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The Importance of Human Capital for Economic Growth

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Abstract

Recent theoretical contributions to the growth literature emphasize the role of human capital in the process of economic growth. Meanwhile, the empirical literature on the link between human capital and growth has changed course several times over the last decade. On balance, the evidence now seems to indicate that educational expansion does contribute to output growth. There also appear to be grounds for thinking that human capital has a substantial impact on technological catch-up, possibly through improving a country's capacity to adopt new technologies. However, the literature is subject to many methodological and conceptual weaknesses, such as the inadequacy of empirical human capital proxies and reverse causality. Therefore, these conclusions have to be considered preliminary and fragile.

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The Importance of Human Capital for Economic Growth

Florian Schütt*

1 Introduction

The idea that human capital plays an important role in explaining income differences has been present in economists' thinking for a long time. By some accounts, it can even be traced to the work of *Adam Smith* and *Alfred Marshall*,[1] although it was not until the middle of the 20th century that *Gary Becker*[2] and others developed a theory of human capital. This theory, according to which a person's level of education and experience determine his or her (labor) income, was originally envisaged in a microeconomic context, but has subsequently been applied to macroeconomics. Growth accountants such as *Denison*[3] and *Jorgenson/Griliches*[4] examined to what extent changes in the quality of the workforce could explain the "residual" total factor productivity (TFP) unaccounted for by increases in labor and capital inputs.

However, it was the emergence of 'new growth theory' and, in particular, the important contribution by *Lucas*[5] that really sparked interest in the relationship between human capital and growth. The past decade has seen a flood of cross-country regressions which, besides testing for convergence, have attempted to reveal the determinants of growth differences across nations.[6] While countless variables have been included in those regressions, one of the most researched possible sources of growth is human capital. The objective of this paper is to survey and evaluate the empirical findings on the link between human capital and economic growth that this literature has produced. It will address the question whether the prominent role accorded to human capital in recent theories of economic growth is supported by the evidence. Only cursory attention will be devoted to the microeconomic literature and to the contributions of growth accounting.

It seems appropriate to discuss some terminological aspects before proceeding. Human capital is a complex theoretical concept that is not defined in a uniform manner. In its most general form, it refers to the resources in people.[7] It has been defined by the OECD as "the knowledge, skills, competences and other attributes embodied in

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1 See *Wößmann* (2000); *Piazza-Georgi* (2002).

2 See *Becker* (1975, first published in 1964).

3 See *Denison* (1967).

4 See *Jorgenson/Griliches* (1967).

5 See *Lucas* (1988).

6 For a review of the "new growth evidence", see *Temple* (1999a).

7 See *Becker* (1975: 9).

individuals that are relevant to economic activity".[8] This is a broad definition because it is not restricted to education but encompasses all investments in humans which are made to improve their skills. These can include schooling and parental education as well as on-the-job training and learning-by-doing (i.e., acquiring skills through work experience) or other activities that help a person put his or her skills to productive use.[9] In addition, just like physical capital, human capital may depreciate (as people forget what they have learned and as certain abilities deteriorate with age, for example) or become obsolete.

Unfortunately, mainly due to problems of data availability, the empirical cross-country research which is the focus of this paper has been limited to studying the impact of formal education on economic growth. In addition, a lack of theoretical insights concerning the mechanisms governing the depreciation of human capital has for the most part prevented the inclusion of depreciation in empirical studies. Accordingly, the scope of the present paper is constrained in both of these regards.

An important distinction which should be made is between human capital and abstract technological knowledge.[10] Although human capital involves the acquisition of knowledge, it differs in one respect from abstract knowledge such as an invention or a design. Human capital is a private good in that it is tied to a person and is therefore rival and excludable.[11] To take *David Romer's* example, if an engineer devotes his full effort to one activity, his skills cannot be used simultaneously in another activity.[12] By contrast, technological knowledge is nonrival because it can be used in many different activities at the same time. Its replication may not be entirely without cost, but in an era of photocopiers and computers it is arguably negligible, whereas training a second person is as costly as training the first.[13]

The remainder of this paper is structured as follows. Section 2 will present the main approaches taken to model the role of human capital in economic growth. It will explain in which way human capital affects output in each of these models and derive some predictions which lend themselves to empirical testing. Section 3 will turn to the empirical evidence. As we will see, the importance of human capital for economic growth has been an intensely debated topic. After summarizing the results of some of the most influential studies, the section will take a detailed look at the methodological and conceptual issues which have to be taken into account when interpreting their findings, and try to assess which of the obtained results are most reliable. Section 4 summarizes the preceding discussion and provides some concluding observations.

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8 See *OECD* (1998: 9).

9 Some authors reckon that human capital should be defined not only in terms of skills but also in terms of health, and have studied health as another possible source of growth (e.g., *Bloom/Canning/Sevilla* 2001). Health-related aspects, however, will not be reviewed here.

10 See *Paul Romer* (1990: S74-S75); *David Romer* (2001: 133).

11 Although, as will be discussed later, human capital may be only partially excludable because of possible externalities. It could then not be classified as a purely private good.

12 See *David Romer* (2001: 133).

13 See *Paul Romer* (1990: S75).

2 The role of human capital in theoretical models of economic growth

This section does not attempt to give an exhaustive overview of theories of growth involving human capital. Instead, it will present those models that have had the biggest impact on the empirical literature that is the subject of section 3. These are the augmented neoclassical growth model, the *Lucas* (1988) model and the *Romer* (1990) model, which will successively be examined below. Beforehand, the section offers a brief (verbal) review of the original *Solow* model.

2.1 Exogenous growth models

2.1.1 Main features of the original *Solow* model with technological progress

The centerpiece of the standard neoclassical growth model developed by *Solow*[14] is an aggregate production function of the form $Y_t = F(K_t, L_t \cdot A_t)$, where Y is output, K is capital, L is labor and A is an index of technology or efficiency. *Solow* posits that F has the usual neoclassical properties; in particular, it is characterized by constant returns to scale, decreasing returns to each input, and a positive and constant elasticity of substitution. The fundamental dynamic equation of the model relates the evolution of the capital stock to a constant rate of saving and a constant rate of depreciation. Labor and the level of technology grow at exogenous exponential rates.
If there were no technological progress, growth in this model would eventually come to a halt. However, the formulation of the model is chosen so as to allow increases in efficiency to offset the diminishing returns to capital. The economy therefore converges to a steady state in which output and capital per worker both grow at the exogenous rate of technological progress. Accordingly, in the long run, economic growth is unaffected by changes in the rate of saving or population growth. Changes in these parameters alter only the *level* of the long-run growth path, but not its slope.

2.1.2 The human-capital augmented Solow model

Starting from the *Solow* model, the simplest way to introduce human capital is the one chosen by *Mankiw/Romer/Weil*.[15] In their influential contribution, they present a simple extension to the *Solow* model by letting human capital enter as a separate input into an otherwise standard Cobb-Douglas production function with Harrod-neutral (i.e., labor-augmenting) technological progress.[16] The production technology in this model, which

[14] See *Solow* (1956).

[15] See *Mankiw/Romer/Weil* (1992).

[16] The Cobb-Douglas case is an exception insofar as the existence of a steady state is compatible with other concepts of neutrality too. This does not pertain to the more general form of a neoclassical production function, which requires Harrod-neutrality for a steady state to exist. Formal proof of this is given by *Barro/Sala-i-Martin* (1995: 54-55).

has come to be known as the human-capital augmented *Solow* model, thus takes the form:

$$Y_t = K_t^{\alpha} H_t^{\beta} (A_t L_t)^{1-\alpha-\beta}, \tag{1}$$

where Y is output, K is capital, H is the stock of human capital, A is the level of technology and L is "raw" labor. The exponents α, β and 1-α-β measure the elasticity of output to the respective inputs. *Mankiw/Romer/Weil* assume $\alpha + \beta < 1$, so that the function exhibits constant returns to scale but diminishing returns to reproducible factors.[17] Like in the *Solow* model, the population and the level of technology grow at the exogenous rates n and g, respectively, while capital depreciates at the rate δ.
Mankiw/Romer/Weil make three other important assumptions; namely

- that people invest in human capital just like they invest in physical capital; that is, by foregoing consumption and devoting a fraction s_H of their income to the accumulation of human capital (analogous to the fraction s_K invested in physical capital),
- that human capital depreciates at the same constant rate δ as physical capital, and
- that output (the homogeneous good produced in the economy) can be used for either consumption or investment in (physical or human) capital.[18]

We will briefly present the fundamental differential equations of the model and its steady-state properties as they will prove useful both for deriving empirical predictions and for understanding one of the most frequently used econometric specifications when reviewing the empirical literature in section 3. First, rewriting equation (1) in intensive form (i.e., in units of effective labor) yields:

$$\hat{y}_t = \hat{k}_t^{\alpha} \hat{h}_t^{\beta}, \tag{2}$$

where $\hat{y} = Y / AL$, $\hat{k} = K / AL$ and $\hat{h} = H / AL$. Given the above-mentioned assumptions, the behavior of physical and human capital per effective worker is then described by

$$\begin{aligned} \dot{\hat{k}}_t &= s_K \hat{y}_t - (n + g + \delta)\hat{k}_t = s_K \hat{k}_t^{\alpha} \hat{h}_t^{\beta} - (n + g + \delta)\hat{k}_t \\ \dot{\hat{h}}_t &= s_H \hat{y}_t - (n + g + \delta)\hat{h}_t = s_H \hat{k}_t^{\alpha} \hat{h}_t^{\beta} - (n + g + \delta)\hat{h}_t. \end{aligned} \tag{3}$$

Mankiw/Romer/Weil show that, by setting $\dot{\hat{k}}_t$ and $\dot{\hat{h}}_t$ to 0 and solving the resulting system of equations, one obtains the following steady-state values for $\hat{k}$ and $\hat{h}$:[19]

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17 This makes sure that the economy converges to a steady state, a property of the model which, as will be shown later, has important implications for the long-run behavior of the economy.

18 See *Mankiw/Romer/Weil* (1992: 416).

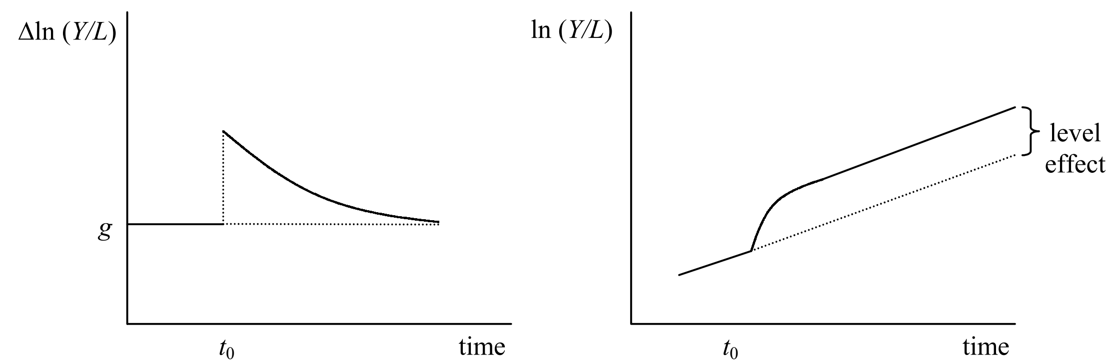
19 See *Mankiw/Romer/Weil* (1992: 417).

$$\hat{k}^* = \left(\frac{s_K^{1-\beta} s_H^{\beta}}{n + g + \delta} \right)^{1/(1-\alpha-\beta)}$$
$$\hat{h}^* = \left(\frac{s_K^{\alpha} s_H^{1-\alpha}}{n + g + \delta} \right)^{1/(1-\alpha-\beta)} . \quad (4)$$

Because of the assumption of diminishing returns to "broad" capital (human and physical) and just like in the original *Solow* model, measured in effective units of labor, all quantities are constant in the steady state, so that output per worker (*Y/L*) and capital per worker (*K/L* and *H/L*) grow at the exogenous rate of technological progress *g*. This implies that an increase in the rate of investment in human capital s_H has no effect on the long-run growth rate of the economy. Although there is no rate effect, the increase does have a level effect. As the steady-state equations (4) indicate, the level of steady-state income per capita is positively related to the rates of investment in physical and human capital and negatively related to the rate of population growth. Therefore, a (permanent) increase in the fraction of income devoted to the accumulation of human capital shifts the steady-state level of income upwards, leading to a higher long-run growth path.

The transitional dynamics of this model are similar to those of the original *Solow* model too. In particular, an upward shift of the steady state due to an increase in either rate of investment leads to a temporarily higher growth rate while the economy converges to its new steady state. As the economy approaches its higher growth path, the rate of growth gradually returns to its initial value. The transitional dynamics and the corresponding level effect are illustrated in figure 1, with the left-hand graph showing the evolution of the growth rate (denoted Δln (*Y/L*)) and the right-hand graph that of log output per capita following a permanent increase in either investment rate at time t_0.

Fig. 1: Effect of an increase in s_H or s_K in the augmented *Solow* model



Source: *Jones* (1998: 38-39).

One important difference in comparison to the original *Solow* model concerns the magnitude of the effect of a change in the saving rate on the level of income. In the augmented neoclassical growth model, the elasticity of income with respect to the rate of investment is higher. This is because a higher saving rate raises the steady-state level of income, thereby raising human capital accumulation as well, even if the rate of investment in human capital remains unchanged.[20,21] Consequently, the level effect due to a change in the investment rate is more pronounced in the augmented *Solow* model than in the original version without human capital.

In summary, the human-capital augmented *Solow* model treats human capital basically as an additional, ordinary input in production. Human capital is modeled in exactly the same way as physical capital: It is accumulated by investing a fraction of income in its production, depreciates at the same rate as physical capital, and is produced with the same technology as both physical capital and consumption. Meanwhile, like in the original *Solow* model, long-run growth is exogenous, its rate equaling the pace of technological progress.

2.2 Endogenous growth models

The most unsatisfactory feature of the growth literature of the 1950s and 60s was the fact that the main subject of study, the long-run growth rate, was exogenous to the model. 'New growth theory', jumpstarted by *Romer*[22], attempted to 'endogenize' the sources of growth, so that the rate of growth would be determined *within* the model. The endogenous growth literature has produced two distinct approaches on how to incorporate human capital into models of economic growth.[23] The first, which is due to Lucas, regards the *accumulation* of human capital as the engine of growth[24] (subsection 2.2.1). The second approach emphasizes the role of the human capital *stock* in the process of innovation and adoption of new technologies[25] (subsection 2.2.2).

2.2.1 Growth driven by human capital accumulation

In the model formulated by *Lucas*,[26] human capital enters into the production function similarly to the way in which technology does in the *Solow* model, that is, in labor-augmenting form (which would seem like a rather natural way to conceptualize things). The economy consists of identical individuals (or representative agents) maximizing life-time utility. Agents have control over two variables: the level of consumption, and the allocation of time between work and skill acquisition. The first variable determines

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20 See *Mankiw/Romer/Weil* (1992: 432-433).

21 Obviously, the argument can be applied in the same way to a change in the rate of human capital accumulation.

22 See *Romer* (1986).

23 See *Aghion/Howitt* (1998: 327).

24 See *Lucas* (1988).

25 See *Romer* (1990); *Nelson/Phelps* (1966).

26 See *Lucas* (1988).

the accumulation of physical capital, while the second variable affects an agent's future productivity. *Lucas* proposes the following production technology:[27]

$$Y_t = AK_t^{\beta}\left(u_t h_t L_t\right)^{1-\beta} h_{a,t}^{\gamma}, \tag{5}$$

where *Y*, *A*, *K* and *L* are, once again, output, technology, capital and labor, while *u* is the fraction of an individual's time allocated to work, *h* is the skill level or human capital of the representative agent, and h_a is the average human capital in the economy.[28] The level of technology, *A*, is assumed to be constant (so that it could in principle be dropped from the expression or subsumed within the capital term). Population growth is taken as exogenous. Setting aside the last term on the right-hand side for the moment, the most important assumption of the model concerns the law of motion according to which the human capital variable evolves over time. *Lucas* writes:

> *"To complete the model, the effort* 1-u_t *devoted to the accumulation of human capital must be linked to the rate of change in its level,* h_t. *Everything hinges on exactly how this is done."*[29]

Specifically, *Lucas* assumes the function relating the fraction of time allocated to skill acquisition $1\text{-}u_t$ to the growth rate of human capital $\frac{\dot{h}_t}{h_t}$ to have a linear form, so that:

$$\dot{h}_t = h_t\delta\left(1-u_t\right) \Leftrightarrow \frac{\dot{h}_t}{h_t} = \delta\left(1-u_t\right), \tag{6}$$

where the parameter δ is the maximum attainable growth rate of *h*, which one might refer to as the productivity of schooling.[30] The linearity assumption implies that the growth rate of human capital is independent of its level. In other words, no matter how much human capital has been accumulated, a given effort always produces the same percentage increase. *Romer* has offered a possible explanation why this may be plausible: The acquisition of skills may in fact facilitate or prepare learning.[31] As an example, he states that in primary school, children are taught basic knowledge (such as literacy) which may not improve their ability to contribute to production by very much. Instead, it may be a prerequisite for the acquisition of productivity-enhancing skills throughout the rest of their education and their professional career.

Because there are no diminishing returns to the acquisition of skills, human capital can grow without bound, thereby generating endogenous growth. The properties of the

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27 See *Lucas* (1988: 18).

28 Obviously, h_a is equal to *h* in an economy populated by identical agents. *Lucas* (1988: 18) chooses this alternative notation to set the last term off against the one directly affecting the quality of labor, because it represents an external effect. This feature of the model will be examined below.

29 *Lucas* (1988: 18).

30 See *Aghion/Howitt* (1998: 330).

31 See *Romer* (2001: 134).

steady state in the *Lucas* model depend on whether there are external effects of human capital, which is the case if $\gamma \neq 0$. In that case, the term $h^{\gamma}_{a,t}$ in (5) is different from 1 and therefore affects output.[32] The externality arises from the fact that the effect on h_a of individual decisions with regard to the acquisition of human capital is too small to be perceived by individual agents. This is because the benefits of higher average human capital are being spread over the whole population and cannot be appropriated by an individual.[33] We will turn to possible reasons for the existence of external effects shortly.

In the steady state, if there is no externality ($\gamma = 0$), output, physical and human capital per capita grow at the same rate (constituting a so-called balanced growth path). As *Temple* points out, one consequence of this is that, because the ratio of human capital to physical capital is constant in the steady state, there is an imbalance effect: When an exogenous shock happens to increase the level of human capital, this will trigger an equiproportional rise in physical capital to restore the steady-state ratio.[34] Stated differently, one would expect that an increase in human capital per worker would lead to higher investment in physical capital too. In the case where there is a positive external effect ($\gamma > 0$), physical capital per worker will grow faster than h.[35] In addition, in the presence of an external effect, a competitive equilibrium will lead to suboptimal growth (which might justify government intervention).

In any case, the growth rate of human capital, as can be seen from (6), depends on δ and the determinants of the equilibrium value of the fraction of time devoted to skill acquisition ($1-u^*$) which, in turn, depends on the following parameters:

- the rate of time preference, which is negatively associated with $1-u^*$. That is, a higher discount rate leads to lower human capital growth;
- the coefficient of relative risk aversion, which is also negatively related to the time spent acquiring skills; and
- the productivity of schooling δ, which positively affects $1-u^*$.

Although the existence of spillovers from human capital is not a necessary condition for sustained growth in this model (what is truly responsible is the fact that there are constant returns to human capital production), the question of whether or not there are externalities to the average level of skills in the workforce is clearly of significance. One example of positive human capital externalities may be social benefits such as crime reduction.[36] *Lucas* himself offers an alternative explanation, and presents some general observations which support the existence of positive externalities.[37] He points out that in the arts and sciences (the "creative professions"), the interaction between colleagues has great benefits and will often prove stimulating for their intellectual

32 In fact, as observed by *Rudd* (2000), average human capital "acts as a Hicks-neutral shift-term in the production function."

33 See *Lucas* (1988: 18).

34 See *Temple* (2001a: 78).

35 See *Lucas* (1988: 23).

36 See *Krueger/Lindahl* (2001: 1107).

37 See *Lucas* (1988: 38-40).

output. Moreover, he argues that "economic life is creative in much the same way".[38] According to Lucas, there are two facts which can be interpreted as largely supportive of this view: immigration, and the existence of cities. First, if there were no externalities to human capital, it would offer the highest returns in countries were it is in scarce supply. Thus, one would expect to observe migration of skilled workers from rich to poor countries, instead of the observed flows in the opposite direction.[39] Second, without external effects, there is no reason for cities to exist: Capital and labor could just as well move to the countryside, where the rental price of land is much lower. The prospect of revealing evidence confirming the existence of human capital externalities has been one of the major motivations for the empirical macroeconomic literature looking into the importance of human capital for growth.[40,41]

It is instructive to consider the differences between the *Lucas* model and the augmented neoclassical growth model from the previous section (apart from the fact that the *Lucas* model allows for an external effect). *Lucas* assumes that individuals invest in human capital by spending part of their *time* acquiring skills, instead of a fraction of their *income*, like in *Mankiw/Romer/Weil* (1992). Besides, *Lucas* ignores depreciation of human capital. More importantly, and contrary to *Mankiw/Romer/Weil*, in the *Lucas* model, there are two sectors of production: one for consumption goods and physical capital, and another for human capital. The only input in the production of human capital is human capital.[42] This takes into consideration that education "relies heavily on educated people as an input".[43] Above all, of course, the *Lucas* model is characterized by self-sustained growth, which is driven by the accumulation of human capital. If, for some reason, the equilibrium value of $1-u$ (the time spent acquiring skills) were to rise, this would lead to a permanent increase of growth. Therefore, additional skill acquisition has a rate effect in the *Lucas* model, as opposed to the augmented *Solow* model, where (permanently) higher human capital accumulation only causes a level effect. Note, however, that a one-off increase in the *stock* of human capital has no effect on the rate of growth. This is the fundamental feature differentiating the *Lucas* model from the endogenous growth models discussed in the following subsection.

2.2.2 Human capital and technological change

A second category of endogenous growth models maintains the assumption underlying the *Solow* model that technological progress is at the heart of economic growth. However, by no longer leaving technological change unmodeled, these theories acknowledge that a large portion of inventions is the result of purposeful research and

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38 *Lucas* (1988: 38).

39 There may, of course, be alternative explanations for the observed migration flows, such as capital-skill complementarity or technology-skill complementarity.

40 Whether cross-country studies can actually serve this purpose is another matter. See section 3.3.

41 See *Krueger/Lindahl* (2001: 1108); *Temple* (2001a: 78).

42 One can arrive at similar results without making the extreme assumption that no physical capital at all is used in the production of human capital. It is sufficient to assume that human capital production is relatively intensive in human capital (see *Barro/Sala-i-Martin* 1995, chapter 5).

43 *Barro/Sala-i-Martin* (1995: 200).

development (R&D) activities carried out in reaction to economic incentives. This changes the role for human capital, which enters into these models as a catalyst of technological progress rather than as an independent source of sustained growth.

Nelson/Phelps were the first to contend that people's educational attainment may have a significant influence on their ability to adapt to change and introduce new technologies.[44] Accordingly, a higher level of human capital would speed up the process of technological diffusion in the economy. This would enable countries lagging behind the world technology frontier to catch up faster to the technological leader. However, in the model developed by *Nelson/Phelps*, the evolution of the best-practice level of technology is left exogenous, so that human capital only plays a role in helping countries narrow the gap to the technological frontier.[45] *Romer* has extended this concept beyond the adoption of existing technologies to the creation of new ones, starting from the observation that R&D activities require highly skilled labor as the single most important input.[46] A major implication of both of these approaches is that technological progress, and thus growth, depends on the *stock* of human capital (as opposed to its accumulation). In what follows, the analysis will be limited to a brief description of the general structure of the *Romer* model. In accordance with the subject of this paper, the aim is to highlight the role of human capital.

In *Romer's* model, the economy has three sectors: a final-goods sector, an intermediate-goods sector, and a research sector.[47] The research sector uses human capital and the existing stock of knowledge to produce designs for new capital goods, which are sold to the intermediate-goods sector. The latter uses the designs and the economy's savings to produce intermediate capital goods, which are combined in the final-goods sector with labor and human capital to produce final output. The production function for the final-goods sector is:[48]

$$Y = H_Y^{\alpha} L^{\beta} \sum_{i=1}^{A} x_i^{1-\alpha-\beta} , \qquad (7)$$

where Y and L are output and labor, H_Y is human capital employed in production, A is the stock of knowledge, and x_i are the intermediate producer durables used in final goods production. The disaggregation of capital into different types of intermediate inputs which have additively separable effects on output is the distinctive feature of *Romer's* production technology. As can be seen from (7), the number of different intermediate capital goods in the economy depends on the stock of knowledge, A. Knowledge is assumed to be a nonrival good,[49] which, as will be shown, has important

44 See *Nelson/Phelps* (1966).

45 See *Nelson/Phelps* (1966: 71).

46 See *Romer* (1990).

47 See *Romer* (1990).

48 To simplify mathematical treatment, *Romer* (1990) uses a continuous formulation of the production function, which becomes $Y = H_Y^{\alpha} L^{\beta} \int_0^A x_i^{1-\alpha-\beta} di$. This does not change the basic idea.

49 See the introduction for an explanation of why abstract knowledge is generally considered as nonrival.

consequences. A major simplifying assumption of the model is that both the supply of labor, L, and the total stock of human capital in the economy, H, are constant over time.
Each intermediate good is produced by a different, monopolistically competitive firm which acquires the (infinitely-lived) patent for its production from the research sector. The choice of this particular market structure (monopolistic competition) is dictated by the nonrivalry of knowledge. As *Romer* points out, the existence of a nonrival input (which constitutes a fixed cost) necessarily leads to increasing returns to scale,[50] which are widely known to be incompatible with perfect competition.[51] In a competitive equilibrium where output sells at marginal cost, the remuneration of the rival inputs (capital and labor) exhausts the firms revenues, so that it could not pay for the fixed cost. Consequently, under perfect competition, no research would be undertaken. In *Romer's* model with monopolistic competition, the price of intermediate goods exceeds their marginal cost because of monopoly rents. This allows the firms in the intermediate-goods sector to pay for the patents and thereby finance the R&D activities. However, the firms in the intermediate-goods sector cannot appropriate these monopoly rents because they are fully paid out to compensate the research sector.
A second consequence of the nonrivalry of ideas concerns the production of knowledge itself. The number of designs created in the research sector represents the stock of knowledge, which *Romer* assumes to evolve as follows:[52]

$$\dot{A} = \delta H_A A \Leftrightarrow \frac{\dot{A}}{A} = \delta H_A . \tag{8}$$

H_A is human capital employed in research (subject to $H = H_Y + H_A$), while δ is a parameter measuring the productivity of research. Equation (8) says that the creation of new knowledge is a function of human capital allocated to R&D activities and of the existing knowledge stock.
The reasons for sustained growth in this model are twofold.[53] First, there is an increasing variety of products which expands with the stock of ideas, A. Second and more importantly, *Romer* assumes that there are knowledge spillovers because all researchers have unrestricted access to the existing stock of knowledge. This is why A enters into the production function of new knowledge in (8).[54] Moreover, the linearity assumption in (8) is equivalent to supposing that the productivity of human capital employed in research increases in proportion with A. This makes sure that knowledge can grow without bound, and generate endogenous growth.
In the steady state, capital, output and the stock of knowledge all grow at the same rate, driven by technological progress. Equation (8) implies that the growth rate of A depends on the amount of human capital employed in research, H_A, which, as *Romer* shows, is a linear function of the *total* stock of human capital (that is, $H_A + H_Y$) and the rate of

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50 In this particular case, the nonrival input is the idea or design which constitutes a fixed cost because it obviously does not have to be reproduced to increase output.

51 See *Romer* (1990: S75-S76).

52 See *Romer* (1990: S83).

53 See *Aghion/Howitt* (1998: 37).

54 This is an effect that *Jones* (1998: 93) relates to Newton's famous statement, "If I have seen farther than others, it is because I was standing on the shoulders of giants."

interest (which is not of much relevance in this context).[55,56] What this means is that a rise in the stock of human capital will permanently speed up growth. This is what distinguishes *Romer's* model from the *Lucas* model, where a rate effect requires an increase in the *rate of accumulation* of human capital. In the *Romer* model, a one-time increase of the stock of human capital is sufficient to augment the rate of economic growth forever.

2.3 Testable predictions generated by the models

On a theoretical level, the three models presented above differ significantly from each other. Their main distinguishing features are summarized in table 1. Given these differences, it is interesting that the empirically testable predictions which can be derived from the models do not vary as radically as the theoretical debate might lead one to expect.

Table 1: Differences between models of economic growth which include human capital

	Augmented *Solow* model	***Lucas* model**	***Romer* model**
Human capital is accumulated by…	investing a fraction of income	spending a fraction of time acquiring skills	not modeled
Technology for production of human capital	same production function for C, K and H	separate sector for production of H using only human capital	not modeled
Role of human capital	input in production	input in production of Y and H	input in production of Y and A
Growth rate determined…	outside of the model	within the model	within the model
Determinant of long-run growth	Exogenous technological change	rate of human capital accumulation	stock of human capital
Effect of a permanent change in the variable governing the accumulation of human capital	level effect (relevant variable: s_H)	rate effect (relevant variable: 1-u*)	rate effect (though not explicitly modeled)
Effect of a one-off increase in the stock of human capital	level effect	level effect	rate effect

Reversing the order of the earlier presentation, we turn first to the endogenous growth models of section 2.2 and their empirical implications concerning the way in which human capital may influence cross-country differences in growth rates. In the *Lucas*

55 See *Romer* (1990: S92).

56 The interest rate is negatively related to H_A. The intuition behind this is that a lower interest rate and therefore a lower discount rate raises the return to research because it increases the net present value of the stream of profits to be collected by the researcher.

model (taken literally), a country's rate of growth depends on the fraction of time spent acquiring skills which, in turn, is a function of a number of preference parameters.[57] Those parameters are (at best) extremely difficult to observe, and theory offers no explanation why they should vary across time and space. It should be noted that *Lucas* concedes that his model is unable to explain diversity over countries or over time (it was not devised to do so, either).[58] However, moving away from such a narrow interpretation of the model, what drives output growth in *Lucas's* model is the accumulation of human capital (i.e., how much the level of skills of the population is increasing over time). Therefore, a country's rate of economic growth would be expected to rise with the growth rate of human capital, but it should be unrelated to the initial level of skills in the population.

By contrast, according to the approach chosen by *Romer* (1990) and *Nelson/Phelps* (1966), it is the *level* of human capital which influences the rate of productivity growth, not its rate of accumulation. This result is due to the fact that in these models, human capital is an input in the production of new ideas, and therefore an important determinant of the pace of innovations. Consequently, economic growth should tend to accelerate as more human capital is employed in research. *Jones* observes that this last prediction is of course at odds with empirical evidence: Although the number of scientists and other high-skilled workers engaged in research has grown substantially over the last 40 years, growth rates show no discernible trend.[59] This strongly rejects the (somewhat arbitrary) assumption made by *Romer* that the productivity of human capital employed in research is proportionally related to the state of technology. Nevertheless, *Jones* notes that other formulations, where the productivity of researchers is less than proportional to the stock of knowledge, also allow for the kind of knowledge spillovers which are essential for sustained growth.[60] Hence, while the precise functional form assumed by *Romer* does not seem plausible, the basic idea, namely, that the stock of human capital has an effect on technical change, remains valid.

The human-capital augmented *Solow* model predicts that, other things being equal, a country should have a higher level of per capita income if it has a high amount of human capital. In particular, steady-state income depends on the rate of investment in human capital. However, the emphasis of this paper being on growth rather than levels of income, the more interesting implications of the model are those concerning economic growth. Recall that in the steady state, growth depends only on the rate of exogenous technological progress. Thus, if all countries were in their steady states, differences in growth rates could arise only because of different rates of technical progress across countries, and the model gives no reason why these should vary.[61] But if countries converge slowly to their steady states, so that most of them could be expected to be out of their steady states, the transitional dynamics of the model allow one to make

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57 See section 2.2.1.

58 See *Lucas* (1988: 40).

59 See *Jones* (1995: 761-762).

60 See *Jones* (1995: 765). Formally, this would mean rewriting equation (8) as $\dot{A} = \delta H_A A^{\phi}$, with $0 < \phi < 1$.

61 It would be odd to assume differences in the rate of technological progress across countries in the framework of the neoclassical model. This would essentially mean assuming that the "manna from heaven" (*Jones* 1998: 33) falls more generously on some countries than on others.

propositions also about differences in growth rates. Like the original *Solow* model, *Mankiw/Romer/Weil's* model predicts *conditional convergence*.[62] That is, a country is expected to grow faster the further it is from its steady state. The rate of economic growth of a country therefore depends on its initial level of income and on the determinants of its steady state.

In this context, the concept of convergence is relevant only insofar as the rate of investment in human capital, s_H, is a determinant of a country's steady state.[63] This implies that, *ceteris paribus*, a country's growth rate should be positively correlated with its rate of investment in human capital. Controlling for other influences, especially initial income, a higher amount of resources devoted to human capital accumulation is indicative of a greater distance to the steady state, so that it should be associated with more rapid growth. Notice that this prediction is similar to the one derived from the *Lucas* model in that both suggest a relationship between the variable governing human capital accumulation and output growth.[64]

To confuse matters even more, sometimes a country's initial stock of human capital is used to proxy for steady-state income. Countries with a high amount of human capital would be expected to have a higher level of steady-state income.[65] In this case, the prediction delivered by the augmented *Solow* model would be equivalent to the one made by *Romer* and *Nelson/Phelps*: Growth should be positively correlated with the initial level of human capital.

By now, it should have become clear that, despite different modeling approaches, the testable predictions of the various models on the role of human capital in growth bear a remarkable resemblance to each other. The consequence of this "observational equivalence"[66] is that regardless of the findings which empirical investigations may yield, they will not allow us to discriminate between the *Solow* model and the more recent models of 'new growth theory'.[67] At best, they may give some clues regarding the question which of the two alternative endogenous growth approaches is more appropriate.[68] This is an example of a more general problem: Because "long-run

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62 See *Mankiw/Romer/Weil* (1992: 422-423). For a discussion of the concept of conditional convergence, see *Barro/Sala-i-Martin* (1995: 26-30).

63 See section 2.1.2.

64 This is even more so since the fraction of resources devoted to human capital accumulation is difficult to measure and proxied for by school enrollment rates in *Mankiw/Romer/Weil* (1992). Enrollment does not correspond closely to either the fraction of income or the fraction of time devoted to skill acquisition.

65 See *Topel* (1999: 2962); *Krueger/Lindahl* (2001: 1112).

66 *Gemmell* (1996: 12).

67 This does not mean that the *Solow* model and models of endogenous growth always make the same predictions. That is true as far as the role of human capital is concerned, but on other issues, the theories tend to disagree sharply. The most fiercely disputed question concerns the nature of technology. The proponents of the *Solow* model believe that technology is a public good which is available to all countries, and that hence, differences in technology or total factor productivity (TFP) cannot account for income differentials. The opposing view is that efficiency levels vary significantly across countries and are a major source of income disparities. See the contribution by *Easterly/Levine* (2002) for a recent (though not impartial) account of this debate.

68 Even this is disputable, however. *Cannon* (2000) demonstrates that more general versions of the *Romer* (1990) model predict that the human capital to output ratio (as opposed to the absolute level of H) determines growth, which he claims is also a feature of the *Lucas* (1988) model.

growth" is a theoretical abstraction, we are unable to differentiate empirically between permanent and transitory changes in growth rates. The endogenous growth models predicting permanent effects have the same empirical implications as the *Solow* model predicting only transitory effects through the convergence mechanism.

Nevertheless, the models highlight the theoretically not seriously challenged assertion that the skills and competences of workers should have a significant impact on productivity and technical change. In addition, there is reason to believe that this may feed through to rates of economic growth in one way or another. It remains to be seen whether there is robust empirical evidence to corroborate this hypothesis.

3 Empirical evidence on the importance of human capital for growth

3.1 Results

The number of empirical studies which include some variable meant to capture the notion of human capital in their growth regressions is large and growing. As stated in the introduction, these studies have adopted a somewhat narrow focus on education, or, more precisely, schooling. Among the most popular proxies for human capital are school enrollment rates (i.e., the percentage of the relevant part of the population enrolled in school) and educational attainment measured in years of schooling (i.e., the average years of formal education of the working-age population). The most widely-used data set is the one assembled by *Barro/Lee*,[69] some remarks on its construction will be given below. The structure of this section follows *de la Fuente/Ciccone* in organizing studies by econometric specification and devoting a separate subsection to recent work that has concentrated on improving data quality.[70] Unless otherwise stated, all indications of statistical significance refer to a 95 percent confidence level.

3.1.1 Studies based on convergence equations

The studies in this category estimate an equation that is based on the assumption of conditional convergence, as predicted by neoclassical growth models.[71] This specification relates the rate of economic growth to the initial level of output – with the expectation that countries which start from low levels of income should grow faster –

69 See *Barro/Lee* (1993, updated in 1996 and 2001).

70 See *de la Fuente/Ciccone* (2002).

71 The neoclassical model is not the only one consistent with convergence, endogenous growth models may be, too. As *Sala-i-Martin* (2002: 7) notes, this applies to the *Lucas* (1988) model and to some models of technological diffusion, though not to the original *Romer* (1990) model.

and other variables intended to control for the determinants of the steady state. A simple equation summarizing this approach is[72]

$$\Delta \ln y = g + \lambda(\ln y^* - \ln y_t), \qquad (9)$$

where $\Delta \ln y$ is the growth rate of per capita output, y_t is per capita output at time t, y^* is the steady-state level of per capita output, g is the steady-state growth rate and λ is a parameter measuring the speed of convergence to the steady state. The studies pursuing this approach can be categorized according to whether the variables supposed to proxy for y^* are selected in an ad-hoc manner (subsection 3.1.1.1) or derived by manipulating an explicit theoretical model (subsection 3.1.1.2).

3.1.1.1 Ad-hoc specifications

The use of cross-country regressions to study a variety of variables potentially linked to growth was made possible thanks in large part to the publication of the Penn World Tables compiled by *Summers/Heston* (released for the first time in 1988),[73] and was popularized by *Barro*.[74] The estimated equation in this kind of investigation usually takes the form

$$\Delta \ln y_i = \beta_0 + \beta_y \ln y_{0i} + \sum_{j=1}^{n} \beta_j Z_{i,j} + \varepsilon_i, \qquad (10)$$

where $\Delta \ln y_i$ is the average growth rate of per capita output of country i between some initial date t_0 and a second date t_1, ln y_{0i} is the log of per capita output of country i at t_0, and ε_i is an error term, while $Z_{i,j}$ represents a number of other variables deemed relevant by the researcher. This would include some measure of the initial level of human capital and/or its rate of change. It would also include a variety of variables related to government policies and institutions, such as the share of government spending in GDP, the inflation rate, an index of the rule of law, or the black market premium on foreign exchange, to name just a few.

Romer was among the first to run this kind of regression for the purpose of "exploratory data analysis" in connection with the theoretical model he proposed (an earlier version of *Romer* (1990)).[75] He uses adult literacy rates as a proxy for the stock of human capital. For a sample of 112 countries, he regresses the average rate of growth between 1960 and 1985 on the initial level of income, the investment rate, government spending as a share of GDP and the literacy rate in 1960. He finds that the literacy rate is significant and has the expected positive effect on growth. When adding the change in the level of literacy to the regression, however, this variable does not enter significantly.

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72 See *Topel* (1999: 2961).

73 See *Summers/Heston* (1988).

74 See *Barro* (1991).

75 See *Romer* (1989).

Romer conjectures that literacy may act through the investment rate, and finds some evidence of this, but cautions that his empirical results are not particularly robust and may be subject to measurement error and problems due to omitted variables.[76]
Barro, whose work inspired a great deal of subsequent research, notes that the drawback of literacy rates is that they appear to be inconsistently measured across countries.[77] He uses school enrollment rates instead, arguing that they should be more consistent cross-sectionally, although he is aware of the fact that enrollment rates relate more closely to the flow of investment into human capital than to its stock.
Barro's findings for the period of 1960 – 1985 and a sample of 98 countries indicate that the rates of primary and secondary school enrollment in 1960 are significantly positively related to subsequent growth (when controlling for initial income and other variables).[78] *Barro* interprets this as supportive of his assumption that, for a given initial income, the level of initial schooling has a positive effect on per capita growth. Nevertheless, he expresses some concern that, if enrollment rates proxy for investment in human capital rather than for its stock, the correlation between enrollment rates and growth may be due to favorable economic conditions which drive up both the investment in human capital and the rate of economic growth. Moreover, when *Barro* estimates a second equation in which he includes the fertility rate and the share of investment in GDP as additional explanatory variables, the estimated coefficients on the schooling variables become much smaller (while fertility is negatively and the investment ratio positively related to growth). In addition, higher human capital is found to be associated with lower fertility and a higher investment rate. This might suggest that part of the positive effect of human capital on growth is transmitted via reduced fertility and increased investment in physical capital, rather than through enhanced productivity of labor.[79]
The use of school enrollment rates in *Barro* (1991) and other studies had been dictated by data availability. It was soon recognized, though, that school enrollment ratios have serious shortcomings, even as a flow variable.[80] First, there is a considerable time lag between the moment a child enrolls in school and the moment it increases the stock of human capital by entering the workforce, if it does enter the workforce at all. Second, (gross) enrollment rates poorly reflect the actual flow because they do not correct for dropouts and repetition of grades (which are frequent especially in less developed countries). Motivated by these and other concerns, *Barro/Lee* construct a data set of the educational attainment (measured in years of schooling) of the population aged 25 and over for a wide range of countries.[81] Where available, they make use of census data on attainment levels,[82] from which they infer the years of schooling by using information on the number of years typically associated with a certain level of education in a

76 See *Romer* (1989: 37-38).

77 See *Barro* (1991: 422).

78 See *Barro* (1991).

79 See *de la Fuente/Ciccone* (2002: 89).

80 See *Barro/Lee* (1993); *Gemmell* (1996); *Wößmann* (2000).

81 See *Barro/Lee* (1993).

82 The attainment levels considered by *Barro/Lee* (1993) are: no schooling, incomplete primary schooling, complete primary schooling, first cycle of secondary schooling, second cycle of secondary schooling, incomplete higher education and complete higher education.

particular country. They fill the remainder of the cells by means of a so-called "perpetual inventory method" using lagged values of enrollment ratios.

In *Barro/Lee* (1994), the authors exploit their own data set in a cross-country study of the sources of growth. *Barro/Lee* modify the empirical framework introduced by *Barro* (1991) slightly.[83] They basically double the sample size by splitting the data into two periods of ten years (1965-1975 and 1975-1985).[84] Besides, they differentiate between primary, secondary and higher schooling, as well as between male and female attainment at each of these levels. As far as the role of education is concerned, the numerous regressions they run yield the following main results:

- The attainment variable showing a significantly positive coefficient is the average years of *male* secondary schooling observed at the beginning of each decade (that is, in 1965 and 1975);
- the initial level of *female* secondary schooling is negatively related to subsequent growth. One possible explanation for this surprising result is offered by *Barro/Lee*, who speculate that "a high spread between male and female secondary attainment is a good measure of backwardness; hence, less female attainment signifies more backwardness and accordingly higher growth potential through the convergence mechanism"[85];
- the change in male secondary attainment also enters significantly positively in the growth equation, while the estimated coefficient on the change in years of female secondary schooling is, once again, significantly negative; and
- none of the other attainment variables (male and female primary and higher education) are significant.

Because of the puzzling finding that female secondary schooling has a negative effect on growth and the less than convincing explanation given by *Barro/Lee*, the reliability of their results has been questioned.[86] Nevertheless, *Barro/Sala-i-Martin* report broadly the same findings in an investigation similar in methodology, differing from *Barro/Lee's* mainly with respect to the number of countries included in the sample and the selected control variables.[87] In particular, the coefficient on male secondary attainment is found to be significant and positive, while the coefficient on female secondary schooling is negative (though insignificant). Moreover, contrary to *Barro/Lee* (1994), university education is also statistically significant for both sexes and displays the same pattern of signs on the estimated coefficients as for secondary education: positive on male, and negative on female higher schooling.

An important difference in *Barro/Sala-i-Martin* (1995) is that, when they add the changes of male and female secondary and higher schooling, none of these variables enter significantly in the equation. This is a result that has tended to recur in other studies and will be discussed in more detail in the following sections. Citing *Nelson/Phelps* (1966) and their theory of technological diffusion, *Barro/Sala-i-Martin* also include in their regressions an interaction term between initial GDP per capita and a

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83 See *Barro/Lee* (1994).

84 This procedure is referred to as the pooling of data, the result being a pooled data set.

85 *Barro/Lee* (1994: 18).

86 This issue is deferred to section 3.2.1.2.

87 See *Barro/Sala-i-Martin* (1995, chapter 12).

composite measure of schooling and health. This interaction term is supposed to pick up the effect of human capital raising the ability to absorb new technologies. The coefficient on this term is significant and has the expected sign, prompting *Barro/Sala-i-Martin* to conclude that convergence is indeed more rapid when the level of human capital is high.[88] A higher amount of human capital would then enable countries to catch up faster to more advanced economies.
Finally, *Barro* (1998) extends this literature to include data up to 1995. He studies the three 10-year periods of 1965-1975, 1975-1985, and 1985-1995. He combines secondary and higher attainment to form a single schooling indicator. Barro once again finds the initial level of schooling for males aged 25 and over to have a significant and positive effect on growth, while female secondary and higher schooling has no significant explanatory power.[89] Primary schooling also is insignificant. *Barro* goes on to report a finding that contradicts his earlier results (from *Barro* (1991)) with regard to the link between human capital and investment in physical capital. Education (as proxied for by years of male secondary and higher schooling) no longer has a significant correlation with the investment ratio, casting doubt on the hypothesis that human capital raises investment in physical capital.

3.1.1.2 Structural convergence equations

The use of structural convergence equations goes back to *Mankiw/Romer/Weil* (1992), who infer the regressors and the functional form of the estimating equation directly from manipulations of the production function they employ (namely, a Cobb-Douglas function with human capital entering as an additional input; see equation (1)). In this case, the selection of variables proxying for the steady-state level of income, y^* in equation (9), is based on an explicit theoretical model. By contrast, the studies described in the previous subsection choose the explanatory variables for their regressions in an ad-hoc manner, depending on the respective authors' opinion regarding the factors potentially important for the growth process.
Mankiw/Romer/Weil approximate around the steady state and substitute for y^* using the steady-state values of $\hat{k}^*$ and $\hat{h}^*$ given in equation (4), which allows them to express equation (9) in terms of the rates of investment in physical and human capital, the population growth rate, the rate of depreciation and the rate of technological progress.[90] Specifically, they obtain the following expression describing the behavior of the economy during the transition to its steady state:

$$\ln y_t - \ln y_0 = \left(1 - e^{-\lambda t}\right) \cdot \left[\ln A_0 + gt + \frac{\alpha}{1-\alpha-\beta} \ln s_K + \frac{\beta}{1-\alpha-\beta} \ln s_H - \frac{\alpha+\beta}{1-\alpha-\beta}\left(n+g+\delta\right) - \ln y_0 \right], \tag{11}$$

88 See *Barro/Sala-i-Martin* (1995: 432).

89 See *Barro* (1998).

90 See *Mankiw/Romer/Weil* (1992: 422-423).

where A_0 reflects not only the initial level of technology but also possible differences in natural resource endowments, among other things. All other notations are the same as before. As mentioned above, for a given initial income, an economy is expected to grow faster if it has a higher level of steady-state output. Equation (11) yields the determinants of the steady state to be included in the empirical analysis (which have been discussed in section 2.1.2) as well as the functional form linking these variables to the rate of economic growth.

An important problem for estimation purposes is that A_0 and the rate of technological progress, g, are unobservable. *Mankiw/Romer/Weil* make the assumption that g is constant for all countries (they suppose $g + \delta = 0.05$), an assumption which is based on the justifiable but not uncontroversial view that technology (in the sense of abstract knowledge) is a public good available to all countries.[91] Moreover, in order to be able to estimate (11) for a single cross-section, they also have to subsume A_0 into the error term, because an ordinary least squares regression does not allow for country-specific effects. Implicitly, therefore, they assume A_0 to be uncorrelated with the regressors or, alternatively, to be approximately constant across countries.[92] To be able to relax this assumption, one has to adopt a panel data approach, as have some studies which are to be discussed below.

Mankiw/Romer/Weil estimate equation (11) for a sample of 98 countries, using data for the period of 1960-1985. In addition, they run separate regressions for two subsamples: one "intermediate" sample excluding the least developed countries, and one sample comprised only of OECD countries. For the rates of investment in physical capital and population growth rates, they use averages over the entire period. For the rate of investment in human capital, they use a crude measure of the average percentage of the working-age population enrolled in secondary school which is based on school enrollment ratios.

Mankiw/Romer/Weil find that adding their human capital variable considerably improves the fit of the neoclassical model.[93] For the whole sample, the independent variables explain 46 percent of the variance in growth rates (and even 65 percent for the OECD sample).[94] The coefficient on schooling is highly significant and has the expected (positive) sign. Hence, the investment in human capital is found to contribute positively to the growth of output for the broad sample of countries. However, schooling is insignificant for the OECD sample. The results do not change very much when *Mankiw/Romer/Weil* impose the restriction that the coefficients on s_K, s_H and $(n + g + \delta)$ sum to zero (as a Cobb-Douglas production technology would require).[95] Furthermore, the values for α and β implied by the coefficients they estimate are 0.4 and 0.2, respectively. Bearing in mind that theory would predict those parameters to equal the respective factor shares in national income, this would mean that 40 percent of output serves to remunerate physical capital, while about a third of the remaining income would go to human capital and the rest to raw labor. Those values would appear

91 See *Mankiw/Romer/Weil* (1992: 410).

92 See *Islam* (1995: 1134).

93 See *Mankiw/Romer/Weil* (1992: 425-428).

94 An R^2 of this order of magnitude has to be considered quite satisfactory in view of the erratic nature of growth rates (*Cohen/Soto* 2001: 23).

95 See *Mankiw/Romer/Weil* (1992: 429).

to be within a realistic range. Overall, *Mankiw/Romer/Weil* conclude that the international evidence on growth is consistent with the *Solow* model if it is augmented to include human capital. The only disturbing finding among their original results may be that, for the OECD sample, human capital has no significant effect on growth.

Gemmell's (1996) paper contains a possible explanation for this. He starts from the same equation as *Mankiw/Romer/Weil* but breaks down human capital into primary, secondary and tertiary education. Because of collinearity problems among the three human capital variables, he retains only one of them for each of the samples he studies. *Gemmell* reports that the form of human capital (primary, secondary or tertiary) significantly related to income growth differs across subsamples "in intuitively plausible ways": It is primary education which is most important for the least developed countries, secondary education for intermediate developing countries, and tertiary education for OECD countries.[96] This might explain why *Mankiw/Romer/Weil* found *secondary* schooling to be insignificant for their OECD sample.[97]

Gemmell also tries to differentiate between effects stemming from stocks of human capital and its accumulation. He constructs measures of the stock of human capital by means of a procedure relying solely on school-enrollment rates. The procedure is simpler than that adopted by *Barro/Lee* (1993), but – as argued by *Gemmell* – one which may avoid inconsistencies and better reflect the human capital embodied in the actual workforce (rather than in the population aged 25 and above).[98] He finds that both the initial level of human capital in 1960 and its subsequent accumulation have significant positive effects on economic growth.

Apart from its narrow focus on secondary schooling, the major weakness of *Mankiw/Romer/Weil's* contribution arguably is their assumption that A_0 is roughly the same across countries or, at least, uncorrelated with investment and fertility rates. Given the fact that A_0 is supposed to reflect not only technical efficiency, but also resource endowments, climate and institutions, this supposition has struck some researchers as being rather far-fetched. One solution that has been put forward to tackle this issue is the adoption of an econometric technique allowing for country-specific effects. *Islam* implements a panel data approach which is just such a technique because it makes it possible to take into account heterogeneity in the production technology across economies.[99] By moving from a single cross-section spanning the entire period (in this case, 1960-1985) to cross-sections for the several shorter periods that constitute it, the panel data approach adds a temporal dimension to the data. The time-series variation in

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96 See *Gemmell* (1996: 21).

97 The exclusive reliance on secondary schooling by *Mankiw/Romer/Weil* (1992) is also the subject of a paper by *Klenow/Rodriguez-Clare* (1997), who take a very critical stance on what they call the "neoclassical revival in growth economics". *Klenow/Rodriguez-Clare* (1997) argue that ignoring primary education exaggerates the fraction of output growth attributable to human capital accumulation. Because primary enrollment varies much less across countries than secondary enrollment, the exclusion of the former overstates the actual variance in human capital investment. Accordingly, when using an alternative measure of schooling which includes primary attainment, they find accumulation of human capital to have only a small role in explaining growth. Their findings are, however, difficult to compare with *Mankiw/Romer/Weil's* (1992) because they adopt a very different methodology that is closer to growth accounting exercises.

98 See *Gemmell* (1996: 16).

99 See *Islam* (1995).

the data can then be exploited to estimate individual country effects.[100] In terms of equation (11), this means treating ln A_0 as a time-invariant country-effect term.[101]
Islam conjectures that the conventional estimation method using data from a single cross-section may lead to substantial omitted variable bias.[102] In particular, he argues that it may conflate the effects of technological or institutional differences and those of factor accumulation or "capital deepening" on growth. In his analysis, he uses the schooling data from *Barro/Lee* (1993) instead of school enrollment rates. He follows *Mankiw/Romer/Weil* in studying three different samples. *Islam's* estimation of a dynamic panel model with country-specific fixed effects delivers the result that human capital is *negatively* related to economic growth. Although the coefficient on the schooling variable is statistically significant only for the broad sample and not for the intermediate and OECD subsamples, this finding is perplexing and runs counter to both theory and virtually all previously presented empirical studies. Yet, in another panel estimation, *Caselli/Esquivel/Lefort* obtain results which are qualitatively similar to those of *Islam* – namely, they report a significant negative coefficient on human capital for a sample of 97 countries.[103]
How much weight one ought to attach to these results is debatable. For instance, *Temple* dismisses them altogether.[104] Even when taking a more moderate position, though, it is important to mention some of the drawbacks of dynamic panel models. Quite generally, due to the necessary transformations, the use of panel data entails a significant loss of variance in the explanatory variables. This may deprive them of much of their information content, leading to imprecise results.[105] More particularly, in the case of human capital and growth, we have seen that, according to some theories, the level of human capital may influence technology. Therefore, the effect of human capital on A_0 may not be distinguishable from a fixed country effect.[106] These limitations may in part explain the negative results from panel data studies. Another reason for the results may be measurement error, as will be discussed later.[107]

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100 The main difference between a panel estimation and a pooled regression framework (as in, e.g., *Barro/Lee* (1994)) is that the pooled estimation does not allow for individual country effects. It also usually considers longer time spans (mostly ten-year periods, instead of five-year periods).

101 See *Islam* (1995: 1136).

102 This applies if the explanatory variables, namely investment and population growth rates, are correlated with the A_0s and, correspondingly, with the error term.

103 See *Caselli/Esquivel/Lefort* (1996).

104 See *Temple* (2001a: 94).

105 See *Aghion/Howitt* (1998: 34).

106 See *Sianesi/Van Reenen* (2002: 64). *Islam* (1995) also suspects that human capital may work not through the conventionally assumed channel (i.e., as an input in production), but through technology, and indeed finds a correlation between human capital and the A_0s he estimates. However, as pointed out by *de la Fuente/Ciccone* (2002: 101), this argument "merely sidesteps the problem: we know that human capital variables work well with cross-section data, but if they really had an effect on the level of technical efficiency they should be significant when entered into the panel equation."

107 See section 3.2.1.1 below.

3.1.1.3 Brief summary of the evidence from studies estimating convergence equations

In view of the diverse estimation methods, schooling proxies, and results of the studies reviewed above, it seems appropriate at this stage to make an attempt to bring out some general patterns emerging from this literature. Table 2, which contains a summary of the methodology and findings of the different studies, is helpful for this purpose.
Although there is no really consistent pattern in the results, several things stand out. First, coefficients on initial stocks of human capital are always positive and significant when cross-section or pooled specifications are employed, regardless of the measure of schooling. Second, they become significantly negative in panel data studies. Third, coefficients on the change of (or investment in) human capital are significantly positive in cross-section specifications using human-capital proxies based on school-enrollment rates, but only in one out of two pooled specifications using years of schooling. Overall, therefore, there seems to be a tendency for the results to become weaker with an increasing amount of time-series variation of the data.[108] An interpretation of this will have to wait until section 3.2.1.1 below.

3.1.2 Studies estimating an aggregate production function

The data requirements of structural convergence equations (see previous section) are such that they nicely match what is widely available for large cross-country samples. In particular, by requiring only data on investment rates, the approach avoids having to use capital stocks, for which reliable data are hard to come by. In contrast, directly estimating an aggregate production function is impossible without having at one's disposal data on capital stocks. Nevertheless, a small number of studies has estimated a macroeconomic production function using some sort of measure of physical capital stocks.

108 See *Islam* (1995: 1153); *de la Fuente/Domenech* (2000: 1).

Table 2: Methodology and findings of studies based on convergence equations

	Specification and period(s) studied	Human capital proxy	Coefficient on initial stock of human capital [1)]	Coefficient on change of (or investment in) human capital [1)]
Romer (1989)	single cross-section (1960 – 1985)	literacy rate	positive (significant)	sign not reported (insignificant)
Barro (1991)	single cross-section (1960 – 1985)	school-enrollment rate	positive (significant)	not included [2)]
Barro and Lee (1994)	pooled (1965-1975, 1975-1985)	years of schooling (from Barro and Lee (1993))	positive (significant) for male secondary [3)]	positive (significant) for male secondary [3)]
Barro and Sala-i-Martin (1995)	pooled (1965-1975, 1975-1985)	years of schooling (from Barro and Lee (1993))	positive (significant) for male secondary and higher [4)]	positive (insignificant) for male secondary and higher [5)]
Barro (1998)	pooled (1965-1975, 1975-1985, 1985-1995)	years of schooling (from Barro and Lee (1993))	positive (significant) for male secondary and higher [6)]	not included / not reported
Mankiw, Romer and Weil (1992)	single cross-section (1960 – 1985)	school-enrollment rate	not included [2)]	positive (significant)
Gemmell (1996)	single cross-section (1960 – 1985)	own measure of attainment constructed using enrollment rates	positive (significant)	positive (significant)
Islam (1995)	panel (5-year periods between 1960 – 1985)	years of schooling (from Barro and Lee (1993))	negative (significant) [7)]	not included
Caselli, Esquivel, and Lefort (1996)	panel (5-year periods between 1960 – 1985)	school-enrollment rate	not included	negative (significant)

Notes: 1) Reported findings apply to the largest sample for which equations have been estimated. Statistical significance based on t-values judged against a 95% confidence level.

2) Barro (1991) and Mankiw, Romer and Weil (1992) both use school-enrollment rates, but interpret them in different ways: as stocks in the former, and as investment rates in the latter.

3) Barro and Lee (1994) report a significantly negative coefficient on female secondary schooling. All other schooling variables are insignificant.

4) Barro and Sala-i-Martin (1995) report negative coefficients on female secondary and higher schooling (insignificant for the former, significant for the latter).

5) Barro and Sala-i-Martin (1995) report insignificant negative coefficients on female secondary and higher schooling.

6) Barro (1998) combines secondary and higher schooling in a single measure. He reports insignificant negative coefficients on the female schooling variable.

7) Islam (1995) does not actually use beginning-of-the-period levels of schooling, but end-of-the-period levels which are intended to proxy for the steady-state value of human capital.

Those studies start from a production function of the form $Y_t = A_t K_t^{\alpha} H_t^{\beta} L_t^{\gamma}$ which is similar to the one presented in equation (1).[109] Rewriting the function in per capita terms, taking logs, and differentiating with respect to time yields an equation in growth rates[110] (denoted by Δln) for country *i* at time *t*:

$$\Delta \ln y_{it} = \Delta \ln a_{it} + \alpha\, \Delta \ln k_{it} + \beta\, \Delta \ln h_{it}\,. \qquad (12)$$

Equation (12) may seem reminiscent of conventional growth accounting exercises which analyze the growth experience of a particular country by decomposing the growth rate of output into growth in inputs and (residual) total factor productivity (TFP). The difference is that in this case, the analysis relates to a cross-section of countries. It has correspondingly sometimes been labeled cross-country growth accounting.
Note that this approach circumvents the problem that A_0 is unobservable by working with growth rates and thereby eliminating the A_0 term.[111] This is a major advantage. However, equation (12) still contains the (unobservable) growth of technical efficiency, $\Delta\ln a_{it}$, which needs to be dealt with in some way. For example, if it is assumed to be constant across countries, it can be estimated as the regression constant.[112]
Benhabib/Spiegel were among the first to implement this cross-country growth accounting approach to study the role of human capital.[113] In their influential paper, they use various measures of the physical capital stock constructed from observed investment flows and estimates of initial capital-output ratios (their results reportedly not being sensitive to the choice of alternative measures). Their preferred human capital proxy is derived through a procedure in which the educational attainment of the labor force is first regressed on enrollment rates for a sample of countries for which both are available. The relationship thus found is then extrapolated to a larger sample for which only school-enrollment ratios are available.
Benhabib/Spiegel find that the growth of human capital between 1965 and 1985 has an insignificant effect on per capita output growth, and enters with mostly negative coefficients.[114] This result proves robust to the inclusion of several "ancillary variables" (such as the initial level of income) among the regressors, and to the use of alternative measures of human capital, especially the years of schooling measure from *Barro/Lee* (1993). Moreover, *Benhabib/Spiegel* are unable to confirm their suspicion that the results may be driven by a few African countries which, despite having expanded education considerably relative to their low starting levels, experienced extremely slow

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109 The coefficients on *K*, *H*, and *L* are assumed to sum to one.

110 Equation (12) is taken from *Pritchett* (2001). Alternatively, the equation can be differenced, an approach chosen by *Benhabib/Spiegel* (1994). The estimating equation then becomes $\ln y_{it} - \ln y_{i0} = (\ln a_{it} - \ln a_{i0}) + \alpha(\ln k_{it} - \ln k_{i0}) + \beta(\ln h_{it} - \ln h_{i0})$. This is conceptually equivalent to the version in growth rates presented here.

111 The same holds true for the version of equation (12) in log differences (see the previous footnote).

112 See *de la Fuente/Ciccone* (2002: 24).

113 See *Benhabib/Spiegel* (1994).

114 See *Benhabib/Spiegel* (1994: 149-150).

growth of output over the considered period. The insignificant and negative coefficient on the education variable is not sensitive to the inclusion of a regional dummy variable for Africa.[115] Neither is it sensitive to the exclusion of African countries from the sample.

Benhabib/Spiegel interpret their findings as an indication that the conventional way of incorporating human capital, that is, as an additional input in production, may be mis-specifying its role in the growth process. Indeed, they do find some evidence of a relationship running from initial levels of human capital to the rate of economic growth when the initial level of income is held constant. They also estimate a more structural specification inspired by *Nelson/Phelps* (1966) and *Romer* (1990)[116] with TFP growth as the dependent variable in which they include elements intended to capture the effect of human capital on technological catch-up and innovation. The catch-up term turns out to be significant for the broad sample as well as for the sample of the poorest countries,[117] whereas for the richest third of the sample, the innovation term is found to be more important than the catch-up term. Finally, they report results indicating that human capital attracts physical capital, suggesting some degree of complementarity between the two factors. *Benhabib/Spiegel* regard all this as supportive of their view that human capital affects growth through channels other than the ones usually allowed for within a growth-accounting framework.

In another well-known contribution, *Pritchett* extends this literature by constructing 'Mincerian' stocks of human capital.[118] His starting point is the well-documented microeconomic evidence on the wage increments resulting from additional years of education. *Mincer* found empirically that a log-linear relationship where the log wage is a linear function of the years of formal education a person has received (along with his or her years of work experience) fits the data exceptionally well.[119] This formulation implies that, on average, each additional year of schooling yields a constant *percentage* increase in the wage. At the same time, obviously, the n^{th} year of schooling increases the wage by a greater *absolute* amount than the $n\text{-}1^{th}$ year.

Pritchett defines human or educational capital as the discounted value of the wage premia due to education (a premium being defined with respect to the unskilled wage).[120] With some further assumptions, this allows him to write the proportional growth rate of the human capital stock as the growth rate $\frac{\dot{H}}{H}$ of the expression[121]

115 Such a dummy variable would usually take a value of one for African countries, and a value of zero for all other countries. If it turned out to be significant or to strongly alter the original results, this would indicate the omission of important variables.

116 See section 2.2.2.

117 More recently, *Engelbrecht* (2002) has investigated a similar specification and confirmed *Benhabib/Spiegel's* (1994) result that human capital is important for technological catch-up in developing countries.

118 See *Pritchett* (2001, first circulated in 1996).

119 See *Mincer* (1974).

120 See *Pritchett* (2001: 372).

121 Equation (13) is not the expression *Pritchett* (2001) theoretically derives for the *stock* of human capital. It applies only to its growth rate. The equation for the stock of human capital, which follows directly from the assumption of a Mincerian school-earnings relationship and the

$$H(t) = e^{\theta S(t)} - 1, \tag{13}$$

where θ is the percentage increment to wages resulting from an additional year of schooling while *S(t)* is years of schooling at time *t*. He assumes $\theta = 10$ % (a value based on consensus estimates from labor economics). For *S*, he uses the data on average years of schooling from *Barro/Lee* (1993) and a second group of authors.

With this information, he obtains an aggregate measure of the growth of educational capital per worker for a large sample of countries, which he uses to estimate equation (12) above. Like *Benhabib/Spiegel*, *Pritchett* reports a negative and insignificant coefficient on the growth of human capital.[122] This contrasts sharply with the expected value for the coefficient β in (12). β should reflect human capital's share in income and therefore, according to *Pritchett*, ought to be between 0.2 and 0.4. The result is robust against outliers (i.e., influential and atypical observations) and, once again, to the exclusion of African countries and to other variations of the sample composition, as well as to the inclusion of regional dummies.

Pritchett contends that these findings constitute a "micro-macro paradox": although the microeconomic literature finds consistent evidence of substantial private returns to education in the form of higher wages, macroeconomic studies are unable to come up with proof that growth in education spurs income growth. He goes on to present some interesting explanations with the potential to reconcile these apparently conflicting observations:

> *"Where has all the education gone? I do not propose a single answer, but put forward three possibilities that could account for the results:*
>
> - *The newly created educational capital has gone into piracy; that is, privately remunerative but socially unproductive activities.*
> - *There has been slow growth in the demand for educated labor, so the supply of educational capital has outstripped demand and returns to schooling have declined rapidly.*
> - *The education system has failed, so a year of schooling provides few (or no) skills."*[123]

The first possibility refers to rent-seeking and other distortions in the economy.[124] The third possibility is compatible with a signaling model of wages in the spirit of *Spence*,

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adopted definition of human capital, takes the form: $\ln HK(t) = \ln\left(\sum_{t=0}^{T} \delta^t\right) + \ln w_0(t) + \ln\left(e^{\theta S(t)}\right)$, where δ is the discount factor and w_0 is the unskilled wage. By differentiating with respect to time and assuming that the discount rate and the unskilled wage are constant over time, Pritchett (2001) arrives at the equation $\frac{\dot{H}}{H} = \frac{d \ln(e^{\theta S(t)} - 1)}{dt}$, which is the growth rate of the expression in equation (13).

122 See *Pritchett* (2001: 375).

123 *Pritchett* (2001: 382).

124 *Griliches* (1997: S338-S339) suggests another possible explanation which does not require that human capital is put to socially dysfunctional use. There is evidence that in many developing countries, much of the growth in educated labor is absorbed in the public sector. Even if highly-

where schooling creates no skills but still leads to higher wages by signaling qualities like ambition or innate ability to the employer (because individuals with those qualities may find it easier to obtain a degree).[125]

3.1.3 Recent studies focusing on data quality

The discouraging results from both panel data studies and, more importantly, the cross-country growth accounting studies by *Benhabib/Spiegel* and *Pritchett* have brought about two distinct reactions on the part of researchers looking into the role of human capital in economic growth. One of the directions that has been taken is to question the conceptual foundations of the literature, and especially the adequacy of the employed human capital proxies. This is to be discussed in section 3.2.2 below. A second direction has been to improve the quality of the data, and use more sophisticated econometric techniques, while hanging onto the conventional measures of human capital (mostly years of educational attainment). It is to this second approach that we now turn.

Krueger/Lindahl draw attention to the possibility that measurement error may be responsible for the negative findings on the growth impact of changes in education, and for the results produced by other specifications where human capital is measured at short (e.g., five-year) intervals.[126] Because this issue appears to be an important one, a separate subsection (3.2.1.1) is devoted to the clarification of why and how measurement error may bias estimated coefficients downward. Briefly, *Krueger/Lindahl* argue that there is so much noise relative to the true variation in the education data that barely any signal remains, and that this measurement error is exacerbated by differencing the data.

Krueger/Lindahl show that two things are critical to *Benhabib/Spiegel's* findings: First, the extremely low reliability of the educational attainment measure they use for calculating changes over time (relative to alternative measures such as *Barro/Lee* (1993)), and second, controlling for the change in the physical capital stock.[127] This is because the remaining amount of 'true' variation in the schooling variable is highly correlated with physical capital growth, so that conditional on physical capital accumulation, the growth of education no longer conveys any signal at all. When they re-estimate the equation without including the growth of capital and with the *Barro/Lee* (1993) data, *Krueger/Lindahl* indeed find the effect of schooling to be large, positive, and significant, especially when they correct for the downward bias due to measurement error.[128]

Two groups of authors have followed the lead of *Krueger/Lindahl*, and concentrated on improving the quality of the educational attainment data: *de la Fuente/Domenech* for a

skilled state-employed workers are productive in a variety of ways, this may not show up in national accounts data because the output of the public sector is difficult to measure.

125 See *Spence* (1973).

126 See *Krueger/Lindahl* (2001).

127 See *Krueger/Lindahl* (2001: 1113-1118).

128 See *Krueger/Lindahl* (2001: 1119).

sample of 21 OECD countries,[129] and *Cohen/Soto* for a less exclusive sample of 95 countries.[130] In addition, *Bassanini/Scarpetta* have exploited the *de la Fuente/Domenech* (2000) data set to apply a novel econometric technique. All of these studies find human capital accumulation to be an important determinant of output growth.

In spite of its lack of scientific rigor in constructing the data set, the work of *de la Fuente/Domenech* has been praised by *Temple* for being "impressively careful and detailed."[131] When they scrutinize the available data sets on years of schooling, *de la Fuente/Domenech* notice a number of irregularities in both the cross-country and time-series profiles of the data. The correlation between alternative data sets is often quite low, with some unusually large divergences between the respective figures on educational attainment for certain countries. There are also some implausibly sharp breaks and changes in attainment levels over very short periods of time, which *de la Fuente/Domenech* attribute to changes in classification criteria.[132] In an attempt to construct a new series on years of schooling with more plausible attainment profiles for each country, they incorporate new data from national statistical agencies and the OECD where available, and remove unreasonable jumps by choosing the one that appears most valid among alternative figures or interpolating between available estimates. Although this procedure obviously relies to a large extent on guesswork, *de la Fuente/Domenech* report that their series performs extremely well in terms of some indicators of statistical reliability.[133]

They go on to use their new data set for an empirical examination of the link between human capital and growth. In what follows, we will focus on the findings from the updated and extended version of their paper (*de la Fuente/Domenech* 2002). In that paper, a number of growth specifications for the six five-year periods between 1960 and 1990 are tested, invariably producing results which are supportive of a prominent role of human capital. The estimated coefficients display the expected positive sign, and they are generally sizable and significant even in specifications expressed in growth rates or log differences of the included variables, as well as in panel data specifications. This finding can be considered as particularly encouraging in the light of previous studies using such methodologies which had failed to find evidence of a significantly positive effect of schooling on growth (see the preceding sections). Moreover, in their preferred specification which allows for technological diffusion and country-specific effects, *de la Fuente/Domenech* find reasonable values of the production function parameters α and β, which are estimated at 0.345 and 0.394, respectively.[134] They perform a few simple robustness tests (checking – among other things – the importance of outliers), none of which call their conclusions into question.

There are two possible limitations to *de la Fuente/Domenech's* contribution. First, their results pertain only to a sample of OECD countries and might therefore lack generality.

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129 See *de la Fuente/Domenech* (2000, 2002).

130 See *Cohen/Soto* (2001).

131 *Temple* (2001a: 76).

132 See *de la Fuente/Domenech* (2000: 11).

133 See *de la Fuente/Domenech* (2002: 21-25), and section 3.2.1.1 for details.

134 See *de la Fuente/Domenech* (2002: 29).

Second, their preferred specification is not based on a Mincerian measure of human capital, the use of which has recently been advocated by a number of researchers.[135] Both of these limitations are overcome by *Cohen/Soto*, who compile a new data set on educational attainment for a sample of 95 countries.[136] Their data cover the period of 1960-2000 and provide an estimate of the average years of schooling of the population aged 15 to 64 at ten-year intervals. *Cohen/Soto's* schooling series is based on data for 38 countries recently released by the OECD, and extended to the larger group of countries using census data from UNESCO and national sources. If census data are unavailable for a given period, estimates are extrapolated from an earlier (or later) census based on the assumption that the attainment of the part of the population aged T at the earlier (later) census equals the attainment of the population aged T+10 (T-10) in the considered period.[137] Remaining gaps are filled using school-enrollment ratios.

Cohen/Soto then regress per capita growth rates on the (absolute) change in years of schooling for each of the four decades covered by their data set, including in the regression urbanization rates and developing-country dummies to proxy for differences in technology levels, but excluding the change in physical capital.[138] They find a significantly positive and reasonably large effect of the change in years of schooling on growth when using their data set. By contrast, when using the *Barro/Lee* (2001) series to estimate the same equation, the coefficient on the change in schooling loses significance. Furthermore, they find that adding the initial level of schooling to the regression does not significantly improve its explanatory power, prompting them to declare the debate on whether levels or changes of human capital explain growth rates settled (at least for their data). However, this conclusion has to be viewed with caution because problems of collinearity between the two variables may be involved when including both in the same regression, which would make it difficult to disentangle their respective effects.[139]

Finally, *Bassanini/Scarpetta* update the *de la Fuente/Domenech* (2000) schooling series with OECD data to cover the period of 1971-1998 and use a previously unexploited technique for panel data analysis called pooled mean group estimation (PMG).[140] This technique has the advantage of allowing the short-run coefficients and convergence speeds to differ across countries, while requiring identical coefficients in the long-run (arguably, this is an accurate description of reality for developed economies). *Bassanini/Scarpetta* rewrite the structural convergence equation derived by *Mankiw/Romer/Weil* (see equation (11)) so that it relates to human capital levels, rather than to investment rates. This yields a formulation which conforms to the data at their

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[135] See, e.g., *Topel* (1999: 2963). The Mincerian specification posits that the relationship between income and education should be log-linear, instead of log-log as in equation (12) above. Therefore, in terms of equation (12), years of schooling would enter for ln H rather than for H. See section 3.2.2.1 for a discussion of the implications of using Mincerian human capital stocks.

[136] See *Cohen/Soto* (2001).

[137] This assumption is valid in a strict sense only if mortality is independent of educational attainment and if migrants have the same structure of school attainment as the resident population. See *Cohen/Soto* (2001: 12).

[138] See *Cohen/Soto* (2001: 23-24).

[139] See *de la Fuente/Ciccone* (2002: 109).

[140] See *Bassanini/Scarpetta* (2001).

disposal. *Bassanini/Scarpetta* argue that working with data at five-year intervals leads to a loss of information.[141] Therefore, they make use of one-year intervals, partially obtained through linear interpolations from five-year observations.[142]
After an extensive process involving tests of various specifications, estimation methods, and the robustness of the results, *Bassanini/Scarpetta* retain the PMG estimator as the most efficient, and report that their most reliable estimates suggest that the long-run elasticity of per capita output with respect to years of schooling (i.e., the parameter β in the augmented Cobb-Douglas production function) is significantly different from zero and takes a value of around 0.6.[143] This is an even higher estimate than the one obtained by *de la Fuente/Domenech*, although its magnitude turns out to be sensitive to the inclusion of Finland in the sample. *Bassanini/Scarpetta* claim that, on the whole, their results favor an endogenous growth model à la *Lucas* (1988) over the human-capital augmented *Solow* model.[144]
Overall, the studies reviewed in this section tend to confirm the hypothesis that data quality matters. The main implication of this is that deficiencies in older data sets on educational attainment may have led to a downward bias of the estimated coefficients on schooling variables in studies relying on those older data. Additional, more direct evidence to substantiate this presumption will be presented in section 3.2.1.1 which is concerned with measurement error.

3.2 Interpretation

The general purpose of this section is to put the findings of the literature reviewed in section 3.1 in perspective, and prepare their evaluation. In particular, it will try to clarify important issues, and raise a number of questions regarding methodological (3.2.1) and conceptual aspects (3.2.2) of the empirical work which has been outlined above.

3.2.1 Methodological issues

The empirical literature on human capital and growth is subject to a number of methodological problems, both at the level of the underlying data and at the level of the methods with which these data are statistically analyzed. As we have seen, a number of recent studies have emphasized that educational attainment has been measured with error. Subsection 3.2.1.1 will discuss how measurement error can give rise to an underestimation of the contribution of educational expansion to economic growth, how the reliability of data series can be measured, and whether there is a relationship between statistical indicators of reliability and the estimated coefficients on schooling

141 See *Bassanini/Scarpetta* (2001: 7).

142 *Bassanini/Scarpetta* (2002: 7) acknowledge that one-year observations are subject to short-term influences such as business cycles, and argue that they control for this by using a so-called error correction form of their equation which includes short-run regressors.

143 See *Bassanini/Scarpetta* (2001: 19).

144 See *Bassanini/Scarpetta* (2001: 22).

variables. Subsection 3.2.1.2 will turn to various econometric concerns. It will examine the issues of robustness, parameter heterogeneity, and non-linearity.

3.2.1.1 Measurement error

The international data on educational attainment have long been known to be of doubtful quality stemming from inconsistencies in the primary data used in their construction. *Krueger/Lindahl* point out that this may at least partly explain why earlier studies found the evolution of human capital to be uncorrelated with output growth.[145]
A well-established fact in econometrics is that measurement error reduces the explanatory power of a variable. In the case of human capital and growth, the measured values of educational attainment will diverge from their true values by the amount of error or noise in the data, which, by definition, should be a random disturbance. Consequently, the measured stock of human capital will display a certain amount of fluctuations which are not accompanied by changes in the skills of the workforce, so that they cannot influence output. This causes the relationship between schooling and growth to become blurred and leads to an attenuation of the estimated coefficients on educational variables.
To assess the amount of measurement error in the data and the associated attenuation bias, *Krueger/Lindahl* put forward a statistical indicator of reliability.[146] They define the reliability of a data set as the ratio of the variance of 'true' schooling to the variance of measured schooling. Writing measured schooling as true schooling plus noise then yields

$$R_1 = \frac{\operatorname{var} S^*}{\operatorname{var} S_1} = \frac{\operatorname{var} S^*}{\operatorname{var}(S^* + \varepsilon_1)} = \frac{\operatorname{var} S^*}{\operatorname{var} S^* + \operatorname{var} \varepsilon_1}, \tag{14}$$

where R_1 is the reliability ratio of a given measure of schooling S_1 which contains a measurement error denoted ε_1 (assumed to be uncorrelated with S^* or any other right-hand-side term in the growth equation), while S^* is true schooling. It can be shown that if there is a second, independent measure of schooling $S_2 = S^* + \varepsilon_2$, then the covariance between S_1 and S_2 is an approximation of the variance of S^*. Hence, R_1 can be estimated as

$$\widetilde{R}_1 = \frac{\operatorname{cov}(S_1, S_2)}{\operatorname{var} S_1}. \tag{15}$$

This expression is identical to the formula for calculating the coefficient on S_1 in a univariate regression where S_2 is the dependent and S_1 the independent variable. Thus, one can obtain an approximate value of the reliability of a data set by using it to estimate a second series, provided that the two are independent measures of schooling. This last requirement will not always be met, of course. In the likely case that the

145 See *Krueger/Lindahl* (2001).

146 See *Krueger/Lindahl* (2001: 1115).

measurement errors ε_1 and ε_2 are positively correlated, the obtained estimate will be an upper bound on the reliability of a data set.[147]

By means of this procedure, *Krueger/Lindahl* calculate the reliability ratios of the *Barro/Lee* (1993) data set and the one used by *Benhabib/Spiegel* (1994).[148] It turns out that the data *in levels* do quite well, with estimates of reliability ranging from 0.77 to 0.97 (although these are upper bounds which probably overstate the actual reliabilities). However, as mentioned earlier,[149] the performance of the data *in changes* is dismal, with the reliability ratio of the series used by *Benhabib/Spiegel* amounting to just 0.195 for the 20-year change between 1965 and 1985. According to *Krueger/Lindahl*, this implies that the coefficient on schooling will be underestimated by at least 80 percent when these data are used in a multivariate regression. Quite generally, taking growth rates or log differences of the data exacerbates any measurement error, and the magnitude of this effect increases with the frequency at which observations are taken. That is, the shorter the intervals between observations, the stronger the measurement error.[150]

Krueger/Lindahl and *Topel* provide some indirect evidence that this may indeed drive the results of empirical analyses.[151] They estimate very simple growth equations, cutting the considered time span into periods of varying length. Both of them find that the size and significance of the estimated coefficients on schooling are inversely related to the frequency at which observations are taken. At five-year intervals, the change in years of schooling is small and only marginally significant. Over periods of ten or twenty years, however, the estimate rises considerably and becomes highly significant. A clear explanation why measurement error is likely to be responsible for this pattern of results is given by *Krueger/Lindahl*:

> *"Over short time periods, there is little change in a nation's true mean schooling level, so the transitory component of measurement error in schooling would be large relative to variability in the true change. Over longer periods, true education levels are more likely to change, increasing the signal relative to the noise in measured changes."*[152]

More direct support for this kind of argument comes from *de la Fuente/Domenech*, who examine the relationship between the reliability ratios of eight different educational data sets and the size of the coefficients on schooling obtained with those same data series in a number of growth equations.[153] Figure 2 plots the average coefficients they obtain in various specifications against the average reliability ratios they calculate for each of the data sets.

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147 See *Krueger/Lindahl* (2001: 1115).

148 See *Krueger/Lindahl* (2001: 1116).

149 See section 3.1.3.

150 *Krueger/Lindahl* (2001: 1118) explain that this owes to the fact that the serial correlation of true schooling is higher than the serial correlation of the errors.

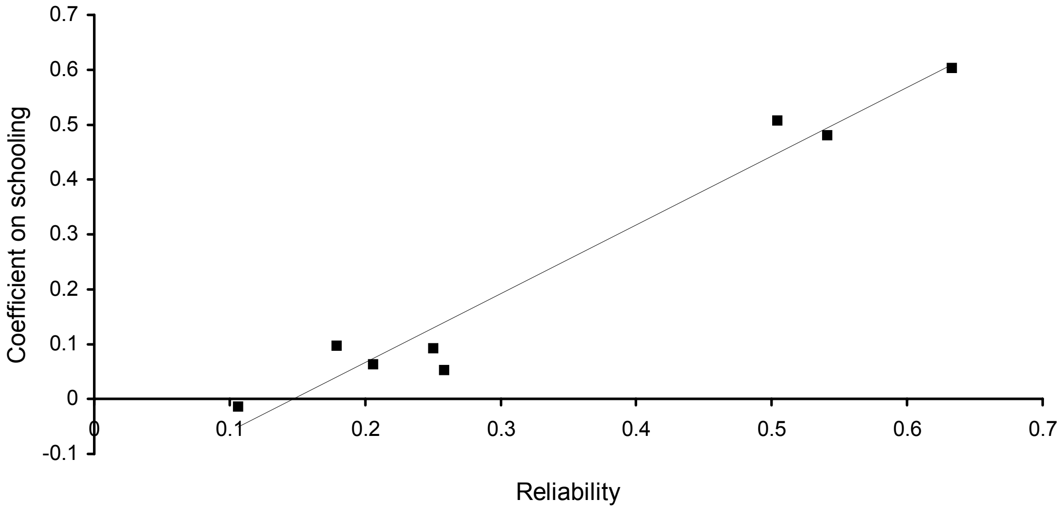
151 See *Krueger/Lindahl* (2001: 1119) and *Topel* (1999: 2968).

152 *Krueger/Lindahl* (2001: 1119).

153 See *de la Fuente/Domenech* (2002: 31). *De la Fuente/Domenech* use a weighted average of "pairwise" reliability ratios (for each of the eight data sets, they calculate a separate reliability ratio with every one of the seven other data sets in the manner described above, and weight the obtained estimates so as to minimize the variance of the composite indicator).

Figure 2 illustrates that there is a clear positive relationship between data quality and the size of estimated coefficients on schooling (the correlation between the two is 0.98), suggesting that earlier studies have suffered from severe downward bias, and that better data are supportive of a significant growth impact of education. Besides, figure 2 also indicates that the three data series ranked highest in terms of reliability, which are those constructed by *de la Fuente/Domenech* (2000 & 2002) and *Cohen/Soto* (2001), represent a substantial improvement over earlier data sets (and also over the recently updated *Barro/Lee* (2001) data).

Fig. 2: The relationship between the reliability of data sets and the size of coefficients



Source: Based on calculations by de la Fuente and Domenech (2002, p. 24 and 29).

Still, whether measurement error entirely explains the negative findings of earlier research is disputable. *Pritchett* argues that his findings are not the result of pure measurement error.[154] He claims that one of the statistical methods he employs (namely, instrumental variable estimation using an alternative schooling series as an instrument for the *Barro/Lee* (1993) measure of educational capital) corrects for the kind of attenuation bias envisaged by *Krueger/Lindahl* (2001), and is even conceptually equivalent to their approach. Yet, this argument does not contradict the above finding concerning the link between data quality and the size of coefficients, because correcting for downward bias is not exactly the same as using better data.[155] In any case, the "*Pritchett* hypothesis"[156] – i.e., that schooling growth has had little effect on output

154 *Pritchett* (2001: 377-378).

155 In addition, we have seen that if the two error terms are positively correlated (which they quite possibly are in Pritchett's case), the method proposed by *Krueger/Lindahl* (2001) gives only a ceiling on the reliability of the data sets, and therefore only makes it possible to correct for the downward bias associated with the uncorrelated fraction of the disturbances.

156 This expression is due to *Temple* (2001b).

growth – has been surprisingly hard to reject,[157] and reasons other than measurement error may be responsible for his findings. We will return to this below.

3.2.1.2 Econometric concerns

The difficulties faced by studies adopting a panel data approach have already been commented upon in subsection 3.1.1.2 above. This subsection will examine more general econometric issues relevant to a broader range of studies. These are robustness (to alternative regressors and outliers), parameter heterogeneity, and non-linearity.

- Robustness:

Since the important paper of *Levine/Renelt*,[158] economists have been well aware of the fragile nature of some of the results in the empirical growth literature. *Levine/Renelt* found that the sign and significance of the coefficients on various variables included in growth regressions were highly sensitive to the selection of other explanatory variables. Estimated coefficients turned out to regularly change sign or lose significance when the composition of the vector of regressors was altered. It can be regarded as encouraging that they found human capital (as proxied for by secondary school-enrollment rates) to be among the more robust variables. Nonetheless, a large amount of uncertainty still surrounds the robustness of educational variables in growth equations. An illustration of this is that in his recent overview of the most robust findings produced by the "new growth evidence", *Sala-i-Martin* concludes that "the relation between most measures of human capital and growth is weak."[159] In the light of this testimony, schooling variables deserve no 'presumption of innocence': the results from growth regressions have to be interpreted with great caution.

This is the more so since robustness can be assessed from different viewpoints. A second dimension apart from the one examined by *Levine/Renelt* is the sensitivity of results to influential observations and outliers. While researchers have recently begun to pay more attention to checking the effects of deleting selected observations from their samples, outliers are a potentially important problem for a number of earlier studies.

One of the studies whose findings have been called into question as a result of a subsequent sensitivity analysis is *Barro/Lee* (1994). The fact that *Barro/Lee* found male schooling to be positively related to economic growth, whereas female schooling entered negatively, motivated *Lorgelly/Owen* to subject their study to extensive robustness testing.[160] *Lorgelly/Owen's* analysis reveals that the results are indeed extremely fragile. When the four Asian tigers (Hong Kong, Singapore, Taiwan and Korea) are deleted from the sample, both male and female schooling lose significance. In addition, when female schooling is dropped from the equation, the coefficient on male schooling, though remaining significant for the whole sample, becomes

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157 See *Temple* (2001b).

158 See *Levine/Renelt* (1992).

159 *Sala-i-Martin* (2002: 10).

160 See *Lorgelly/Owen* (1999).

considerably smaller, and again turns insignificant upon deletion of the four Asian countries.

Outliers may work in the opposite direction too. That is, the positive relationship between schooling and growth that exists in a majority of economies may be hidden by a small number of unrepresentative yet influential countries. *Temple* shows that this is the case for *Benhabib/Spiegel's* (1994) study.[161] He uses a robust regression technique to identify those countries with the largest residuals as outliers, and re-estimates the remaining sample with ordinary least squares. *Temple* shows that it is indeed possible to arrive at a highly significant coefficient on the change-in-schooling variable in this manner. However, this requires dropping 14 out of 78 countries from the sample.

- Parameter heterogeneity:

Pritchett interprets this last result by *Temple* not as evidence of a small number of unrepresentative observations driving results, but as evidence of important differences in parameters across countries.[162] In his view, the fact that the size of the sample needed to be cut by almost a fifth for the coefficient on schooling to turn significant and positive suggests that the impact of increases in education on growth has varied widely across countries. This would imply heterogeneous production function parameters. Additional support for this hypothesis comes from studies which have split their sample into several smaller subsamples (according to the level of economic development of countries, for example), and estimated separate equations for each of the subsamples. As noted in section 3.1, these studies often report important differences between the parameter values estimated for each subsample.[163] In addition, the micro literature points to international heterogeneity in the private returns to education.[164]

As one would expect given these *a priori* considerations, a statistical test conducted by *Krueger/Lindahl* finds that the assumption of homogeneity of coefficients across countries is strongly rejected by the data.[165] When they estimate a more flexible model that exploits the time-series variation in the data to allow for country-specific schooling parameters, coefficients are found to vary substantially across countries. Surprisingly, the average country displays a negative (though insignificant) slope coefficient, a result which is unlikely to be caused by classical measurement error.

Despite all this, the majority of growth regressions imposes a constant coefficient on educational variables. This is partly due to the limited time span for which data have been available, especially for large cross-sections of countries. Still, it is in such large samples which include a wide range of countries with very diverse characteristics that parameter heterogeneity is likely to be most important. *Sianesi/Van Reenen* therefore doubt that much can be learned about average parameter values from such regressions, and question the usefulness of deriving policy prescriptions for individual countries from them.[166] In a similar spirit, *Temple* stresses the need to thoroughly look into the

161 See *Temple* (1999b).

162 See *Pritchett* (2001: 368).

163 See, e.g., *Gemmell* (1996), *Benhabib/Spiegel* (1994).

164 See *Psacharopoulos/Patrinos* (2002).

165 See *Krueger/Lindahl* (2001: 1127-1129).

166 See *Sianesi/Van Reenen* (2002: 15).

possibility of parameter heterogeneity with appropriate statistical methods in order to be able to make valid generalizations.[167]

- Non-linearity:

A third and related potential problem of the literature is the assumption of a linear relationship between human capital and growth. Again, *Krueger/Lindahl* show that relaxing this assumption leads to very different results.[168] They investigate an equation relating growth to the initial level of schooling and find that a quadratic function of education yields a better fit than the usual linear function. This non-linear specification implies an inverted-U shaped relationship between human capital and growth. That is, the growth effect of the initial level of education is positive only up to a certain point, and becomes negative when initial schooling is beyond this point. *Krueger/Lindahl* estimate the peak of this curve to be at 7.5 years of schooling, meaning that the average OECD country (with an attainment of 8.4 years) is located on the downward-sloping part. They conclude that only low-productivity countries appear to benefit from a positive effect of initial schooling on growth. While this particular result is probably at least as fragile as any other, it epitomizes the uncertainty about the correct econometric specification and, more generally, about the nature of the relationship between human capital and growth.

3.2.2 Conceptual issues

It has already been mentioned in section 3.1.3 that, in search of explanations for the failure of some earlier studies to find a significant correlation between schooling and growth, the literature has moved forward in two separate directions. The first, blaming poor data quality, has been pursued with promising results (see sections 3.1.3 and 3.2.1.1 above). This section will present a second direction of research, which has offered alternative explanations for the negative results starting from the acknowledgement that years of education may be a poor proxy for human capital. The reasons for this are numerous. It may not adequately reflect the theoretical concept of human capital (section 3.2.2.1), and in particular, it may neglect the qualitative dimension of education and the importance of efficient resource allocation, as discussed in a separate subsection (3.2.2.2). In addition, section 3.2.2.3 will raise a fundamental issue in the empirics of economic growth – namely, that the sense of the relationship between growth and education may well run both ways.

3.2.2.1 The adequacy of empirical human capital proxies

The review of the empirical literature has shown that, since *Barro/Lee* (1993), a large majority of studies has used the average number of years of formal education of the

167 See *Temple* (2001b).

168 See *Krueger/Lindahl* (2001: 1129-1130).

workforce (or working-age population) to proxy for human capital. Errors in the recording of the data aside, a number of authors argue that this is a far from perfect measure of the theoretical concept it is supposed to reflect. In what follows, we will discuss some of its general flaws, present attempts to bring it more in line with human capital theory by adjusting the functional form relating years of schooling to human capital, and consider some additional, more fundamental concerns.

Equating years of schooling with human capital is problematic for several reasons. *Mulligan/Sala-i-Martin* name the following shortcomings of the approach:[169]

- In aggregating heterogeneous workers, it assumes that workers with a given level of attainment are perfect substitutes for workers with any other attainment level, and that the elasticity of substitution across workers of different attainment levels is constant. To take an extreme example, this assumption implies that "in principle a sufficiently large group of university professors could substitute for an Olympic athlete"[170].
- It assumes that each year of schooling increases the productivity of a worker by a constant absolute amount, regardless of the worker's level of schooling. In the aggregate, this means that raising average years of schooling from 0.5 to 1 doubles the stock of human capital just like raising years of schooling from five to ten years. Moreover, if the production function is Cobb-Douglas, output would increase by the same factor in both cases too, which does not seem plausible.
- One year of schooling is assumed to yield the same productivity increase in all fields of study, and in all educational institutions or systems, regardless of their quality.

This last point will be discussed in greater detail in the following subsection. As to the second point (and, to a lesser extent, the first), the main obstacle to improving on that aspect is finding an adequate "aggregator function" linking attainment at different levels to the stock of human capital.[171] That is, we are looking for a function of the form $H = f(S_1, S_2, \ldots, S_n)$, where S_i is the number of years of schooling at a particular level of education i.

Under the conventional approach using years of schooling as a proxy for human capital, this function would simply be

$$H = S, \text{ with } S = \sum_i S_i \,. \qquad (16)$$

169 See *Mulligan/Sala-i-Martin* (2000: 216).

170 *Temple* (2001b: 914).

171 To measure the stock of human capital, *Mulligan/Sala-i-Martin* (2000) propose constructing index numbers by weighting the number of workers in different education categories by the labor-income share of each education category. However, this requires very detailed information on the wage distribution of the economy, which has thus far prevented the use of this measure for international analyses. *Mulligan/Sala-i-Martin* (2000) do implement their approach for the states of the US, and find that it delivers results which diverge strongly from those found with average years of schooling proxying for human capital. In particular, they report that, measured in their way, the stock of human capital grew twice as fast as the years of schooling.

Note that this is equivalent to a log-log specification of the relationship between schooling and human capital, where ln H = ln S, which has the aforementioned implication that the returns to an additional year of schooling are much higher at low levels of education than at high levels. By contrast, as stated in section 3.1.2, human capital theory[172] would suggest a log-linear relationship between productivity and education (provided that the wage differentials observed at the micro level are attributable to actual differences in skills rather than to mere signaling effects[173]). A number of authors have argued that the relationship between schooling and human capital should be formulated in an analogous – i.e., Mincerian – way at the macro level.[174] The simplest specification would be for f to take the form

$$\begin{aligned} H &= e^{\theta S} \\ \Leftrightarrow \ln H &= \theta S, \end{aligned} \tag{17}$$

where θ measures the increase in skills due to an additional year of schooling. This increase is assumed to be constant in *percentage* terms, regardless of the level of education, in this basic formulation. Hence, unlike with equation (16), raising the average years of schooling of the population from 1 to 2 years delivers the same percentage increase (θ) in the stock of human capital as raising years of schooling from 9 to 10 years. One may notice that equation (17) is similar to the specification adopted by *Pritchett*.[175] However, as we will see below, there is one important difference.

A further extension to the Mincerian approach allows the parameter θ to vary across levels of schooling. For example, it is possible that the percentage increase in productivity arising from an extra year of schooling diminishes with the level of education. One way to conceptualize this is by assuming a piecewise linear function such as

$$\ln H = \theta_{prm} S_{prm} + \theta_{scd} S_{scd} + \theta_{trt} S_{trt}, \quad \text{with } \theta_{prm} > \theta_{scd} > \theta_{trt}, \tag{18}$$

where the indexes *prm*, *scd* and *trt* denote primary, secondary and tertiary education. Some authors reckon that this formulation is more adequate because there is evidence that the private returns to education are higher for low levels of schooling. The question is, however, whether the *cost-inclusive* return to education – which is quite probably higher for low levels of education because the opportunity cost of an additional year of schooling in terms of foregone wage earnings is smaller – is the relevant parameter for the specification of the stock of human capital. *Pritchett* argues that it is the increment to wages which matters, not the rate of return.[176] In any case, the proposition that returns are decreasing is based on international differences in the coefficients produced by estimations of Mincerian earnings functions. The fact that in Sub-Saharan African

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172 See *Mincer* (1974), *Becker* (1975).

173 For a review of the evidence on signaling effects, see *Weiss* (1995).

174 See *Klenow/Rodriguez-Clare* (1997), *Topel* (1999), *Hall/Jones* (1999), *Bils/Klenow* (2000), and *Wößmann* (2000).

175 See *Pritchett* (2001) and equation (13) above.

176 See *Pritchett* (2001: 373).

countries (where average attainment typically does not exceed primary schooling) the coefficient is usually found to be much higher than in OECD countries is supposed to confirm the premise that returns at low levels of schooling are higher than at high levels of schooling always and everywhere. For obvious reasons, this argument is not entirely convincing, especially since micro data within countries typically yield constant Mincerian returns to education.[177]

What this shows is that no consensus on the exact functional form of the linkage between schooling and human capital has evolved as yet. Nonetheless, from a theoretical point of view, there is reason to believe that a Mincerian log-linear specification is preferable to the conventionally adopted log-log formulation. As pointed out by *Cohen/Soto*, the main implication of this is that, because schooling now enters linearly into the growth equation, it is the absolute change in years of schooling (ΔS) that matters, rather than its growth rate ($\Delta \ln S$).[178] Whereas developing countries have caught up with industrialized countries in relative terms over the last 40 years, they have been unable to narrow the gap in absolute terms. The next step is to investigate whether the adoption of a Mincerian measure of human capital affects the results of studies which have used other specifications.

Topel speculates that the log-log formulation chosen by *Benhabib/Spiegel* (1994) accounts for their negative results,[179] but *Krueger/Lindahl* show that it is only part of the story.[180] Interestingly, *Topel* makes the same case against *Pritchett*.[181] Recall from section 3.1.2 that *Pritchett* assumed $H = e^{\theta S}$-1. *Topel* demonstrates that this formulation, even though being derived from a Mincerian definition of human capital, has the same shortcoming as the log-log specification, namely, that an extra year of schooling is assumed to generate ever higher percentage increases in the stock of human capital as S tends to zero (a problem which the *usual* log-linear specification overcomes).[182] In other words, under Pritchett's assumption, an additional year of education raises human capital by a significantly greater proportional amount in countries with low levels of attainment than in countries with high levels of attainment. Pritchett's measure of human capital is therefore subject to the same criticism as the one expressed above with regard to years of schooling.

It turns out that this remark by *Topel* constitutes the most serious challenge to *Pritchett's* results thus far. *Topel* himself provides indirect support to his claim that an unconventional formulation is crucial for *Pritchett's* findings by noting that estimating

177 See *Card* (1994).

178 See *Cohen/Soto* (2001: 13).

179 See *Topel* (1999: 2972).

180 See *Krueger/Lindahl* (2001: 1113). As discussed earlier (see section 3.1.3), the extremely low signal in *Benhabib/Spiegel's* education data conditional on physical capital growth is crucial for their findings.

181 See *Topel* (1999: 2971-2972).

182 This can easily be seen by deriving the expression for ln H with respect to years of schooling. In the case of a log-log specification, $\frac{d \ln H}{dS} = \frac{1}{S}$. In the case of *Pritchett's* specification, $\frac{d \ln H}{dS} = \frac{\theta}{e^{\theta S} - 1}$. Both of these expressions tend to infinity as S tends to zero. In fact, the graphs of the two derivatives are astonishingly similar.

his own equation using *Pritchett's* specification also yields an insignificant coefficient on human capital. Meanwhile, *Temple* comes up with direct support for *Topel's* claim.[183] He re-analyzes *Pritchett's* data using a Mincerian human capital specification like in equation (17) instead of *Pritchett's* original one. *Temple* (2001b) reports that this indeed causes the coefficient on human capital to become positive and significant. One should mention, however, that *Temple* himself has reservations about the generality of his result because a second estimation with a robust regression technique delivers a much lower coefficient, which – according to *Temple* – indicates that parameter heterogeneity may be a problem.

In a different paper, the same author notes a more fundamental flaw of educational attainment as an empirical equivalent of the theoretical concept of human capital envisaged in growth models such as Lucas (1988).[184] In fact, we have seen in section 2.2.1 that in *Lucas's* model, sustained economic growth arises from the fact that human capital per worker can grow without bound. Even in other models, there is generally no upper bound on the stock of human capital. For example, in the augmented *Solow* model, the accumulation of human capital mirrors that of physical capital, which is obviously not hypothesized to be bounded. At the same time, for simple investment reasons, it is difficult to imagine indefinite growth of the average number of years of schooling (even in the unlikely event that life expectancy continues increasing forever).

Hanushek/Kimko and *Wößmann* contend that one way to reconcile theories of growth with an empirical measure of education is to adjust for differences in the quality of education across countries and over time.[185] The underlying assumption is that a year of schooling is associated with more skill acquisition in a good education system than in a bad one, and – more importantly in this context – that the knowledge that students are taught in 2000 is superior to what they were taught in 1950.[186] Yet, as far as the temporal improvement of schooling quality is concerned, *Temple* (2001a, p. 60) is not convinced.[187] He maintains that the nature of the skills taught in primary and secondary school (e.g., literacy and numeracy) is such that continuous qualitative improvements are hardly possible. At the level of higher education, advances in the knowledge that is being taught may have an effect on productivity in certain fields of study but not in others. Overall, he remains skeptical about the idea that increases in the quality of education lead to unbounded human capital growth.

Whereas the aforementioned criticism that the years-of-schooling measure is at odds with microeconomic human capital earnings functions requires only more or less cosmetic changes to the specification of the human capital stock, this last objection is clearly of a more serious nature. The same pertains to the issues raised in a report by the *OECD* investigating the data requirements for accurate human capital measurement.[188] Based on the broad definition of human capital quoted in the introduction, the report identifies a number of general limitations with educational attainment as a proxy for acquired skills. In essence, the report argues that equating individuals' skills with what

183 See *Temple* (2001b: 912-913).

184 See *Temple* (2001a: 59).

185 See *Hanushek/Kimko* (2000: 1185); *Wößmann* (2000: 22).

186 See also the following subsection (3.2.2.2).

187 See *Temple* (2001a: 60).

188 See *OECD* (1998).

they have (supposedly) learned during their youth ignores less formal adult learning, such as on-the-job training and other forms of adult education which do not lead to recognized qualifications. It also neglects the depreciation of human capital.[189] The report also cites research which points to important productivity effects of enterprise-based training.[190] This suggests that this aspect of human capital accumulation can only be safely ignored if it is positively correlated with years of schooling. There may be reasons for the existence of such a correlation. For instance, as education is sometimes said to be about learning to learn, schooling may prepare other forms of lifelong learning.[191] But very little is known about this, and therefore, even when educational attainment is found to be important for growth, it is unclear whether this captures the effect of human capital or of something else. In any case, the correlation assumption needs to be made explicit.

More direct measures of the skills of the labor force have the potential to overcome some of the limitations associated with a measure of educational attainment such as years of schooling, which is restricted to the pure quantity of education. They are the subject of the following section.

3.2.2.2 Quality of education and efficiency of resource allocation

Educational attainment is not a very complete measure of human capital, as the preceding discussion has shown. It may not even be a good proxy for the skills acquired at school, because it measures only the quantity of education while neglecting quality. National education systems are likely to vary considerably in their capacity to impart knowledge and skills. Thus, a year of education may induce quite different increases in students' skills depending on the quality of schooling. This has very early been recognized in labor economics.[192] In the empirical growth literature, two distinct ways to account for qualitative differences across education systems have been explored: First, including input-oriented indicators of quality (such as educational expenditure per student, student-teacher ratios or teacher salaries) in regressions, and second, including output-oriented, direct measures of skills based on student performance in standardized international tests. There is little support for a robust relationship between educational inputs and a schooling system's output in terms of test performance.[193] Therefore, the focus here will be on output-oriented indicators of educational quality.

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189 See *OECD* (1998: 21-22). Human capital depreciation may be of particular importance for workers who remain out of employment for a prolonged period of time. For example, *Bassanini/Scarpetta* (2001: 8) cite data which show that, for the OECD, there is a tendency for the gap between the human capital of employed and unemployed persons to widen over time. This suggests that macroeconomic studies using output per capita rather than output per worker will be particularly affected by the negligence of depreciation.

190 See *OECD* (1998: 60-61).

191 See *Temple* (2001a: 93).

192 See *Behrman/Birdsall* (1983).

193 See *Wößmann* (2000: 19); *Hanushek/Kimko* (2000: 1192). *Lee/Barro* (2001) do find some evidence that school resources are related to test performance, however.

Hanushek/Kimko derive such quality measures using student scores from six international tests in mathematics and science, delivered between 1965 and 1991.[194] They justify their focus on mathematics and science by making reference to recent theories of growth stressing the importance of research and development (see section 2.2.2). *Hanushek/Kimko* combine all test scores available for individual countries into a single measure of cognitive achievement.[195] Of course, this procedure makes it impossible to compute changes in quality over time.[196] Accordingly, they are able to examine only the impact of the *stock* of human capital on growth. Their series covers 31 countries (for which both test scores and the economic data necessary for an analysis of growth rates are available).

Hanushek/Kimko's ensuing investigation of the growth effects of schooling quality yields several interesting results.[197] Their first step consists in estimating a familiar equation including only the *quantity* of schooling (i.e., years of formal education), which produces rather standard results (conditional on initial income, the schooling variable displays a significantly positive coefficient) and explains around 40 percent of the variance in growth rates. In a second step, they add their measure of schooling quality to the equation. The consequences of this are twofold: On the one hand, quality is found to have a highly significant positive effect on growth and to increase the explanatory power of the regression by more than 30 percentage points (the R^2 rises to 0.73). On the other hand, the coefficient on the quantity of education becomes much smaller and loses significance. These findings are robust to the exclusion of the Asian tigers and to variations in the set of explanatory variables.

Hanushek/Kimko proceed to perform several additional tests in an attempt to give the relationship a causal interpretation. First, they look into the possibility of causality running from growth to quality of schooling rather than the other way around, which might be the case if higher income leads to better education through increased spending on schools. They refute this hypothesis based on their finding of a non-relationship between school resources and student performance which "eliminates the feedback loop".[198] Second, they try to assess the likelihood of omitted variable bias, i.e., that some overlooked influence (such as cultural, racial or parental characteristics) determines both students' cognitive achievement and the economic performance of their country of origin (via its inhabitants' productivity). *Hanushek/Kimko* examine the determinants of the wages of a sample of people having migrated to the United States and find that the quality of education in their native country matters only if they completed their education before migrating, and not if they did so after coming to the U.S. They infer from this finding that omitted variable bias is unlikely to be of major importance.

194 See *Hanushek/Kimko* (2000).

195 See *Hanushek/Kimko* (2000: 1186).

196 In any event, *Hanushek/Kimko* (2000: 1189) note that instead of changes in the quality of students, changes in the quality of the labor force are what is relevant. Given that there is no immediate effect of the former on the latter, looking at changes in test achievement is impractical.

197 See *Hanushek/Kimko* (2000: 1189-1190).

198 *Hanushek/Kimko* (2000: 1193).

Hanushek/Kimko conclude that, overall, their results point to an important causal effect of the quality of education on economic growth.[199] Moreover, the fact that by including quality they achieve a substantial improvement in the explanatory power of their regression shows that accounting for qualitative differences of education systems across countries clearly is an advance over existing human capital estimates.

Another much neglected yet potentially important aspect, which can only be mentioned *en passant*, though, is the allocation of resources between different levels of schooling. This point is emphasized by *Judson*, who evaluates the efficiency of past educational spending allocations in a number of countries by judging them against what would have been optimal under the assumption of a given return-to-education function, a fixed budget for all education, and given costs for a year of education at each level.[200] In a subsequent growth regression, she finds that countries which were identified to inefficiently allocate school resources benefit substantially less from investments in human capital than countries with an efficient allocation.

3.2.2.3 Reverse causation

This section turns to a concern which has hampered the entire empirical literature on economic growth: uncertainty about the direction of causality between growth and a large majority of supposedly exogenous variables.[201] For instance, *Caselli/Esquivel/Lefort* present evidence indicating that endogeneity plays a major role in explaining the correlation between output growth and the rate of investment in physical capital or even the rate of population growth.[202] Consequently, estimated coefficients will suffer from an upward bias.

Bils/Klenow pick up this theme in the context of the growth-and-schooling debate.[203] The possibility of a feedback effect from a country's *level* of income to its demand for schooling is rather obvious (education being not only an investment but also a consumption good), so that an equation with the level of per capita output as dependent variable will almost certainly overestimate the coefficient on education. But *Bils/Klenow* identify another channel through which the (anticipated) *growth rate* may affect the demand for schooling, and therefore induce reverse causation bias in growth

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199 Once again, though, there is controversy over whether or not the negligence of the qualitative dimension of education is responsible for the negative findings of some earlier studies. One argument against the explanation of those results with differences in quality is that quantity and quality are positively correlated. Therefore, the failure to adjust for quality should bias the coefficient on the quantity of schooling upward and lead one to *overstate* the importance of educational attainment for economic growth (see *Behrman/Birdsall* 1983, *Pritchett* 2001). However, according to *Barro/Lee* (2001: 556), the correlation between a country's average years of schooling and its test performance is actually quite low, which suggests that both may in fact measure different things (namely, quantity and quality of the stock of education).

200 See *Judson* (1998).

201 *Mankiw* (1997: 104) reckons that the problem of identifying causation is the „weak link“ in empirical research on growth.

202 See *Caselli/Esquivel/Lefort* (1996).

203 See *Bils/Klenow* (2000).

equations too.[204] In their model, the return to schooling is a positive function of future rates of economic growth because higher growth has a favorable effect on wages. Hence, individuals will demand more education if they anticipate faster output growth.
Bils/Klenow use a Mincerian measure of human capital and calibrate a model of growth with parameter values chosen mostly to reflect microeconomic estimates. Their analysis reveals that no more than 30 percent of the empirical correlation between initial (= 1960) school-enrollment rates and subsequent economic growth can be attributed to a causal effect of schooling on growth. They go on to test the reverse causality channel, where they make the assumption that individuals anticipate between a quarter and one half of the deviation of their country's growth rate from the world average. *Bils/Klenow* find that, depending on the choice of parameter values, reverse causation can explain between 33 and 100 percent of the observed correlation between growth and enrollment.[205] Of course, in the latter case, there would be no effect at all of schooling on growth, all of the empirical relationship being due to reverse causation. They concede, however, that their results are subject to the qualification that the high value which they assume for the elasticity of the demand for schooling with respect to the return to education is out of line with microeconomic estimates.
In addition, the fact that *Bils/Klenow* concentrate on school enrollment rates leaves open the question of how much of a concern reverse causality is for studies using measures of educational attainment, rather than enrollment. *De la Fuente/Ciccone* argue that, because attainment is a stock variable calculated as an average over the entire working-age population, it is affected by changes in enrollment only with a considerable time lag.[206] This means that while the rate of economic growth in a given period will quite possibly feed back into enrollment via the channel identified by *Bils/Klenow*,[207] it is less likely to influence the contemporaneous stock of human capital, as measured by years of schooling. Accordingly, the upward bias in the estimated coefficient on educational attainment is probably less severe than for enrollment ratios. However, as acknowledged by *de la Fuente/Ciccone*, if the equation is estimated in differences or growth rates, the extent of the problem depends on the length of the interval between observations. If the time period over which differences are calculated is long enough for changes in enrollment to propagate through the labor force (thereby affecting the economy's human capital stock), the issue of reverse causality can certainly not be ignored.
The flip side of this argument gives reason to be more optimistic, though. *De la Fuente/Ciccone* and *Temple* point out that if growth rates or differences are computed over short periods, reverse causation bias is probably negligible.[208] Thus, panel data studies such as those by *Bassanini/Scarpetta* (2001) and *de la Fuente/Domenech* (2002) which consider data at one-year and five-year intervals, respectively, should be unaffected by the endogeneity of schooling.

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204 See *Bils/Klenow* (2000: 1163-1164).

205 See *Bils/Klenow* (2000: 1176-1177).

206 See d*e la Fuente/Ciccone* (2002: 27).

207 *Temple* (2001a: 77) puts forward a different channel through which reverse causality may work, which takes account of the fact that governments are often responsible for decisions on educational investment. He observes that increases in output raise tax revenues, allowing governments to spend more on the expansion of education.

208 See d*e la Fuente/Ciccone* (2002: 28); *Temple* (2001a: 77).

3.3 Assessment

This final section concerned with empirical evidence will attempt to evaluate the results of the studies reviewed in section 3.1 against the background formed by the different methodological and conceptual issues raised in section 3.2. In addition, it will make some remarks on the magnitudes of the estimated effects and what they imply for the debate on human capital externalities.

The results from earlier studies, be it those based on convergence equations or those estimating production functions, should be looked upon with suspicion. Each of those studies is likely to suffer from at least one, and probably several of the shortcomings identified above. All of them are affected by measurement error, which can explain to a large extent the inability of a number of researchers to find the expected growth effects of human capital. This applies particularly to equations in differences and growth rates (e.g., *Benhabib/Spiegel* 1994), as well as to panel data approaches (e.g., *Islam* 1995). Other empirical investigations finding negative effects may be mis-specified in the sense that the assumed relationship between human capital and years of schooling is at odds with human capital theory and with the closely related microeconomic evidence on Mincerian earnings functions. In particular, this could pertain to *Pritchett* (2001); nevertheless, *Pritchett's* work is notable not only because his results have proved exceptionally difficult to overturn, but also because of the economics behind his hypothesis, which certainly deserve attention. The important point made by *Pritchett* is that expanding education does not in itself lead to faster growth. Rather, its success depends on getting peoples' incentives right. This has recently been emphasized also by *Easterly*, who notes that creating skills is worthless in a country where the most profitable activities are redistributive ones such as "lobbying the government for favors", instead of productive ones which increase output.[209]

Turning to those studies which did find a significant and positive effect of human capital on growth, there are also a number of qualifications to be made. Given the extreme crudity of school-enrollment ratios as a proxy for human capital (even compared with years of schooling which has to be considered seriously flawed itself), it may have come as a surprise to learn that studies using enrollment rates generally found a strong positive correlation between schooling and growth (e.g., *Mankiw/Romer/Weil* 1992). This fact looks a lot less puzzling once one takes into account possible reverse causality or omitted variable bias, as highlighted by *Bils/Klenow*.[210] School-enrollment ratios may be a poor proxy for human capital, but to a limited extent, they should reflect the flow into education, which, in turn, is likely to be strongly affected by levels and growth rates of income, or simultaneously determined with (subsequent) growth by some other variable (such as certain government policies).

Still, it is noteworthy that early studies estimating convergence equations for cross-section or pooled data consistently point to a large and significant effect of the initial stock of human capital on subsequent growth, even when average years of schooling is used. As explained in section 3.2.2.3, average attainment evolves slowly in response to

209 See *Easterly* (2001: 82-83).

210 See *Bils/Klenow* (2000).

changes in enrollment, so that these findings should not be due to the endogeneity of schooling. Many of those studies (e.g., *Barro/Lee* 1994) may be somewhat sensitive to influential observations or to the choice of explanatory variables. Meanwhile, others (e.g. *Barro/Sala-i-Martin* 1995) find only the initial level of education to matter for growth, and not the change, which does not really make sense.[211] In fact, it implies that all the impact from schooling on growth would have to come from human capital externalities and none of it from direct productivity effects of education, which is implausible. In addition, the estimated coefficients are often too large to be attributed solely to the causal influence of schooling on growth.[212] Despite all this, the consistency with which this literature reports a significant growth effect of initial schooling is remarkable.

More recent work (section 3.1.3) has overcome some of the earlier shortcomings by improving data quality, sometimes adopting a Mincerian specification of the human capital stock, and by paying more attention to issues of robustness. This increases the confidence in the findings of this research, which appear to be more plausible in a number of respects too. Above all, the change in schooling does seem to be positively related to output growth after all, just as labor economists would have expected.[213]

However, there continues to be a variety of reasons to be skeptical even about the results from this more recent literature. Parameter heterogeneity and non-linearity may be of concern, and everything that has been said about years of schooling being an incomplete measure of human skills (section 3.2.2.1 and 3.2.2.2) remains valid. Reverse causation should be less problematic because of the use of data for short time periods, except, perhaps, for *Cohen/Soto* (2001) who use data at ten-year intervals.

These later studies are in marked contrast to the rest of the literature in that they find only the change in schooling to matter for growth, and do not find a significant effect of the initial level of human capital. This is surprising because the theoretical argument in support of such an effect (see section 2.2.2) seems solid, and earlier research tended to confirm it. Moreover, the case for an effect of the human capital stock on growth has been considerably strengthened by *Hanushek/Kimko* (2000) who use a direct measure of the skills of the labor force to proxy for human capital (section 3.2.2.2).

A possible explanation may be the following. Both *de la Fuente/Domenech* and *Bassanini/Scarpetta* restrict their analysis to OECD countries.[214] Meanwhile, although *Cohen/Soto* examine a broader sample comprised of developed as well as less developed countries,[215] the fact that they include both the change and the initial stock of human capital in their equation makes them vulnerable to collinearity problems.[216]

211 See *Easterly* (2001: 77); *Pritchett* (2001: 381).

212 See *Topel* (1999: 2964). For example, *Topel* computes that the return to schooling implied by *Barro/Sala-i-Martin's* (1995) coefficient on initial education is 30 percent – three times as high as the average estimate of private returns.

213 *Topel* (1999: 2972) even contends that it is beyond question that increases in educational attainment should raise output: "The key empirical issue is not whether schooling raises aggregate output – evidence to the contrary should be regarded with great suspicion".

214 See *de la Fuente/Domenech* (2002); *Bassanini/Scarpetta* (2001).

215 See *Cohen/Soto* (2001).

216 Collinearity may arise because of a high negative correlation between initial levels and subsequent growth rates of schooling. See *de la Fuente/Ciccone* (2002, p. 29).

Thus, leaving aside *Cohen/Soto*, one observes that the human capital stock does not seem to contribute to differences in growth rates *for developed countries*. This is consistent with the finding of an inverted U-shaped relationship between schooling and growth reported by *Krueger/Lindahl*, implying that the positive growth effect of initial schooling is restricted to low productivity countries.[217]

The picture that starts to emerge from this is one in which human capital plays an important role for technological adoption, thereby helping countries that lag behind the technological leader to catch up, as originally suggested by *Nelson/Phelps*.[218] Additional support for this comes from studies which allow for technological diffusion or include some kind of catch-up mechanism.[219] If one recognizes that developed countries are probably not far from the technological frontier, it is evident that for them, technological catch-up would be of relatively minor importance. Consequently, and consistent with the evidence outlined above, not much of the variance in rates of economic growth across OECD countries should be explained by the variance in initial stocks of human capital.

Note that none of this necessarily contradicts the theory developed by *Romer*. In his model, the stock of human capital should not only contribute to technological adoption but should also spur growth through its impact on the creation of new ideas in the R&D sector. One might infer that *Romer's* model predicts initial human capital to determine relative growth rates across developed economies as well. However, his model may be more suitable for describing the process of knowledge growth in the industrialized world *as a whole* (i.e., the evolution of the world technology frontier) than for explaining differences in growth rates across nations.[220]

To sum up, recent research has given support to the hypothesis that expanding education does pay off in terms of output growth. There is also reason to believe that human capital plays an important part in technological catch-up. In spite of the fact that educational attainment, measured in years of schooling, reflects only the quantity of education, the latest findings suggest that there are some useful things to be learned from the analysis of its role in the growth process. It is also likely, however, that adjusting for the qualitative dimension of education will considerably improve our understanding,[221] which is currently still rather limited. In his recent review of the literature, *Temple* concludes that "estimates that are sufficiently accurate and robust to allow confident conclusions are some way off."[222] He argues that results will become more reliable as data for longer time spans become available.

Furthermore, it is possible that the importance of human capital has increased over time, at least if the view (which is currently en vogue) that economic activity has shifted to more knowledge-based industries is correct. Hence, future research working with data covering the 1990s and beyond may find different parameters than earlier studies analyzing data for periods up to 1990.

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217 See *Krueger/Lindahl* (2001).

218 See *Nelson/Phelps* (1966).

219 These include *Benhabib/Spiegel* (1994), *Barro/Sala-i-Martin* (1995), and *Engelbrecht* (2002).

220 See *Jones* (1998: 89); *Barro* (1998: 3).

221 See *de la Fuente/Ciccone* (2002: 87).

222 *Temple* (2001a: 81).

With this in mind, we will briefly take a look at the range of parameter values for the Mincerian return to schooling in OECD countries, as calculated by *de la Fuente/Ciccone* on the basis of the regression coefficients found by recent studies using more reliable data.[223] This parameter measures the percentage increase in output resulting from an additional year of schooling, and has therefore been interpreted as the social return to schooling. According to *de la Fuente/Ciccone* (2002), the Mincerian return to schooling implied by macroeconomic research ranges from approximately 4 to 13 percent. This is consistent with microeconomic estimates of the private returns to schooling, which are usually considered to range from about 5 to 15 percent.[224]

The fact that social and private returns to education are of roughly the same magnitude has been interpreted by some authors as evidence that there are no externalities to human capital.[225] However, this is true only if there are no signaling effects either. If the private returns are partly the result of signaling rather than actual productivity effects (which *Weiss* argues they are[226]), they should exceed the social returns in the absence of positive externalities. Hence, equality of social and private returns would indicate that externalities do exist, and that they contribute to the growth of output, as suggested by *Lucas*.[227] The problem can only be resolved by further clarification of the extent to which private returns can be explained by signaling effects.

4 Conclusion

This paper has dealt with the role of human capital in the process of economic growth. A number of theoretical approaches to incorporating human capital in models of growth have been presented, ranging from the augmented *Solow* model to the endogenous growth models of *Lucas* (1988) and *Romer* (1990). Although the empirical predictions derived from these models are to a large extent "observationally equivalent",[228] in the sense that it is difficult to distinguish between them empirically, they tend to agree that human capital should matter for growth. The channels through which it may affect output growth include direct productivity effects and more indirect effects due to externalities, facilitated technological adoption, or enhanced productivity of R&D.

Although having been spawned by the enthusiasm surrounding the 'new growth theory', the vast empirical literature on economic growth has used a framework which, as noted by *Barro*, draws more heavily on the older neoclassical model.[229] The evidence on the importance of human capital for growth which it has produced is somewhat mixed.

223 See *de la Fuente/Ciccone* (2002: 115-118).

224 See *Krueger/Lindahl* (2001: 1103).

225 A more precise formulation is the one retained by *Temple* (2001a: 81), who notes that macroeconomic studies allow for a direct test of the productivity effects (including those due to externalities).

226 See *Weiss* (1995).

227 See *Lucas* (1988).

228 *Gemmell* (1996).

229 See *Barro* (1998: 2).

Research on the topic has changed course several times over the last decade. A first round of studies, inspired by *Barro* and *Mankiw/Romer/Weil*,[230] relied on convergence equations. These studies delivered results which were generally supportive of a prominent role for human capital in explaining differences in growth rates across countries. They were followed by a revisionist set of studies led by *Benhabib/Spiegel* and *Pritchett* who found changes in human capital to be largely uncorrelated with economic growth.[231] Their findings seemed to be confirmed by a number of studies adopting a panel data approach[232] which sometimes even reported a negative effect of human capital on growth. Finally, the literature took another turn following the influential paper by *Krueger/Lindahl* who suggested that measurement error may account for the negative results.[233] Several authors have recently focused on improving the quality of the data series on educational attainment.[234] To the extent that their results point to a significantly positive effect of *increases* in human capital on growth, this approach has brought the literature back in line with theoretical predictions.

When interpreting all of these findings, a number of methodological and conceptual issues have to be taken into account. While poor data quality indeed seems to be responsible for some of the negative results, there are some important econometric concerns, such as parameter heterogeneity and non-linearity, which may limit the generality of positive findings as well. Moreover, it is widely accepted that educational attainment is a severely flawed measure of the theoretical concept of human capital. Some of the criticism it has attracted can be responded to by making more or less cosmetic changes, such as altering the function relating years of schooling to the aggregate stock of human capital. Other objections are more fundamental. For example, investments in human capital other than formal education, such as on-the-job training, are neglected. In addition, the quality of education is likely to vary considerably across countries. Failure to adjust for this may lead to biased estimates.[235]

Apart from the limitations of years of schooling as a proxy for human capital, another conceptual problem is the possibility of reverse causation. In fact, there is reason to believe that higher anticipated growth may feed back into the demand for education.[236] This could lead to an overestimation of the causal effect of human capital on growth.

Based on the preceding discussion, the last section has made an attempt to evaluate the empirical literature and identify the most plausible results it has generated. On balance, the evidence seems to indicate that educational expansion does contribute to output growth, and that the estimated magnitude of the social returns to schooling is consistent with the evidence on private returns from labor economics. There also appear to be grounds for thinking that human capital has a substantial impact on technological catch-up, possibly through improving a country's capacity to adopt new technologies.

230 See *Barro* (1991) and *Mankiw/Romer/Weil* (1992).

231 See *Benhabib/Spiegel* (1994) and *Pritchett* (2001, first circulated in 1996).

232 See, e.g., *Islam* (1995).

233 See *Krueger/Lindahl* (2001).

234 See, e.g., *de la Fuente/Domenech* (2002).

235 See *Hanushek/Kimko* (2000).

236 See *Bils/Klenow* (2000).

However, given the literature's above-mentioned weaknesses, these conclusions have to be considered preliminary and fragile.

One should not be too hasty in putting the blame for the limited knowledge in this field on empirical economists being unable to come up with adequate measures of human capital. As *Aghion/Howitt* have pointed out in a slightly different context, theorists also carry their share of the blame. With regard to the concept of abstract knowledge, *Aghion/Howitt* observe:

> *"[F]ormal theory is ahead of conceptual clarity. (...) [T]he real question is one of meaning, not measurement. Only when theory produces clear conceptual categories will it be possible to measure them accurately."*[237]

While their statement refers to the stock of knowledge rather than human capital, the latter concept clearly shares some of the problematic attributes of the former. Therefore, as recently suggested by *Piazza-Georgi*, it may be fertile to split the all-encompassing notion of human capital into several sub-categories.[238]

Finally, for all the discussion about education's role in growth, it should not go unmentioned that investment in education does not need to be justified by economic benefits. It is well-known that education is associated with a number of wider benefits to individuals and society.[239] To give some examples, better educated people tend to be healthier and show more active social and political participation. Education may also reduce crime, and produce more efficient consumers.

Nonetheless, understanding the economic benefits of education, and human capital in general, is undoubtedly of significance, not least because human capital accumulation is one area in which government policy can truly make a difference. *Temple* and *Wößmann* argue that in order to be more useful to policy makers, economic research will have to go beyond the simple question of whether human capital matters for growth, and address issues such as how to efficiently allocate resources and improve the quality of schooling.[240] Yet, given the lack of solid knowledge on the role of human capital, replicating and extending the results of recent research concerning the contributions of both quantity and quality of schooling to economic growth should also remain a high priority.

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237 *Aghion/Howitt* (1998: 435).

238 See *Piazza-Georgi* (2002). Specifically, *Piazza-Georgi* proposes to distinguish between human skills capital and entrepreneurship.

239 See *OECD* (2001: 32-35) for details.

240 See *Temple* (2001b: 917); *Wößmann* (2000: 39).

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