Human Capital Inequality, Life Expectancy and Economic Growth*

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Abstract

This paper presents a model in which inequality affects per capita income when individuals decide to invest in education taking into account their life expectancy, which depends to a large extent on the human capital of their parents. Our results show the existence of multiple steady states depending on the initial distribution of education. The low steady state is a poverty trap in which children raised in poor families have low life expectancy and work as non-educated workers. The empirical evidence suggests that the life expectancy mechanism explains a major part of the relationship between inequality and human capital accumulation.

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JEL Classification: J10, O10, O40.

Increases in life expectancy and human capital accumulation have accelerated since the post-World War II period in most parts of the world. However, in spite of the convergence in life expectancy across countries during this period (see, for example, Becker et al., 2005), in 2000 there was still an immense gap between the rich and the poor world: life expectancy was 78 years in OECD countries but only 47 years in Sub-Saharan Africa, where the gap with rich countries is increasing nowadays due to AIDS being widespread. Likewise, the striking disparities in human capital are also evident. Whereas the secondary school enrolment rate was almost 100% in rich countries, more than 70% of children in Sub-Saharan Africa were not enrolled in secondary schooling and, therefore, entered the

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labour market as unskilled workers from childhood. These disparities in schooling are also accompanied by huge differences in the distribution of education. Thus, the human capital Gini coefficient in Sub-Saharan Africa (0.56) is twice as high as that of OECD countries (0.21). In this paper we argue that high human capital inequality, low life expectancy and low human capital accumulation rates reinforce each other and may explain the persistence of poverty in a great part of the world.

In particular, we analyse a mechanism that connects inequality and growth through differences in life expectancy among individuals that have 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 empirical evidence (see, among others, Case et al., 2002, or Currie and Moretti, 2003). Given their expected survival probability, individuals choose the optimal time devoted to becoming educated in order to maximize their intertemporal utility. Consistent with the evidence, poor individuals invest optimally a low amount of human capital since their low life expectancy increases their opportunity cost of becoming educated. At the same time, this low investment in human capital will hamper their descendents survival probability, generating a source of poverty persistence across generations. In contrast, rich individuals have more incentives to invest in human capital since the time horizon to enjoy the returns of their investment is longer. Similarly, the higher stock of human capital of rich individuals benefits the time horizons of their future generation and, as a result, high investment rates persist in the rich dynasty. Therefore, the model offers an explanation for the observed persistence of poverty and inequality not only between countries but also within an economy.

In spite of its simplicity, an interesting characteristic of our model is that it relies on elements that can be easily approximated, such as years of schooling and Mincer coefficients, which allow us to offer some quantitative results. In particular, the model exhibits multiple steady states for realistic values of the parameters. Furthermore, we also find that for interior solutions a mean-preserving spread in the survival probability reduces the average human capital in the economy. Therefore, inequality not only affects human capital in the long run but also in the transition to the steady state, suggesting that those countries with higher inequality in the distribution of education will experience lower human capital accumulation rates. As parents' human capital determines children's survival probability, the distribution of education affects average life expectancy, therefore influencing the human capital investment rate in the economy.

The predictions of the model are highly supported by empirical evidence. For a sample of 92 countries, on the one hand, we find that less human capital inequality is significantly related to higher life expectancy even controlling for the stock of human capital. On the other hand, higher life expectancy is found to positively influence the accumulation of human capital. Moreover, as an additional support to our model, we obtain that once we control for life expectancy the significant influence of human capital inequality on secondary school enrolment rates disappears, which suggests that the strong positive association between human capital inequality and the accumulation of human capital operates mainly through the life expectancy channel.

This paper is closely related to the extensive literature on the effects of inequality on economic growth. Whereas traditional channels have mainly focused on fiscal policy distortions (Bertola, 1993, Alesina and Rodrik, 1994, or Persson and Tabellini, 1994) and credit market constraints (Galor and Zeira, 1993, Banerjee and Newman, 1993, Aghion and Bolton, 1997, Piketti, 1997 and other references in Aghion et al., 1999), here we concentrate on how human capital inequality may discourage growth by reducing life expectancy and investment in education, rather than by increasing fertility, as in De la Croix and Doepke (2003) and Moav (2005).

In recent years the role played by life expectancy in determining optimal education decisions has received increasing attention. Most of these contributions have examined different aspects of the link between the "demographic transition" and long-run development incorporating mortality rates or life expectancy in the analysis (e.g., Kalemli-Ozcan, 2002, Cervellati and Sunde, 2005, Soares, 2005, or Tamura, 2006) or, alternatively, through investment in health capital as a prerequisite for sustained economic growth (Chakraborty, 2004). However, although the evidence shows clearly that poor and rich individuals display differences in their life expectancy, previous contributions have not analysed the influence that disparities in life expectancy can have on the accumulation of human capital among individuals and how this affects inequality.

Moreover, the paper also contributes to the emerging empirical literature that analyses the influence of life expectancy and adult mortality on economic growth. For example, Sala-i-Martin et al. (2004) have found that life expectancy seems to be one of the most robust factors affecting growth rates. The specific channels through which life expectancy may influence growth have been analysed by Lorentzen et al. (2006), who find that higher adult mortality reduces investment, lowers the accumulation of human capital and increases fertility (in line with previous results, such as Bloom et al., 2003, or Zhang and Zhang, 2005) explaining a great part of Africa's tragedy. Our paper complements these results not only by analysing the effect of life expectancy on the accumulation of human capital but also by estimating the effects of human capital inequality on average life expectancy. Apart from corroborating that higher life expectancy encourages the accumulation of human capital, we provide evidence that human capital inequality reduces countries' life expectancy.

One of the interesting findings of our paper is that its policy implications differ from those that obtain poverty persistency assuming credit market imperfections and non-convexities. According to our model, even if credit markets are perfect, poor individuals with low life expectancy may optimally invest in a low amount of education since the time span to enjoy the investment returns is very short. In this context, our model suggests that those policies oriented towards bringing the life expectancy of the poor closer to that of rich individuals would enhance human capital investment and growth much more than direct income transfers.

The structure of the paper is as follows. Section 1 displays the basic structure of the model. In order to find a specific function for the survival probability in accordance with the evidence, Section 2 reviews some of the empirical literature that studies the relationship between socioeconomic variables and life expectancy. We then parameterize the model and analyse the relationship between inequality and growth. Section 3 studies the implications of the model empirically. Finally, Section 4 presents the conclusions reached.

1. The model

In this section we present a very simple model to analyse 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 entire first period is one, whereas the probability of living until the end of the second period is π_{t+1}. At the end of the first period each individual gives birth to another so all individuals have a descendent. In every period the economy produces a single good that is used for consumption.

1.1 Life Expectancy

The economy is populated by individuals that differ in terms of family wealth but which 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. In line with the empirical evidence, individuals born into rich families have higher 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, a less healthy diet or less use of preventive and curative medical services. 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.[1]

The probability of an individual i born in period t surviving period $(t+1)$ is as follows:

$$\pi^t_{it+1} = \pi^t_{it+1}(h^{t-1}_{it}), \tag{1}$$

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

1.2 *Technology*

As there are several mechanisms that connect inequality and growth, our aim 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 as in most of the literature that analyses the effect of longevity on growth.[2] This assumption is not too strong considering that this model will mainly be applied to poor countries where life expectancy is particularly low, their technology is labour-intensive 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^t_{it} units towards producing final goods with the following technology:

$$Y^t_{it} = A_t L^t_{it}, \tag{2}$$

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

$$A_t = A(1+g)^t, \tag{3}$$

which allows us to rewrite the production function in efficiency levels

$$y^t_{it} = AL^t_{it}, \tag{4}$$

[1] In Section 2.1 we summarize some empirical evidence that widely supports our assumptions. For a recent survey on the determinants of mortality see for example Cutler et al. (2006).

[2] See, among others, Ehrlich and Lui (1991), Boucekkine et al. (2002) and Soares (2005). As an alternative to this assumption, one could also consider a small open economy with a fixed interest rate and a Cobb-Douglas technology with capital and labour, in which all capital is being held by foreigners.

where $y_{it}^t \equiv Y_{it}^t/(1+g)^t$.

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

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

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

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

$$y_{it+1}^t = AL_{it+1}^t e^{\alpha h_{it+1}^t}, \tag{6}$$

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

$$\ln y_{it+1}^t = \ln A + \alpha h_{it+1}^t. \tag{7}$$

Therefore, the coefficient α (the Mincer coefficient) 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 such 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 there is a large literature that provides empirical estimates of the value of the Mincer coefficient α (see Krueguer and Lindahl, 2001).

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, the aggregate average of 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 human capital technology in order to isolate the effect of inequality on growth through differences in the life expectancy of individuals.

Whereas the isolation of the life expectancy channel is made at the cost of building a very simple economy, the advantage of this simplicity is that the human capital part relies exclusively on elements that can be measured, such as years of schooling and the Mincer coefficient.

1.3 Preferences

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

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

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 by the endogenous survival probability $\pi_{it+1}^t(h_{it}^{t-1})$ and by the rate of time preference ρ, where $\gamma = 1/(1+\rho)$.

During the first period, agents can finance their consumption with income gained from the production of goods (y_{it}^t) which, as equation (4) states, is a function of the time devoted to production. Thus, the level of consumption in t is given by

$$c_{it}^t = AL_{it}^t. \tag{9}$$

Notice that, since income is defined in efficiency units, preferences are also defined over consumption in efficiency units, an assumption which does not affect the first-order conditions of the optimisation problem. In the second period, total income is used to finance private consumption. The budget constraint of the individual in the second period is:

$$c_{it+1}^t = AL_{it+1}^t e^{\alpha h_{it+1}^t}. \tag{10}$$

Many models separate the period when individuals acquire formal education from the period in which individuals work and consume. Nonetheless, in our model we seek to point out that in a lot of developing countries many individuals start working in their childhood. Moreover, some theoretical models also 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, we assume there are no bequests in the model.[3]

1.4 *Optimal Education Years*

The optimal behaviour 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 function of h_{it+1}^{t} in terms of h_{it}^{t-1} and the different parameters of the model (see Appendix A):

$$h_{it+1}^{t} = \frac{\gamma \pi_{it+1}^{t}(h_{it}^{t-1})\alpha\theta - 1}{\gamma \pi_{it+1}^{t}(h_{it}^{t-1})\alpha}. \tag{11}$$

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 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. In contrast, 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 parents to children are nonexistent.

Equation (11) also makes clear that for an interior solution schooling years is a concave function of the survival probability. Therefore, a mean-preserving spread in the survival probability will lower average education.[4] The intuition is straightforward, if we

[3] Chackraborty and Das (2005) analyse a model of intergenerational mobility and equality that operates through investment in health capital. In this model the intergenerational transmission of poverty is through bequest and, in order to obtain persistence they assume that annuities markets are imperfect. In contrast, our model is able to explain the relationship between human capital inequality, life expectancy and human capital accumulation without the need to rely on any imperfection in the credit or annuities market.

[4] Following Rothschild and Stiglitz (1970, 1971), if π_2 is a mean-presearving spread over π_1 and g a concave function then:

$$E[g(\pi_1)] > E[g(\pi_2)].$$

move mass from the middle of the distribution of the survival probability to the tails, keeping the mean constant, the concavity of the function implies that the low human capital stock of poor individuals more than compensates the slight increase in the human capital of rich individuals. That is, as a result of the concavity of $h^t_{it+1}(\pi^t_{it+1})$ the average stock of human capital reduces after a mean-presearving spread because the decrease in the human capital of poor agents exceeds the increase in human capital of wealthy agents. Therefore, equation (11) implies a negative effect of human capital inequality on growth even if the relationship between parents' human capital and offspring's survival probability were linear. In the next section we will show that the relationship between human capital and survival probability is also concave, by which the basic negative effect of human capital inequality on growth will be amplified.

2. Inequality and Growth

In this section we quantitatively analyse the relationship between inequality in the distribution of education, life expectancy, human capital accumulation and per capita income. Firstly, we parameterize the model. We then 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.

2.1 Parameterization

In order to propose a functional form for equation (1) it is convenient to review the empirical evidence on the relationship between socio-economic status and mortality. The negative association between socio-economic status and mortality has been widely analyse in the literature. For instance, Marmot et al. (1991) found a positive association between the grade of employment of British civil servants and their health status in the Whitehall II study, a result already obtained in the first Whitehall study initiated in 1967. More recently, using data for the United States, Deaton and Paxon (1999) have found that higher income is associated with lower mortality, whereas Lleras-Muney (2005) findings reveal

In our case it is straightforward to prove that g is a concave function

$$\frac{\partial h^t_{it+1}}{\partial \pi^t_{it+1}} = \frac{1}{\gamma\alpha(\pi^t_{it+1})^2} > 0$$

$$\frac{\partial^2 h^t_{it+1}}{\partial \left(\pi^t_{it+1}\right)^2} = -\frac{2}{\gamma\alpha\left(\pi^t_{it+1}\right)^3} < 0$$

for γ, α and $\pi^t_{it+1} > 0$.

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 relationship 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.[5] 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 and 1991). In addition, using an instrumental variable procedure for the United States, Currie and Moretti (2003) suggest that the positive effect from maternal education on children health is causal.

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 future diseases and illnesses that an individual may suffer from.[6] For example, Ravelli et al. (1998) investigate glucose tolerance in people born around the time of the 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 foetuses 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.

Therefore, it is realistic to assume that an individuals life expectancy will depend on the socioeconomic status of the family in which the individual is born into and, more

[5] Smith et al. (2001), using the HRS, find that subjective perceptions of mortality are good predictors of observed mortality.

[6] Marmot and Wadsworth (1997) review some studies that link health in childhood with health in adulthood.

specifically on the human capital of their parents. In line with Blackburn and Cipriani (2002), we assume the following specific function for survival probability in the second period:

$$\pi^t_{it+1}(h^{t-1}_{it}) = \frac{\underline{\pi} + \overline{\pi}\varpi(h^{t-1}_{it})^{\phi}}{1 + \varpi(h^{t-1}_{it})^{\phi}} \qquad \text{with } \varpi \text{ and } \phi > 0. \tag{12}$$

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

$$\frac{\partial \pi^t_{it+1}(h^{t-1}_{it})}{\partial h^{t-1}_{it}} > 0 \tag{13}$$

and is bounded by $\underline{\pi}$ and $\overline{\pi}$ since

$$\pi^t_{it+1}(0) = \underline{\pi} \tag{14}$$

and

$$\lim_{h \to \infty} \pi^t_{it+1}(h^{t-1}_{it}) = \overline{\pi} \leq 1. \tag{15}$$

Apart from its theoretical properties, on an empirical basis 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 due to the fact that micro data relating parents' education with offspring life expectancy are not available for a large number of countries. 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 aged 25 and over in 1960, from Barro and Lee (2001). The different reference years for these two variables intends to ensure the exogeneity of human capital and 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 $t-1$.[7] This figure shows a clear concave relationship between the stock of human capital and life expectancy.[8] The fitted function in Figure 1 is obtained for $\theta = 40$, $\underline{\pi} = 0$, $\overline{\pi} = 1.0$, $\varpi = 0.5$ and $\phi = 1.4$. Given these parameters, agents

[7] 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.

[8] 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. Moreover, we find a convex relationship between adult mortality and the stock of human capital as well.

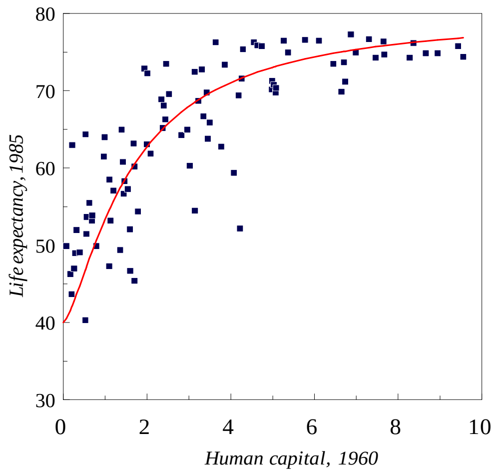

Fig. 1: *Life expectancy in 1985 versus average years of schooling in 1960, 92 countries.*

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. Notice that, since this function is identified using cross-country data, we are just approximating the curvature of the function for the cross-section of individual in a given country, which may look flatter. If that were the case, it would suggest that the life-expectancy channel, including the possibility of multiple steady states, is stronger in a cross-country setting.

The Mincer coefficient α in the schooling function is set to 0.1, in the middle of the range from 0.05 to 0.15 of its estimated values, as shown by Krueger and Lindahl (2001). Finally, the rate of time preference, ρ, is calibrated as 0.021 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 (such as, for example, in the sample used by De la Fuente and Doménech, 2006). With these reasonable 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.

2.2 *The Evolution of Human Capital*

Equation (11) summarizes the dynamics of the model across generations and is represented in Figure 2, given the values of the parameters discussed above and the properties of the first order condition (see Appendix A).[9] As can be observed, the number of years

[9] A previous version of this model, which included taxes and public expenditure in education, also exhibited

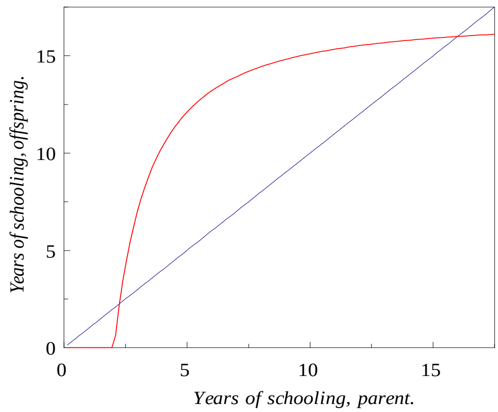

Fig. 2: *Human capital dynamics.*

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 2.3 years of schooling, and a high steady state of 16 years of schooling. However, as $h_{it}^{t-1} = h_{it+1}^{t} = 2.3$ is not a stable steady state, the dynamics of the model mean that individuals with parents having less than 2.3 years of education (as is the case, for example, with more than 40% of countries in Figure 1 which are below this value) will converge to the lowest steady state with no schooling. The fact that the steady state of 2.3 years of education is unstable can be easily seen by following the dynamics displayed in Figure 2. The picture shows that if parents have 2.3 years of education their children will also have 2.3 years of education and the children of their children also. However, if the parents are placed in the neighbourhood of 2.3 years of education their future generations will end up in a different steady state.[10]

In Figure 3 we present the sensitivity of human capital steady states to changes in

multiple steady states and similar dynamics for human capital to Figure 2.

[10] Other models with heterogeneous agents that generate multiple steady states without assuming non-convexities in the production process include Moav (2005) or Eicher and García-Peñalosa (2001). Azariadis (2001) offers an excellent survey of the literature about poverty traps. For empirical papers that give evidence in favour of multiple steady state models see for example, Quah (1993a, b, 1996), who 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.

the different parameters of our model. An increase in the returns of education or in the life horizon (α and θ, respectively) and a reduction of the rate of time preference (ρ) produce an upward shift in the function bacause investing in education is more profitable. Similarly, an increase of the survival probability for any given level of h_{it}^{t-1}, through higher $\overline{\pi}$, ϕ or ω, creates more education incentives.

Figure 2 also 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 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. For example, using Barro and Lee's (2001) data for the year 2000, at least 20% of the population aged 15 and over was illiterate in 50 of the 108 countries in the sample. In 25 of these countries, at least 40% of the population was illiterate. The share of the population with no education was 80 percent in Mali and Niger, where life expectancy at birth was 43 and 46 years, respectively.

The dynamics of the model also predict that governments could bring individuals out of the no-schooling poverty trap if they guarantee access to a minimum level of education for some generations and increase life expectancy. Consequently, the policy implications of our model are also different to those of previous contributions. For example, in models in which poverty persistence is the result of credit market imperfections and non-convexities, as in Galor and Zeira (1993), restricted poor individuals would invest more human capital if capital markets were perfect. In our model, there are no credit market imperfections, but poor individuals invest optimally a low amount of human capital since their low life expectancy increases their opportunity cost of becoming educated. Thus, as shown in Figure 3, according to this model public founds should be better targeted to measures that increase the survival perspectives of the poor and the returns to schooling. Incentives to invest in education are especially important as they would increase the survival probability of future generations at the same time.

2.3 Human Capital Distribution, Life Expectancy and Economic Growth

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

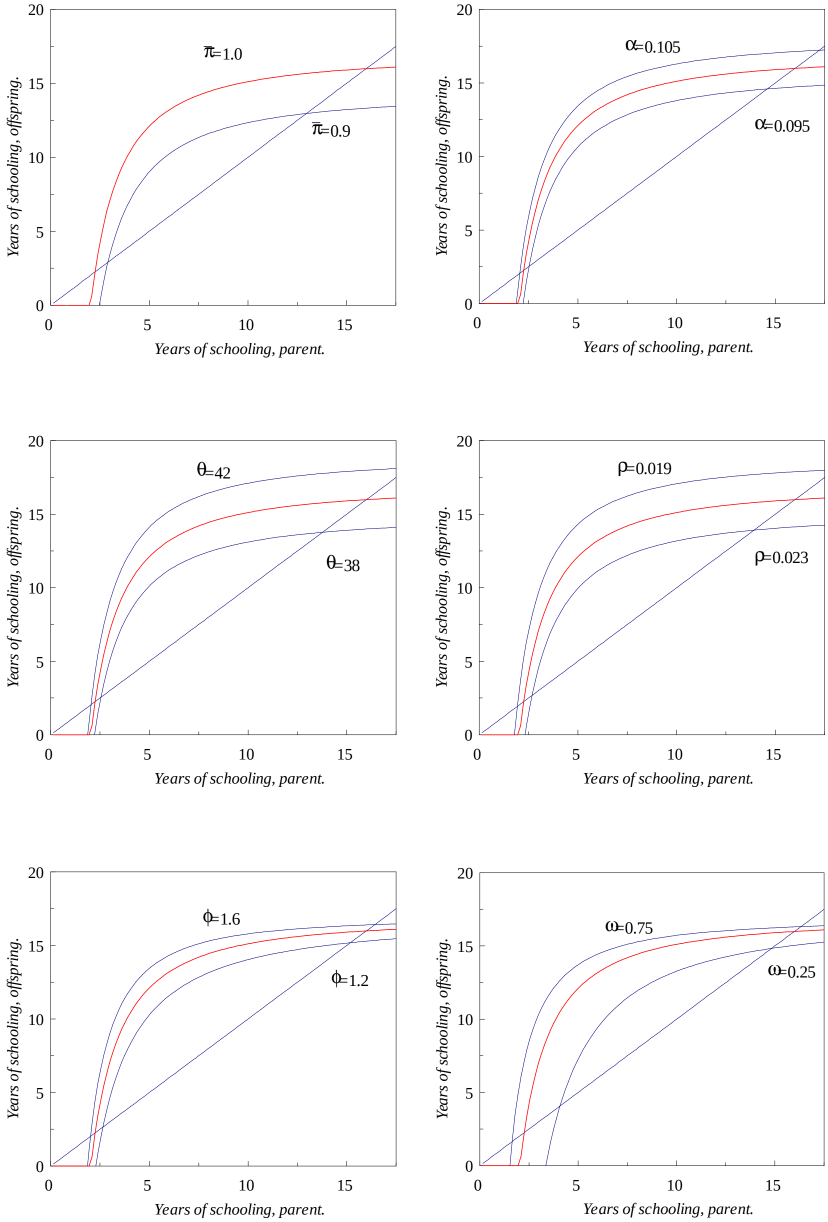

Fig. 3: *Sensitivity analysis of human capital steady states to changes in the benchmark values of* $\overline{\pi}$ (1.0), α (0.1), θ (40), ρ (0.021), ϕ (1.4) *and* ω (0.5).

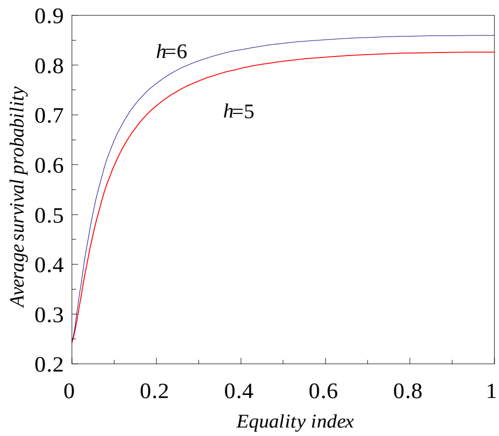

Fig. 4: *Average survival probability and human capital equality index* $(h_{p,t}^{t-1}/h_{r,t}^{t-1})$.

income in the economy.

Under the assumption of imperfect credit markets and indivisibilities in human 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 steady state 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.

In this subsection we display some quantitative results that illustrate how greater inequality in the distribution of education may reduce an economy's life expectancy and how this affects the human capital in the following generations. In the first place we show 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 average 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 poor individuals, denoted by p, in Figure 4 we have represented the

Table 1
Dynamics of human capital

Initial equality index	Initial human capital	Average human capital Generations				
		1	2	3	4	5
1.00	3.00	7.05	13.96	15.80	15.98	16.00
0.75	3.00	6.79	13.56	15.75	15.98	16.00
0.44	3.00	4.86	6.30	9.92	14.80	15.89
0.43	3.00	4.73	3.90	3.99	4.00	4.00
0.30	3.00	3.36	3.93	3.99	4.00	4.00

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

$$e_t = \frac{h_{p,t}^{t-1}}{h_{r,t}^{t-1}}. \tag{16}$$

As can be observed, for an equality index higher than 0.4 the average survival probability increases very slowly as equality increases, 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

$$\overline{h}_t = \lambda h_{r,t}^{t-1} + (1-\lambda) h_{p,t}^{t-1}. \tag{17}$$

For a starting level of schooling $\overline{h}_t$ 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 $h_{r,t}^{t-1} = h_{p,t}^{t-1} = \overline{h}_t$ 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

$$h_{p,t}^{t-1} = \frac{\overline{h}_t - \lambda 16}{1-\lambda}. \tag{18}$$

In Table 1 we have assumed that initially $\overline{h}_t$ is equal to 3 years, above the unstable steady state, and we have simulated the dynamics of average human capital, using equation (11) 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 five generations if human capital is evenly distributed. Economies with a low inequality index reach a high steady state in which $h^{t+j-1}_{r,t+j} = h^{t+j-1}_{p,t+j} = 16$ and the transition is more rapid the higher the equality in the initial distribution of human capital. In contrast, when $e_t \leq 0.43$ the average human capital reaches a low steady state in which $h^{t+j-1}_{r,t+j} = 16$ and $h^{t+j-1}_{p,t+j} = 0$. 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. 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 the fact that the distribution of human capital could have extraordinary effects upon the economic prospects of societies.

Finally, we analyse the effect of changes in the distribution of population. Up to now we have considered the distribution of population between rich and poor individuals to be constant. However, the existence of multiple steady states makes clear that at lower levels of education the percentage of poor individuals is crucial for the economy to escape the poverty trap. As an example, our simulations suggest that an economy that starts with an average of 2 years of schooling may end up in a steady state with 4, 2.4 or 0.8 years of schooling depending on whether the percentage of poor individuals in the society was 75, 85 or 95%, respectively. It is also convenient to note that the percentage of poor individuals can be easily related to a common measure of inequality used in empirical studies such as the Gini coefficient. In fact, if poor individuals have zero years of schooling, the human capital Gini coefficient is equal to the percentage of poor individuals in the population.[11] Therefore, the implications of the model suggest that we should observe that those countries that initially showed high levels of human capital inequality should display lower human capital investment rates in the following generations.

3. Empirical Evidence

This section analyses the relationship between human capital inequality, life expectancy and human capital accumulation empirically. In order to test the link between inequality

[11] For two groups of individuals, we follow De la Croix and Doepke (2004), and compute the Gini coefficient as $Gini^h = \left[\frac{\lambda^P}{\lambda^R}(1 - \frac{h^P}{\overline{h}})\right] / \left[(1 + \frac{\lambda^P}{\lambda^R})\right]$. Thus, when $h^P = 0$ then $Gini^h = \lambda^P$.

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. We then proceed to analyse 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:

$$LE_{i,1985} = \theta_{\min} + (\theta_{\max} - \theta_{\min})\pi_{i,1985}(h_{i,1960}) + \mu Gini^{h}_{i,1960}, \tag{19}$$

where i refers to the different countries in the sample. The dependent variable is life expectancy in 1985 (from the World Bank), h is measured as the average years of schooling in 1960 (from Barro and Lee, 2001), estimated surviving probability π_i is given by equation (12), and $Gini^h$ is the Gini coefficient of human capital in 1960 taken from Castelló and Doménech (2002), in deviations from the sample average.[12] 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 1985 and the regressors 1960 we minimize possible endogeneity problems in this regression.

The results of the estimation of equation (19) by OLS are presented in Table 2. In column (1) we regress LE on a constant and $Gini^h$, which in equation (19) is equivalent to imposing that $\theta_{\max} = \theta_{\min}$. The results show that the Gini coefficient of human capital has a negative and statistically significant effect on life expectancy, confirming the prediction of the model that countries with a more unequal distribution of human capital will exhibit lower life expectancy. Moreover, the effect of human capital inequality on life expectancy is also economically meaningful: a reduction in one standard deviation in the Gini index (0.28) would increase life expectancy by 8.28 years. For example, if in 1960 Sub-Saharan African countries (where $Gini^h = 0.78$) had had a level of human capital inequality similar to that of Latin American countries ($Gini^h = 0.47$), in 1985 life expectancy in Sub-Saharan Africa would have been 9.23 years higher. More strikingly, if human capital inequality in Sub-Saharan Africa had been that of OECD countries ($Gini^h = 0.23$) the increment in life expectancy would have been about 16.3 years.

In column (2) we also include 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 twice the estimated standard error

[12] See Appendix B for the definition and source of the variables used in this section.

Table 2
Life expectancy and inequality

	(1)	(2)	(3)	(4)	(5)	(6)
$\theta_{\min}$	64.385***	64.728***	66.520***	54.310***	52.081***	56.815***
	(0.604)	(0.495)	(0.775)	(4.404)	(2.889)	(2.789)
$\theta_{\max}$	64.385‡	64.728‡	66.520‡	71.077***	73.176***	73.380***
				(7.505)	(5.025)	(4.690)
μ	-29.577***	-29.763***	-25.099***	-14.431**	-10.687**	-10.443**
	(2.007)	(1.578)	(2.031)	(6.961)	(5.049)	(4.700)
d_1		-12.832***	-9.505***		-13.539***	-10.721***
		(0.861)	(0.876)		(1.109)	(1.358)
d_2		11.344***	8.311***		11.759***	8.497***
		(1.270)	(1.502)		(1.263)	(1.233)
laam			-2.046**			-2.461***
			(0.968)			(0.923)
safrica			-6.516***			-5.856***
			(1.469)			(1.426)
asiae			1.570			-0.594
			(2.046)			(1.848)
R^2	0.670	0.833	0.884	0.696	0.873	0.903
Obs.	92	92	92	92	92	92

Notes: OLS estimations. Robust standard errors in parenthesis. *** 1 per cent significance level, ** 5 per cent significance level, * 10 per cent significance level. ‡ 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, d1 and d2 are country dummies (d1 includes Lesotho, Malawi, Senegal, Sierra Leone, Uganda and Bolivia and d2 includes Tunisia, Iraq, Kuwait and Portugal), and regional dummies for Latin American, Sub-Saharan African and East Asian countries.

of the residuals. The results show that the human capital Gini coefficient and the two dummies alone explain more than 80 percent of the variance in life expectancy across countries. However, the fact that Sub-Saharan African countries are distinguished by very low life expectancy as well as very high human capital inequality implies that the coefficient of the human capital Gini index could be capturing region-specific characteristics. Thus, in column (3) we control for continental dummies. 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.

In the remaining columns we introduce the estimated survival probability, π, as an additional regressor, allowing $\theta_{\max}$ and $\theta_{\min}$ to differ. The results displayed in column (4) suggest that even controlling for the estimated survival probability the negative effect of human capital inequality on life expectancy holds. Moreover, the negative effect remains when we control for outliers (column (5)) and continental dummies (column (6)). The estimated size effect of inequality on life expectancy is reduced in the last column, but remains sizeable; a reduction of one standard deviation in education inequality would increase life expectancy in 3 years.

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

To complete the analysis, we need to take a second step 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 enrolment 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 and over, and the fertility rates in 1960. According to the model, since the distribution of education is a relevant channel for the effects of life expectancy on human capital accumulation, we use two-stage 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 when controlling for per capita income, average years of schooling and regional dummies. In column (4) we check the effect of human capital inequality on human capital accumulation directly. Then, instead of including the life expectancy in the estimated equation, we analyse the direct effect of the inequality on 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 is no longer statistically significant when 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 diminishes. Certainly, column (5) shows that once we control for life expectancy the coefficient of the human capital Gini index is no longer 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 that are highly related to human capital inequality such as the fertility rates, we include the fertility rates in the set of explanatory

Table 3
Dependent variable: Human Capital Accumulation in 1985

	(1)	(2)	(3)	(4)	(5)	(6)
constant	-1.380***	-0.787***	-0.909***	-0.050	-0.953***	0.174
	(0.123)	(0.268)	(0.265)	(0.276)	(0.286)	(0.394)
lny_{60}	0.042	0.048	0.030	0.088**	0.027	0.070
	(0.046)	(0.048)	(0.033)	(0.037)	(0.035)	(0.045)
LE_{85}	0.025***	0.012**	0.019***		0.020***	
	(0.005)	(0.006)	(0.005)		(0.005)	
$School_{60}$		0.044***	0.021*	0.003	0.022	0.004
		(0.014)	(0.012)	(0.014)	(0.016)	(0.014)
$Gini^h_{60}$				-0.496***	0.025	-0.448***
				(0.142)	(0.188)	(0.141)
$Fertility_{60}$						-0.018
						(0.020)
laam			-0.141***	-0.202***	-0.138***	-0.174***
			(0.041)	(0.041)	(0.043)	(0.058)
safrica			-0.083	-0.242***	-0.075	-0.237***
			(0.065)	(0.057)	(0.061)	(0.061)
asiae			-0.037	0.004	-0.039	0.011
			(0.063)	(0.086)	(0.063)	(0.089)
R^2	0.804	0.796	0.851	0.777	0.851	0.780
Obs.	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 enrolment ratio in secondary education. Explanatory variables: log of per capita income in 1960 (lny_{60}), life expectancy in 1985 (LE_{85}), average schooling years in the total population aged 25 years and over measured in 1960 ($School_{60}$), human capital Gini coefficient in 1960 ($Gini^h_{60}$), fertility rates ($Fertility_{60}$) and regional dummies for Latin American (laam), Sub-Saharan African (safrica) and East Asian (asiae) countries. The instrument for LE_{85} in columns (1)-(3) is the human capital Gini coefficient measured in 1960 ($Gini^h_{60}$) and in column (5) it is life expectancy measured in 1960.

variables in column (6) instead of life expectancy. 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 human capital accumulation rates is mainly driven by a negative association between human capital inequality and life expectancy.

These results also reveal that, although the coefficient of the Latin American dummy is smaller when life expectancy is accounted for, it remains statistically significant in all specifications, indicating that there are other factors, apart from life expectancy, that explain the low human capital investment rates in Latin America. On the contrary, once we control for life expectancy, the Sub-Saharan Africa dummy is no longer statistically significant, suggesting that the backwardness of human capital accumulation in this region is mainly explained by reduced life expectancy. The impact of an increase in life expectancy is also economically meaningful. For example, according to column (3), an increase in one standard deviation in life expectancy (9.98 years) would have raised the human capital accumulation rate in 1985 by 0.19 points. This impact is quite high given that the total gross enrolment ratio in secondary education in Sub-Saharan Africa in 1985 was only 0.21 points.

In line with our theoretical model, in the empirical section we have used life expectancy as the variable that connects inequality and human capital investment rates. However, our model is quite restrictive in the timing of mortality and it rules out any early death before the age of 40. As is well known, life expectancy is highly related to infant mortality and some studies have found that child mortality should not necessarily have a negative influence on education when mortality is realised before education starts (e.g., Doepke, 2005, Azarnert, 2006). Nevertheless, the empirical evidence on the relationship between longevity and the accumulation of human capital holds with alternative variables such as adult mortality. For instance, using adult mortality rates, instead of life expectancy, Lorentzen et al. (2006) obtain similar results to those in Table 3 regarding the positive effect of longevity on the accumulation of human capital and the role of the Sub-Saharan Africa dummy in this relationship.[13] Moreover, the prevalence of AIDS, which is nowadays the main cause of reduction in life expectancy around the world, affects mainly adult people. For instance, according to data from UNAIDS/WHO, at the end of 2004, in Sub-Saharan Africa 23.2 out of the 25 million people living with HIV/AIDS were adults. These staggering figures and the previous evidence suggest that the human capital investment rates of present and future generations in Sub-Saharan Africa could be seriously affected. In fact, using a panel of African countries from the period 1985-2000,

[13] Our results also hold if in Table 3 we replace life expectancy in 1985 by adult mortality in 1980. The difference in the reference years is due to data availability (from World Development Indicators, 2004).

Kalemli-Ozcan (2006) finds that AIDS has had a strong negative effect on the primary school enrolment rates in this region.[14]

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

4. Conclusions

This paper has analysed 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 empirical evidence.

Based on this assumption the paper develops an overlapping generation model in which individuals always live through 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 analyse the relationship between inequality and growth we have simulated a life expectancy function according to the data of schooling years provided by Barro and

[14] Nevertheless, the positive effect of longevity on income and growth has been questioned recently. Acemoglu and Johnson (2006) have challenged the positive effect of life expectancy on economic growth by estimating a model in first differences and instrumenting life expectancy by predicted mortality. The authors do not find evidence that an exogenous increase in life expectancy implies an increase in the growth rate of per capita income. However, Sub Saharan African countries are not included in their study due to data limitations. Other articles have also challenged the impact of AIDS on income. For example, Young (2005) simulates the impact of AIDS on the welfare of future generations in South Africa. The simulated results suggest that, by lowering fertility and population, AIDS could increase the standard of living of survivors.

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 higher life expectancy. Their long life expectancy encourages them to devote 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.

Although the result of multiple steady states seems to be similar to that in models which relate inequality and growth assuming that capital markets are not perfect, the reasons that explain the existence of poverty traps are quite different. Credit market imperfections imply that capable individuals do not undertake a profitable investment because they do not have the necessary funds to finance the project. The interesting finding of our paper is that 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 empirical evidence supports the life expectancy channel. In the first place we analyse the relationship between inequality and life expectancy. We then question whether higher life expectancy is related to greater human capital accumulation rates. The results suggest that most of the negative relationship between inequality and human capital accumulation is due to 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 by guaranteeing a minimum compulsory level of education for some generations and, at the same time, investing in health policies that increase life expectancy. Here, the contribution of external aid to finance public education and health 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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6. Appendix A

The optimisation problem for an individual i is given by

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

subject to

$$c_{it}^t = A L_{it}^t \tag{A1.2}$$

$$c_{it+1}^t = A \exp\{\alpha\theta(1 - L_{it}^t)\} \tag{A1.3}$$

$$L_{it}^t \geq 0 \tag{A1.4}$$

$$L_{it}^t \leq 1 \tag{A1.5}$$

The Lagrange function for this problem is as follows:

$$£ = u_i^t(L_{it}^t) + \mu \left(1 - L_{it}^t\right) \tag{A1.6}$$

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

$$\begin{aligned} \frac{\partial £}{\partial L_{it}^t} &\leq 0; \qquad L_{it}^t \geq 0; \qquad L_{it}^t \frac{\partial £}{\partial L_{it}^t} = 0 \\ \frac{\partial £}{\partial \mu} &\geq 0; \qquad \mu \geq 0; \qquad \mu \frac{\partial £}{\partial \mu} = 0 \end{aligned} \tag{A1.7}$$

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

$$\mu = 0 \qquad \text{and} \qquad \frac{\partial u_i^t}{\partial L_{it}^t} = 0 \tag{A1.8}$$

Using (A1.2) and (A1.3) we get

$$L_{it}^t = \frac{1}{\gamma \pi_{it+1}^t (h_{it}^{t-1}) \alpha\theta} \tag{A1.9}$$

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

Given the values of the parameters for the survival probability function, discussed in subsection 2.1, when $h_{it}^{t-1} = 0$ then $\pi_{it+1}^{t}(h_{it}^{t-1}) = 0$, that is, when parents have no education, offspring only live during the first period. In such a case individuals face the following optimisation problem:

$$\underset{L_{it}^{t}}{Max}\ u_{i}^{t} = \ln c_{it}^{t} \tag{A1.10}$$

subject to

$$c_{it}^{t} = AL_{it}^{t} \tag{A1.11}$$

$$0 \leq L_{it}^{t} \leq 1 \tag{A1.12}$$

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.

7. 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 (2002)
Education inequality ($Gini^h$)	Human capital Gini coefficient for population 25 years and over	Castello and Domenech (2002)
Level of education ($School$)	Average schooling years in the total population aged 25 years and over	Barro and Lee (2001)
Life Expectancy (LE)	Life expectancy at birth	WDI (2004) and Barro and Lee (1994)
Human capital accumulation	Gross enrolment ratio in secondary education	Unesco, WDI (2004) and Barro and Lee (1994)
Fertility Rate ($Fertility$)	Total fertility rate (children per woman)	Barro and Lee (1994)