Human Capital and International Differences in Income Levels*

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1. Introduction

The literature on exogenous growth has emphasised the importance of physical capital accumulation as a factor in economic growth (at least in the medium period). More recently, however, new growth theory has shown that a country's economic development process is endogenous to the economic system in the sense that it is determined by a deliberate endeavour to accumulate mainly non-material capital (for example, human capital) by agents (individuals and/or firms) driven by the search for greater returns (wages and/or profits).

The aim of this paper is to merge these two branches of the literature and to propose the simplest model *à la* Solow (1956)-Uzawa (1965)-Lucas (1988), the purpose being to analyse the role of international differences in *levels of human capital* in explaining differences of *per capita income level* across countries. Our rationale for adopting this approach is that, to date, study of this particular research topic (the explanation of income levels), especially at empirical level, has attracted little interest in the scientific community.[1] Instead, much closer attention has been paid to analysis of the correlation between *human capital accumulation* and *economic growth*. Moreover, in this latter area of empirical research the results do not appear to be conclusive, in that they depend closely on the method used (*cross-country growth accounting*[2] versus *cross-country growth regressions*[3]), on the measure of human capital employed[4] (some studies use a flow-measure of human capital[5] - school enrolment rates - while other, more recent ones use the stock of human capital[6] - total mean years of schooling), and finally on the type of data utilized (cross-country versus panel[7]).[8]

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[1] This is all the more curious if one considers the fact that endogenous growth theory first arose with, amongst other things, the objective of explaining cross-country differences in income levels.
[2] Benhabib and Spiegel (1994); Krueger and Lindahl (2001); Pritchett (2001).
[3] See Barro (1999); Barro and Sala-I-Martin (1995); Easterly and Levine (1997) and Islam (1995).
[4] Wößmann (2003) provides a complete survey of all the main measures of human capital used to date by empirical studies on growth (in particular, adult literacy rates, school enrolment ratios and average years of schooling of the working-age population), analysing the pros and cons of each of them and assessing their coherence/incoherence with the original *theory of human capital* developed by Becker (1964) and Schultz (1964), and later resumed by Mincer (1974).
[5] See, in particular, the works by Barro (1991), Mankiw, Romer and Weil (1992) and by Levine and Renelt (1992).
[6] Barro and Sala-I-Martin (1995), Barro (1997, 2001), Benhabib and Spiegel (1994), Gundlach (1995), Islam (1995), Krueger and Lindahl (2001), O'Neill (1995) and Temple (1999a).
[7] Studies which use cross-section data, unlike those based on panel data, general find that human capital accumulation has a positive effect on the rate of growth of per capita income. In this regard Islam (1995) writes: *"...whenever researchers have attempted to incorporate the temporal dimension of human capital variables into growth regressions, outcomes of either statistical insignificance or negative sign have surfaced"*.
[8] See Kalaitzidakis et al. (2001, pp. 229-34) for a brief survey of empirical studies on the relationship between human capital accumulation and economic growth. Using semiparametric estimation techniques, and extending the studies by Durlauf and Johnson (1995) and Liu and Stengos (1999), the authors cited find that the effect of human capital (defined in various ways and disaggregated by educational level and by sex) on the growth rate of per capita income is non-linear (it is negative for low levels of human capital, positive for intermediate levels of human capital, and non-significant for countries with extremely high levels of human capital). As said above, our aim in this article is to study the impact of human capital (in levels) on international differences in levels of per capita income.

An important exception is the influential article by Mankiw-Romer-Weil (1992) - MRW, henceforth - which uses the *cross-country regressions* methodology to conduct extensive analysis of the impact of human capital on the level of per capita income and finds a high, positive and statistically significant effect. The theme is indubitably topical, given that, although estimation (on micro-data) of earnings regressions *à la* Mincer confirms the fundamental role of formal education in explaining levels of work income or wages, the evidence obtained using macro data is anything but definitive.[9]

Our study introduces two important novel features with respect to MRW (1992): one is empirical while the other is strictly theoretical. Firstly, at empirical level we use a different proxy (one today more widely used in the literature, namely the mean years of schooling) to measure the stock of human capital[10] and a more recent database. Secondly, at the theoretical level, and within an aggregate model where physical and human capital grow at the same constant rate in the long run (balanced growth path equilibrium), we endogenize the allocation of individual skills among the different economic activities which demand this factor input.[11]

In more detail, our theoretical model assumes the existence of only two perfectly competitive sectors. The final sector produces a homogeneous good by combining physical and human capital through a constant returns to scale technology, while the education sector produces individual skills. As in the Solow's model (1956) physical capital is accumulated with a positive, constant and exogenous fraction of total output (final good) being devoted in each period to this activity. In the steady state equilibrium the ratio of physical to human capital is constant, so that these two production factors grow at the same rate. This rate is a function of the economy's exogenous parameters (technological and preference parameters) and depends positively on the amount of resources invested in human capital accumulation. The model allows us to conclude that, in the long run, whilst income growth is driven solely by investment in education, the level of per capita income depends not only on those variables (mainly the saving rate) already put forward by the

[9] Temple (1999b, p. 139) writes: "*Another problem to emerge is that changes in human capital appear to explain little of the variation in changes in output, casting doubt on the augmented Solow formulation. This macroeconomic evidence conflicts with the finding of the micro literature that schooling has a significant return in terms of higher wages. The failure to discern this effect at the macro level is worrying*".

[10] MRW (1992) use enrolment rates at upper secondary school (*"…the percentage of the working-age population that is in secondary school"*), and therefore employ a *flow* measure of a country's educational level to proxy the rate of human capital accumulation. The use of this indicator to measure human capital accumulation has been criticised by Klenow and Rodriguez-Clare (1997) and more recently also by Judson (2002, p. 211), and MRW themselves are aware of its drawbacks (*"…this variable…is clearly imperfect:…the variable does not include the input of teachers, and it completely ignores primary and higher education"*). Owing to the fact that today data on the human capital stock are also available (see Barro and Lee, 2001), we believe that a stock measure is more appropriate (and therefore preferable to a flow measure) when the intention is to study the effects of human capital on a country's level of well-being (income).

[11] In MRW (1992), the allocation of the resources available (final consumption goods) between the sectors of physical and human capital accumulation is exogenously given.

neoclassical model with exogenous technical progress[12] but also and crucially (i.e. with unitary elasticity) on the stock of human capital possessed by each individual.

In the light of what has been said, the article is organized as follows. The next section illustrates the main features of the reference economic system and states the laws of physical and human capital accumulation. Section 3 describes the steady state equilibrium of the model and determines the allocation of human capital between the two activities in which this production factor can be used (production and education), the equilibrium growth rate, and the ratio between human and physical capital in the steady state. The fourth section obtains the level of equilibrium per capita income, which is our estimation equation. Section 5 carries out the empirical investigation by considering various cross-sections relative, respectively, to the years 1980, 1985, 1990 and 1995 and a total of 92 countries at different stages of economic development. The principal aim of this section is not to subject the theoretical model to a real '*empirical verification*', but rather to use the data to analyse the importance of human capital in the explanation of the differences in per capita GDP among countries, and to determine the coherence of the results with the theoretical model. Section 6 concludes and suggests some directions for further research.

2. The model

The economy considered consists of two sectors, both perfectly competitive. The final output sector produces a homogeneous consumption good combining physical and human capital as inputs via the following Cobb-Douglas technology with constant returns to scale:

$$(1) \quad Y_t = K_t^{\alpha}\left(H_{Yt}\right)^{1-\alpha}, \qquad \alpha \in (0,1).$$

In (1), Y_t represents the total quantity of the final good (the numeraire in the model)[13] produced at time t, while K_t and H_{Yt} denote the aggregate quantities of factors used in the production process, again at time t (respectively physical and human capital). In the above relation, α is a technological parameter (strictly comprised between zero and one), that can be easily interpreted as the share of national income going to physical capital.[14] Population at time t (L_t) consists only of educated individuals, and each of its members is endowed with a stock of human capital (per *efficiency unit*) equal to h_t, which is defined as:

[12] See Barro and Sala-I-Martin (1995), Chap. 1, pp. 34-5.
[13] $P_Y = 1$.
[14] In the model, all markets are competitive and there are no market distortions or failures.

(2) $$h_t \equiv \frac{H_t}{A_t L_t},$$

where H_t and A_t respectively represent the total stock of human capital available in the economy (the population's total number of years of education) and the state of the technology at time t. It follows from (2) that H_t can also be written as:

(2') $$H_t \equiv (A_t h_t) L_t .$$

In (2') the term in brackets ($A_t h_t$) represents the human capital possessed by each member of the population (or *per capita* human capital, i.e. the mean number of years of education).

There is full employment in this economy, and all the human capital available (H_t) can be used in two alternative activities. A fraction u_t of human capital (equal to H_{Yt}) is used at time t to produce the homogeneous final consumption good, while its complement to one (1-u_t) is used to accumulate new human capital. In other words, the human capital stock employed to produce the final good in t is:

(3) $$H_{Yt} = u_t H_t = u_t \left[(A_t h_t) L_t \right].$$

Using (3), the aggregate production function can thus be recast as:

(1') $$Y_t = K_t^{\alpha} \left[u_t (A_t h_t) L_t \right]^{1-\alpha}$$

and the income per *efficiency unit of the population* is:

(4) $$y_t \equiv \frac{Y_t}{A_t L_t} \equiv f(k_t; u_t; h_t; \alpha) = k_t^{\alpha} (u_t h_t)^{1-\alpha}, \qquad k_t \equiv \frac{K_t}{A_t L_t}.$$

2.1. The laws of physical and human capital accumulation

As in the models developed by Solow (1956) and MRW (1992), we assume that aggregate investment in physical capital is financed by allocating to it, at each instant, a positive, exogenous and constant fraction (equal to s) of total available output. Following the two works just cited, we also postulate that both the population (L) and the state of the technology (A) grow at a rate (respectively n and g_A) which is positive, exogenous and constant ($L_t = e^{nt}$, $L_0 \equiv 1$; $A_t = e^{g_A t}$, $A_0 \equiv 1$), and that the sum of n and g_A (which we denote with δ) is strictly comprised between zero and one. Therefore:

(5) $\dot{k}_t = sf(k_t; u_t; h_t; \alpha) - \delta k_t$, $0 < s < 1$, $0 < \delta \equiv g_A + n < 1$,

$\frac{\dot{A}_t}{A_t} \equiv g_A > 0$, $\frac{\dot{L}_t}{L_t} \equiv n > 0$.

Equation (5) is obtained by considering a closed economy in which aggregate saving (sY_t) in equilibrium is equal to aggregate investment ($I_t \equiv \dot{K}_t$) at every *t*. For the sake of simplicity, we assume that the aggregate stock of physical capital (K) is not subject to material depreciation.

Unlike Solow's (1956) model, ours includes accumulation of non-material capital (human capital). In this regard, and differently from MRW (1992), where this factor is produced with the same production technology as used for the final output,[15] here we assume that a fraction (equal to $1\text{-}u_t$) of the total human capital available at time *t* is employed to accumulate and produce further human capital (in other words, our hypothesis is that the education sector is skill-intensive).

More in detail, we hypothesise that in one unit of time $\dot{H}_t$ units of new individual skills are obtained with the following aggregate production function:

(6) $\dot{H}_t = (1 - u_t)H_t = (1 - u_t)[(A_t h_t)L_t]$.

Hence, our model explicitly incorporates the same technology of human capital accumulation as used by Uzawa (1965) and Lucas (1988).

It is evident from equation (6) that we also assume that the production of human capital comes about at constant returns to scale. This assumption, which is shared by many other models as well,[16] can be justified by envisaging either the existence of external effects in education (and such that the decreasing returns to this activity at the individual level are converted into constant returns at the aggregate one) or that the production of new human capital involves not only the time spent on pure educational activity but also other production factors (in this case, human capital should be considered in the broad sense).[17]

Equation (6) and the definition of *h* can be used to find the law of (gross) accumulation of human capital in *efficiency units of population*:

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15 *"…We are assuming that the same production function applies to human capital, physical capital and consumption. …Lucas (1988) models the production function for human capital as fundamentally different from that for other goods. We believe that, at least for an initial examination, it is natural to assume that the two types of production functions are similar"* (MRW, 1992).

16 Among others, Azariadis and Drazen (1990), Becker, Murphy and Tamura (1990), Stokey (1991), Glomm and Ravikumar (1992), Buiter and Kletzer (1995) and Redding (1996).

17 See Rebelo (1991), Milesi-Ferretti and Roubini (1994). For a wider discussion of the use of a linear human capital production technology in endogenous growth models, see Blackburn *et al.* (2000, p. 195).

(7) $\dot{h}_t + \delta h_t = (1 - u_t) h_t , \qquad 0 < u_t < 1 , \quad \forall t .$[18]

Note from (7) that, like the stock of physical capital, also the stock of human capital is subject - when expressed in efficiency units of population - to a process of (effective) obsolescence in the production of new human capital (the term δ). The reason for this is simple: if the rate of investment in human capital ($1\text{-}u_t$) were equal to zero, then the human capital stock in efficiency units of population would tend to diminish over time, partly because of population growth (at rate n) and partly because of technological progress (g_A). This amounts to saying that the more rapid the technical progress, and the faster the population growth, the more rapidly obsolescent becomes the stock of knowledge (h_t), available at present (but accumulated in the past) and on the basis of which new human capital is formed.

In the next section we characterize the steady-state equilibrium of the model presented.

3. The steady-state equilibrium

In this section we determine the level of income (per efficiency unit of population) that prevails in the steady-state equilibrium. First, however, we provide a formal definition of steady-state equilibrium.

DEFINITION: STEADY-STATE EQUILIBRIUM

We define as steady-state equilibrium a situation in which all the endogenous state variables grow at constant rate.

In the model being analysed, the endogenous state variables are physical capital and human capital (both measured in efficiency units of population, respectively k and h). On applying the definition just given to equation (7), we find that in the long run, with $\delta \equiv g_A + n$ constant and exogenous, the shares of human capital devoted respectively to production of the homogeneous final consumption good (u_t) and to production of new human capital ($1\text{-}u_t$) are constant. Moreover, from equations (4) and (5) we obtain the following (in order to ease the notation, henceforth we shall omit the subscript t appended to time-dependent variables):

[18] The constraint that we impose on u is taken to be inequality in the strict sense (u is assumed as a variable strictly comprised between two limit values). Indeed, we are interested in an equilibrium solution in which human capital is always used simultaneously in the sector producing the final good and the education sector.

(8) $\frac{\dot{k}}{k} = \frac{sk^{\alpha}(uh)^{1-\alpha}}{k} - \delta = constant \qquad \Rightarrow \qquad s \cdot u^{1-\alpha}\left(\frac{h}{k}\right)^{1-\alpha} = constant + \delta$.

With s and δ constant (and exogenously given), and with u also constant, two fundamental conclusions can be drawn from equation (8):

(8a) in the steady-state equilibrium, h and k grow at the same constant rate given by $\gamma = (1-u) - \delta$;

(8b) $\frac{uh}{k} = f(\gamma;\delta;s;\alpha) = \left(\frac{\gamma+\delta}{s}\right)^{\frac{1}{1-\alpha}} = \left(\frac{1-u}{s}\right)^{\frac{1}{1-\alpha}}$, so that it too is constant.

The fact that in the long run h and k grow at the same rate implies that in the steady state their ratio is constant at every t (equation 8b). From equation (4), and bearing in mind that in the steady state $\frac{\dot{h}}{h} = \frac{\dot{k}}{k} = \gamma$ and u is constant, one obtains:

(9) $\frac{\dot{y}}{y} = \frac{\dot{k}}{k} = \frac{\dot{h}}{h} \equiv \gamma = (1-u) - \delta$.

Equation (9) suggests that, under the hypotheses of our model, there exists a steady-state equilibrium which takes the form of a balanced growth path equilibrium: along the balanced growth path, income, physical capital and human capital (all measured in efficiency units of population) grow at the same constant rate (which is a linear function of u, still to be determined).

In order to characterize the level of income per efficiency unit of population in the steady-state equilibrium (y_{ss}), we must first identify k_{ss}. Accordingly, we reconsider equation (8) above (knowing that in the steady state the rate of growth of k is equal to γ) and obtain:

(10) $k_{ss} = \left(\frac{s}{\gamma+\delta}\right)^{\frac{1}{1-\alpha}} \cdot (u_{ss}h_{ss})$,

where x_{ss} represents the level assumed by the variable x in the steady-state equilibrium.

Given k_{ss}, y_{ss} can be immediately obtained from equation (4):

(4') $y_{ss} = (k_{ss})^{\alpha}(u_{ss}h_{ss})^{1-\alpha} = \left(\frac{s}{\gamma+\delta}\right)^{\frac{\alpha}{1-\alpha}} \cdot (u_{ss}h_{ss})$.

3.1. General equilibrium and steady-state allocation of human capital between production and education

There are three endogenous variables in the model: 1) the ratio between the two state variables, *h/k*; 2) the inter-sectoral allocation of human capital, *u*; and 3) the rate of growth of the variables expressed in efficiency units of population, γ.

Because the education sector is perfectly competitive, in equilibrium the following condition must hold:

$$(11) \qquad P_h = (1-\alpha)\left(\frac{k}{uh}\right)^{\alpha} \equiv w .$$

This equation states that the (shadow) price of human capital in units of goods (P_h) must be equal to the ratio between the marginal product of the human capital employed in the manufacturing sector (the wage rate, *w*) and the marginal product of the human capital employed in the education sector.[19] Put otherwise, the productivity (in value) of the human capital employed in the education sector (the left-hand side of (11)) must be equal to the productivity (in value) of the human capital employed in the production of goods (the right-hand side of (11)). Accordingly, equation (11) can be interpreted as an arbitrage condition for the allocation of the available human capital between the two sectors demanding this resource as an input. Compliance with this condition ensures that in equilibrium both the activities in which human capital is utilized as a production factor are undertaken and can therefore co-exist.

In the presence of a perfectly competitive capital market, it should make no difference, from the point of view of the returns on the two kinds of asset, to an economic agent to hold physical capital or human capital. Because the return (in terms of goods) from possessing one unit of human capital coincides with the wage rate (*w*), while that from possessing one unit of physical capital coincides with the real interest rate (*r*, i.e. with the productivity of physical capital in the goods sector), the second condition that we impose is the following:

$$(12) \qquad r = (1-\alpha)\left(\frac{k}{uh}\right)^{\alpha}, \qquad \text{with } r = \alpha\left(\frac{uh}{k}\right)^{1-\alpha} .$$

Solving this equation in (*uh*/*k*) yields:

$$(13) \qquad \frac{uh}{k} = \left(\frac{1-\alpha}{\alpha}\right).$$

[19] See Barro and Sala-i-Martin (1995, p. 181). In particular, see their equation (5.16) with A=B=v=1 and $\eta = 0$.

Equation (13) states that in equilibrium the ratio between human capital (*uh*) and physical capital (*k*) in the production of goods must be equal to the ratio between their respective distributive shares (1-α and α).[20]

Equation (13) gives us another expression for the ratio between *uh* and *k*. Equalizing this equation with equation (8b) yields a closed form solution for u_{ss} and $(1-u_{ss})$. Respectively, the share of human capital employed in steady state by each agent to produce the homogeneous final consumption good and to produce skills is:

$$(14) \qquad u_{ss} = 1 - s\left(\frac{1-\alpha}{\alpha}\right)^{1-\alpha};$$

$$(15) \qquad (1-u_{ss}) = s\left(\frac{1-\alpha}{\alpha}\right)^{1-\alpha}.$$

Given u_{ss}, it follows from equation (8a) that the balanced growth rate of this economy is:

$$(16) \qquad \gamma = s\left(\frac{1-\alpha}{\alpha}\right)^{1-\alpha} - \delta .$$

Finally, given u_{ss}, it follows from equation (8b) - or alternatively from equation (13) - that:

$$(17) \qquad \left(\frac{h}{k}\right)_{ss} = \frac{(1-\alpha)}{\alpha - s\alpha^{\alpha}(1-\alpha)^{1-\alpha}} .$$

In the steady-state equilibrium, u, γ and h / k depend solely on the model's exogenous variables (g_A; n) and on the technological (or distributive, α) parameters, and the preference parameters (s). However, the growth rate (γ) is endogenous, because it depends on u (which we have determined endogenously). We may accordingly consider our model as a *semi-endogenous* growth model.[21]

We note finally that, unlike the model with physical capital accumulation alone (Solow, 1956), the possibility for agents to invest also in human capital gives rise to a balanced growth rate (γ) which is constant and positive even in the absence of technical progress and exogenous demographic dynamics (i.e., when $g_A = n = 0$).

The model just described also suggests the following:

[20] See again Barro and Sala-I-Martin (1995), p. 174, equation 5.6.

[21] According to Jones (1995) and Funke and Strulik (2000, p. 492), a growth model is *semi-endogenous* when the steady-state growth rate is determined by the (preference and technological) parameters, which are exogenous within the same model. This is exactly the case of our model. See Bucci (2003, section 5) for a more comprehensive discussion of some of the most important and recent models of *semi-endogenous* growth.

Proposition 1:

The relation between the model's parameters that must be satisfied for it to be simultaneously the case that:

$$\gamma > 0, \qquad 0 < u_{ss} < 1 \quad \textit{and} \quad \left(\frac{h}{k}\right)_{ss} > 0,$$

is that:

$$\delta\left(\frac{\alpha}{1-\alpha}\right)^{1-\alpha} < s < \left(\frac{\alpha}{1-\alpha}\right)^{1-\alpha} < 1.$$

Proof:

The proof of this proposition follows immediately from equations (14), (16) and (17).

In other words, when the saving rate (s) is strictly comprised between the two extremes just stated, the equilibrium that arises (equations (14) through (17)) ensures:

- the existence of a positive rate of balanced growth;
- the existence of a decentralized allocation of human capital between the two sectors which use it such that each simultaneously employs this factor input.

Notice that we are assuming that $\alpha < 1/2$. Hence, the restriction $\left(\frac{\alpha}{1-\alpha}\right)^{1-\alpha} < 1$ applies for each $\alpha \in (0;1)$. This hypothesis is in line with the evidence that the physical capital share of income is approximately equal to 1/3 (and in any case less than ½).

In order to convey the intuition behind the above proposition, let us see what would happen in the steady-state equilibrium if the saving rate were instead 'too' low ($s \to 0$) or 'too' high ($s \to 1$). If the saving rate were 'too' low, in the long run there would be, *ceteris paribus*, no physical capital ($k \to 0$), and only human capital would be used to produce the final good ($u \to 1$). This would naturally subtract resources from investment in education ($1 - u \to 0$), and the growth rate would gradually diminish until it became negative ($\gamma \to -\delta$). This possibility is explicitly ruled out by our proposition. By contrast, if the saving rate were 'too' high, the reverse situation would obtain. In fact, under the hypothesis that the share of income going to physical capital is less than ½ ($\alpha <$ ½), if s tended to one, then *(1-u)* and u would tend respectively to one (from above) and to zero (from below). This would imply that, unlike the previous case, now only physical capital is used to produce goods, while all human capital is employed in the education sector, to the obvious benefit of economic growth. Yet also this second extreme possibility, like the first one, is excluded by the above proposition.

Before introducing in the next section the equation we shall estimate in the empirical part of this paper, the following table gives the comparative statics results with regard to the model's main variables:[22]

a) $\frac{\partial u_{ss}}{\partial s} < 0$	e) $\frac{\partial u_{ss}}{\partial \alpha} > 0$
b) $\frac{\partial (1-u_{ss})}{\partial s} > 0$	f) $\frac{\partial (1-u_{ss})}{\partial \alpha} < 0$
c) $\frac{\partial \gamma}{\partial s} > 0$	g) $\frac{\partial \gamma}{\partial \alpha} < 0$
d) $\frac{\partial (h/k)_{ss}}{\partial s} > 0$	h) $\frac{\partial (h/k)_{ss}}{\partial \alpha} < 0$

Table 1: *Comparative statics results on the model's main variables in the steady state equilibrium.*

All the comparative statics results set out in the table have a clear economic intuition. For example, an increase in s will increase the stock of available physical capital (k). This greater availability of k, combined with the fact that physical capital is used solely for the production of goods, will have two effects: (i) human capital in the manufacturing sector will be substituted (in equilibrium u will diminish); (ii) the shadow-price of human capital will increase (P_h will rise because k is higher and because u is now smaller, *ceteris paribus*). The increase in P_h will stimulate investment in education (($1-u$) will be greater in equilibrium), making human capital relatively more abundant than physical capital (in equilibrium also h/k will increase). Vice versa, an increase in the share of income spent on physical capital (α) in equilibrium will reduce - u remaining equal - the h/k ratio (the physical capital available will be relatively more abundant than human capital), and this will increase the productivity of human capital in the goods sector and the share of this factor used in that sector (u increases in equilibrium). Eventually, the increase in u will reduce the investment in new human capital ($1-u$) and drive down the balanced growth rate of growth (γ).

[22] Results e), f) and g) were obtained under the hypothesis that $\alpha < 1/2$, while all the other results in the table hold for every $\alpha \in (0,1)$ and for every $s \in (0,1)$.

4. The estimation equation: the level of steady-state per capita income

The equation that we estimate for a sample of countries at different stages of industrialization consists in the logarithm of the steady-state per capita income (y_{ss}^{pc}). It follows from equations (4), (4') and (9) that the steady-state per capita income is:

$$(18) \qquad y_{ss}^{pc} \equiv y_{ss} A_{ss} = \left(\frac{s}{1-u_{ss}} \right)^{\frac{\alpha}{1-\alpha}} \cdot u_{ss} \cdot \left(A_{ss} h_{ss} \right) = \left(\frac{\alpha}{1-\alpha} \right)^{\alpha} \cdot \left[1 - s \left(\frac{1-\alpha}{\alpha} \right)^{1-\alpha} \right] \cdot \left(A_{ss} h_{ss} \right),$$

where $\left(A_{ss} h_{ss} \right)$ is the steady-state per capita human capital.

Taking the logarithm of (18), the equation considered in the empirical exercise we perform in the next section is therefore:

$$(18') \qquad \ln y_{ss}^{pc} = \alpha \ln \left(\frac{\alpha}{1-\alpha} \right) + \ln \left[1 - s \left(\frac{1-\alpha}{\alpha} \right)^{1-\alpha} \right] + \ln \left(A_{ss} h_{ss} \right).$$

Given the aim of this article, equation (18') suggests that, besides the saving rate, also the level of per capita human capital is a variable of potential interest for the determination of a country's equilibrium level of per capita income. Moreover, (18') is similar to the equation that MRW (1992) estimate in their celebrated work, although ours was obtained from a considerably richer theoretical model in which human and physical capital are two production factors that in the long run grow at the same rate, and the allocation of human capital between economic activities is endogenous. Finally, equation (18') also appears to predict that the elasticity of per capita income with respect to the per capita stock of human capital is exactly equal to one in the steady state. In this the predictions of our model differ from those of MRW (1992), whose equation of per capita income, which includes the level of human capital among the explanatory variables (equation 12 on p. 418 of their article), predicts an elasticity of per capita GDP to the stock of human capital per effective worker[23] equal to $\beta/(1-\alpha)$, where α and β are the distributive shares of physical capital and human capital respectively. Attributing to the two parameters values coherent with the empirical evidence, and which the three authors take as their reference (p. 417) – i.e. $\alpha=1/3$ and $1/3<\beta<1/2$ – yields elasticities ranging from a minimum of 0.5 to a maximum of 0.75. Also this latter aspect will be examined in the empirical part of this article.

However, before turning to the data, we shall first conduct some simple comparative statics exercises on equation (18'). We analyse in particular the impact of s on $\ln y_{ss}^{pc}$, as suggested by the model. The result is as follows (we assume that in the steady state A_{ss} and h_{ss} are given):

[23] In our case also the elasticity of per capita GDP to human capital per effective worker is unitary.

(19) $$\frac{\partial \ln y_{ss}^{pc}}{\partial s} = \frac{-\left(\frac{1-\alpha}{\alpha}\right)^{1-\alpha}}{1-s\left(\frac{1-\alpha}{\alpha}\right)^{1-\alpha}}.$$

The sign of this first derivative is ambiguous *a priori* and depends on the sign of the denominator of the above fraction. Given the steady-state per capita income:

$$y_{ss}^{pc} = \left(u_{ss} \cdot \frac{h_{ss}}{k_{ss}}\right)^{1-\alpha} \cdot \left(A_{ss} k_{ss}\right),$$

and given A_{ss} and k_{ss}, this ambiguity depends on the fact that an increase in s simultaneously reduces u_{ss} and increases h_{ss} / k_{ss} (see Table 1). However, under the condition that $s < \left(\frac{\alpha}{1-\alpha}\right)^{1-\alpha}$, the sign of the above first derivative becomes unambiguously negative. In this specific case, therefore, the negative effect exerted by an increase in s on u_{ss} always dominates the positive effect exerted by the same increase in the saving rate on h_{ss}/k_{ss}, thereby reducing y_{ss}^{pc}. This result is equally evident if we look at equation (5), which can be rewritten as:

$$\left(\frac{\dot{k}_t}{k_t}\right)_{ss} = s \cdot \left(\frac{y_t}{k_t}\right)_{ss} - \delta .$$

δ and k_{ss} remaining equal, an exogenous increase in s must in steady state give rise to a proportional reduction in y_{ss} for $\left(\dot{k} / k\right)_{ss}$ to be kept constant.

Although the empirical exercise conducted in the next section focuses mainly on human capital as the source of international differences in income levels, it will also analyse the role that investment in physical capital plays in determining the individual level of well-being in a country.

5. An empirical application

In this section we develop an empirical application of the theoretical model set out in the previous sections. The main concern of the empirical application will be the model's predictions with regard to the causes of differences among countries in their levels of steady-state per capita income, with particular emphasis on the role of human capital.

As is well known, a model is always a simplification of reality. In our specific case we have decided to neglect several factors which in the real world may explain much of the differences in per capita GDP across countries, our intention being to concentrate only on the effect of certain variables deemed to be of especial interest. We would point out that all the theoretical analysis carried out in Sections 3 and 4 refers to the steady state, so that the expressions derived for the level of per capita GDP (18) and for the same expressed in logarithms (18') are steady-state equations. In other words, they give the values of the above-mentioned variables when the short-term adjustment process has already occurred. Consequently, on moving from the theoretical model to the empirical application, a simplification that becomes immediately necessary is the use of proxy variables for the steady-state levels of per capita income, the saving rate (assumed in the theoretical model to be exogenous and constant), and the human capital stock. Hence, from this point of view the econometric analysis performed in this section should not be strictly considered an empirical 'verification'; rather, it is an application of the theoretical model whose main aim is to draw some qualitative implications about the role of human capital in international differences in levels of per capita income. The exercise will more closely resemble an empirical 'verification', the better the quality of the proxies used for the model's steady-state variables.

In order to analyse the importance of human capital and the rate of physical capital accumulation in explaining differences in per capita GDP among countries, we used multivariate regression analysis and cross-country data. The equation estimated was derived from equation (18') in Section 4. The model that we estimated with the ordinary least squares – OLS – method in the cross-section was therefore the following:

(20) $ly_{it} = \alpha_0 + \alpha_1 inv_{it} + \alpha_2 lh_{it} + \varepsilon_{it}$,

where *i* and *t* are respectively the subscripts for country *i* and period *t*.

There follows a brief description of the dependent variable and the explanatory variables:

1. ly_{it} is the natural logarithm of GDP per member of the working-age population[24] (i.e., in the age range between 15 and 64) expressed in terms of purchasing power parity (PPP) in the year *t* (source: Penn World Table version 6.1, 2002).[25] This was our dependent variable in the regressions and we used it as a proxy for the steady-state level of per capita GDP in natural logarithm ($\ln y_{ss}^{pc}$ in the theoretical model).

[24] In the rest of the article we refer to this variable also as per capita GDP, even though 'per capita' should be always understood as denoting a member of the population aged between 15 and 64. We consider the working-age population rather than the labour force mainly because the statistics on the latter in the developing countries are unreliable. The same approach is taken by MRW (1992).

[25] See Summers and Heston (1988) for an introduction to previous versions of the Penn World Table.

2. inv_{it} is the average of the investment rate (investment over real GDP) in the five-year period ending in year *t*: that is, in the five-year period preceding the year in which the differences in per capita GDP are analysed. inv_{it} is considered a proxy for the exogenous and constant saving rate (s) in the theoretical model (source: Penn World Table version 6.1, 2002). We considered the five-year average in order to attenuate the effect of any cyclical fluctuations.
3. lh_{it} is the natural logarithm of the human capital stock per individual aged over 14 five years before year *t*. This variable is used as a proxy for the steady-state stock of per capita human capital ($A_{ss}h_{ss}$ in the theoretical model).[26] We considered the last point in time in which the variable is available prior to the period analysed, because on the basis of a process of convergence of the economic variables to the steady state the value in more recent years can be considered a better proxy for the value in the steady state. This variable is available in the Barro-Lee database (see Barro and Lee, 2001).
4. ε_{it} is an error term which we for the moment assume not to be correlated with the explanatory variables included in the right-hand side of (20). It captures the effect of all the variables omitted from our model either because they are not of specific interest to our analysis or because they are not observable.

To be noted is that we are not estimating exactly (18'), which is evidently non-linear in *s*. For this reason we reported in Section 4 the effects of comparative statics for *s* not in logarithm, and *inv* was therefore included in (20) not in logarithm. In Section 4 we calculated the expected signs of the effects of all the explanatory variables included in equation (20). We again emphasise that the purpose of our empirical analysis is only to verify whether the qualitative predictions of the theoretical model are borne out by the data – in particular its prediction concerning the important role of human capital. Our analysis is not a 'test' of the model, given that the equation estimated is not exactly (18'), and given that we do not know the steady-state values of either the dependent variable or the regressors.

In the regressions we focused on a sample of 92 countries. The complete list of the countries included in the sample is given in Appendix 1. In order to test the robustness of the results with respect to the period analysed, we estimated the regression on several cross-sections (namely, 1980,

[26] In the present article we use a better proxy for the stock of human capital than that used in previous studies. MRW (1992), for example, and as already mentioned, consider the proportion of the working-age population enrolled at upper secondary school, while Bucci and Checchi (2003) use schooling enrolment rates. See Judson (2002) for a critique of these proxies for human capital.

1985, 1990 and 1995), including in each cross-section the same set of countries (i.e., those for which the variables of interest were non-missing in 1980).

Some aspects of our procedure require further qualification. Firstly, we focused on relatively recent cross-sections (from 1980 onwards) in order to minimize the possible incidence of the *sample selection bias* (Heckman, 1979). Other studies have already highlighted, indeed, the effect that a non-random selection of the sample may have on the estimates.[27]

The theoretical model's exogenous explanatory variables which we included in the regression were considered at a date (the beginning of the previous five-year period for stock variables and the average of the previous five-year period for flow variables) that was prior to the one referred to by the variable to be explained (the level of per capita GDP). This was in order to deal with the endogeneity problems that might have arisen from the fact that, besides human capital, also other variables (considered in the theoretical model to be exogenously determined with respect to the per-capita GDP level) may in reality be choice variables for the individual. In particular, the economic literature offers examples of how the saving rate may result from an intentional choice by rational economic agents (see, for example Ramsey's (1928) neoclassical model of growth). In other words, the problem of endogeneity may arise from the fact that the levels of per capita GDP, the saving rate, and human capital are simultaneously determined by the model's 'true' exogenous variables. In this case, the correlations estimated in equation (20) would simply be spurious correlations which do not reflect any causal relation between the dependent variable and the independent ones. By contrast, considering the independent variables at an earlier date makes them *predetermined* with respect to the current level of per capita GDP that one intends to explain. This procedure is very similar to the one that consists in the use of the instrumental variables (IV) method, in which the lagged values of the endogenous explanatory variables are considered to be 'instruments'. In our case, rather than applying the IV method, the 'instruments' were directly included as explanatory variables in the regression, estimating a sort of reduced form.[28] This applied *a fortiori* to the level of the stock of per-capita human capital in logarithm (*lh*), which is endogenous in our theoretical model.

[Table 2 about here]

[27] See on this De Long (1988), who, when analysing convergence among countries in the growth rates of their per capita GDP, points out that those countries with rather long time series, given that these latter are constructed retrospectively, are also the most industrialized ones. This entails that in a given period if we consider a sample of developing countries for which data on growth rates (or per capita GDPs) are available, they are also those countries that were initially relatively poor and which achieved sustained growth during the period considered. This has obvious implications in terms of the results obtained if convergence is being studied (in the sense that the bias is evidently towards obtaining this result). A similar bias arises in studies on the level of per capita GDP (which at a certain instant of time is given by per capita GDP at the beginning of the period considered multiplied by the relative rate of growth).

[28] This practice is widely adopted in the econometrics of time series in order to obtain valid conditional inference (see Davidson and MacKinnon 1993, p. 624).

Table 2 reports the estimates of the cross-country regressions relative to the years 1980, 1985, 1990 and 1995. It is possible to notice that the qualitative results of the estimates are robust to variation in the estimation period. The regressions have considerable explanatory power (R^2). Such explanatory power progressively increases as more recent cross-sections are considered, and ranges from a minimum of 0.65 in 1980 to a maximum of 0.73 in 1995. The increasing explanatory power of our econometric model over time is what one would expect in the light of the transition of countries to their steady-state equilibrium, in the sense that both the variable to explain (the level of per capita GDP) and the explanatory variables included in the right-hand side of the regression (20) are in more recent periods better proxies for the values that they will assume in the steady state.

The effect of the level of human capital on the level of per capita GDP is always positive and statistically significant at the 1% level. The relative coefficient tends to increase over time, ranging from 0.81 in 1980 to 1.27 in 1995. It is therefore clear that the empirical evidence is consistent with the pronounced effect exerted by the level of per capita human capital on the level of per capita GDP envisaged by our model, as well as by others. Hence, our results confirm those of MRW (1992): even when a different sample of countries and different periods are examined, human capital plays a key role in accounting for the differences in international per capita GDP levels.[29] Moreover, the Wald tests reported in Table 1 also show that, in any of the cross-sections analysed, it is not possible to reject (at the 5% statistical level) the hypothesis that the elasticity of per capita GDP to the stock of per capita human capital is unitary.

To deepen our analysis, we can use the fact that the availability of diverse temporal observations for certain countries makes it possible to exploit the longitudinal nature of the data. This enables estimation of models wherein explicit account can be taken of the unobserved heterogeneity among countries, i.e. of specific factors which have not been explicitly controlled for and which may characterize a country, influencing its level of per capita GDP and human capital. The use of panel estimates is also suggested by Temple (1999b) as a further control on the robustness of the results obtained. In the case of panel estimates, the equation estimated becomes:

(21) $$ly_{it} = \alpha_0 + \alpha_1 inv_{it} + \alpha_2 lh_{it} + u_i + \varepsilon_{it},$$

[Table 3 about here]

[29] For the sake of completeness, we set out in Appendix 2 the results of the estimates of the individual 1980-1995 cross-sections obtained by considering a sample similar to the one analysed by MRW (1992) - in effect, all the countries considered by them for which the variables of interest are non-missing - and the specification suggested by them in equation 12 of their article (p. 418).

where u_i represents, according to the type of model used (fixed effects or random effects), respectively a country-fixed effect (or dummy variable) or a random effect not correlated by hypothesis with the explanatory variables on the right-hand side of (21).[30] As was done previously for the cross-sections, we again restricted the period to between 1980 and 1995 when conducting the panel estimates, the purpose being to limit the incidence of the sample selection bias. In fact, panels in which the temporal dimension is longer (that is, starts from further back in time) are generally unbalanced (i.e. not all the countries are observed an equal number of times) and the years for which data are missing are not distributed randomly over time and across countries. Typically, data are missing for less developed countries and increasingly so for less recent periods. Consequently, the availability of data (the likelihood that data are non-missing) is generally correlated with a country's level of development, and therefore with its level of per-capita (or per-worker) GDP – which is the variable to be explained – generating sample selection bias in the estimates. Hence, if relatively recent years are selected, it is possible to obtain balanced panels while simultaneously reducing the risk that samples affected by selection problems will be considered.

Table 3 shows the estimates of the models with random effects and fixed effects.[31] In the former case it is assumed that the error in (21) can be decomposed into a country-specific component which does not vary over time (u_i) and a component which is time-varying (ε_{it}). In the latter case, unobserved heterogeneity can be controlled for simply by including a dummy variable for each country among the regressors. Note that, because of the short time-span observed, some variables may display scant variability over time at the individual country level. This may be the case of the stock of per capita human capital, which depends on variables (like the age structure of the population, or school enrolment rates) which change to a substantial extent only in the medium and long term. The matrix of the correlations among country levels of human capital in 1975-1980, given in Table 4, shows indeed the scant variation over time of the proxy for human capital used. This implies that the level of human capital may be closely correlated with the country dummies in the fixed effects model. Consequently, the country-fixed effects (which do not vary over time) may partly capture the effect of human capital – which has also been observed by Temple (1999a, p. 132).[32] Moreover, given the short time dimension of the panel (we have only two time observations

[Table 4 about here]

[30] As is usual in the literature, we have used *u* to denote this effect. However, this variable has nothing to do with the share of human capital employed to produce the final consumption good, which is also denoted by *u* in the theoretical model (see Section 2).
[31] See Greene (1997).
[32] See on this also Griliches and Mairesse (1995).

for each country), the estimates of the fixed effects are inconsistent, and the model is markedly over-parameterized.

In the specification with fixed effects we obtained a negative but not statistically significant coefficient. This is not an unusual occurrence and has been already observed with cross-country growth regressions.[33] We believe that there are two main problems connected with fixed effects models when use is made of panels with a relatively short time horizon – whether regressions on levels of per capita GDP or growth regressions are being estimated. The first problem, which we have already mentioned, is that by its nature the mean number of years of education per member of the active population (aged 15 and over), like other measures of human capital, changes very slowly over time. Consequently, it displays little variation in the five-year periods[34] considered in the panel and is closely correlated with the country-fixed effects. Indeed the fixed effects model is sometimes also referred to as the 'within-groups estimator'[35] in that it uses only within-groups variance (i.e. for one country over time) for estimates, while it entirely neglects between-groups variance (i.e. between countries). Also the second problem derives in part from the nature of the proxy used for human capital. The mean number of years of formal education of the active population refers to persons aged 15 and over, independently of whether they are in employment or whether they are completing their own educations. Especially when relatively short periods (5 years) are considered, it is highly likely that much of the variation in the mean number of years of education is generated by individuals who are still in education[36] and who have not yet entered the labour market. For this reason one may expect a non-significant, or even negative, effect of education on output per member of the active population in the short term, given that the individuals who are still completing their education are not engaged in production, and that the resources devoted to education may be subtracted from other more immediately productive investments. Moreover, besides the problems with the proxy used for human capital, there is also the problem of the timing with which education exerts its effect on productivity. Are the new generations of more educated individuals entering the labour market immediately more productive than the previous ones with less education, or does investment in education require a certain lapse of time to exert its effects on productivity? Until now, theoretical models have paid scant attention to the problem of the timing of education's effect on productivity. However, it is very likely to manifest itself with a certain

[33] Islam (1995).
[34] The correlation between levels of human capital over time is extremely high even if ten-year variations are considered.
[35] See Greene (1997).
[36] This effect is also attributable to the fact that education is usually organized into cycles and that individuals tend to enter the labour market at the end of one such cycle. This problem with the proxy variable for human capital may particularly affect the more developed countries where labour market entry takes place on average considerably later than the age of 15.

amount of delay.[37] Initially, less educated individuals, who have therefore entered the labour market earlier, may themselves have accumulated a substantial stock of human capital which takes forms other than education – for example, on-the-job training – and their productivity may be even greater than that of individuals with higher levels of education but less experience.[38] We accordingly believe that one should not be surprised by the possible non-significance of the stock of years of education, or even by a negative effect of this variable when fixed effects models (which consider only over time variance) are used on panels with short time horizons. In this regard, the availability in the future of longer time series may alleviate the first problem, of econometric nature, and also help shed light on the timing of the education effect.

When use is made of the *between-groups estimator* – which is the antithesis of the *within-groups estimator*, given that it uses only variance among countries while ignoring within-groups variance – the results are very similar to those obtained for the cross-sections: the effect of human capital is statistically significant (at the 1% level), positive, and of considerable magnitude. The results of the estimations by the random effects model – given that this is a weighted average of the two within-groups and between-groups estimators (see Greene 1997, p. 625) – lie midway between those of the fixed effects model and those of the between-groups estimator. Also the random effects model shows a positive and statistically significant effect of human capital, although this is less than that obtained in the cross-section estimates or with the between-groups estimator.

Although the qualitative results (in terms of sign and significance) of our cross-section regressions are generally robust with respect to panel specifications – with the only exception of the fixed effects model, which we anyway regard as problematic for the reasons given above – the problem still arises of explaining the differences in the magnitude of the coefficients when panel models are considered. As said, a possible reason for these differences is the 'stickiness' of the level of human capital whereby it is closely correlated with the country dummies (in the fixed effects model) or with the time invariant part of the regression error (in the case of the random effects model) in the panel models typically estimated (where the time dimension is relatively short), so that the coefficient estimated is lower than the cross-section estimates.

[Table 5 about here]

[37] Temple (1999b, p. 139) observes that: "*Certainly it has been much harder to find an effect of human capital in panel data studies, although it is also true that too few researchers think carefully about the specification. Rather optimistically, they tend to expect a change in school enrollments to raise growth almost instantly*".

[38] For a discussion of micro-econometric analyses see e.g. Light (1998). For a broader definition of human capital which does not comprise solely formal education see Kendrick (1976).

An alternative explanation is that the positive effect of human capital accumulation on growth (and the positive correlation between level of human capital and per capita GDP) results from a process which takes place only in the long run. This may explain why the differences among countries in their levels of per capita human capital are generally highly correlated with differences in levels of per capita income in the regressions using cross-sections or panels and the between-groups estimator. The country differences in levels of human capital have developed over numerous decades and have had sufficient time to exert their positive effect on the per-capita GDP growth process, and consequently also on the level of per capita GDP. By contrast, an equally pronounced effect (indeed, one which is sometimes not even statistically significant or of opposite sign to the one expected) of human capital is not found at the level of individual countries when one considers only variations over time (fixed effects models) and relatively short time series in which the positive effect of human capital accumulation may not yet had sufficient time to manifest itself.

Temple (1999b) points out in his survey that heterogeneity among countries in the parameters of the regression may be a problem. Put otherwise, different countries may have different coefficients in equation (20). What is sometimes done in this case is to estimate the coefficients in subsamples – although the definition of the latter is often arbitrary. In order to account for possible heterogeneity effects in the parameters among countries, we also estimated a random coefficient model[39] which can be expressed as:

$$ly_{it} = \alpha_0 + \alpha_1 s_{it} + \alpha_2 lh_{it} + u_{0i} + u_{2i} inv_{it} + u_{3i} lh_{it} + \varepsilon_{it}$$

where $(u_0,u_1,u_2) \sim N(0\ ,\ \Sigma\ )$, and the variance-covariance matrix Σ is estimated together with the model's other parameters. The results of the estimates are given in Table 5, where we see that the coefficient of human capital remains statistically significant at the 1% level, and that its size is lower than in the cross-section estimates. Although here only from the qualitative point of view, the positive and significant role of human capital is once again confirmed.

6. Conclusions

The aim of this article has been to study – using a model in which it is possible to accumulate both physical and human capital – the long-run impact of certain variables (principally the level of human capital possessed and the saving rate) on levels of per capita income. Compared to other and better-known articles on the same topic (most notably MRW, 1992), the distinctive feature of our approach is its greater richness in both the theoretical model presented and the empirical analysis

[39] On the estimation of these models see Rabe-Hesketh at al. (2001).

conducted. As regards the former, we built a model of balanced growth in which we endogenously determined the equilibrium allocation of human capital between alternative uses (production and education). An implication of the model was that the elasticity of per capita income to per capita human capital is unitary.

At the empirical level we used a better (compared to MRW, 1992) proxy for the human capital stock and a more recent database. The aim of this second part of the article was to verify whether the theoretical model's qualitative implications (relative to the sign of the human capital effect) and quantitative implications (relative instead to the size of the above effect) were borne out by the data. To this end, we estimated the model on a sample of countries at different stages of development, considering different cross-sections (1980, 1985, 1990 and 1995) and five-year panel data (1980-1995). We found that the human capital effect was of the same sign as predicted by the theoretical model. In particular, in all the models estimated, both cross-section and panel, and with the only exception of the fixed effects panel model (in Section 5 we gave some possible explanations for this exception), the stock of per capita human capital has a positive, statistically significant, and marked effect on the level of per capita GDP. Moreover, none of the cross-section estimates rejected (at the 5% level) our model's quantitative implication of a unitary elasticity of per capita GDP to the stock of per capita human capital.

As regards future research, we believe it would be interesting to verify empirically whether and how the results obtained by this study might change if technical progress (via Research and Development effort) and/or saving were made endogenous to the theoretical model.

Tables

Table 2: *Cross-section* estimates (OLS) of the determinants of GDP per member of the working-age population.

Variables	Years 1980 Coef.		1985 Coef.		1990 Coef.		1995 Coef.	
inv	0.02	*	0.03	**	0.04	***	0.03	***
	(0.01)		(0.01)		(0.01)		(0.01)	
lh	0.81	***	0.89	***	0.94	***	1.27	***
	(0.11)		(0.12)		(0.13)		(0.16)	
constant	7.49	***	7.17	***	6.91	***	6.28	***
	(0.13)		(0.12)		(0.14)		(0.22)	
N. observations	92		92		92		92	
R^2	0.65		0.69		0.73		0.73	
Wald test lh=1[(a)] (p-value)	3.05 (0.08)		0.82 (0.37)		0.22 (0.64)		2.75 (0.10)	

Notes. *significant at 10%; **significant at 5%; ***significant at 1%. [(a)] Wald test for elasticity of the human capital stock equal to one.
Standard errors robust to the presence of heteroskedasticity in brackets.

Table 3: *Panel* estimates (1980-1995) of the determinants of GDP per member of the working-age population.

Variables	*Within-groups estimator* Coef.		*Between-groups estimator* Coef.		*Random effects model* Coef.	
inv	0.01	***	0.03	***	0.02	***
	(0.00)		(0.01)		(0.00)	
lh	-0.08		0.96	***	0.27	***
	(0.05)		(0.11)		(0.05)	
constant	8.88	***	6.96	***	8.16	***
	(0.10)		(0.14)		(0.11)	
N. groups	92		92		92	
N. observations	368		368		368	
F-test (p-value)	7.88 (0.00)		114.41 (0.00)		-	
Wald test (p-value)	-		-		74.14 (0.00)	
Wald test lh=1[(a)] (p-value)	410.99 (0.00)		0.12 (0.73)		195.63 (0.00)	

Notes. *significant at 10%; **significant at 5%; ***significant at 1%. [(a)] Wald test for elasticity of the human capital stock equal to one.
Standard errors robust to the presence of heteroskedasticity in brackets. The panel is balanced and includes four quinquennial observations (1980, 1985, 1990, 1995) for 92 countries.

Table 4: Correlation matrix between measures of human capital stock in natural logarithm - $ln(h_t)$ - relative to the various cross-sections

	1975	1980	1985	1990
1975	1			
1980	0.9796	1		
1985	0.9706	0.9919	1	
1990	0.9453	0.9683	0.9799	1

Table 5: Estimates of the random coefficients model of the determinants of GDP per member of the working-age population for the period 1980-1995

Variables	Coef.	
inv	0.01	***
	(0.00)	
lh	0.21	**
	(0.10)	
constant	8.19	***
	(0.19)	
N. groups	92	
N. observations	368	
Log-likelihood	65.60	

Notes. *significant at 10%; **significant at 5%; ***significant at 1%.
Standard errors robust to the presence of heteroskedasticity in brackets. The sample includes four quinquennial observations (1980, 1985, 1990, 1995) for 92 countries. The estimated covariances between the random coefficients (see Section 5) are respectively (with standard errors in brackets): cov(2,1)= -0.011 (.004); cov(3,1)= -.529 (.276); cov(3,2)= 0.004 (.003).

Appendix 1 – List of the countries included in the sample (n=92)

Argentina, Australia, Austria, Belgium, Benin, Bangladesh, Bolivia, Brazil, Barbados, Botswana, Central African Republic, Canada, Switzerland, Chile, China, Cameroon, Colombia, Costa Rica, Cyprus, Denmark, Dominican Republic, Algeria, Ecuador, Egypt Arab Rep., Spain, Finland, Fiji, France, United Kingdom, Ghana, The Gambia, Greece, Guatemala, Guyana, Hong Kong (China), Honduras, Haiti, Hungary, Indonesia, India, Ireland, Iran Islamic Rep., Iceland, Israel, Italy, Jamaica, Jordan, Japan, Kenya, Korea Rep., Sri Lanka, Lesotho, Mexico, Mali, Mozambique, Mauritius, Malawi, Malaysia, Niger, Nicaragua, Netherlands, Norway, Nepal, New Zealand, Pakistan, Panama, Peru, Philippines, Papua New Guinea, Poland, Portugal, Paraguay, Rwanda, Senegal, Sierra Leone, Singapore, El Salvador, Sweden, Syrian Arab Republic, Tanzania, Togo, Thailand, Trinidad and Tobago, Tunisia, Turkey, Uganda, Uruguay, United States, Venezuela RB, South Africa, Zambia, Zimbabwe.

Appendix 2 – Estimates of the Mankiw-Romer-Weil model (MRW, 1992)

In this appendix we use the same econometric specification and set of countries as considered by MRW (1992), but different periods (1980, 1985, 1990, 1995) and our own data set, in order to compare the resulting estimates with those reported in Section 5. The econometric specification used is equation 12 in MRW (1992, p. 418) is:

$$\ln(y_{it}) = \alpha_0 + \alpha_1 \ln(inv_{it}) + \alpha_2 \ln(n_{it} + g_A + \delta) + \alpha_3 \ln(h_{it}) + \varepsilon_{it},$$

where – for simplicity omitting the subscripts for countries and time – y is per capita GDP (or per worker, given that in the model the entire population works), *inv* the investment rate, n the growth rate of the working-age population (source: World Bank 2002), g_A the rate of technical progress, δ the rate of physical capital depreciation, and h the stock of human capital per member of population in efficiency units. As already stated in Section 4, the model predicts an elasticity of GDP per worker to the human capital stock per worker which is equal to $\beta/(1-\alpha)$, where α and β are the distributive shares of physical capital and human capital respectively.[40] Like MRW, we assume that $g_A + \delta = 0.05$ (= 5%). The number of countries used in the various cross-sections differs from that used in the original article by MRW (1992) - 98 countries - for two reasons. The first is that we use the stock of human capital (the mean number of years of education available in Barro and Lee 2001), which is not available for some countries, and not the rate of human capital accumulation (i.e. rates of secondary school attendance). The second reason is that we consider the five-year rates for the flow variables (and not from 1960 to 1985 as in MRW),[41] and for some countries and some period the argument of the natural logarithm may be negative or nil, so that the relative observation is omitted from the analysis. One notes immediately that the level of per capita human capital is expressed in natural logarithm in both MRW's specification and ours. This is immediately reflected in the explanatory power of the regressions and in the estimated effect of human capital, which are similar to those reported in Section 5.

[40] The elasticity is the same to the human capital stock per worker.
[41] This is so that the estimates are comparable with those in Section 5.

Table A2: Cross-section estimates (OLS) of the determinants of GDP per member of the working-age population. Mankiw-Romer-Weil's (1992) model and sample

Variables	Years							
	1980		1985		1990		1995	
	Coef.		Coef.		Coef.		Coef.	
$\ln(n+g_A+d)$	-1.45	***	-1.72	***	-1.89	***	-1.80	***
	(0.29)		(0.36)		(0.30)		(0.42)	
ln(inv)	0.34	***	0.44	***	0.54	***	0.61	***
	(0.13)		(0.13)		(0.16)		(0.13)	
ln(h)	0.70	***	0.72	***	0.74	***	0.94	***
	(0.09)		(0.11)		(0.12)		(0.14)	
constant	10.04	***	10.17	***	10.20	***	9.27	***
	(0.69)		(0.81)		(0.77)		(1.04)	
N. observations	81		81		82		84	
R^2	0.74		0.78		0.83		0.84	

Notes. *significant at 10%; **significant at 5%; ***significant at 1%.
Standard errors robust to the presence of heteroskedasticity in brackets.

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