ISSN 2042-2695

CENTRE *for* ECONOMIC PERFORMANCE

CEP Discussion Paper No 1087

November 2011

The Role of Educational Quality and Quantity in the Process of Economic Development

Amparo Castelló-Climent and Ana Hidalgo-Cabrillana

THE LONDON SCHOOL OF ECONOMICS AND POLITICAL SCIENCE

E·S·R·C ECONOMIC & SOCIAL RESEARCH COUNCIL

Abstract
We develop a theory of human capital investment to study the channels through which students react to school quality when deciding on investments in secondary education and above, and to study how educational quality affects economic growth. In a dynamic general equilibrium closed economy, primary education is mandatory but there is an opportunity to continue on in education, which is a private choice. High-quality education increases the returns to schooling, and hence the incentives to accumulate human capital. This is caused by two main effects: higher quality makes higher education accessible to more people (extensive channel), and once individuals decide to participate in higher education, higher quality increases the volume of investment made per individual (intensive channel). Furthermore, educational quality plays a central role in explaining the composition of human capital and the long-run level of income. Cross-country data evidence shows that the proposed channels are quantitatively important and that the effect of the quality and quantity of education on growth depends on the stage of development.

JEL classifications: I21, O11, O15, O4
Keywords: Quality of education, human capital composition, economic growth

This paper was produced as part of the Centre's Macro Programme. The Centre for Economic Performance is financed by the Economic and Social Research Council.

Acknowledgements
The authors thank Mauro Sylos for helpful discussions and comments. We are grateful for the hospitality of the Economics Department at Columbia University and of the CEP at the London School of Economics, where part of this research was conducted, as well as for the helpful comments and discussions received at MMM 2009 Indiana, EEA 2009 in Barcelona, and LACEA 2009 in Buenos Aires, SAE 2009 in Zaragoza, RES 2010 in London, SED 2010 in Montreal, IWAEE 2010 in Catanzaro, AMES 2011 in Seoul, and macroseminars at the University of Salamanca 2009, and Granada, 2010. Financial aid from Fundación Ramón Areces is greatly appreciated. Amparo Castelló gratefully acknowledges financial support from the Spanish Ministry of Education through project ECO2011-29283 and the Ramón y Cajal Programme. Ana Hidalgo gratefully acknowledges the financial support provided by the Spanish Ministry of Science and Innovation through program ECO2010-19596.

Amparo Castelló-Climent was a visitor from the University of Valencia, Spain with the Macro Programme at the Centre for Economic Performance, London School of Economics. Ana Hidalgo-Cabrillana is an assistant professor in the Department of Economics at Universidad Carlos III in Madrid.

Published by
Centre for Economic Performance
London School of Economics and Political Science
Houghton Street
London WC2A 2AE

1 Introduction

This paper seeks to understand what drives schooling decisions regarding higher education (i.e., secondary and tertiary education) and why educational attainment levels differ widely with the level of economic development. Two salient features are worth noting. First, most of the population in poor coutries have only a primary education or none at all. Second, higher education attainments increases with income and differs substantially across countries. Possible explanations for this could be, for example, the typical credit constraints story (e.g., Galor and Zeira, 1993; Mookherjee and Ray, 2003) and the existence of skill-biased technical change (e.g., Galor and Moav, 2000). In this paper, we analyze an alternative explanation that posits cross-country differences in the quality of the educational system.

As preliminary evidence of how important the quality of education may be, we plot enrollment rates in secondary education and a measure of educational quality in each country.[1] The results are striking. Figure 1 shows a positive correlation between educational quality and enrollment rates in secondary schooling when the quality of education is relatively high —a correlation that disappears when the quality of the educational system is below a threshold level. Moreover, the upper and lower extremes in the figure also show that, on average, the countries with a high-quality educational system are mainly the high-income OECD economies, whereas those with low-quality educational systems are the less-developed countries.[2]

Motivated by these observations, we develop an analytical theory to study how the quality of the educational system influences individuals' decisions to invest in higher education, which in turn affects the distribution of educational attainment and allows for different paths of development. Specifically, the objective of this paper is to shed light on the following questions: Can educational quality account for higher education, which is essentially non-mandatory education? And if so, what are the channels through which educational quality operates? And how can educational quality affect the long-run income level?

To answer these questions, we present a model of schooling decisions where growth results from the accumulation of physical and human capital. We find a simple closed-form solution, which allows us to identify the mechanisms at work and thus provides a theoretical foundation to check the results empirically. Our theory is based on the following assumptions. First, the quality of the educational system is exogenous and, motivated by the evidence of Hanushek and Woessmann (2008), affects the returns on education so that high-quality education provides more human capital per level of schooling. Second, agents are heterogeneous along two dimensions —ability and inherited wealth—

[1] The quality of the educational system is measured through scores in internationally comparable tests, taken from Hanushek and Kimko (2000); the enrollment rates in secondary education are taken from Barro and Lee (1994) and UNESCO.

[2] A potential problem with these internationally comparable test scores is that they could measure innate abilities. First, it seems reasonable to assume that average ability of students does not vary across countries. Second, even assuming that high-ability agents in developing countries would enter secondary schooling more often than low-ability agents in the same countries, and that the average ability level of secondary students would decline as secondary education expands, we would then expect a negative correlation between quality and enrollment rates across income levels. This would imply that Figure 1 is still robust to these assumptions.

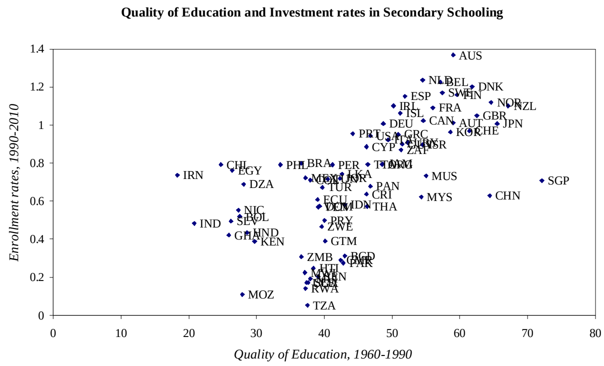


Figure 1: Quality and Quantity of Education

but capital markets are perfect. The essential implication of this last assumption is that schooling decisions are made independently of the current distribution of wealth levels. Although capital markets for education are far from perfect in reality, this assumption allows us to isolate and best illustrate the role played by education quality. Adding imperfections in the capital markets would reinforce our results. Third, every individual is assumed to have the elementary skills that are taught in primary school, since primary schooling is compulsory and publicly provided. People can choose to continue with their education, but this decision requires the investment of private resources. That is, agents decide whether or not to pursue higher education, and if so, how much to spend on it. Accordingly, our focus is on the evolution of higher education, under the assumption that the goal of universal basic literacy has already been met.

Our proposed theoretical model makes several predictions. It identifies two potential channels through which the quality of the educational system affects human capital accumulation. On the one hand, low educational quality decreases the returns from education and discourages access to higher schooling across a broader segment of the population. As a result, low quality could act as a barrier to pursuing higher education. We refer to this effect as the extensive channel. On the other hand, once individuals participate in higher education, high-quality educational systems raise the investments in higher schooling made by each person. We call this the intensive channel. Our empirical evidence, based on cross-country data, suggests that the proposed channels are quantitatively important.

General equilibrium forces also impact schooling choices through changes in prices, reinforcing the effects of quality on educational attainment. As output per capita increases, agents have more incentives to invest in higher education. Higher per capita GDP affects the returns as well as the cost of education, since as wages increase, the marginal returns on education rise, while its opportunity cost —given by the interest rate— falls.

We show that in every period, the economy, as an aggregate, is entirely characterized by the aggregate output per worker, and that how this variable evolves depends on the level of educational quality. Therefore, this parameter determines the level of income in the long run. Indeed, when educational quality is relatively low, only the extensive channel is at work. Individuals would optimally decide to stop after completing primary education and invest only in physical capital, but then aggregate output would be low. This would bring low returns to secondary education, discouraging individuals from going to secondary school, and so on. Conversely, when educational quality is very high, everyone goes on to a secondary education or beyond. Additionally, all people make the optimal investment in higher schooling, so that the economy is at the maximum possible income level in the steady state. Therefore, in our model, higher education is larger in relatively developed economies, and is positively correlated with the quality of the educational system.

Studying the quality of the educational system is important in itself, since education translates into a more productive and efficient labor force. However, while the quantitative aspects of human capital have been studied intensively, less attention has been given to the qualitative aspects of education. An exception is the recent research seeking to quantify the role of educational quality as a determinant of cross-country income differences (see e.g., Erosa et al., 2010; Manuelli and Seshadri, 2007; Schoellman, forthcoming).[3] Our paper concentrates on the effect of education quality on higher education and on how educational quality determines the long-run income level. Surprisingly, there is a continuing dearth of papers addressing this issue, and we contribute to filling this gap in several respects.[4]

First, no study so far has analyzed how educational quality affects decisions to enter higher education, and once enrolled, how much to invest in higher schooling.[5] We show that, due to the extensive channel, educational quality could become a barrier to investments beyond the primary level. Consequently, we complement the literature on multiplicity of equilibria by providing an alternative theory that focuses on the importance of the quality of the educational system instead of emphasizing the typical role of borrowing constraints in producing an obstacle to human capital accumulation.[6]

Second, our model focuses on how human capital composition changes with income per capita. We differentiate between primary and higher levels of education (secondary and tertiary), and we test whether quality affects primary, secondary, and tertiary education in similar ways. Using several measures of the quality of education for a broad number of countries (e.g., Barro and Lee, 2001; Hanushek and Kimko, 2000; Hanushek and Woessmann, 2009; and the Shanghai Jiao Tong University Academic Ranking), the empirical results reveal a statistically significant positive effect of educational quality on attainment levels in secondary and tertiary education. Moreover, when

[3] In Erosa et al. (2010) and Manuelli and Seshadri (2007), educational quality is captured by the total aggregate spending on education. Nevertheless, empirical evidence shows that increasing the amount of resources spent does not always translate into better learning among students (e.g., Hanushek, 1995). This issue motivates the inclusion in our model of educational quality as a parameter that varies across countries and is exogenous to the individuals deciding about higher education.

[4] Tamura's (2001) theoretical analysis was one of the first to include teacher quality in the production function of human capital to study the importance of teacher quality versus class size for growth.

[5] For paper a studying how educational quality affects dropout decisions, see Hanusek et al. (2008).

[6] Hidalgo-Cabrillana (2009) shows that when credit market imperfections are endogenized, poverty traps may be avoided and intergenerational mobility may increase. On the other hand, papers that obtain multiple equilibria without assuming credit market restrictions include Galor and Tsiddon (1997) and Castelló-Climent and Doménech (2008).

controlling for the stock of human capital, countries with better educational quality are those with higher enrollment rates in secondary and tertiary education as well. Furthermore, consistent with the fact that primary education is publicly provided and compulsory in most parts of the world, the effect of educational quality barely influences primary schooling. These results are not due to omitted variable bias; they hold when controlling for the initial level of development, a measure of current financial development, years of compulsory education, and several time-invariant variables that reflect cultural, geographical, and institutional characteristics of each country. Results are also robust against outliers and are unlikely to be driven by reverse causation.

Finally, the predictions of our theory are tested on a broad sample of countries using regression analysis rather than natural experiments and retrospective analysis in a particular country (e.g., Case and Deaton, 1999; Duflo, 2001; Hanushek et al., 2008). As far as we know, we are the first to take a macroeconomic perspective by testing the effect of the quality of schooling on primary, secondary, and tertiary schooling, and by using aggregate data on several countries at different stages of development to examine whether increases in the quality and quantity of education have the same effect at the initial levels of development as they do at later stages. Whereas Hanushek and Kimko (2000) were the first to highlight the importance of the quality of education in promoting economic growth rates, the analysis in this paper goes one step further and shows that quality does not affect economic growth in countries at the bottom end of the quality distribution, yet better educational quality has a clear positive influence on economic growth in the remaining economies. Moreover, although both educational quality and investments in higher education are important determinants of economic growth in developing countries, our results show a predominant effect of quality of education over investment rates in more developed economies.

The paper is organized as follows. Section 2 presents the model under partial equilibrium. Section 3 analyzes the economy in a general equilibrium context. Section 4 describes the data. Section 5 empirically analyzes the channels through which quality influences the quantity of schooling. Section 6 examines the link between education and growth, and Section 7 states the conclusions.

2 The Model

We study a model in which growth dynamics result from physical and human capital accumulation in a context where the quality of the educational system is exogenous. Our economy consists of one sequence of overlapping generations that live for two periods. Agents have primary education that is compulsory and publicly provided. However, they can invest in higher education by spending private resources, and there is a perfect capital market for human capital accumulation. In the second period, agents work and earn an income consistent with their human capital investment.

2.1 Production

In every period, the economy produces a single homogeneous good that can be used for consumption and investment, using the following production function:

$$Y_t = K_t^{\alpha} H_t^{1-\alpha} = H_t k_t^{\alpha}, \tag{1}$$

where K_t, H_t are quantities of physical and human capital (measured in efficiency units) and employed in production at time t, k_t is the capital-labor ratio, and $\alpha \in (0, 1)$. The production function is strictly monotone increasing and strictly concave, and satisfies the neoclassical boundary conditions that ensure the existence of an interior solution to the producers' profit-maximization problem.[7]

Producers operate in a perfectly competitive environment. Given the wage rate per efficiency unit of labor, and the rate of return to capital, in period t producers choose the level of employment of capital K_t and the efficiency units of labor H_t so as to maximize profits. The producers' inverse demand for factors of production is therefore given by

$$\begin{aligned} r_t &= f'(k_t) = \alpha k_t^{\alpha-1}, \\ w_t &= f(k_t) - f'(k_t)k_t = (1-\alpha)k_t^{\alpha}, \end{aligned} \tag{2}$$

where r_t is the rate of return to capital and w_t is the wage rate per efficiency unit of labor. For simplicity, we assume that capital depreciates fully, $\delta = 1$, and thus $R_{t+1} = 1 + r_{t+1} - \delta = r_{t+1}$.

2.2 Individuals

In every period, a generation consisting of a continuum of individuals of measure 1 is born. Each individual has a single parent and a single child. Individuals are identical in preferences, within as well as across generations, but they differ in inherited wealth as well as in abilities. We denote ability type as a_j with $j = H, L$. Agents can be of a high ability type a_H, which occurs with probability $1 - \gamma$ or of a low ability a_L type, with probability γ.[8]

Agents live for two periods. In the first period of their lives, individuals devote all of their time to the acquisition of human capital, while in the second period agents supply their efficient units of education. Primary education is compulsory, such that every individual is assumed to have the basic skills that are taught in primary school. Higher education requires private investments in education instead. Thus, in the first period of their lives, agents make decisions on whether or not to acquire higher education, so that even in the absence of expenditures, all individuals acquire primary education. Accordingly, our focus is on the evolution of secondary education, assuming that universal basic literacy has already been met.

In the second period of their lives (adulthood), individuals supply their efficiency units of labor and allocate the resulting wage income, along with their inheritance and capital income —the second

[7] For models where growth is also given by physical and human capital accumulation, see, for example, Galor and Moav (2004) and Galor et al. (2009).

[8] Introducing ability as a continuous variable would not change the results qualitatively.

period income y^i_{t+1}— between consumption, c^i_{t+1}, and bequests to their children, b^i_{t+1}, where the upper index i refers to the individual. The preferences of individual i are given by[9]

$$u^i_t = (1-\beta)\ln c^i_{t+1} + \beta \ln b^i_{t+1},$$

where $\beta \in (0,1)$. The budget constraint is given by

$$c^i_{t+1} + b^i_{t+1} \leq y^i_{t+1}.$$

Notice that by using first order condition, a fixed fraction β of total income is saved $b^{i*}_{t+1} = \beta y^i_{t+1}$ and the remaining income is consumed $c^{i*}_{t+1} = (1-\beta)y^i_{t+1}$, such that the indirect utility function can be written as

$$U^i_t = \ln(1-\beta)^{1-\beta}\beta^\beta y^i_{t+1}.$$

2.3 Formation of human capital

If agents choose to invest in higher education, they need to decide what level of private expenditures to make, which in our model is given by I_t. Alternatively, we can introduce investment in time spent on schooling in the production function of human capital. We have chosen the first formulation to stress that even with perfect capital markets, educational quality may play a crucial role in schooling decisions.[10] The production function for higher education is

$$h^{high}_{t+1,a_j} = a_j\theta(\mu + \theta I_t)^\varepsilon \text{ with } j = H, L \text{ and } \varepsilon < 1. \tag{3}$$

The human capital production function depends on the quality of the educational system, which is exogenous and measured by θ, and on the level of ability a_j. When $I_t = 0$, the acquired level of human capital is primary schooling, $h^{pri}_{t+1,a_j} = a_j\theta\mu^\varepsilon$, with μ being an exogenous investment in primary schooling made by the government. Talented individuals have larger total returns and marginal returns on higher education than less talented ones. Although the marginal returns to investment in higher schooling diminish with the real resources invested, rising school quality shifts the marginal returns upward over all educational levels. Notice that there are increasing marginal returns to quality and that the effect of θ on I_t is different from its effect on μ. This approach is important to remain consistent with the empirical evidence showing that quality affects education decisions —see, for example, Hanushek et al. (2008) and Hanushek and Woessmann (2008).

Both secondary and tertiary education share the same human capital technology given by condition (3). Due to this simple setup, differences between these two levels of schooling result from differences in the investments in education, such that the higher I_t, the higher the schooling level attained.[11]

[9] This "joy-of-giving" altruism is the common form discussed in the literature on income distribution. It is supported empirically by Altonji et al. (1997).

[10] If time were the input into the production of human capital, the qualitative results would not be affected, as long as the time invested in the formation of human capital increases with the capital-labor ratio.

[11] Using data from the OECD Education at a Glance (2009), we see that the correlations between public and private expenditures on secondary and tertiary educational institutions as a percentage of GDP in the year 1995 and enrollment rates in secondary and tertiary education are 0.516 and 0.575, respectively.

The aggregate stock of efficiency units of human capital will be the sum of primary and higher levels of education.

2.4 Investment decisions

We assume that capital markets are perfect. While this assumption is far from reality, we make it to emphasize the role of the quality of the educational system. Its main implication is that when agents decide to invest beyond primary education, everybody makes the optimal investment such that the current gross interest rate equals the expected marginal product of human capital so as to maximize expected income irrespective of one's initial wealth.

In the presence of the log utility function and perfect capital markets, efficient human capital accumulation decisions are those that maximize the lifetime income of the individual. Therefore, when agents decide whether or not to invest in higher education, they solve the following maximization problem for a given level of wages and interest rate:

$$Max_{\{I_t \geq 0\}} \quad y^i_{t+1} = w_{t+1} h^{high}_{t+1,a_j} - R_{t+1}(I_t - b^i_t).$$

We can find a θ low enough such that individuals optimally remain at the primary level, $I^*_{t,a_j} = 0$.[12] Otherwise, the optimal interior solution, I_t, equates the marginal return to physical capital and human capital,

$$w_{t+1}\theta^2 \varepsilon(\mu + \theta I_t)^{\varepsilon-1} a_j = R_{t+1}. \tag{4}$$

This FOC tells us that the optimal investment is given when the opportunity cost of investing in higher education (R_{t+1}) is equal to the marginal returns thereof. The following equation gives us the interior solution:

$$I^*_{t,a_j} = \left(\frac{w_{t+1}\theta^{1+\varepsilon}\varepsilon a_j}{R_{t+1}}\right)^{\frac{1}{1-\varepsilon}} - \frac{\mu}{\theta}. \tag{5}$$

Since the quality of the educational system positively affects the returns on education, education quality is a force that causes higher investment. We call this effect the *intensive channel*; the higher the quality, the higher the investment per person in higher schooling. In the next sections, we will show that this effect also holds under general equilibrium.[13] The optimal level of higher education is increasing with ability, such that talented individuals choose longer schooling.[14] As expected, the optimal investment is increasing with the wage rate and decreasing with the opportunity cost of the educational investment. Note that, due to perfect capital markets, the optimal investment in higher education is independent of inherited wealth.

[12] This is the case because $\lim_{I_j \to 0} \frac{\partial h^{high}_{t+1,a_j}}{\partial I_{a_j}} < \infty$ holds.

[13] Berkowitz and Hoekstra (2011), using US data, show that high school quality matters because it increases the possibility of going to more selective universities.

[14] Indeed, consistent with empirical evidence reported by Carneiro and Heckman (2002) and Belley and Lochner (2007), a positive relationship exists between cognitive ability and college attendance for all family income and wealth levels in both the National Longitudinal Survey of Youth 1979 (i.e., NLSY79) and NLSY97.

Let's define the threshold level of educational quality in which agents are indifferent between investing in higher education or not

$$\widetilde{\theta}_{a_j} = (\frac{\mu^{1-\varepsilon}}{a_j \varepsilon}\left(\frac{R_{t+1}}{w_{t+1}}\right))^{\frac{1}{2}}. \tag{6}$$

This threshold depends not on individuals' inherited wealth, since capital markets are perfect, but on their differences in ability. In particular, it decreases with ability since talented agents have more incentives to invest in higher education. It is increasing in the opportunity cost of higher education R_{t+1}, so that an increase in the interest rate tightens the constraints on higher investment. If the wage per efficiency unit of labor increases, the constraint on education loosens since, with higher wages, the returns on investments in higher education are higher as well.

Equation (6) identifies what we call the *extensive channel*. It states that when quality is below the threshold, educational quality becomes a barrier to entering higher education. By contrast, when quality is above a threshold, individuals enter higher schooling. Indeed, for a given level of w_{t+1}, R_{t+1}, Y_t, and θ, the composition of human capital depends on the quality of the school system in the following way:

Regime I) If $\theta < \widetilde{\theta}_{a_H}$ holds, that is, when the quality is relatively low, all agents receive primary education.

Regime II) If $\widetilde{\theta}_{a_H} \leq \theta < \widetilde{\theta}_{a_L}$ holds, only talented agents invest in higher education, while low-ability agents obtain primary schooling.

Regime III) If $\widetilde{\theta}_{a_L} \leq \theta$ holds, that is, when the quality is high enough, all agents invest in higher education.

Up to now, we have analyzed partial equilibrium, showing that quality is an important variable explaining the human capital composition. This is the case because, first, educational quality below a threshold would imply that some agents would prefer to remain with primary education –the extensive channel–, and second, better educational quality implies a higher level of investment per person in higher education –the intensive channel. In what follows, we study the model when performed in a general equilibrium setting.

3 General Equilibrium

In this section we will show that the results found under partial equilibrium are reinforced since as the economy develops, higher output would entail a change in prices that provides incentives for agents to invest in higher education.

3.1 The economy's output accumulation path

In this section, we first analyze the threshold level of educational quality under general equilibrium, which allows us to distinguish the different stages of development. And second, we show that in every period, the economy, as an aggregate, is entirely characterized by the aggregate output per worker or per capita, Y_t. Finally, we study its law of motion at each stage and along the process of development in order to understand the dynamic implications of the model for the composition of human capital, output, and educational quality.

Let us find the analytical solution under general equilibrium of the lower bound of the threshold of quality —that is, $\widetilde{\theta}_{t,a_H}$. From section 2.4, we know that if quality is relatively low, i.e., $\theta < \widetilde{\theta}_{t,a_H}$ holds, all agents receive primary education and the aggregate capital stock at $t+1$ is as follows:

$$K_{t+1} = B_t = \beta Y_t.$$

Since capital depreciates at rate $\delta = 1$, the aggregate capital stock at $t+1$ comes from aggregate savings, which are given by the aggregate level of bequest. The aggregate stock of human capital is given by $H_{t+1} = \gamma h^{pri}_{t+1,a_L} + (1-\gamma) h^{pri}_{t+1,a_H}$, and the capital-labor ratio is as follows:

$$k_{t+1} = \frac{\beta Y_t}{\theta \overline{a} \mu^{\varepsilon}} = k^I(Y_t, \theta),$$

with $\overline{a} = \gamma a_L + (1-\gamma) a_H$ being the average ability and $k^n(Y_t, \theta)$ the capital-labor ratio under Regime n with $n = I, II, III$. The capital-labor ratio k_{t+1} is increasing in Y_t and decreasing in θ. Taking into account this capital-labor ratio and equations (2) and (6), the threshold level of education quality for high ability agents is

$$\widetilde{\theta}_{t,a_H} = \frac{\mu \overline{a} \alpha}{\beta Y_t a_H \varepsilon (1-\alpha)}. \tag{7}$$

The upper bound of the threshold of quality is given by $\widetilde{\theta}_{t,a_L}$.[15] If $\theta > \widetilde{\theta}_{t,a_L}$ holds, all agents invest in higher education and thus, the aggregate capital stock is given by

$$K_{t+1} = \beta Y_t - \gamma I^*_{t,a_L} - (1-\gamma) I^*_{t,a_H}.$$

The aggregate stock of human capital is

$$H_{t+1} = \gamma h^{high}_{t+1,a_L} + (1-\gamma) h^{high}_{t+1,a_H} = \gamma \theta a_L (\mu + \theta I^*_{t,a_L})^{\varepsilon} + (1-\gamma) \theta a_H (\mu + \theta I^*_{t,a_H})^{\varepsilon}.$$

After some calculation the capital-labor ratio is given by

$$k_{t+1} = \frac{(\beta Y_t + \frac{\mu}{\theta})^{1-\varepsilon}}{\theta^{1+\varepsilon} \widetilde{a}^{1-\varepsilon} (\frac{1-\alpha}{\alpha} \varepsilon)[1 + \frac{\alpha}{(1-\alpha)\varepsilon}]^{1-\varepsilon}} = k^{III}(Y_t, \theta), \tag{8}$$

with $\widetilde{a} = \gamma a_L^{\frac{1}{1-\varepsilon}} + (1-\gamma) a_H^{\frac{1}{1-\varepsilon}}$. Clearly, k_{t+1} is increasing in Y_t and decreasing in θ. Considering this capital-labor ratio and equations (2) and (6), the threshold level of education quality for low-ability agents is

$$\widetilde{\theta}_{t,a_L} = \frac{\mu[\alpha \widetilde{a} + (1-\alpha)\varepsilon(\widetilde{a} - a_L^{\frac{1}{1-\varepsilon}})]}{\beta Y_t a_L^{\frac{1}{1-\varepsilon}} \varepsilon (1-\alpha)}. \tag{9}$$

For a given Y_t, $\widetilde{\theta}_{t,a_H} < \widetilde{\theta}_{t,a_L}$ holds.[16] The threshold level of education quality varies systematically with the level of development. Figure 2 shows the dynamics of the *extensive channel* as

[15] The subscript t on the threshold of quality is because the capital-labor ratio depends on Y_t.

[16] This is so because $\frac{\overline{a}}{a_H} < 1$ and $\frac{\widetilde{a}}{a_L^{\frac{1}{1-\varepsilon}}} > 1$ always hold.

a function of per capita output. In particular, it is decreasing with Y_t since as output per capita increases, the equilibrium prices change because the interest rate decreases and wages increase. As a result, the constraints on quality are relaxed as the economy develops.

[*Insert Figure* 2].

The threshold level of per capita output is defined by $\widetilde{Y}_{a_j}(\cdot) = (\widetilde{\theta}_{a_j})^{-1}$, with $\widetilde{\theta}_{a_j}$ given by equations (7) and (9).[17] Figure 2 shows that educational quality is a crucial variable in determining educational choices and thus human capital composition. Indeed, the following three regimes are distinguished:

Regime I) $\theta < \widetilde{\theta}_{t,a_H} < \widetilde{\theta}_{t,a_L}$(or similarly $Y_t < \widetilde{Y}_{a_H} < \widetilde{Y}_{a_L}$), with all agents having primary education. The aggregate output per capita is given by

$$Y_{t+1} = (\beta Y_t)^{\alpha}(\theta \overline{a} \mu^{\varepsilon})^{1-\alpha}. \tag{10}$$

The evolution of aggregate output per capita under Regime n can be defined as $Y_{t+1} = Y^n(Y_t, \theta)$ with $n = I, II, III$.

Regime II) $\widetilde{\theta}_{t,a_H} \leq \theta < \widetilde{\theta}_{t,a_L}$ (that is, $\widetilde{Y}_{a_H} \leq Y_t < \widetilde{Y}_{a_L}$), with only talented individuals with higher education. The aggregate stock of physical capital is

$$K_{t+1} = \beta Y_t - \gamma I^*_{t,a_H}.$$

We add across people using the population share in each education category to obtain an aggregate measure of human capital

$$H_{t+1} = \gamma h^{pri}_{t+1,a_L} + (1-\gamma) h^{high}_{t+1,a_H} = \gamma \theta a_L \mu^{\varepsilon} + (1-\gamma)\theta a_H (\mu + \theta I^*_{t,a_H})^{\varepsilon}.$$

The capital-labor ratio is

$$k_{t+1} = \frac{\beta Y_t - (1-\gamma) I^*_{t,a_H}}{\gamma \theta a_L \mu^{\varepsilon} + (1-\gamma)\theta a_H (\mu + \theta I^*_{t,a_H})^{\varepsilon}}, \tag{11}$$

Notice that I^*_{t,a_j} is strictly increasing in k_{t+1}. Equation (11) implicitly defines $k_{t+1} = k^{II}(Y_t, \theta)$, and using the implicit function theorem, the partial derivatives are $\partial k_{t+1}/\partial \theta < 0$, $\partial k_{t+1}/\partial Y_t > 0$.

The aggregate output per capita is given by

$$Y_{t+1} = (\beta Y_t - (1-\gamma) I^*_{t,a_H})^{\alpha} (\gamma \theta a_L \mu^{\varepsilon} + (1-\gamma)\theta a_H (\mu + \theta I^*_{t,a_H})^{\varepsilon})^{1-\alpha},$$

or similarly as $Y_{t+1} = Y^{II}(Y_t, \theta)$.

Regime III) $\widetilde{\theta}_{t,a_H} < \widetilde{\theta}_{t,a_L} \leq \theta$ (or similarly $\widetilde{Y}_{a_H} < \widetilde{Y}_{a_L} \leq Y_t$), where all agents have higher education and the aggregate output per capita is given by

$$Y_{t+1} = (\beta Y_t - \gamma I^*_{t,a_L} - (1-\gamma) I^*_{t,a_H})^{\alpha} (\gamma \theta a_L (\mu + \theta I^*_{t,a_L})^{\varepsilon} + (1-\gamma)\theta a_H (\mu + \theta I^*_{t,a_H})^{\varepsilon})^{1-\alpha}, \tag{12}$$

with $Y_{t+1} = Y^{III}(Y_t, \theta)$.

[17] Notice that since educational quality is exogenous, $\widetilde{Y}_{a_j}(\cdot)$ is time independent.

In short, the evolution of output per worker is given by the following expression:

$$Y_{t+1} = \begin{cases} Y^{III}(Y_t,\theta) & \text{if} \quad \widetilde{Y}_{a_L} \leq Y_t \\ Y^{II}(Y_t,\theta) & \text{if} \quad \widetilde{Y}_{a_H} \leq Y_t < \widetilde{Y}_{a_L} \\ Y^{I}(Y_t,\theta) & \text{if} \quad Y_t < \widetilde{Y}_{a_H}. \end{cases} \tag{13}$$

The next proposition explains how educational quality affects educational choices. It states that educational quality affects the access to higher education as well as how much investment to spend on its acquisition. In section 5, the two channels will be tested.

Proposition 1. *[The extensive and intensive channels under general equilibrium] Educational quality affects investment in higher education through two different channels: higher quality increases the access to higher education (extensive channel), and once individuals decide to participate in higher education, higher educational quality increases the volume of investment made (intensive channel).*

Proof. *See Appendix.*

In the next section, we discuss the most interesting equilibrium dynamic paths.

3.2 The dynamics of output per worker

The equilibrium dynamic path for output per worker will depend upon Y_0, the initial output per worker, as well as on how the variables $\widetilde{Y}_{a_H}, \widetilde{Y}_{a_L}$ and Y_{ss}^{III}, Y_{ss}^{II}, Y_{ss}^{I} are related —with the steady state denoted by the subscript ss. First, under Regime III all agents maximize income, and thus output per worker is the highest. Therefore for any Y_t, $Y_{t+1}^{III} > Y_{t+1}^{I}$ and hence $Y_{ss}^{III} > Y_{ss}^{I}$. Second, Regime II is a convex combination of Regime I and III. Therefore for any Y_t, $Y_{t+1}^{I} < Y_{t+1}^{II} < Y_{t+1}^{III}$ and hence $Y_{ss}^{I} < Y_{ss}^{II} < Y_{ss}^{III}$. Finally, from Figure 2, $\widetilde{Y}_{a_H} < \widetilde{Y}_{a_L}$ holds.

[*Insert Figure* 3].

Let us consider two of the most interesting dynamic paths of output per worker:

Case A: $\widetilde{Y}_{a_L} < Y_{ss}^{I}$.

The dynamics of Case A are depicted in Figure 3. We assume that initially there is a low level of output per worker, i.e., $Y_0 < \widetilde{Y}_{a_H}$ so that the economy is in Regime I. At this stage of development, the extensive channel is at work, and agents optimally attend only primary education. As capital accumulates, and due to the general equilibrium price effect, the economy enters into Regime II, in which only the more intelligent agents invest in higher education. However, for low ability agents, the educational quality constraint remains binding and they stay with primary schooling instead. Along the transition from Regime I to Regime II, the output per capita is pushed onto a higher dynamic path.[18] Economic growth increases the returns from investing in higher education relative to physical capital, raising the opportunities for less talented individuals to pursue education beyond the primary level. The economy enters Regime III where everyone makes the optimal investment, and the current gross interest rate equals the expected marginal product of higher education. As

[18] The large discrete jump in output per capita is due to the assumptions of perfect capital markets and ability only taking two values. Relaxing both hypotheses would allow us to have a more gradual movement to a higher path.

a result, the economy is at the maximum possible income level in the steady state. At this last stage of development, an exogenous increase in educational quality induces agents to invest further in higher education due to the intensive channel.

In summary, Figure 3 shows the interdependence among economic growth, the distribution of educational attainment, and the quality of the educational system. As we move along the three development paths, output per worker increases, which in turn, due to general equilibrium effects, increases the future output per worker and changes the equilibrium prices. Specifically, higher output per worker increases the wage per efficient unit and decreases the interest rate (see equation 2), inducing agents to acquire higher education. Consequently, as output increases, more people can enter higher education —the constraint on quality is relaxed, as can be seen from Figure 2— and once agents decide to invest in higher education, the investment per person also increases. Both effects end up fostering the accumulation of human capital.[19]

The next paragraph summarizes the equilibrium and some of its properties. Proposition 2 says that under Case A, the steady state is unique. The second part of the proposition briefly examines the effect of changes in the quality of education. It is of particular interest, since varying quality corresponds to changing the technology for producing human capital. It shows that education quality influences transitional dynamics. Indeed, controlling for initial income, educational quality is positively associated with growth because countries with higher quality are further from the steady state, and thus, grow faster. Consequently, if educational quality increases, the growth rate of output per worker increases and output per worker increases in all subsequent periods.

Proposition 2: *[The steady state and educational quality under transitional dynamics] If aggregate output per worker is given by the law of motion in equation (13), and if $\widetilde{Y}_{a_L} < Y^I_{ss}$ holds, Y^{III}_{ss} is the unique steady state equilibrium. Moreover, along the transition from below, countries with a better educational quality will experience more growth.*

Proof. *See Appendix.*

The evolution of output per capita or per worker, $Y_{t+1} = Y^{III}(Y_t, \theta)$, is given by expression (12). Changes in educational quality on output per worker can be decomposed into two differentiated effects, i.e.,

$$\frac{\partial Y^{III}_{t+1}}{\partial \theta} = \frac{\partial Y^{III}_{t+1}}{\partial \theta} + \frac{\partial Y^{III}_{t+1}}{\partial I^*_{t,j}} \frac{\partial I^*_{t,j}}{\partial \theta} > 0 \text{ for any } a_j \text{ with } j = H, L.$$

The first term, which is strictly positive, is called the first-order effect of quality on output. The second term is the indirect effect of educational quality on output through the level of investment. It cancels out because $I^*_{t,a_j} = \arg\max Y^{III}_{t+1}$ and thus by the envelope theorem $\frac{\partial Y^{III}_{t+1}}{\partial I^*_{t,j}} = 0$. Consequently, the following corollary provides the first glimpse of the role of educational quality and quantity as potential determinants of the dynamics of output per worker. It states that, under Regime III, educational quality matters more than educational quantity in explaining the evolution of output per capita.

[19] The "jump" in Figure 3 can be interpreted as the experiences of countries like South Korea and Taiwan in the 1940s, which were making enormous initial investments in education to implement sweeping educational reforms, and both countries moved to a higher steady state thereafter. We want to thank an anonymous referee for this interpretation.

Corollary 1: *Under Regime III when all agents are investing optimally in human capital, the dynamics of output per worker is driven by educational quality and not by quantity of schooling.*

Proof. *See Appendix.*

Clearly, we will expect that cross country data show that in developed countries, where fewer agents are credit constrained and more agents would invest optimally —compared with poor countries, only quality would raise the rate of growth of output per worker. By contrast, in less developed countries, we would expect that both variables matter for growth. The implications of both Proposition 2 and Corollary 1 will be tested in Section 6.

Case B: $Y_{ss}^{I} < \widetilde{Y}_{a_H} < Y_{ss}^{II} < \widetilde{Y}_{a_L}$

We assume that the initial output per worker Y_0 is below Y_{ss}^{I}. Since $Y_{ss}^{I} < \widetilde{Y}_{a_H}$ holds, the economy converges to the low stable steady state Y_{ss}^{I}, where agents only have primary education. For any level of output between the thresholds $\widetilde{Y}_{a_H}$ and $\widetilde{Y}_{a_L}$, the economy converges to Y_{ss}^{II}. And for any level of output above $\widetilde{Y}_{a_L}$ the economy converges to the highest stable steady state under Regime III, Y_{ss}^{III}.

It is interesting to analyze the conditions under which the country can remain stuck at the low steady state where agents only have primary education. This may occur when the marginal propensity to save is low, since Y_{ss}^{I} is increasing with β and $\widetilde{Y}_{a_H}$ is decreasing instead. In our model, more education is given by transforming physical capital into human capital. Therefore, economies with a low savings rate will accumulate less physical capital and thus per capita output at a lower rate. Similarly, when θ is very low, it could trap the economy at a low level of development since, with an initially very low quality of the educational system, the extensive channel becomes effective, so that $\widetilde{Y}_{a_H}$ will be relatively high and Y_{ss}^{I} will be relatively low.

4 Data

The predictions of our theoretical model regarding the influence of schooling quality on the quantity invested in education and its influence on the process of development are analyzed empirically for a broad sample of countries. One of the main drawbacks in this regard is that quality of schooling is difficult to measure, and data on educational quality across countries are scarce. The existing data on educational quality for a broad sample of countries comes from two main sources. The first includes measures of schooling inputs, such as expenditures per student, teacher-pupil ratio, and teachers' salaries, among others. The second refers to direct measures of output or cognitive skills. In this paper, we use the second since it directly measures the knowledge acquired while in school. In fact, several papers conclude that more resources spent in school do not always improve students' performance (see, e.g., Hanushek, 1995).

Hanushek and Kimko (2000) is the first attempt to compile measures of the quality of schooling across countries based on students' cognitive performance in various international tests of academic achievement in math and science. By combining all available information, these authors computed a single measure for 90 countries averaged over the period 1960-1991.[20] Hanushek and Woessmann

[20] Originally, only 39 countries participated in international tests of academic achievement. The authors extended

(2009) extend previous measures to improve direct comparisons of student knowledge over time, across tests, and across age groups. The new data comprises 77 countries, and observations are updated up to 2003. However, in spite of its improvement in comparability terms, for many of the countries, there are no available data on per capita GDP for the period 1960-2004. As a result, when using Hanushek and Woessman (2009) with other data sets, the number of observations in the sample is reduced considerably. Panel data are available in Barro and Lee (2001), who compile scores on examinations in science, mathematics, and reading for students of different age groups in various years for 58 countries. Finally, we use the Shanghai Jiao Tong University Academic Ranking of World Universities. The measure aggregates six different indicators of research performance at the university level, such as alumni and staff winning Nobel prizes, highly cited researchers, and articles indexed in major citation indices.[21]

Data on the quantity of education are taken from two different sources. As a measure of the stock of human capital, we use the share of individuals with a given level of schooling, proxied by data on the share of population aged 25 and above for whom primary, secondary, and tertiary is the highest level of school attained. The source is the latest Barro and Lee (2010) data set available from 1950 to 2010. The investment in education is proxied by enrollment rates in primary, secondary, and tertiary education, taken from Barro and Lee (1994) and updated with UNESCO data. The time span for enrollment rates is from 1960 to 2008.

To avoid the results being biased by omitted variables, we control for an array of measures that could influence the decisions of individuals to invest in higher education as well as other variables that are related to both the quantity and quality of schooling. Next we define the additional controls, and in the next section we discuss in detail why these variables should be included in the analysis.

We control for the degree of credit market imperfection. Following the literature (e.g., Iyigun and Owen 2004), we measure credit market restrictions through the private credit provided by deposit money banks divided by GDP, taken from Beck and Demirgüç-Kunt (2010). Although the variable of financial development (FD) does not measure the imperfections in credit markets directly, we expect there to be fewer problems obtaining credit when the financial system is more developed.

To control for the number of years that are compulsory at the secondary level ($YearsC$), we take data on duration of compulsory education from UNESCO.[22] The cultural characteristics are proxied by the share of the population professing a religion (taken from La Porta et al. 1999), the number of school days per year (Barro and Lee 2001), and a dummy for East Asian countries. Political institutions are proxied by a dummy for democratic countries ($Institutions$), taken from Papaioannou and Siourounis (2008). Geographical characteristics are measured with a dummy for countries located in tropical areas ($tropical$), taken from Easterly and Sewadeh (2002). Finally, as

these measures to other countries by imputing missing values from international test score regressions. We use the quality variable QL2 taken from Table C-1 in Hanushek and Kimko (2000).

[21] To control for scale effects, we use the methodology suggested by Aghion et al. (2007, 2009), which transforms the original index into a measure that takes the country's population into account and that can be interpreted as a fraction of the US per capita performance.

[22] The main drawback of the data on years of compulsory education is that they are available only from 2000 onwards.

additional controls, we add public spending on education as a share of GDP ($PSEduc$), taken from the World Development Indicators and Barro and Lee (1994), and the share of total population living in urban areas ($lnurb$), from Easterly and Sewadeh (2002).

For the estimation of the growth equation, we use data on real per capita GDP (lny), the physical capital investment rate (I/GDP), the government share of real GDP (G/GDP), and exports plus imports divided by real GDP ($Trade$), all taken from the PWT 6.2. Finally, the inflation rate ($Inflation$), measured as the annual growth rate of consumer prices, is taken from Easterly and Sewadeh (2002).

5 Channels through which quality influences quantity

5.1 Hypothesis to be tested

Extensive channel [H1]: In countries where educational quality is higher, the stock of people with secondary schooling will be larger.

A cross-country implication of the extensive channel states in Proposition 1 is that, as the number of people with higher education will be influenced by the quality of the educational system, we expect that, other things being equal, those countries with a better quality of education will have a larger proportion of individuals with secondary schooling. The empirical strategy to test this hypothesis will be the following:

$$Education_{i,t} = \alpha_0 + \alpha_1 Quality^h_{i,t-\tau} + \alpha_2 \ln y_{i,t-\tau} + \alpha_3 FD_{i,t-\tau} + \alpha_4 YearsC_{i,t-\tau} + \alpha_4 X_{i,t-\tau} + \nu_{i,t}, \quad (14)$$

where $Education_{\mathrm{i,\ t}}$ is measured as the share of population 25 years and above with secondary and tertiary education as the highest level of school attained, i stands for the country, and t for the time. To minimize reverse causation, all explanatory variables are lagged τ periods. According to our theory, the quantity of higher education is determined by educational quality, as well as by the equilibrium prices, which in turn depend on the aggregate level of per capita output. To avoid that the coefficient of quality is also picking up the general equilibrium effect, we control for the initial level of per capita income ($\ln y$). Likewise, the specification also includes an array of additional controls to address any bias caused by omitted variables. We expect $\alpha_1 > 0$ since the higher the quality of education ($Quality^h$), the higher the number of individuals with secondary schooling will be.

Intensive channel [H2]: Once individuals have decided to invest in higher education, a better-quality educational system will imply a higher investment in schooling.

Proposition 1 shows that once people decide to enter higher education, education quality is a force that increases their investment in education. Thus, higher quality implies higher investment when the quality of education is above a threshold level. We check for a differential effect of low and higher educational quality by interacting the quality measure with low- and high-quality dummies, i.e.,

Dm_{QLTi}^{LOW} and Dm_{QLTi}^{HIGH}, respectively.[23] We test the intensive margin with the following econometric specification:

$$\dot{h}_{i,t} = \beta_0 + \beta_1 Quality_{t-\tau}^{h} * Dm_{QLTi}^{LOW} + \beta_2 Quality_{t-\tau}^{h} * Dm_{QLTi}^{HIGH} + \beta_3 \ln y_{i,t-\tau} + \beta_4 Education_{i,t-\tau} + \mu_{i,t}, \quad (15)$$

where $\dot{h}$ stands for the accumulation of higher education. Using the enrollment rates as the dependent variable and controlling for the initial stock of secondary education (*Education*), we should find no relation between quality and education investment when quality is very low and a positive effect of quality on the human capital investment rate when quality is suficently high. Thus, we expect $\beta_1 \approx 0$ and $\beta_2 > 0$.

It has been common in the literature to differentiate between the flow of human capital, or its accumulation, proxied by enrollment rates, and the stock of human capital, which has usually been measured by years of schooling.[24] We follow Mankiw et al. (1992) and Lorentzen et al. (2008) and use secondary school enrollment rates as a proxy for human capital investment. Although enrollment rates is an imperfect measure of how long a typical student stays in school, since it does not take dropouts into account, we would expect enrollment rates to be higher when people spend more time in school. We test the robustness of the results with a measure of the average years of secondary and tertiary schooling.

5.2 Empirical results

In order to correct for potential endogeneity bias, we measure the explanatory variables lagged several years. Specifically, given that the variable on educational quality is available as an average over the period 1964-1991,[25] we split the whole sample into two sub-periods and measure the explanatory variables from 1960 to 1990, and the dependent variable from 1990 to 2010, so that there is no direct simultaneity in the specification. Table 1 displays the results for the extensive channel —that is H1– in columns (1-6) and those for the intensive channel —that is H2– in columns (7-10).

Controlling for the initial level of development, the results in column (1) show that a higher-quality educational system has a positive and statistically significant effect on the subsequent attainment levels in secondary schooling. The estimated coefficient suggests that an increase in one standard deviation in the quality indicator (11.9) increases attainment levels in secondary schooling by 6 percent. This effect is not the result of atypical observations. Column (2) includes dummy variables that control for outliers, and the estimated coefficient of the quality of schooling does not

[23] The low-quality dummy is equal to one if the value of quality is lower than the mean of the high income OECD countries minus two times its standard deviation, and zero otherwise. The dummy of high-quality countries is equal to one if the quality value is higher than this threshold level, and zero otherwise.

[24] A clear example of this difference is the method followed by Barro and Lee (2001, 2010) to compute attainment levels and years of schooling. Overall, the procedure consists of using enrollment data, with appropiate lags, to measure the new entrants as flows that add to the stock of education.

[25] We use Hanushek and Kimko's (2000) data since it contains a greater number of countries. Nevertheless, we will show that the results are robust to alternative measures of educational quality.

change.[26] Moreover, the importance of the quality aspect of education is also reflected in its explanatory power, since the initial level of development and the quality of schooling explain about 60 percent of the variation across countries in secondary schooling attainment levels.

Whereas our model suggests that causality goes from quality to quantity of education, it is possible that a society's level of development and education influence the resources devoted to schools and the production of human capital. In fact, more developed and educated societies may demand a higher-quality educational system. Hence, governments cannot directly affect outcomes, but they can increase the resources spent on education or promote policies that improve the quality of schooling. For example, governments may respond to these demands by providing more computers and schooling materials, by increasing the number of teachers, by increasing teachers' salaries and so on. Thus, we control for the share of public spending on education, which comprises all of the aforementioned items. Moreover, since access to school and skilled jobs may be easier to obtain in urban areas than in rural ones, we also control for the share of population living in urban areas. The results, displayed in column (3), show that higher spending on education and a greater share of population living in urban areas are related to higher attainment levels in secondary education. However, even when controlling for all of these variables, the positive, statistically significant effect of educational quality on attainment levels in secondary schooling still holds.[27]

It may also be possible that countries with a higher-quality educational system are also those in which governments ascribe high importance to education. Thus, it could be that instead of quality, we are picking up the higher number of years of compulsory secondary education in these countries. To rule out this possibility, in column (4) we control for the number of years of education that are compulsory at the secondary level. The estimated coefficient of this variable is positive, although not statistically significant at the standard levels. Nevertheless, our results show that controlling for this variable does not change the coefficient and significance of the measure of quality of schooling.

Results do not change either if we control for a proxy of restrictions in the credit market, which has been the channel analyzed most frequently in the literature to explain underinvestments in education. Column (5) shows that economies with a better financial system also have higher attainment levels in secondary education. However, controlling for a proxy of credit constraints does not change the positive and statistically significant coefficient of the quality of schooling.

Finally, to proxy for fixed effects, we directly control for specific country characteristics, such as cultural, political, and geographical factors that may influence both the quality and the quantity of schooling. In fact, cultural and religious features may affect individuals' values and attitudes toward education. For example, Guiso et al. (2003) find that religious beliefs are associated with economic attitudes. Thus, to account for cultural values, we control for the share of population professing Muslim, Catholic, or Protestant religious beliefs; an East Asian dummy, since the high value that people in East Asian countries place on education may explain why these economies score high

[26] Countries whose residuals exceed the estimated standard error of the residuals by more than two times include Ghana and Sri Lanka with a positive value and New Zealand with a negative one.

[27] The results do not change if we control for other inputs determined by the government that directly affect secondary schooling, such as the pupil-teacher ratio in secondary school and the share of government educational expenditures per pupil at the secondary level, taken from Barro and Lee (2001).

on international tests and have higher levels of schooling than other countries with similar levels of development; and the number of school days per year in primary school, since this can also reflect the importance society ascribes to education.[28] Political institutions and geographical characteristics are controlled for through a dummy for democratic countries and a dummy for countries in tropical regions.[29] Our results, displayed in column (6), show that Muslim countries, on average, have lower attainment levels than countries in which the majority of the population profess a different religion. Our results also show that whereas democratic countries have a larger share of the population with secondary schooling, being located in tropical areas seems to discourage educational attainment. Nevertheless, controlling for all of these specific country characteristics does not change the positive and statistically significant effect that the quality of education has on the number of individuals who attain higher levels of education.

Overall, our results show a quite robust and positive effect of the quality of education on the subsequent proportion of the population with secondary schooling. Next, we test whether once individuals decide to enter higher education, a higher-quality educational system implies higher investment rates as well. Results for the intensive channel are displayed in columns (7-10), where the educational investment rates are proxied through enrollment rates in secondary schooling. The findings reveal that even when controlling for the stock of human capital, a higher-quality educational system is associated with higher investment rates in secondary schooling; the coefficient of the quality indicator is positive and statistically significant at the 1 percent level. However, as stated by proposition 1, we should expect the quality of education to have a positive effect on the human capital investment rates only when quality is above a threshold level. In line with the predictions of the model, column (10) shows that when quality is very low, the estimated coefficient of quality is close to zero, whereas when quality is sufficiently high, results display a positive and statistically significant effect of quality on the human capital investment rate.

5.3 Robustness of the results

Alternative measures of the quality of education. In Table 2, we test the robustness of H1 and H2 with alternative measures of the quality of schooling. In the first place we use Barro and Lee's (2001) data set, which includes observations of test scores for different years. By exploiting the temporal dimension of the data, we can estimate a pool with explanatory variables lagged five years and thereby minimize endogeneity concerns. However, this comes at the cost of reducing the number of countries by almost half.[30] The results displayed in the upper part of Table 2 show that using Barro and Lee's (2001) data set produces similar results to those found for a broader set of

[28] This variable, taken from Barro and Lee (2001), is not available for higher levels of schooling. A more informative variable might be the number of school hours per year. However, information on this measure is only restricted to a small number of countries.

[29] Sachs and Warner (1997) find that being located in tropical areas is a geographical disadvantage for development.

[30] The results refer to test scores in science, for which there are a few more observations available than for test scores in math. Nevertheless, the results do not change with math scores. The use of math and science and not the reading scores is based on the idea that research activities and the creation of new ideas are important sources of growth (e.g., Romer, 1990).

countries with cross-sectional data.

The results also hold with the measure of quality updated by Hanushek and Woessmann (2009), which is a clear improvement in terms of comparability over time, across tests, and across student age groups. However, it also comes at the cost of reducing the sample to only 45 countries. The results, displayed in Panel B, also show a positive and significant effect of a better quality of education on the share of individuals with secondary schooling. Likewise, once controlling for the stock of secondary education, higher quality also boosts the investment rates in education, as reflected by the higher enrollment rates. However, the results do not display any differential effect in the countries with low and high quality of schooling. A plausible explanation could be the reduced number of countries and the large representation of high income economies in the sample.

Since Hanushek and Woessmann's (2009) data on quality are computed as an average up to the year 2003, it is more difficult to control for endogeneity in this scenario. In the bottom part of Table 2 we follow an instrumental variable approach and use the measure of Hanushek and Kimko (2000), averaged over the period 1960-1990, as an instrument for the quality measure of Hanushek and Woessmann (2009). The proposed instrument appears to be a good candidate for several reasons. First, the correlation among both variables is high (0.71). Second, the quality variable of Hanushek and Kimko (2000) should not influence attainment levels or enrollment rates directly, except as an instrument for the quality of education. Finally, the high value of the F-test in the first-stage regression suggests the instrument is not weak. Nevertheless, the instrument is unlikely to truly be a source of exogenous variation and, given that the model is just identified, we cannot properly test whether the instrument is exogenous. Thus, results should be interpreted with caution since the potential endogeneity of quality to other unmeasured determinants of increased schooling suggests that the quantitative effect of quality could be biased upwards. This approach, however, could correct for potential measurement error bias in the measure of quality.[31] Findings reveal that the positive effect of the quality of education on the quantity of schooling continues to be positive and significant. In fact, the estimated coefficient of quality is now higher than its OLS counterpart in Panel B, suggesting that the instrumental variable approach could be correcting the attenuation bias caused by measurement error. Nevertheless, in quantitative terms the impact on attainment levels is similar to that found in Table 1. According to column (1), a one standard deviation increase in the quality of schooling (0.592) increases the secondary attainment levels by 5 percent.[32]

Alternative measures of the quantity of education. The measure of investment in education refers to students enrolled in school at a particular grade or age in period t. The advantage of this measure is that it is very unlikely that students enrolled in period t may determine the test

[31] To reduce attenuation bias caused by measurement error, Pritchett (2001) and Krueger and Lindahl (2001) use a former measure of years of schooling by Nehru et al. (1995) and Kyriacou (1991), respectively, as an instrument for an updated measure of years of schooling by Barro and Lee (2001). Schoellman (forthcoming) uses test scores by Hanushek and Kimko (2000) and Hanushek and Woessman (2009) as an instrument for educational quality, measured by estimated returns to schooling of foreign-educated immigrants in the United States.

[32] Whereas the F-statistic in the first stage is above 10 in almost all specifications and, therefore, it is an indication that the instrument is not weak, the low value of the F-statistic in column (10) suggests that the low and high quality measures, computed with Hanushek and Kimko's (2000) data, are weak instruments for the low and high quality measures computed with Hanushek and Woessmann's (2009) data.

scores of students enrolled $t - \tau$ years back. Likewise, we test whether the results with the measure of attainment levels, which refer to the population 25 years and above, are influenced by the oldest generations. In Panel A of Table 3, we check H1 with a measure of secondary attainment levels of the population 25-39 years old. Results are very similar to those with the total population, suggesting that previous findings are not influenced by the oldest cohorts. On the other hand, in columns (7-10) we use the average years of education in secondary and tertiary schooling as an alternative measure for the investment rates.[33] In line with the results in Table 1, findings reveal a positive and statistically significant coefficient of the quality of education on the average years of schooling as well. Moreover, the positive effect of quality is mainly found when the quality of education is sufficiently high (column (10)).

In Section 2 we model higher levels of education in a reduced form, since the human capital production function is similar for secondary and tertiary education. However, in Table 3 we check that the extensive and intensive channels, H1 and H2, also hold at the university level. We proxy the quality of tertiary education with international rankings of the performance of the top 500 universities in year 2003, taken from the Shanghai Jiao Tong University Academic Ranking.[34]

Panel B of Table 3 shows the results of the effect of university quality on attainment levels and enrollment rates in tertiary education. Column (1) shows that higher per capita income is positively and significantly related to higher attainment levels in tertiary education. Moreover, even controlling for the level of development, countries with a higher number of universities in the top 500 also have a higher share of the population with university education. In quantitative terms, the effect implies that an increase of one standard deviation in the quality indicator (0.44) is associated with an increase of 2.6 percent in attainment levels in tertiary education. Furthermore, column (9) shows that once individuals decide to enter tertiary education, the higher the quality, the higher the investment rates as well.

In our model, we assume that the primary level of education is publicly provided by the government and that individuals' decisions to invest in education mainly refer to higher schooling. The reason is that in most countries, primary education is compulsory and financed by the government. In fact, according to UNESCO data, in the year 2000, primary education was compulsory in every country in the world. Therefore, we would expect that any effect of higher-quality education on the quantity of education should be stronger in secondary and tertiary education than in primary education. Certainly, using the measure of quality of education from Hanushek and Kimko (2000), the lower part of Table 3 shows no effect of the quality of education on the share of individuals with

[33] We have measured investment rates as the cumulative years of education in secondary and tertiary schooling. When the dependent variable is the average years of schooling in secondary education or the total average years of education of the population 25-39 years old, the estimated coefficient of quality is 0.038 (st.err.: 0.012) and 0.033 (st.err.: 0.015), respectively.

[34] The quality of secondary education is not always related to quality at the tertiary level. For instance, according to the international test scores compiled by Hanushek and Kimko (2000), the quality of secondary education in the United States is lower than that in other countries with similar or lower levels of development (see Figure 1). However, when it comes to tertiary education, American universities are by far the best in the world. The correlation of the quality measure from Hanushek and Kimko (2000) with the transformed measure of university performance is 0.570 for the top 500 institutions.

primary education and the investment rates in primary schooling; the coefficient of the quality of education is close to zero in almost all specifications.

6 Education and growth

6.1 Hypothesis to be tested

Effect of the quality of education on the process of development [H3]: The higher the educational quality, the higher the rate of growth.

Proposition 2 shows that educational quality is positively associated with output growth since the country is further from its steady state. Our identification strategy will be to differentiate among high- and low-quality countries in an otherwise standard growth equation. Specifically:

$$\Delta \ln y_{i,t} = \gamma_0 + \gamma_1 Quality^h_{i,t-\tau} * Dm^{LOW}_{QLTi} + \gamma_2 Quality^h_{i,t-\tau} * Dm^{HIGH}_{QLTi} + \gamma_3 \ln y_{i,t-\tau} + \gamma_4 X_{i,t-\tau} + \mu_{i,t}, \quad (16)$$

where $\Delta \ln y$ is the growth rate of per capita income and the explanatory variables include initial per capita income ($\ln y_{i,t-\tau}$), to control for conditional convergence, and other standard determinants of growth ($X_{i,t-\tau}$). We would expect a negligible effect on growth when quality is below a threshold level, that is, $\gamma_1 \approx 0$, and a positive effect when quality is above that level, $\gamma_2 > 0$.

Effect of quality and quantity of education on development [H4]: Investment in higher education will be relatively more important than educational quality in explaining growth when the country is further from its steady state.

In our theory, the effect of quality on output is driven by two differentiated effects; in addition to the indirect effect of increasing the incentives to invest in higher education, quality is good in itself —a direct effect— because it reveals the degree of effectiveness of accumulating human capital. Corollary 1 shows that when all agents choose investment optimally, that is, under the highest regime, the indirect effect disappears because when the economy is in its steady state the level of investment is maximized. A cross-country implication of this corollary is that if both quality and investment are introduced in a growth regression, we would expect that investment matters only if the economy is poor and far away from its steady state. That is, we expect that in these countries, due to several constraints on education, investment in higher schooling is not going to be optimal. This hypothesis is difficult to test since knowing whether a country is at its steady state is not straightforward. Nevertheless, as an approximation, we assume that rich countries are more likely to be closer to their steady state than poorer economies. We test H4 by interacting the educational investment rate with a dummy of low and high income countries, and we use the following econometric specification:[35]

$$\Delta \ln y_{i,t} = \rho_0 + \rho_1 \dot{h}_{i,t-\tau} * Dm^{LOW}_{Income} + \rho_2 \dot{h}_{i,t-\tau} * Dm^{HIGH}_{Income} + \rho_3 Quality^h_{i,t-\tau} + \rho_4 \ln y_{i,t-\tau} + \rho_5 X_{i,t-\tau} + \mu_{i,t}. \quad (17)$$

We should expect a positive effect of the quality of education on growth ($\rho_3 > 0$). However, the effect of the investment rate should be higher in those countries that are further to their steady states, $\rho_1 > 0$ and $\rho_2 \approx 0$.

6.2 Empirical results

We test H3 and H4 in Table 4, in which the average growth rate of per capita income for the period 1960-2004 is regressed on the initial per capita income, to reflect convergence in incomes across countries, and other standard determinants of growth, such as the physical capital investment share, the public spending share, the imports plus the exports divided by GDP, and the inflation rate. We use Hanushek and Kimko's (2000) data on the quality of education since the variable is available for a broad number of countries, including those with low and high educational quality, as well as those with very low and very high income levels. Therefore, we estimate a cross-sectional equation by OLS.[36]

Column (1) in the upper part of the table shows a positive and statistically significant coefficient of the quality indicator, suggesting that, other things being equal, countries with a better-quality educational system have experienced, on average, higher growth rates in per capita income. However, according to H3, the positive effect of the quality of education on the growth of income should be observed only when the quality of education is above a threshold level. Certainly, when we split the quality effect between low- and high-quality countries, our results show that whereas the estimated coefficient of the quality of education is not significant in countries with quality at the bottom end of the distribution, higher-quality educational systems have a positive and statistically significant effect in most of the economies (column (2)).

On the other hand, column (3) shows that higher enrollment rates are positively and statistically significantly related to higher growth rates in per capita income. However, in line with hypothesis H4, the effect is stronger in economies that were relatively poor than in countries with per capita incomes in the top 25$^{\text{th}}$ percentile of the income distribution. Results displayed in columns (4) and (5) show that, although the coefficients of the interaction terms are both statistically significant, the quantitative effect of higher enrollment rates on growth is almost double in lower income countries than in the richest economies.

Hanushek and Kimko (2000) are the first to show that once the quality of education is taken

[35] Dm^{LOW}_{Income} is equal to one if real GDP in 1960 is lower than the 75th percentile of the income distribution in that year and zero otherwise. Likewise, Dm^{HIGH}_{Income} is equal to one if real GDP per capita in 1960 is within the top 25$^{\text{th}}$ percentile of the income distribution, and zero otherwise.

[36] Using Barro and Lee's (2001) data set on quality measures, we have also tried to estimate a dynamic panel data model that controls for country-specific effects with the system GMM estimator. However, even using a low number of lags in the set of instruments, the reduced number of observations makes this estimator less reliable, as reflected by the specification tests.

into account, the effect of the average years of schooling in an otherwise standard growth equation vanishes. In the lower part of Table 4 we test the robustness of the previous results, taking Hanushek and Kimko (2000) as a benchmark. Columns (1) and (2) display results similar to those found by Hanushek and Kimko (2000); that is, the positive coefficient of the average years of schooling (column 1)) disappears once a measure of the quality of education is included in the set of controls (column 2)). Nevertheless, in line with the predictions of our model, column (3) shows that the positive effect of quality on growth is found only when quality is relatively high, which leads to the suggestion that quality is not growth enhancing unless students achieve a minimum level of knowledge. On the other hand, when including the effect of quality and quantity together, whereas the influence of quantity disappears in high-income countries, we still find a positive influence of quantity on growth in lower-income economies.

7 Conclusions

So far, most of the theoretical and empirical literature on human capital and development has focused mainly on the quantity of schooling. This paper reconsiders the role of human capital by emphasizing the importance of the qualitative aspects of education and their effect on schooling decisions about higher education. Our proposed theory implies that, when primary schooling is compulsory and publicly provided, educational quality may affect economic growth by increasing the extensiveness —expanding access to more agents— as well as the intensiveness —increasing the investment made by each agent—of the accumulation of human capital beyond primary education. Our results further suggest that educational quality plays a central role in the composition of human capital and in the long-run level of income. Using cross-country data, we find evidence supporting these predictions of the theory.

From this paper, we can derive some interesting policy implications. First, when seeking to promote human capital formation, policy makers usually focus on expanding access to education, while paradoxically forgetting the qualitative aspects. According to this paper, working to improve educational quality could be an extremely powerful and effective policy approach.[37] Second, the achievement of quality in higher education remains a major challenge in the developing world, and tackling shortcomings in educational quality requires a long-term perspective, implying changes in educational institutions, laws, and policies. A possible short-term solution for local communities could be to promote programs in which prestigious foreign educational institutions open branches in developing countries that have a growing demand for higher education but lack educational systems of adequately high quality. Renowned universities and higher educational institutions operating beyond their own borders could help such developing countries to increase human capital formation and work their way out of poverty.

[37] We are not claiming that extending educational opportunities to a larger portion of the population is not a legitimate policy aim in and of itself. Rather, we are emphasizing the importance of the quality of the educational system.

A logical extension of this work would be to analyze the determinants of educational quality.[38] In this context, it would be interesting to analyze the policy implications of increasing educational quality in detail. This would be crucial if the goal is to identify ways to stimulate development in poor economies. In sum, there appears to exist enormous potential for researchers and policy makers to focus on the qualitative aspects of education, and with this paper, we are only scratching the surface.

8 References

Altonji, J. G., Hayashi, F., and Kotlikoff, L. J. (1997). "Parental Altruism and Inter Vivos Transfers: Theory and Evidence." *Journal of Political Economy*, 105, 1221-1266.

Aghion, P., Dewatripont, M., Hoxby, C., Mas-Colell, A. and Sapir, A. (2007). "Why Reform Europe's Universities?." Bruegel Policy Brief, 2001 (4), 1-8.

Aghion, P., Dewatripont, M., Hoxby, C., Mas-Colell, A. and Sapir, A. (2009). "The Governance and Performance of Research Universities: Evidence from Europe and the US." NBER Working Paper 14851.

Barro, R. J. and Lee, J-W. (1994). "Data Set for a Panel of 138 Countries". Mimeo. (http://www.nber.org/pub/barro.lee/readme.txt).

Barro, R. J. and Lee, J-W. (2001). "International Data on Educational Attainment: Updates and Implications.". *Oxford Economic Papers*, 53(3), 541-563.

Barro, R.J. and Lee, J-W. (2001). "Schooling Quality in a Cross-Section of Countries." *Economica*, 68, 465-488.

Barro, R. J. and Lee, J. W. (2010). "A New Data Set of Educational Attainment in the World, 1950-2010." NBER Working Paper 15902.

Beck, T. and Demirgüç-Kunt, A. (2010). "Financial Institutions and Markets across Countries and over Time: Data and Analysis." Oxford University Press, vol. 24(1), pages 77-92,.

Belley, P. and Lochner, L. (2007). "The Changing Role of Family Income and Ability in Determining Educational Achievements." *Journal of Human Capital*, 1(1), 37-89.

Berkowitz, D., and Hoekstra, M. (2011). "Does High School Quality Matter? Evidence from Admissions Data." *Economics of Education Review*, 30(2), 280-288

Carneiro P. and Heckman, J.J. (2002) "The Evidence on Credit Constraints in Post-Secondary Schooling". *Economic Journal*, 112, 989-1018.

Case, A. and Deaton, A. (1999). "School Inputs and Educational Outcomes in South Africa." *Quarterly Journal of Economics,* 114(3), 1047-1085.

Castelló-Climent, A. and Doménech, R. (2008). "Human Capital Inequality, Life Expectancy and Economic Growth." *Economic Journal*, 118, 653-677.

[38] From an empirical perspective, Yamauchi (2011) studies how the historical and geographical factors determine the quality of public school education in post-apartheid South Africa. For a paper analyzing the role of teacher effectiveness as a key determinant of school quality see Hanushek (2011). Using different approaches, he found that the estimated impact of improving teacher quality appears to be extraordinarily large.

Duflo, E. (2001). “Schooling and Labor Market Consequences of School Construction in Indonesia: Evidence from an Unusual Policy Experiment.” *American Economic Review*, 91(4), 795-814.

Easterly, W. and Sewadeh, M. (2002). Global Development Growth Data Base, World Bank.

Erosa, A., Koreshokova, T. and Restuccia, D. (2010), "On the Aggregate and Distributional Implications of TFP Differences across Countries." *Review of Economic Studies*, 77(4), 1421-1449.

Galor, O. and Moav, O. (2000). "Ability-biased Technological Transition, Wage Inequality and Economic Growth." *Quarterly Journal of Economics*, 115(2), 469-497.

Galor, O. and Moav, O. (2004). "From Physical to Human Capital Accumulation: Inequality and the Process of Development." *Review of Economic Studies*, 71(4), 1001-1026.

Galor, O., Moav, O. and Vollrath, D., (2009). "Inequality in Land Ownership, the Emergence of Human Capital Promoting Institutions and the Great Divergence." *Review of Economic Studies*, 76(1), 143-179.

Galor, O. and Tsiddon, D. (1997). "The Distribution of Human Capital and Economic Growth." *Journal of Economic Growth*, 2, 93-124.

Galor, O. and Zeira, J. (1993). “Income distribution and macroeconomics,” *Review of Economic Studies,* 60, 35-52.

Guiso, L., Sapienza, P. and Zingales, L. (2003). “People’s opium? Religion and economic attitudes,” *Journal of Monetary Economics*, 50(1), 225-282.

Hanushek, E. (1995). "Interpreting recent research on schooling in developing countries." World Bank Research Observer, 10(2), 227-246.

Hanushek, E. and Kimko, D. (2000). “Schooling, Labor-Force Quality, and the Growth of Nations.” *American Economic Review*, 90(5), 1184-1208.

Hanushek, E., Lavy, V. and Hitomi, K. (2008). “Do Students Care About School Quality? Determinants of Dropout Behavior in Developing Countries.” *Journal of Human Capital*, 2(1), 69-105.

Hanushek, E. and Woessmann, L. (2008). “The Role of Cognitive Skills in Economic Development.” *Journal of Economic Literature*, 46(3), 607-68.

Hanushek, E. and Woessmann, L. (2009). “Do Better Schools Lead to More Growth? Cognitive Skills, Economic Outcomes, and Causation.” NBER Working Paper 14633.

Hidalgo-Cabrillana, A. (2009). "Endogenous Capital Markets Imperfections, Human Capital and Intergenerational Mobility." *Journal of Development Economics*, 90(2), 285-298.

Iyigun, M.F. and Owen, A. L. (2004). “Income Inequality, Financial Development, and Macroeconomic Fluctuations.” *Economic Journal*, 114, 352-376.

Krueger, A. and Lindahl, M. (2001). “Education for Growth: Why and For Whom?.” *Journal of Economic Literature*, 39(4), 1101-1136.

Kyriacou, G. (1991). “Level and Growth Effects of Human Capital.” Working Paper C.V. Starr Center, NYU.

La Porta, R., Lopez-de-Silanes, F., Shleifer, A. and Vishny, R.V. (1999). “The Quality of Government.” *Journal of Law, Economics and Organization*, 15(1), 222-279.

Lorentzen, P., McMillan, J. and Wacziarg, R. (2008). "Death and Development." *Journal of Economic Growth*, 13(2), 81-124.

Mankiw, N. G., Romer, D. and Weil, D. (1992). "A Contribution to the Empirics of Economic Growth." *Quarterly Journal of Economics,* 107(2), 407-437.

Manuelli, R. and Seshadri, A. (2007). "Human Capital and the Wealth of Nations." mimeo, University of Wisconsi.

Mookherjee, D. and Ray, D. (2003). "Persistent Inequality." *Review of Economic Studies*, 70(2), 369-393.

Nehru, V. and Dhareshwar, A. (1993). "A New Database on Physical Capital Stock: Sources, Methodology and Results." *Revista de Analysis Economico*, 8(1),. 37-59.

OECD, Directorate for Education (2009). "Education at a Glance: OECD indicators", http://www.oecd.org/edu/eag2009.

Papaioannou, E. and Siourounis, G. (2008). "Economic and Social Factors Driving the Third Wave of Democratization." *Journal of Comparative Economics,* 36(3), 365-387.

Pritchett, L. (2001). "Where Has All the Education Gone?." *World Bank Economic Review*, 15(3), 367-392.

Romer, P. (1990). "Endogenous Technical Change." *Journal of Political Economy*, 99(5), S71-S102.

Sachs, J., and A. Warner (1997). "Fundamental Sources of Long-Run Growth." *A.E.R. Papers and Proc.* 87 (2): 184–88.

Schoellman, T. Forthcoming. "Education Quality and Development Accounting." *Review of Economic Studies*.

Tamura, R. (2001). "Teachers, Growth, and Convergence," *Journal of Political Economy*, 109(5), 1021-1059.

Yamauchi, F. (2011). "School Quality, Clustering and Government Subsidy in post-apartheid South Africa." *Economics of Education Review,* 30(1), 146–156.

9 Appendix

Proof of Proposition 1: *The extensive channel follows from equations (7) and (9) and Figure 2.*

The intensive channel by contrast appears under Regimes II and III. Under Regime III, the investment in higher education among high and low ability individuals is given by $\gamma I^*_{t,a_L}+(1-\gamma)I^*_{t,a_H}$. *Substituting equations (2) and (8) into condition (5), in general equilibrium we have*

$$I^*_{t,a_j}=(\frac{(1-\alpha)}{\alpha}k_{t+1}\theta^{1+\varepsilon}\varepsilon a_j)^{\frac{1}{1-\varepsilon}}-\frac{\mu}{\theta},\text{ with } j=H,L, \tag{18}$$

such that the following expression is obtained: $\gamma I^*_{t,a_L}+(1-\gamma)I^*_{t,a_H}=\frac{(\beta Y_t+\frac{\mu}{\theta})}{1+\frac{\alpha}{(1-\alpha)\varepsilon}}-\frac{\mu}{\theta}$. *Clearly, it is increasing in* θ, *and therefore the larger the quality, the larger the investment in higher education.*

If the economy is under Regime II, only high ability individuals invest in higher schooling and k_{t+1} *is implicitly given by equation (11). One way to have a close solution for* k^{II}_{t+1} *is to study what* *happens if $\gamma \to 0$. In this special case, everyone is a high ability individual and invests in higher education,*[39] *and k_{t+1}^{II} would be given by*

$$k_{t+1} = \frac{(\beta Y_t + \frac{\mu}{\theta})^{1-\varepsilon}}{\theta^{1+\varepsilon} a_H(\frac{1-\alpha}{\alpha}\varepsilon)[1 + \frac{\alpha}{(1-\alpha)\varepsilon}]^{1-\varepsilon}}. \tag{19}$$

By substituting expression (19) into (18), it is easy to check that $\frac{\partial I_{t,a_H}^*}{\partial \theta} > 0$ always holds.

QED.

Proof of Proposition 2: *If $\widetilde{Y}_{a_L} < Y_{ss}^I$ holds, the following order of the parameters $\widetilde{Y}_{a_H} < \widetilde{Y}_{a_L} < Y_{ss}^I < Y_{ss}^{II} < Y_{ss}^{III}$ holds too, so that the only possible equilibrium is under Regime III. We will show that the law of motion of Y_{t+1}^{III} is strictly concave and that the next condition holds: $\lim_{Y\to\infty} \frac{\partial Y_{t+1}^{III}}{\partial Y_t^{III}} = 0$.*

Substituting conditions (8) and (5) into the law of motion of Y_{t+1}^{III} —given by equation (12)— after some math we obtain the following expression:

$$Y_{t+1}^{III} = \left(\frac{(\beta\theta Y_t + \mu)\alpha}{\theta(\alpha + (1-\alpha)\varepsilon)}\right)^{\alpha} \left(\widetilde{a}^{1-\varepsilon}\theta^{1+\varepsilon}\left(\frac{(\beta\theta Y_t + \mu)(1-\alpha)\varepsilon}{\theta(\alpha + (1-\alpha)\varepsilon)}\right)^{\varepsilon}\right)^{1-\alpha} \tag{20}$$

Taking derivatives $\frac{\partial Y_{t+1}^{III}}{\partial Y_t^{III}} = (\alpha + (1-\alpha)\varepsilon)(\beta\theta Y_t + \mu)^{\alpha+(1-\alpha)\varepsilon-1}\Delta > 0$, with Δ being a strictly positive constant, and $\frac{\partial^2 Y_{t+1}^{III}}{\partial^2 Y_t^{III}} < 0$ since $0 < \varepsilon < 1$. Second, $\lim_{Y\to\infty} \frac{\partial Y_{t+1}^{III}}{\partial Y_t^{III}} = 0$, because $\alpha + (1-\alpha)\varepsilon < 1$.

Equation (20) can be rewritten as:
$Y_{t+1}^{III} = (\beta\theta Y_t + \mu)^{\alpha+(1-\alpha)\varepsilon}(\alpha + (1-\alpha)\varepsilon)^{-\alpha-(1-\alpha)\varepsilon}\alpha^{\alpha}\theta^{1-2\alpha}(\widetilde{a}^{1-\varepsilon}(\varepsilon(1-\alpha))^{\varepsilon})^{1-\alpha}$,
and its growth rate is

$$\frac{Y_{t+1}}{Y_t} - 1 = (\frac{\beta\theta Y_t + \mu}{\beta\theta Y_{t-1} + \mu})^{\alpha+(1-\alpha)\varepsilon} - 1.$$

Because Y_{t+1} is increasing in Y_t, $\frac{\partial(\frac{Y_{t+1}}{Y_t} - 1)}{\partial\theta} = (\alpha + (1-\alpha)\varepsilon)(\frac{\beta\theta Y_t + \mu}{\beta Y\theta_{t-1} + \mu})^{\alpha+(1-\alpha)\varepsilon-1}\frac{\beta\mu}{(\beta Y_{t-1}\theta + \mu)^2}(Y_t - Y_{t-1}) > 0$.

QED.

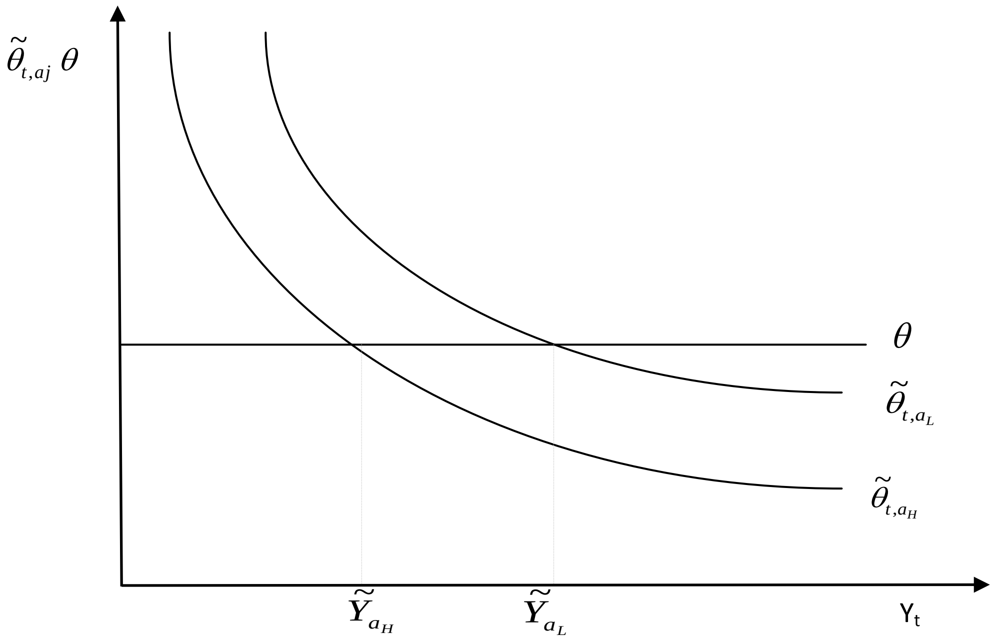
Proof of Corollary 1: *Under Regime III output per worker is given by equation (12), which in turn can be rewrite as $Y_{t+1}^{III} = K_t^{\alpha}H_t^{1-\alpha}$. We know that $I_{t,a^j}^* = \arg\max Y_{t+1}^{III}$, for any a_j with $j = H, L$. Indeed, the FOC of this maximization problem is*

$$\frac{\partial Y_{t+1}^{III}}{\partial I_{t,j}^*} = \alpha K_{t+1}^{\alpha-1}H_{t+1}^{1-\alpha}(-1) + (1-\alpha)K_{t+1}^{\alpha}H_{t+1}^{-\alpha}\{\theta^2 a_j\varepsilon(\mu + \theta I_t^*)^{\varepsilon-1}\} = 0.$$

That is, by using equation (2), the expression above can be rewritten as $R_{t+1} = w_{t+1}\theta^2 a_j\varepsilon(\mu + \theta I_t^*)^{\varepsilon-1}$. As condition 4 shows us, this is the FOC of the optimal level of investment in higher education.

QED.

[39] It does not make sense to study what happens if $\gamma \to 1$, since then everybody is low ability and thus, $I_{t,a_L}^* = 0$.



Regime I	**Regime II**	**Regime III**
$Y_t < \tilde{Y}_{aH}$	$\tilde{Y}_{aH} < Y_t < \tilde{Y}_{aL}$	$\tilde{Y}_{aL} < Y_t$
$\theta < \tilde{\theta}_{t,aH}$	$\tilde{\theta}_{t,aH} < \theta < \tilde{\theta}_{t,aL}$	$\tilde{\theta}_{t,a_L} < \theta$

Figure 2: The evolution of the thresholds

Figure 3: Possible dynamic of aggregate output per worker

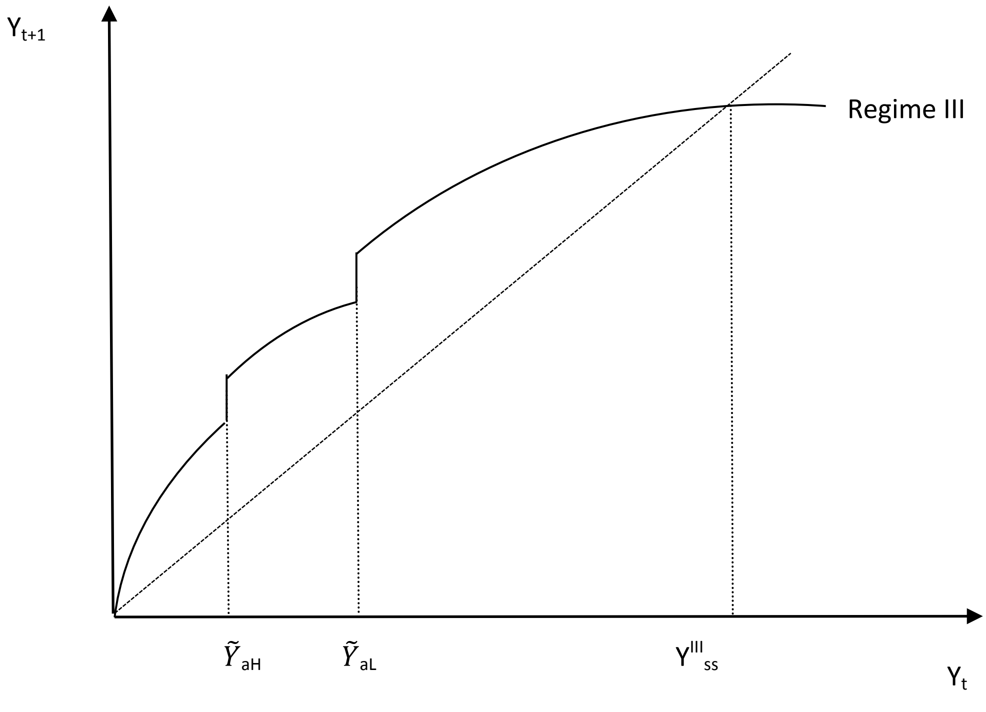


Table 1

Dependent variable: Education at the secondary level

	H1						H2			
	Attainment level ($Education^{SEC}_{1990-2010}$)						Enrollment rates ($\dot{h}^{SEC}_{1990-2010}$)			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
$Quality^{HK}_{60-90}$	0.005^{a}	0.005^{a}	0.004^{a}	0.004^{a}	0.003^{b}	0.003^{b}	0.007^{a}	0.008^{a}	0.007^{a}	
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)	
$Quality^{HK}_{60-90} * Dm^{LOW}_{QLTi}$										-0.000
										(0.003)
$Quality^{HK}_{60-90} * Dm^{HIGH}_{QLTi}$										0.004^{c}
										(0.002)
lny_{60}	0.064^{a}	0.086^{a}	0.007	0.005	0.031	-0.016	0.222^{a}	0.219^{a}	0.201^{a}	0.178^{a}
	(0.022)	(0.020)	(0.029)	(0.030)	(0.030)	(0.024)	(0.028)	(0.028)	(0.031)	(0.028)
d_+		0.350^{a}	0.264^{a}	0.259^{a}	0.295^{a}	0.266^{a}		0.345^{a}	0.342^{a}	0.301^{a}
		(0.063)	(0.037)	(0.044)	(0.040)	(0.033)		(0.038)	(0.037)	(0.036)
d_-		-0.313^{a}	-0.275^{a}	-0.277^{a}	-0.264^{a}	0.264^{a}		-0.354^{a}	-0.335^{a}	-0.283^{a}
		(0.027)	(0.027)	(0.027)	(0.036)	(0.041)		(0.026)	(0.028)	(0.033)
$Education^{SEC}_{60}$									0.324	0.272
									(0.215)	(0.216)
$PSEduc_{60-90}$			0.029^{a}	0.029^{a}	0.026^{a}	0.034^{a}				
			(0.008)	(0.009)	(0.009)	(0.009)				
$lnurb_{60-90}$			0.094^{a}	0.093^{a}	0.087^{a}	0.102^{a}				
			(0.023)	(0.024)	(0.023)	(0.020)				
$Years\ compulsory^{SEC}$				0.002	-0.001	-0.012^{c}				
				(0.008)	(0.007)	(0.006)				
FD_{60-90}					0.014	-0.064				
					(0.054)	(0.058)				
East Asia						0.041				
						(0.045)				
Muslims						-0.001^{b}				
						(0.000)				
Catholics						0.000				
						(0.000)				
Protestants						0.000				
						(0.000)				
School Days						0.001^{c}				
						(0.001)				
Institutions						0.060^{c}				
						(0.032)				
Tropical						-0.097^{a}				
						(0.030)				
Constant	-0.385^{b}	-0.590^{a}	-0.367^{b}	-0.355^{b}	-0.479^{a}	-0.336^{c}	-1.382^{a}	-1.384^{a}	-1.232^{a}	-0.835^{a}
	(0.167)	(0.129)	(0.139)	(0.158)	(0.159)	(0.185)	(0.197)	(0.197)	(0.225)	(0.235)
R^2	0.428	0.603	0.677	0.677	0.698	0.783	0.719	0.754	0.762	0.790
Countries	72	72	66	66	63	63	71	71	71	71

Note: OLS estimation. Robust standard errors in parenthesis. a, b and c stand for significance level at 1, 5 and 10 per cent respectively. Dependent variable is the share of population 25 years and above with secondary education (columns 1-6) and enrollment rates in secondary education (columns 7-10).

Table 2

Dependent variable: Education at the secondary level

	H1						H2			
	Attainment level ($Education_t^{SEC}$)						*Enrollment rates* ($\dot{h}_t^{SEC}$)			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
A- Measure of quality: Barro and Lee (2001), pooled OLS										
$Quality_{t-5}^{BL}$	0.006^b	0.004^c	0.003	0.002	0.005^c	0.003	0.007^b	0.007^b	0.006^b	
	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)	(0.003)	(0.003)	(0.003)	(0.002)	
$Quality_{t-5}^{BL} * Dm_{QLTi}^{LOW}$										0.007
										(0.005)
$Quality_{t-5}^{BL} * Dm_{QLTi}^{HIGH}$										0.006^b
										(0.003)
lny_{t-5}	0.089^a	0.103^a	0.042	0.042	0.058^c	0.057	0.183^a	0.178^a	0.166^a	0.166^a
	(0.027)	(0.025)	(0.033)	(0.032)	(0.030)	(0.044)	(0.025)	(0.024)	(0.027)	(0.027)
R^2	0.392	0.485	0.548	0.564	0.608	0.681	0.655	0.792	0.795	0.795
Countries	40	40	37	37	35	35	40	40	40	40
Obs.	84	84	73	73	68	68	80	80	80	80
B- Measure of quality: Hanushek and Woessmann (2009), OLS										
$Quality_{64-03}^{HW}$	0.052^c	0.061^c	0.072^b	0.072^b	0.056	0.088	0.089^b	0.071^b	0.073^b	
	(0.030)	(0.033)	(0.033)	(0.029)	(0.037)	(0.065)	(0.035)	(0.030)	(0.031)	
$Quality_{64-03}^{HW}$*$\text{dummy}_{Quality}^{LOW}$										0.033
										(0.047)
$Quality_{64-03}^{HW}$*$\text{dummy}_{Quality}^{HIGH}$										0.045
										(0.038)
lny_{60}	0.036	0.061^b	0.004	-0.002	0.013	0.013	0.162^a	0.149^a	0.157^a	0.152^a
	(0.027)	(0.029)	(0.036)	(0.036)	(0.034)	(0.058)	(0.022)	(0.021)	(0.023)	(0.023)
R^2	0.192	0.403	0.503	0.522	0.622	0.670	0.637	0.785	0.788	0.792
Countries	45	45	43	43	41	41	44	44	44	44
C- Measure of quality: Hanushek and Woessmann (2009), IV										
$Quality_{64-03}^{HW}$	0.084^c	0.124^a	0.120^b	0.116^a	0.093	0.184^c	0.177^a	0.177^a	0.187^a	
	(0.045)	(0.044)	(0.045)	(0.041)	(0.073)	(0.098)	(0.048)	(0.043)	(0.050)	
$Quality_{64-03}^{HW}$*$\text{dummy}_{Quality}^{LOW}$										-0.085
										(0.211)
$Quality_{64-03}^{HW}$*$\text{dummy}_{Quality}^{HIGH}$										-0.028
										(0.164)
lny_{60}	0.026	0.031	0.012	0.008	0.023	0.092^c	0.135^a	0.124^a	0.131^a	0.127^a
	(0.027)	(0.021)	(0.036)	(0.035)	(0.036)	(0.054)	(0.021)	(0.020)	(0.019)	(0.026)
R^2	0.169	0.393	0.543	0.557	0.621	0.706	0.609	0.786	0.781	0.755
Countries	44	44	42	42	40	40	43	43	43	43
F-test first-stage	26.15	23.76	35.44	34.52	12.42	8.76	22.22	20.78	18.92	0.97
Additional		d+-	col. 2	col. 3	col. 4	col. 5		d+-	col. 7	col. 7
Controls			$\text{PSEduc}_{t-\tau}$ $\text{lnurb}_{t-\tau}$	YearsComp	$\text{FD}_{t-\tau}$	FE			$\text{Educ}_{t-\tau}^{SEC}$	$\text{Educ}_{t-\tau}^{SEC}$

Note: Robust standard errors in parenthesis. a, b and c stand for significance level at 1, 5 and 10 per cent respectively. Dependent variable is the share of population 25 years and above with secondary education (columns 1-6) and enrollment rates in secondary education (columns 7-10). In panel A dependent variable is measured in period t and explanatory variables also include time dummies. In panel B and C dependent variable is measured as an average over the period 2000-2010.

Table 3

Dependent variable: Quantity of education, averaged 2000-2010

	H1						H2			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
A- Measure of quantity: Secondary Education										
	Attainment level$^{SEC}_{1990-2010}$ population$^{25-39}$						$H^{Years(SEC+TERT)}_{1990-2010}$ $population^{25-39}$			
$Quality^{HK}_{60-90}$	0.005^a	0.006^a	0.005^a	0.005^a	0.003^b	0.003^c	0.060^a	0.048^a	0.034^a	
	(0.002)	(0.002)	(0.002)	(0.002)	(0.001)	(0.001)	(0.015)	(0.013)	(0.012)	
$Quality^{HK}_{60-90}$*dummy$^{LOW}_{Quality}$										0.003
										(0.018)
$Quality^{HK}_{60-90}$*dummy$^{HIGH}_{Quality}$										0.022^c
										(0.011)
lny_{60}	0.067^b	0.076^a	-0.017	-0.016	0.012	-0.021	1.028^a	1.296^a	1.062^a	0.938^a
	(0.027)	(0.024)	(0.032)	(0.034)	(0.034)	(0.039)	(0.199)	(0.166)	(0.172)	(0.171)
R^2	0.359	0.535	0.612	0.613	0.641	0.708	0.621	0.726	0.746	0.761
Countries	72	72	66	66	63	63	72	72	72	72
B- Measure of quantity: Tertiary Education										
	Attainment level$^{TERT}_{2000-2010}$						$\dot{h}^{TERT}_{2000-2010}$			
$Quality^{univ-ranking}_{2003}$	0.061^b	0.062^b	0.065^b	0.064^b	0.063^b	0.059^c	0.082	0.112^a	0.085^b	
	(0.026)	(0.024)	(0.025)	(0.026)	(0.027)	(0.030)	(0.053)	(0.032)	(0.035)	
lny_{1960}	0.056^a	0.054^a	0.031^b	0.030^b	0.034^b	0.025	0.179^a	0.185^a	0.179^a	
	(0.010)	(0.009)	(0.013)	(0.013)	(0.014)	(0.017)	(0.023)	(0.018)	(0.019)	
R^2	0.502	0.724	0.738	0.739	0.738	0.756	0.648	0.814	0.816	
Countries	82	82	75	75	73	73	71	71	70	
C- Measure of quantity: Primary Education										
	Attainment level$^{PRIM}_{1990-2010}$						$\dot{h}^{PRIM}_{1990-2010}$			
$Quality^{HK}_{60-90}$	-0.001	-0.001	-0.001	0.000	0.000	-0.001	-0.001	-0.001^c	-0.001^c	
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)	
lny_{60}	-0.024	-0.034	0.034	0.044	0.057	0.061	0.028	0.020	0.013	
	(0.024)	(0.023)	(0.041)	(0.042)	(0.051)	(0.053)	(0.023)	(0.015)	(0.017)	
R^2	0.042	0.127	0.227	0.254	0.316	0.461	0.041	0.542	0.551	
Countries	72	72	66	66	63	63	71	71	71	
Additional Controls		d+-	col. 2 PSEduc$_{t-\tau}$ lnurb$_{t-\tau}$	col. 3 YearsComp	col. 4 FD$_{t-\tau}$	col. 5 FE		d+-	col. 7 Educ$_{t-\tau}$	col. 7 Educ$_{t-\tau}$

Note: Robust standard errors in parenthesis. a, b and c stand for significance level at 1, 5 and 10 per cent respectively.

Table 4

Dependent variable: *Average Growth rate of real per capita GDP, 1960-2004*

	H3		H4		
	(1)	(2)	(3)	(4)	(5)
lny_{60}	-0.0090^{a}	-0.0110^{a}	-0.0108^{a}	-0.0093^{a}	-0.0094^{a}
	(0.0018)	(0.0016)	(0.0021)	(0.0022)	(0.0020)
$Quality_{60-90}$	0.0005^{a}				0.0004^{a}
	(0.0001)				(0.0001)
$Quality_{60-90} * Dm^{LOW}_{QLT}$		-0.0001			
		(0.0002)			
$Quality_{60-90} * Dm^{HIGH}_{QLT}$		0.0003^{b}			
		(0.0001)			
$\overset{\bullet}{h}{}^{SEC}_{1960}$			0.0310^{a}		
			(0.0091)		
$\overset{\bullet}{h}{}^{SEC}_{1960} * Dm^{LOW}_{Income}$				0.0483^{b}	0.0355^{c}
				(0.0184)	(0.0184)
$\overset{\bullet}{h}{}^{SEC}_{1960} * Dm^{HIGH}_{Income}$				0.0279^{a}	0.0156^{c}
				(0.0081)	(0.0089)
R^2	0.560	0.648	0.534	0.569	0.619
Countries	72	72	72	72	72

	Hanushek and Kimko (2000)		H3	H4	
lny_{60}	-0.0102^{a}	-0.0102^{a}	-0.0111^{a}	-0.0092^{a}	-0.0089^{a}
	(0.0026)	(0.0023)	(0.0020)	(0.0028)	(0.0025)
$Quality_{60-90}$		0.0005^{a}			0.0005^{a}
		(0.0001)			(0.0001)
$Quality_{60-90} * Dm^{LOW}_{QLT}$			-0.0001		
			(0.0002)		
$Quality_{60-90} * Dm^{HIGH}_{QLT}$			0.0003^{b}		
			(0.0001)		
$H^{AverageYears}_{1960}$	0.0021^{a}	0.0008	0.0002		
	(0.0008)	(0.0008)	(0.0007)		
$H^{AverageYears}_{1960} * Dm^{LOW}_{Income}$				0.0028^{a}	0.0017^{b}
				(0.0008)	(0.0008)
$H^{AverageYears}_{1960} * Dm^{HIGH}_{Income}$				0.0018^{b}	0.0005
				(0.0007)	(0.0008)
R^2	0.490	0.567	0.649	0.503	0.588
Countries	72	72	72	72	72

Additional controls:

$(I/GDP)_{60-90}$, $(G/GDP)_{60-90}$, $Trade_{60-90}$, $Inflation_{60-90}$

Note: OLS estimation. Robust standard errors in parenthesis. a, b and c are 1, 5 and 10 per cent significance level respectively. Quality of education is measured through scores in international comparable test, taken from Hanushek and Kimko (2000).

CENTRE FOR ECONOMIC PERFORMANCE
Recent Discussion Papers

1086	Amparo Castelló-Climent Abhiroop Mukhopadhyay	Mass Education or a Minority Well Educated Elite in the Process of Development: the Case of India
1085	Holger Breinlich	Heterogeneous Firm-Level Responses to Trade Liberalisation: A Test Using Stock Price Reactions
1084	Andrew B. Bernard J. Bradford Jensen Stephen J. Redding Peter K. Schott	The Empirics of Firm Heterogeneity and International Trade
1083	Elisa Faraglia Albert Marcet Andrew Scott	In Search of a Theory of Debt Management
1082	Holger Breinlich Alejandro Cuñat	A Many-Country Model of Industrialization
1081	Francesca Cornaglia Naomi E. Feldman	Productivity, Wages and Marriage: The Case of Major League Baseball
1080	Nicholas Oulton	The Wealth and Poverty of Nations: True PPPs for 141 Countries
1079	Gary S. Becker Yona Rubinstein	Fear and the Response to Terrorism: An Economic Analysis
1078	Camille Landais Pascal Michaillat Emmanuel Saez	Optimal Unemployment Insurance over the Business Cycle
1077	Klaus Adam Albert Marcet Juan Pablo Nicolini	Stock Market Volatility and Learning
1076	Zsófia L. Bárány	The Minimum Wage and Inequality - The Effects of Education and Technology
1075	Joanne Lindley Stephen Machin	Rising Wage Inequality and Postgraduate Education
1074	Stephen Hansen Michael McMahon	First Impressions Matter: Signalling as a Source of Policy Dynamics
1073	Ferdinand Rauch	Advertising Expenditure and Consumer Prices

1072	Alberto Galasso Mark Schankerman Carlos J. Serrano	Trading and Enforcing Patent Rights
1071	Daniel Hale John Coleman Richard Layard	A Model for the Delivery of Evidence-Based PSHE (Personal Wellbeing) in Secondary Schools
1070	David Marsden	Individual Voice in Employment Relationships: A Comparison Under Different Forms of Workplace Representation
1069	Ross Levine Alexey Levkov Yona Rubinstein	Racial Discrimination and Competition
1068	Klaus Adam Albert Marcet	Internal Rationality, Imperfect Market Knowledge and Asset Prices
1067	Yanhui Wu	A Simple Theory of Managerial Talent, Pay Contracts and Wage Distribution
1066	Yanhui Wu	Managerial Incentives and Compensation in a Global Market
1065	Nicholas Bloom Helena Schweiger John Van Reenen	The Land that Lean Manufacturing Forgot? Management Practices in Transition Countries
1064	Klaus Adam Pei Kuang Albert Marcet	House Price Booms and the Current Account
1063	Stephen Hansen Michael McMahon	How Experts Decide: Identifying Preferences versus Signals from Policy Decisions
1062	Paul Dolan Daniel Fujiwara Robert Metcalfe	A Step Towards Valuing Utility the Marginal and Cardinal Way
1061	Marek Jarocinski Albert Marcet	Autoregressions in Small Samples, Priors about Observables and Initial Conditions
1060	Christos Genakos Kai Uwe Kühn John Van Reenen	Leveraging Monopoly Power by Degrading Interoperability: Theory and Evidence from Computer Markets
1059	Klaus Adam Albert Marcet	Booms and Busts in Asset Prices

The Centre for Economic Performance Publications Unit
Tel 020 7955 7673 Fax 020 7955 7595
Email info@cep.lse.ac.uk Web site http://cep.lse.ac.uk