini_{i,1960}^h \quad (22)$$

where  $i$  refers to the different countries in the sample. The dependent variable is the life expectancy in 1985 (from the World Bank),  $h$  is measured as the average years of schooling in 1960 (from Barro and Lee, 2001) and  $Gini^h$  is the Gini coefficient of human capital in 1960 taken from Castelló and Doménech (2002), in deviations from the sample average.<sup>12</sup> The estimated value of  $\theta_{\min}$  is the life expectancy of a country where  $\pi_i(h_i) = 0$  and the Gini coefficient is equal to the sample average. Since the endogenous variable is dated in 1985 and the regressors in 1960 we minimize possible endogeneity problems in this regression. The results of the estimation of equation (22) by OLS are presented in Table 2. In column (1) we regress  $LE$  on a constant and  $Gini^h$ , which in equation (22) is equivalent to imposing that  $\theta_{\max} = \theta_{\min}$ , whereas in column (2) we introduce  $\pi$  as an additional regressor. In both specifications, the Gini coefficient of human capital has a negative and statistically significant effect on life expectancy, confirming the prediction of the model that, other things being equal, countries with a more unequal distribution of human capital will exhibit lower life expectancy. Column (3) also includes two dummy variables  $d_1$  (Lesotho, Malawi, Senegal, Sierra Leone, Uganda and Bolivia) and  $d_2$  (Tunisia, Iraq, Kuwait and Portugal) which control for outliers, since their residuals exceed more than two times the estimated standard error of the residuals. The results show that the Gini coefficient and our calibrated function for the survival probability, both dated in 1960, explain a large variance (87.3 per cent) of life expectancy across countries. In column (4) we include an index of political rights averaged over the period 1970-1985. This index takes values from 1 to 7 showing more freedom the lower the index is. The negative and statistically significant coefficient of this index suggest that less freedom is associated with lower life expectancy. Finally, given that Sub-Saharan African countries are distinguished by very low life expectancy as well as very high human capital inequality, the coefficient of the human capital Gini index could be picking up specific characteristics of regions. In order to control for these regional characteristics we include continental dummies in column (5). The results show that although the coefficient of the dummies for Sub-Saharan African and Latin American countries are negative and statistically significant, the coefficient of the human capital Gini index also continues to be negative and statistically significant. Hence, the negative association between human capital inequality and life expectancy is not picking up specific characteristics of regions. However, once we control for regional dummies the coefficient of the political rights index stops being statistically significant.

Therefore, according to the model, these results suggest that more unequal societies experienced on average lower life expectancy than those with a more even distribution. In particular, holding other things constant, those countries with more inequality in the

<sup>12</sup> See Appendix B for the definition and source of the variables used in this section.

distribution of education in 1960 are the societies that had lower life expectancy in 1985.

To complete the analysis, in a second step we need to check if more life expectancy is related to greater rates of human capital accumulation. For this reason in Table 3 the dependent variable is the human capital accumulation rate in 1985, measured as the total gross enrollment ratio in secondary education. The explanatory variables include the log of the per capita income in 1960, life expectancy in 1985, the average stock of human capital in 1960, measured as the average schooling years in the total population aged 25 years and over, and the fertility rates in 1960. According to the model, since life expectancy influences human capital accumulation through the distribution of education, we use two stages least squares and instrument life expectancy in 1985 with the human capital Gini coefficient in 1960.

The results displayed in Columns (1)-(3) of Table 3 show that life expectancy is positively related to human capital accumulation even controlling for per capita income, average years of schooling and regional dummies. In column (4) we check directly the effect of human capital inequality on human capital accumulation. Then, instead of including the life expectancy in the estimated equation we analyze the direct effect of the inequality in the distribution of education including the human capital Gini index in the set of explanatory variables. The results show that the coefficient of the human capital Gini index is negative and statistically significant. In addition, the coefficient of the level of education stops being statistically significant once we control for the distribution of education. However, if human capital inequality affects human capital accumulation mainly through a negative association with life expectancy, we should expect that once we control for life expectancy the effect of human capital inequality on human capital accumulation disappears. Certainly, column (5) shows that once we control for life expectancy the coefficient of the human capital Gini index stops being statistically significant, suggesting that the relationship between education inequality and human capital accumulation is mainly due to the negative association between education inequality and life expectancy. Since there are other demographic variables highly related to human capital inequality such as the fertility rates, in column (6) instead of life expectancy we include the fertility rates in the set of explanatory variables. The results show that when we control for fertility rates the coefficient of the human capital Gini coefficient scarcely changes and continues to be negative and statistically significant. Hence, this result suggests that the negative effect of human capital inequality on the human capital accumulation rates is mainly driven by a negative association between human capital inequality and life expectancy.

On the whole, the empirical evidence of this section gives support to the theoretical model that relates inequality and growth through a negative association between

**Table 2**  
Life expectancy and inequality

	(1)	(2)	(3)	(4)	(5)
$\theta_{\min}$	64.385*** (0.605)	54.310*** (4.404)	52.081*** (2.889)	55.954*** (3.181)	58.743*** (3.021)
$\theta_{\max}$	64.385 <sup>‡</sup>	71.077** (7.505)	73.176*** (5.025)	74.847*** (4.961)	74.277*** (4.577)
$\mu$	-29.577*** (2.007)	-14.431** (6.961)	-10.687** (5.049)	-9.155* (4.756)	-9.559** (4.611)
$d_1$			-13.539*** (1.109)	-12.770*** (1.096)	-10.472*** (1.327)
$d_2$			11.759*** (1.263)	11.766*** (1.444)	8.716*** (1.397)
<i>Pol rights</i>				-0.710*** (0.252)	-0.408 (0.287)
<i>laam</i>					-2.153** (0.956)
<i>safrica</i>					-5.476*** (1.455)
<i>asiae</i>					-0.903 (1.933)
$R^2$	0.670	0.696	0.873	0.884	0.908
<i>Obs.</i>	92	92	92	91	91

Notes: OLS estimations. Robust standard errors in parenthesis. \*\*\* 1 per cent significance level, \*\* 5 per cent significance level, \* 10 per cent significance level. <sup>‡</sup> restricted parameter. Dependent variable: Life Expectancy in 1985. Explanatory variables: human capital Gini coefficient in 1960, simulated survival probability computed with average schooling years in the total population aged 25 years and over measured in 1960,  $d_1$  and  $d_2$  are country dummies ( $d_1$  includes Lesotho, Malawi, Senegal, Sierra Leone, Uganda and Bolivia and  $d_2$  includes Tunisia, Iraq, Kuwait and Portugal), an index of political rights averaged over the period 1970-1985 and regional dummies for Latin American, South African and East Asian countries.

**Table 3**  
Dependent variable: Human Capital Accumulation in 1985

	(1)	(2)	(3)	(4)	(5)	(6)
<i>constant</i>	-1.379*** (0.122)	-0.787*** (0.268)	-0.909*** (0.265)	-0.050 (0.276)	-1.038*** (0.266)	0.174 (0.394)
<i>lny</i> <sub>60</sub>	0.042 (0.046)	0.048 (0.048)	-0.030 (0.328)	0.088** (0.037)	0.022 (0.031)	0.070 (0.045)
<i>LE</i> <sub>85</sub>	0.025*** (0.005)	0.012** (0.006)	0.019*** (0.005)		0.021*** (0.004)	
<i>School</i> <sub>60</sub>		0.044*** (0.014)	0.021* (0.012)	0.003 (0.014)	0.024 (0.015)	0.004 (0.014)
<i>Gini</i> <sub>60</sub> <sup>h</sup>				-0.496*** (0.142)	0.074 (0.179)	-0.448*** (0.141)
<i>Fertility</i> <sub>60</sub>						-0.018 (0.020)
<i>laam</i>			-0.141*** (0.041)	-0.202*** (0.041)	-0.132*** (0.041)	-0.174*** (0.058)
<i>safrica</i>			-0.083 (0.065)	-0.242*** (0.057)	-0.060 (0.049)	-0.237*** (0.061)
<i>asiae</i>			-0.037 (0.063)	0.004 (0.086)	-0.044 (0.062)	0.011 (0.089)
<i>R</i> <sup>2</sup>	0.804	0.796	0.851	0.777	0.852	0.780
<i>Obs.</i>	77	77	77	77	77	77

Notes: 2SLS estimations. Robust standard errors in parenthesis. \*\*\* 1 per cent significance level, \*\* 5 per cent significance level, \* 10 per cent significance level. Dependent variable: Human capital accumulation in 1985, measured as the gross enrollment ratio in secondary education. Explanatory variables: log of per capita income in 1960 (*lny*<sub>60</sub>), life expectancy in 1985 (*LE*<sub>85</sub>), average schooling years in the total population aged 25 years and over measured in 1960 (*School*<sub>60</sub>), human capital Gini coefficient in 1960 (*Gini*<sub>60</sub><sup>h</sup>), fertility rates (*Fertility*<sub>60</sub>) and regional dummies for Latin American (*laam*), South African (*safrica*) and East Asian (*asiae*) countries. The instrument for *LE*<sub>85</sub> in columns (1)-(3) is the human capital Gini coefficient measured in 1960 (*Gini*<sub>60</sub><sup>h</sup>) and in column (5) it is life expectancy measured in 1980.

inequality and life expectancy. On the one hand, the results suggest that more unequal societies have experienced, on average, lower life expectancy. On the other hand, greater life expectancy is associated with greater human capital accumulation rates. In addition, when we analyse the direct effect of human capital inequality on the human capital accumulation rates, the negative and statistically significant coefficient of the human capital Gini index disappears once we control for life expectancy. On the contrary, the negative effect of the human capital Gini index on the human capital accumulation rates remains when we control for other demographic variables, such as fertility rates, suggesting that the association between human capital inequality and human capital accumulation is mainly driven by the life expectancy channel.

## 5. Conclusions

This paper has analyzed an alternative mechanism which explains why inequality in the distribution of income or wealth may be harmful for human capital accumulation. The underlying mechanism is based on the assumption that the life expectancy of individuals is somehow conditioned by the socioeconomic status of the family which they are born into. In particular, we have assumed that life expectancy is an increasing function of the human capital of the parents, an assumption strongly supported by the empirical evidence.

Based on this assumption the paper develops an overlapping generation model in which individuals live for sure during their first period of life and face an endogenous probability of surviving the entire second period. Given this probability, they choose the amount of time devoted to accumulating human capital that maximizes their intertemporal utility. As expected, the results show that the time individuals devote to schooling increases with their expected survival probability.

To analyze the relationship between inequality and growth we have simulated a life expectancy function according to the data of schooling years provided by Barro and Lee (2001). The empirical evidence shows a clear relationship between average schooling years across countries and life expectancy. Given the calibrated survival probability function, the model exhibits multiple steady states depending on initial conditions. Rich individuals, born into families whose parents have high levels of education, have a greater life expectancy. Their long life expectancy encourages them to spend a large number of years in education. On the contrary, individuals who are born into poor families have low life expectancy. Accordingly, since the time they expect to benefit from the returns to education is very short, they devote little time to accumulating human capital. These results imply that the initial distribution of education determines the evolution of the aggregate variables in the model. In particular, the model shows

that inequality may have negative effects upon the growth rate of the economy during the transition to the steady state.

The results are quite similar to the models that relate inequality and growth assuming that capital markets are not perfect. In these models the failure of the market means that capable individuals do not undertake a profitable investment because they do not owe the necessary funds to finance the project. The interesting finding of this paper is that, even individuals who do not have restrictions to finance their education may not undertake an investment project, such as education, when their life expectancy is very low since the time they are going to enjoy the returns of the investment is too short.

The estimation of the structural form of the model widely supports the life expectancy channel. In the first place we analyze the relationship between inequality and life expectancy. Then we ask if more life expectancy is related to greater human capital accumulation rates. The results suggest that most of the negative relation between inequality and human capital accumulation is driven through the strong negative association between human capital inequality and life expectancy.

The policy implications of this study suggest that governments could bring individuals out of the no-schooling poverty trap if they guarantee a minimum compulsory level of education for some generations. Here, the contribution of external aid to finance public education programmes may be crucial. All of them are measures that, at the same time, would generate longer average life expectancy and higher standards of living in the less developed economies in the medium and long-term.

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## 7. Appendix A-1

The optimization problem for an individual  $i$  is given by

$$\underset{L_{it}^t}{\text{Max}} u_i^t = \ln c_{it}^t + \gamma \pi_{it+1}^t (h_{it}^{t-1}) \ln c_{it+1}^t \quad (\text{A1.1})$$

subject to

$$c_{it}^t = AL_{it}^t + \frac{\tau A(1 - L_{it}^t)}{(1 + r_t)} \quad (\text{A1.2})$$

$$c_{it+1}^t = A \exp\{\alpha\theta(1 - L_{it}^t)\} - \frac{\tau A}{\pi_{it+1}^t (h_{it}^{t-1})} (1 - L_{it}^t) \quad (\text{A1.3})$$

$$L_{it}^t \geq 0 \quad (\text{A1.4})$$

$$L_{it}^t \leq 1 \quad (\text{A1.5})$$

The Lagrange function for this problem is as follows:

$$\mathcal{L} = u_i^t(L_{it}^t) + \mu(1 - L_{it}^t) \quad (\text{A1.6})$$

Applying Kuhn-Tucker conditions for the inequality restriction, the first order conditions for this problem are:

$$\begin{aligned} \frac{\partial \mathcal{L}}{\partial L_{it}^t} &\leq 0; & L_{it}^t &\geq 0; & L_{it}^t \frac{\partial \mathcal{L}}{\partial L_{it}^t} &= 0 \\ \frac{\partial \mathcal{L}}{\partial \mu} &\geq 0; & \mu &\geq 0; & \mu \frac{\partial \mathcal{L}}{\partial \mu} &= 0 \end{aligned} \quad (\text{A1.7})$$

The interior solution ( $0 < L_{it}^t < 1$ ) implies that:

$$\mu = 0 \quad \text{and} \quad \frac{\partial u_i^t}{\partial L_{it}^t} = 0 \quad (23)$$

or

$$\frac{1}{c_{it}^t} A \left(1 - \frac{\tau}{(1+r_t)}\right) = \frac{\gamma \pi_{it+1}^t(h_{it}^{t-1})}{c_{it+1}^t} \left[ \alpha \theta A \exp\{\alpha \theta (1 - L_{it}^t)\} - \frac{\tau}{\pi_{it+1}^t(h_{it}^{t-1})} A \right] \quad (\text{A1.8})$$

Substituting  $c_{it}^t$  and  $c_{it+1}^t$ , using (A1.2) and (A1.3) we get

$$\begin{aligned} \left(1 - \frac{\tau}{(1+r_t)}\right) \left( \exp\{\alpha \theta (1 - L_{it}^t)\} - \frac{\tau}{\pi_{it+1}^t(h_{it}^{t-1})} (1 - L_{it}^t) \right) &= \gamma \pi_{it+1}^t(h_{it}^{t-1}) \\ \left( \alpha \theta \exp\{\alpha \theta (1 - L_{it}^t)\} - \frac{\tau}{\pi_{it+1}^t(h_{it}^{t-1})} \right) \left( L_{it}^t + \frac{\tau(1 - L_{it}^t)}{(1+r_t)} \right) & \quad (\text{A1.9}) \end{aligned}$$

where  $L_{it}^t$  is a decreasing function of the expected survival probability.

## 8. Appendix A-2

Given the values of the parameters for the survival probability function, discussed in subsection 3.1, when  $h_{it}^{t-1} = 0$  then  $\pi_{it+1}^t(h_{it}^{t-1}) = 0$ , that is, when parents have no education, offsprings only live during the first period. In such a case individuals face the following optimization problem:

$$\text{Max}_{L_{it}^t} u_i^t = \ln c_{it}^t \quad (\text{A2.1})$$

subject to

$$c_{it}^t = AL_{it}^t \quad (\text{A2.2})$$

$$0 \leq L_{it}^t \leq 1 \quad (\text{A2.3})$$

If  $L_{it}^t$  were not restricted, the optimal value for  $L_{it}^t$  would tend to infinity. However, the restrictions cause the optimal value to take the corner solution in which  $L_{it}^t = 1$ . This means that individuals who do not live in the second period do not accumulate human capital and devote all their time to work in order to maximize their first period consumption.

## 9. Appendix B

Table B: Data definition and source

Variable	Definition	Source
Income (y)	Real GDP per capita (chain), 1996 international prices	Heston, Summers and Aten, PWT 6.1
Education inequality (Gini <sup>h</sup> )	Human capital Gini coefficient	Castello and Domenech (2002)
Level of education (School)	Average schooling years in the total population aged 25 years and over	Barro and Lee (2001)
Political rights (Pol rights)	Index of political rights	Gastil (Barro and Lee (1994))
Life Expectancy (LE)	Life expectancy at birth	World Bank (Barro and Lee (1994))
Human capital accumulation	Gross enrollment ratio in secondary education	Unesco (Barro and Lee (1994))
Fertility Rate (Fertility)	Total fertility rate (children per woman)	World Bank (Barro and Lee (1994))