Open access • Journal Article • DOI:10.1007/BF02707441

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Published on: 01 Jun 1995

Topics: Physical capital and Human capital

Gundlach, Erich

Working Paper

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Kiel Working Paper, No. 659 [rev.]

Provided in Cooperation with:
Kiel Institute for the World Economy – Leibniz Center for Research on Global Economic Challenges

The Role of Human Capital in Economic Growth: New Results and Alternative Interpretations

by

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revised, February 1995

I. Introduction[*]

While it is largely uncontroversial that human capital can be considered as one of the shaping factors of economic growth, no agreement exists on the specific role of human capital formation. Competing theories all stressing different aspects of human capital formation are not in short supply, but the empirical evidence in support of one view or another is largely missing. To be able to discriminate between alternative interpretations, it would be useful to know whether physical or human capital has a larger impact on output per capita and whether the returns to all capital are constant, increasing, or decreasing. Depending on the answers, rather different implications for the role of human capital could emerge.

In a recent paper, Mankiw et al. [1992, henceforth MRW] find that much of the cross-country variation in output per worker can be explained while maintaining the assumption of decreasing returns to all capital, where physical and human capital roughly possess the same weight. This result questions the empirical relevance of endogenous-growth models that assume constant or increasing returns to scale in capital. In this paper, I use the augmented Solow model suggested by MRW to check the robustness of their results. In contrast to MRW, which use a more narrowly defined measure of human capital *investments*, I use new data on average years of schooling as a proxy for the *stock* of human capital per worker, and estimate a larger production elasticity of human capital with respect to output than MRW. My results are consistent with constant returns to all capital, and virtually no return to unimproved labor, without necessarily implying an endogenous-growth model. Moreover, the impact of human capital formation is found to be twice as high as the impact of physical capital formation.

Several reasons exist why these results and MRW's might arise. First, MRW's results could arise either from measurement error in their measure of human capital investments or from their focus on a limited component of human capital. Second, their results might be correct and the results of the present paper could be due to the endogeneity of the stock of human capital. Notwithstanding, I show that a more complex model of economic growth where unimproved labor does not enter the production function but is used for producing human capital can also account for the seemingly conflicting empirical results. These different views have very different implications for the impact of changes in human and physical capital accumulation, and they all appear to be compatible with the cross-country data. Hence the existing empirical evidence does not suffice to clearly discriminate between very different views of the role of human capital in growth.

* I thank Olivier J. Blanchard, Rainer Thiele, and especially an anonymous referee, and seminar participants at the Kiel Institute of World Economics, the University of Konstanz, and the Bologna Center of Johns Hopkins University for helpful comments on an earlier version.

II. Alternative Specifications of the Augmented Solow Model

The augmented Solow model of economic growth developed by MRW can be summarized as follows. Let the production function at time t be

$$Y(t) = K(t)^{\alpha} H(t)^{\beta} (A(t)L(t))^{1-\alpha-\beta}, \tag{1}$$

where the notation is standard: Y is output, K is the stock of physical capital, H is the stock of human capital, A is the level of technology, and L is labor. A and L are assumed to grow exogenously at rates g and n. The model assumes that constant fractions of output, s_k and s_h, are invested in physical and in human capital. Defining k as the stock of physical capital per effective unit of labor ($k = K/AL$) and, similarly, $y = Y/AL$ and $h = H/AL$, the evolution of the economy is governed by

$$\dot{k}(t) = s_k y(t) - (n + g + \delta)k(t), \tag{2a}$$

$$\dot{h}(t) = s_h y(t) - (n + g + \delta)h(t), \tag{2b}$$

where the dot denotes absolute changes of the variables over time, and δ is the depreciation rate. The underlying assumption of this modelling framework is that the same production function applies to human capital, physical capital, and consumption. Hence the depreciation rate is the same both for human and for physical capital.

For decreasing returns to all capital ($\alpha + \beta < 1$), equations (2a) and (2b) give the steady state values k^* and h^* as

$$k^* = \left(\frac{s_k^{1-\beta} s_h^{\beta}}{n + g + \delta} \right)^{1/(1-\alpha-\beta)} \tag{3a}$$

$$h^* = \left(\frac{s_k^{\alpha} s_h^{1-\alpha}}{n + g + \delta} \right)^{1/(1-\alpha-\beta)}. \tag{3b}$$

Substituting equation (3a) and (3b) into the production function (1) by using the definitions for k and h, and taking logs, gives an equation for output per worker as a function of the initial level of technology ($A(0)$), the growth rate of technology (g), the growth rate of the labor force (n), the depreciation rate (δ), and the fractions of output invested in physical (s_k) and human capital (s_h):

$$(4) \qquad \ln\left(\frac{Y(t)}{L(t)}\right) = \ln A(0) + gt - \frac{\alpha+\beta}{1-\alpha-\beta}\ln(n+g+\delta) + \frac{\alpha}{1-\alpha-\beta}\ln(s_k) + \frac{\beta}{1-\alpha-\beta}\ln(s_h) \ .$$

Taking the percentage of the working age population that is in secondary school as a proxy for a flow measure of human capital, this equation is used by MRW to estimate the impact of human capital accumulation and other factors on output per worker. An alternative way to identify the role of human capital in determining output per worker is given by

$$(5) \qquad \ln\left(\frac{Y(t)}{L(t)}\right) = \ln A(0) + gt + \frac{\alpha}{1-\alpha}\ln(s_k) - \frac{\alpha}{1-\alpha}\ln(n+g+\delta) + \frac{\beta}{1-\alpha}\ln(h^*) \ ,$$

which can be derived from solving equation (3b) for s_h and substituting into equation (4). This equation uses the stock of human capital as a right-hand-side variable, and predicts different coefficients on the terms for investment in physical capital and for the growth of the labor force.

Both equations (4) and (5) can be used to identify the elasticity of production with respect to physical and human capital. Given that the available proxies for flow and stock data of human capital are equally useful, and given that the augmented Solow model correctly identifies the data generating process, there is no reason to assume that the alternative specifications should lead to different results. The advantage of equation (5) for the empirical analysis is that it leaves open the question how the accumulation of human capital actually proceeds. E.g., in contrast to MRW, Lucas [1988] models the production function for human capital as different from that for goods and other inputs. A disadvantage of equation (5) is that $\ln(h)$ will be correlated with the error term, if equation (2b) correctly describes the accumulation of human capital. This property may make OLS results difficult to interpret, and, therefore, may require estimation by instrumental variables (IV) instead. On the other hand, viewing equation (5) as part of a simultaneous equation framework is entirely due to the assumed data generating process for human capital. Put differently, the reduced form equation (5) may be compatible with a structural model different from equation (1). Therefore, OLS results may serve as a useful benchmark estimate to start with.

III. Estimation of the Augmented Solow Model

A. *Data and Samples*

For an estimation of equation (5), I use two new sources which provide a proxy for the stock of human capital per worker (h): Both Psacharopoulos and Arriagada [1992] and Barro and Lee [1993] present cross-country data for average years of schooling. These data sets are not perfectly correlated, and differ with respect to sample size and country coverage. Psacharopoulos and Arriagada use census data on the distribution of the population by levels of schooling attainment collected in the 1980s to calculate average years of schooling for selected years. Using similar census data, and interpolation techniques, Barro and Lee have constructed quinquennial time series data for average years of schooling for 129 countries from 1960 through 1985. Thus most of their data are not based on actual observations, but inferred from benchmark estimates. For the estimation presented below, I take the estimates around 1985 (1980-1988) from Psacharopoulos and Arriagada [1992], and the estimates for 1985 from Barro and Lee [1993].

The other variables that are used in the empirical analysis are measured as follows: ($Y(t)/L(t)$) is real gross domestic product per worker in 1985, s_k is the average share of real investment in GDP for the period 1960-1985, n is the annualized growth rate of the working age population for the period 1960-1985, k is real (physical) capital per worker in 1985, and ($\delta + g$) is assumed to be 5 percent.[1] The growth rate of the working age population and the measure for the investment in human capital as proxied by the percentage of the working age population that is in secondary school (s_h) are taken from MRW. All other data are taken from Summers and Heston [1991].

Similar to MRW, I consider alternative samples of countries. "All countries" refers to countries with populations of more than 1 million (in 1985) excluding countries with oil production as the dominant industry.[2] "D countries excluded" refers to the resulting number of countries if those countries with the weakest quality of the data (labelled "D" by Summers and Heston) are excluded from the "All countries" sample. A third sample includes only those countries of the "D countries excluded" sample which provide an entry for k. All samples are matched with the two sources for data on average years of schooling. See Table A1 for each of the samples and the data.

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1 See Mankiw et al. [1992, footnote 6].

2 Syria is excluded because of an implausibly high estimate for real gross domestic product per worker in 1985.

B. Results

In order to provide a point of reference for the empirical analysis, I first re-estimate equation (4) by OLS as suggested by MRW.[3] Since the coefficients on $\ln(s_k)$, $\ln(s_h)$, and $\ln(n+g+\delta)$ are predicted to sum to zero, a restricted version can be estimated and tested. The results are presented in the first two columns of Table 1. They largely resemble the findings of Mankiw et al. [1992, their Table 2]: The imposed restriction on the regression coefficients is not rejected as indicated by the p-value, and α and β are estimated to be about 0.3, notwithstanding the smaller point estimates for α and the higher point estimates for β in the present analysis.

MRW suggest that one production function that is consistent with their empirical results is $Y = K^{1/3}H^{1/3}L^{1/3}$. While the estimate for a resembles capital's share in income as measured in the National Accounts, the estimate for β seems to be rather low. According to Psacharopoulos [1993], one year additional tertiary education offers a rate of return in the range of 10 percent. With 9 to 11 years of schooling, which is the estimated average for the OECD countries [Barro and Lee, 1993; Psacharopoulos and Arriagada, 1992], it follows that investment in human capital as measured by education raises income by a factor of 2.5 to 3.[4] If income is three times higher with human capital than without, the share of human capital in income should be about two thirds of the total labor share. Hence with a labor share of roughly 70 percent, β can be expected to be closer to 0.5 than to 0.3. As a consequence, the share of unimproved labor in income can be expected to be lower than 0.3.

The other columns in Table 1 give the results of OLS estimations of equation (5) based on alternative sources for the data on average years of schooling. While the restricted model again passes the test at conventional levels of statistical significance and the estimate for α is very similar to the previous one, for three samples the estimate for β is more than twice as high as before. This finding implies a much smaller share of unimproved labor in income than was estimated by MRW. The implied estimates for $\alpha+\beta$ show that it is not possible to reject the hypothesis that $\alpha+\beta$ is close to 1, pointing to a near zero income share of unimproved labor. An alternative hypothesis like $\alpha+\beta = 0.67$ as suggested by MRW, and by the first two columns in Table 1, is not supported by these results.

The conflicting findings for β in Table 1 suggest a number of possible alternative interpretations. If the Mankiw et al.-view is correct, the high estimate for β is biased upward due to a correlation between $\ln(h)$ and the error term in equation (5). On the other hand, if the high estimate for β is correct, the low estimate for β derived from the estimation of equation (4) could be biased downward due to a measurement error in $\ln(s_h)$. A third possibility is to interpret the different results for β as simply reflecting different measurement concepts of human capital. While s_h focuses on secondary education, h considers all stages of formal

3 MRW use the data set provided by Summers and Heston [1988].

4 Similar results emerge for other groups of countries, where lower average years of schooling are compensated by higher rates of return to primary and secondary education.

education. Therefore, it may be tempting to conclude that the different estimates for δ indicate an income share of post primary education of about 1/3, and an income share of all human capital of about 2/3. If so, however, as before OLS estimation of equation (5) should produce an upward biased estimate for β, given that equation (2b) adequately describes the process of human capital accumulation and equation (1) is the correct structural model.

To come to grips with these issues, I estimate the structural form production function (1) as an alternative to an estimation of the reduced forms presented in equations (4) and (5). Since K and H are likely to be correlated with the error term in equation (1), estimation by instrumental variables (IV) has to be used. The stocks of K and H can be instrumented by the respective saving rates s_k and s_h, which are independent of the error term due to equations (2a) and (2b). Dividing equation (1) by L, and taking logs, gives

$$\text{(6)} \qquad \ln\left(\frac{Y(t)}{L(t)}\right) = \ln A(0) + gt + \alpha \ln(k(t)) + \beta \ln(h(t)) \ .$$

For 1985, Summers and Heston [1991] provide entries for k only for a rather limited number of countries, mainly from the OECD (see Table A1). This lack of data hinders a direct comparison with the results in Table 1. Re-estimating equations (4) and (5) for the k-sample results in statistically insignificant regression coefficients for $\ln(s_k)$.[5] Moreover, the validity of the implied restrictions remains doubtful according to p-values below 15 percent. These findings neither support the low nor the high estimate for β derived from the larger samples used in Table 1. On the other hand, an IV estimate of equation (6) weakly supports the OLS results for equation (5) presented in columns 3-6 in Table 1:[6]

$$\text{(7)} \qquad \underset{}{\ln(Y/L)} = \underset{(1.06)}{4.77} + \underset{(0.19)}{0.37}\ln(k) + \underset{(0.44)}{0.66}\ln(h)$$

Implied $\alpha + \beta$: 1.02
(0.27)

Standard errors in parenthesis; number of observations = 29

List of instruments: $CONSTANT, \ln(s_k), \ln(s_h)$

$\overline{R}^2 = 0.88$ s.e. = 0.30.

5 Detailed results can be computed from the data given in Table A1; they are available on request.

6 Due to data limitations, estimation of variants of the production functions in stocks is based on data for h taken from Barro and Lee [1993] only, and different sample sizes are not considered.

The high $\overline{R}^2$ and the low statistical significance of the regression coefficients point to a multicollinearity problem.[7] Taken at face value, the estimated regression coefficients are not very informative, but $\alpha + \beta$ is estimated not to be statistically different from 1. This result can be regarded as weak evidence in favor of a large β. Given that a is about 0.3, which is in line with all results in Table 1, equation (6) can be reformulated and estimated by IV as

(8) $$\ln\left(\overline{Y/L}\right) = \underset{(0.30)}{5.13} + \underset{(0.15)}{0.81}\ln(h)$$

Standard errors in parenthesis; number of observations = 29

List of instruments: $CONSTANT, \ln(s_h)$

$\overline{R}^2 = 0.59$ s.e.e. = 0.32

where $\ln\left(\overline{Y/L}\right) = \ln(Y/L) - 0.3\ln(k)$. Again similar to the OLS results for equation (5) in Table 1, the production elasticity of human capital is found to be about two times the production elasticity of physical capital.

As long as data limitations do not allow a direct comparison of results, the findings for the structural model could simply reflect specific properties of the k-sample, similar to the specific properties of the OECD sample found by MRW. Therefore, they cannot be considered as entirely convincing evidence in favor of a high β. If they are taken for granted, however, they would suggest that OLS estimation of equation (5) has not produced an upward biased estimate of β. Hence an IV estimation of equation (5) using $\ln(s_h)$ as an instrument for $\ln(h)$ should succeed in reproducing an estimate for β in the range of 0.7, given that equation (1) is the correct model. If so, the low estimate for β derived from an OLS estimation of equation (4) could be interpreted as a measurement error with respect to $\ln(s_h)$. Conversely, if OLS estimation of equation (5) actually produces upward biased results for β, IV estimation should yield results similar to those presented by MRW.

IV estimation of equation (5) does not perform as expected, however (Table A2). Although the imposed restriction on the regression coefficients is not rejected as indicated by the p-value, and the $\overline{R}^2$ is reasonably high, neither the MRW-like results derived from an estimation of equation (4), nor the OLS results derived from equation (5) are confirmed. As it stands, the implied estimates for a and β are either highly implausible or statistically insignificant and cannot be used to discriminate between the competing hypotheses for β.

Taken together, these empirical findings present a puzzle from the point of view of the augmented Solow model. According to the MRW interpretation, both α and β are about 1/3, and the higher estimated β's when $\ln(h)$ is used as a right-hand-side variable can be

[7] The coefficient of correlation between $\ln(k)$ and $\ln(h)$ is 0.84.

explained as arising from a simultaneous equation bias. A higher β may also result because $\ln(h)$ measures all stages of education, while $\ln(s_h)$ only measures secondary education. Alternatively, the low estimated β's when $\ln(s_h)$ is used as a right-hand-side variable could be due to measurement error. As a consequence, an IV estimation of equation (5) using $\ln(s_h)$ as an instrument which is highly likely to be correlated with $\ln(h)$ despite possible differences in the measurement concept, should resemble either the low or the high estimate for β. Yet, such a clear-cut picture does not emerge.

While the high estimate for β derived from an OLS estimation of equation (5) seems to be confirmed by an estimation of the production function in stocks (equation (6)) using both saving rates as instruments, estimation of equation (5) using only one saving rate as an instrument does not produce the expected result but a loss of efficiency, possibly indicating that IV estimation is not necessary at all. Therefore, neither a measurement error with respect to s_h, nor a simultaneous equation bias with respect to the OLS estimation of equation (5) is likely to explain the different estimates for β derived for alternative specifications of the augmented Solow model. The way out is to think of a modified growth model that gives an alternative interpretation of the regression coefficients in equations (4), (5) and (6), and at the same time allows for an OLS estimation of equation (5).

IV. A Modified Augmented Solow Model

One possibility to reconcile the conflicting empirical results for β is given by a growth model where unimproved labor is used to accumulate human capital, but not to produce output.[8] Unimproved labor (i.e., children) is not useful in producing output, but is useful as an input into producing human capital. Such a growth model could have a production function for final goods as suggested by Rebelo [1991],[9] without implying endogenous growth.

Consider a modified augmented Solow model with the production function

(9) $$Y(t) = BK(t)^{\alpha} H(t)^{1-\alpha} 0 < \alpha < 1,$$

with B as the level of technology, and otherwise the same notation as before. Consider further that physical capital accumulation proceeds through

(10) $$\dot{K}(t) = s_k Y(t) - \delta D(t),$$

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8 I owe this idea to the referee.

9 In the Rebelo model, unimproved labor has virtually no role to play, be it in production or in (human) capital accumulation. Thus from the point of view of the Rebelo model, there is no reason to expect that output is only produced in places where people live.

but that K is not used to accumulate human capital[10]:

(11) $$\dot{H}(t)=[a_H H(t)]^{\tau}[a_L A(t)L(t)]^{1-\tau}-\delta H(t)0<\tau<1,$$

where a_H and a_L are the fractions of H and L devoted to education.[11] As before, L and A grow exogenously at rates n and g, and equal depreciation rates (δ) for K and H are assumed for simplicity. The evolution of the economy is now governed by

(12a) $$\dot{k}(t)=s_k y(t)-(n+g+\delta)k(t),$$

(12b) $$\dot{h}(t)=[a_H h(t)]^{\tau}a_L^{1-\tau}-(n+g+\delta)h(t).$$

The steady state values k^{*} and h^{*} can be derived as

(13a) $$k^{*}=\left(\frac{sB}{n+g+\delta}\right)^{1/(1-\alpha)}h^{*}$$

(13b) $$h^{*}=\left(\frac{a_H^{\tau}a_L^{1-\tau}}{n+g+\delta}\right)^{1/(1-\tau)}.$$

Similar to equations (4) and (5) derived for the augmented Solow model, substituting equations (13a) and (13b) into the production function (9), and taking logs, gives two alternative equations for output per worker for the modified augmented Solow model:

(14) $$\ln\left(\frac{Y}{L}\right)=CONSTANT+\frac{\alpha}{1-\alpha}\ln(s_k)-\left(\frac{\alpha}{1-\alpha}+\frac{1}{1-\tau}\right)(n+g+\delta)+\frac{\tau}{1-\tau}\ln(a_H)+\ln(a_L),$$

(15) $$\ln\left(\frac{Y}{L}\right)=CONSTANT+\frac{\alpha}{1-\alpha}\ln(s_k)-\frac{\alpha}{1-\alpha}\ln(n+g+\delta)+\ln(h^{*}).$$

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[10] For a similar specification, see Lucas [1988], who also assumes that only human capital and unimproved labor are used as inputs for producing human capital. The difference to the present specification is that he assumes non-diminishing returns to human capital accumulation.

[11] The fraction of L not devoted to education is assumed to be used unproductively in the production of final goods.

These equations are almost identical to equations (4) and (5) for the augmented Solow model in terms of right-hand-side variables, but differ with respect to the interpretation of the regression coefficients. Furthermore, in contrast to equation (5), equation (15) can be estimated by OLS. Since K does not enter the $\dot{H}$ equation (11), h is independent of y according to equation (12b). Therefore, h is not correlated with the error term in equation (15). Since a_L, the fraction of unimproved labor devoted to human capital formation, loosely corresponds to s_h, the percentage of the working-age population that is in secondary school, it turns out that for a fairly small τ equations (14) and (15) can be used to reconsider the OLS results for the unrestricted augmented Solow model presented in the upper half of Table 1.

V. Estimation of the Modified Augmented Solow Model

In the modified augmented Solow model outlined in the previous section, there is no degree of freedom to estimate β for a given α. This property helps to reconcile the seemingly different estimates for β derived for the augmented Solow model. Put differently, what has been taken as different estimates of β in terms of the augmented Solow model turns out to be something different in terms of the modified augmented Solow model.

Following equations (4) and (5), for a given α it is possible to calculate β from the regression coefficients on $\ln(s_h)$ and $\ln(h)$. According to Table 1, both regression coefficients are statistically not different from 1. Hence for an α of 1/3, equation (4) predicts a β of 1/3, while equation (5) predicts a β of 2/3. Following equations (14) and (15), however, the different predictions for β disappear. Independent of α, regression coefficients on $\ln(a_L)$ and $\ln(h)$ are both predicted to be 1 which is in line with the results the upper half of in Table 1 if $\ln(s_h)$ is taken as a proxy for $\ln(a_L)$. Neither equation (14) nor equation (15) can be used to estimate β directly. Hence, given that α equals 1/3, β is uniformly predicted to be 2/3 according to equation (9).

A further difference between the augmented and the modified augmented Solow model is that the latter predicts identical regression coefficients on $\ln(s_k)$ for both equations (14) and (15). Given that α is about 1/3, this regression coefficient is predicted to be about 0.5. The point estimates for the regression coefficient on $\ln(s_k)$ in Table 1, which vary between 0.17 and 0.71, support this prediction and are difficult to reconcile with the augmented Solow model which c.p. predicts that the regression coefficient on $\ln(s_k)$ in equation (4) is twice as large as the regression coefficient in equation (5).

In addition, reconsidering equation (6) in terms of equation (9) gives

$$\ln(Y/L) = CONSTANT + \alpha \ln(k) + (1-\alpha)\ln(h). \tag{16}$$

This specification reveals that what has been taken as a direct estimate of β is a restriction which can be tested. As seen from the point of view of the modified augmented Solow model, an estimate for $(1-\alpha)$ of about 0.7 supports the restriction, but it is not an independent estimate of β as was first suggested in Section III.

Hence, it appears that the modified augmented Solow model with α about 0.3 and τ fairly small fits both types of regression results presented in the upper half of Table 1, and the results presented in equation (8). The remaining question is whether restricted versions of this alternative growth model pass the test statistics and also produce reasonable results.

An estimation of equation (14) requires the specification of a proxy for a_H, the fraction of human capital devoted to human capital formation. Since s_h, which can be used to proxy a_L, focusses on secondary education, I use total teaching staff at general secondary education in 1985 divided by the total stock of human capital as a proxy for a_H. The figures for the teaching staff are from the UNESCO Statistical Yearbook, and the total stock of human capital is average years of schooling, either from Barro and Lee [1993] or from Psacharopoulos and Arriagada [1992], times the number of workers in 1985 calculated from Summers and Heston [1991]. Measuring a_H this way reveals that there is only one country where a_H exceeds 0.5 percent, and that the variation across countries is not very large (see Table A1). Therefore, ignoring a_H as in the interpretation of the OLS results for the unrestricted model does not seem to introduce a large bias.

Table 2 presents the results for restricted versions of equations (14) and (15). The two restrictions for equation (14) are that the regression coefficient on $\ln(a_L)$ equals 1 and that the sum of the regression coefficients on $\ln(s_k)$ and $\ln(a_H)$ equals the negative regression coefficient on $\ln(n+g+\delta)$. The two restrictions for equation (15) are that the regression coefficient on $\ln(h)$ equals 1, and that the regression coefficients on $\ln(s_k)$ and $\ln(n+g+\delta)$ add up to 0. Except for one sample, the imposed restrictions are not rejected by the data as indicated by the p-value. For the remaining regressions, the $\overline{R}^2$ is not very high, but statistically significant at the 5 percent level. The implied estimates for α are statistically significant and of the expected order of magnitude in the range of 0.3. The implied estimates for τ are statistically not different from 0, pointing either to a negligible impact of a_H in equation (14), or to a bad proxy for a_H as the present data appear to be not different from a measure of noise. Nonetheless, if a_H actually has an important impact but is not identified correctly, the implied estimates for α from equations (14) and (15) can be expected to differ which is not the case. Hence the findings in Table 2 can be interpreted as weakly supporting the modified augmented Solow model.

Further evidence in favor of the modified augmented Solow model comes from an estimation of equation (16), where only $\ln(k)$ has to be instrumented since $\ln(h)$ is not correlated with the error term due to equation (12b):

(17)
$$\ln(Y/L) = 5.11 + 0.28\ln(k) + 0.90\ln(h).$$
$$\quad (1.23) \quad (0.22) \qquad (0.48)$$

Implied $\alpha + \beta$: 1.19
(0.28)

Standard errors in parenthesis, number of observations = 29

List of instruments: $CONSTANT, \ln(s_k), \ln(h)$

$\overline{R}^2 = 0.84$ s.e.e. = 0.33.

Imposing the statistically significant restriction that the regression coefficients add up to 1 gives

(18)
$$\ln(Y/L) - \ln h = 4.72 + 0.38(\ln k - \ln h)$$
$$\quad (0.77) \quad (0.10)$$

Standard errors in parenthesis, number of observations = 29

List of instruments: $CONSTANT, \ln(s_k)$

$\overline{R}^2 = 0.78$ s.e.e. = 0.33,

where the estimate for α becomes statistically significant, and is not different from the previous estimates in the range of 1/3.

Summarizing, the modified augmented Solow model gives a consistent explanation of the regression results obtained for restricted and unrestricted versions of equations (14), (15), and (16). This model implies a much larger production elasticity for human capital than was estimated by MRW. Independent of the income share of (physical) capital, the elasticity of output per worker with respect to investment in human capital (as measured by the fraction of unimproved labor devoted to education) is 1, as is the elasticity with respect to the stock of human capital per worker. For an income share of physical capital of about 1/3, the model predicts the same elasticities of output per worker with respect to the saving rate and to population growth of about 0.5 and -0.5 that are known from the textbook Solow model, while MRW derive the respective elasticities as 1 and -2.

VI. Conclusion

Recent empirical research on the empirics of growth has demonstrated that an augmented Solow model provides a fairly good description of cross-country data on output per worker. Re-estimating this model by using a proxy for the stock of human capital rather than a flow measure, I find a substantially higher share of human capital in income than MRW. Given the data at hand, this result does not seem to suffer from a simultaneous equation bias, and the MRW result does not seem to suffer from measurement error. Therefore, a modified augmented Solow model is suggested that can reconcile the competing empirical estimates. For an income share of physical capital of about 1/3, the implication of this new growth model is that the impact of human capital formation on output per worker is twice as high as the positive impact of physical capital formation and the negative impact of population growth. The MRW model is less optimistic in this respect: The impact of human and physical capital accumulation is predicted to be the same, and only half as large as the negative impact of population growth.

It has to be conceded, however, that the empirical evidence does not suffice to clearly discriminate between the alternative interpretations of the role of human capital in economic growth. To be able to do so, an extended series for k and alternative proxies for a_H would be needed. Furthermore, it is also questionable whether the true impact of human capital can be captured by measures which only focus on schooling, but not on experience. Despite these criticisms, a Solow growth model extended one way or another seems to provide a reasonable framework to study how human capital formation influences per capita income.

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Table 1 - OLS Estimation of the Augmented Solow Model

Dependent variable: $\ln(Y/L)$						
	Equation (4)		Equation (5)			
Sample:	All countries	D countries excluded	All countries		D countries excluded	
Observations:	89	62	88	45	61	38
CONSTANT	8.24 (1.35)	8.36 (1.52)	5.14 (1.27)	6.35 (1.59)	6.08 (1.36)	5.04 (1.35)
$\ln(s_k)$	0.37 (0.12)	0.43 (0.20)	0.22 (0.13)	0.71 (0.21)	0.37 (0.20)	0.17 (0.23)
$\ln(n+g+\delta)$	-1.42 (0.48)	-1.38 (0.49)	-1.06 (0.47)	-0.97 (0.58)	-0.77 (0.49)	-0.84 (0.48)
$\ln(s_h)$	0.80 (0.09)	0.73 (0.14)	-	-	-	-
$\ln(h)$	-	-	1.00 (0.11)	0.80 (0.18)	1.05 (0.16)	1.21 (0.18)
$\overline{R}^2$	0.73	0.63	0.73	0.72	0.68	0.79
s.e.e.	0.55	0.49	0.54	0.50	0.47	0.37
Restricted regression:						
CONSTANT	8.91 (0.14)	8.89 (0.20)	7.28 (0.12)	7.01 (0.25)	7.05 (0.21)	6.61 (0.26)
$\ln(s_k)-\ln(n+g+\delta)$	0.38 (0.12)	0.47 (0.18)	0.28 (0.13)	0.74 (0.19)	0.44 (0.17)	0.31 (0.20)
$\ln(s_h)-\ln(n+g+\delta)$	0.80 (0.09)	0.75 (0.13)	-	-	-	-
$\ln(h)$	-	-	1.01 (0.11)	0.81 (0.17)	1.07 (0.16)	1.24 (0.18)
$\overline{R}^2$	0.73	0.64	0.72	0.73	0.68	0.79
s.e.e.	0.55	0.49	0.54	0.49	0.46	0.37
Test of restriction:						
p-value	0.62	0.72	0.09	0.68	0.47	0.24
Implied a	0.17 (0.05)	0.21 (0.07)	0.22 (0.08)	0.43 (0.06)	0.31 (0.08)	0.24 (0.11)
Implied β	0.37 (0.04)	0.34 (0.06)	0.79 (0.15)	0.46 (0.14)	0.74 (0.18)	0.95 (0.26)
Implied $\alpha+\beta$	0.54 (0.02)	0.55 (0.03)	1.01 (0.09)	0.89 (0.09)	1.05 (0.12)	1.18 (0.16)

Note. Standard errors in parentheses. Y/L is real GDP per worker in 1985. s_k and n are averages for the period 1960-1985. ($g+\delta$) is assumed to be 0.05. s_h is the percentage of the working-age population in secondary school in 1985. h is average years of schooling. Average years of schooling in the third and fifth column are taken from Barro and Lee [1993], and in the fourth and sixth column from Psacharopoulos and Arriagada [1992].

Table 2 - Estimation of the Restricted Modified Augmented Solow Model

Dependent variable: $\ln(Y/L)-\ln(a_L)$				
	Equation (14)			
Sample:	All countries		D countries excluded	
Observations:	63	30	39	24
CONSTANT	6.79 (0.43)	6.58 (0.52)	6.59 (0.65)	6.06 (0.85)
$\ln(s_k)-\ln(n+g+\delta)$	0.25 (0.11)	0.60 (0.14)	0.53 (0.19)	0.60 (0.21)
$\ln(a_H)-\ln(n+g+\delta)$	-0.08 (0.10)	-0.07 (0.12)	-0.07 (0.14)	-0.20 (0.21)
$\overline{R}^2$	0.05	0.35	0.14	0.25
s.e.e.	0.56	0.45	0.48	0.47
Test of restrictions:				
p-value	0.02	0.65	0.31	0.27
Implied *a*	0.20 (0.07)	0.37 (0.06)	0.35 (0.08)	0.37 (0.08)
Implied τ	-0.09 (0.12)	-0.08 (0.14)	-0.07 (0.16)	-0.25 (0.33)

Dependent variable: $\ln(s_k)-\ln(n+g+\delta)$				
	Equation (15)			
Sample:	All countries		D countries excluded	
Observations:	88	45	61	38
CONSTANT	7.29 (0.09)	6.80 (0.16)	7.11 (0.14)	6.88 (0.17)
$\ln(s_k)-\ln(n+g+\delta)$	0.30 (0.09)	0.59 (0.14)	0.49 (0.13)	0.50 (0.14)
$\overline{R}^2$	0.10	0.28	0.19	0.26
s.e.e.	0.54	0.50	0.46	0.37
Test of restrictions:				
p-value	0.24	0.51	0.71	0.21
Implied *a*	0.23 (0.05)	0.37 (0.05)	0.33 (0.06)	0.34 (0.06)

Note. Standard errors in parenthesis. Y/L is GDP per worker in 1985. s_k and n are averages for the period 1960-1985. $(g+\delta)$ is assumed to be 0.05. a_H is total teaching staff at general secondary education in 1985 divided by the total stock of human capital. h is average years of schooling. Average years of schooling in the first and third column are taken from Barro and Lee [1993], and in the second and fourth column from Psacharopoulos and Arriagada [1992].

Table A1 - Data and Samples

Country	Quality rating	Y/L	n	s_k	s_h	$h(BL)$	$h(PA)$	k	$a_H(BL)$	$a_H(PA)$
Algeria	D	14 417	2.6	25.7	4.5	2.31	4.2	.	0.72	0.39
Benin	D+	2 271	2.4	5.6	1.8	0.98	.	.	0.14	.
Botswana	C	7 175	3.2	23.9	2.9	2.59	4.2	.	0.13	0.08
Cameroon	C-	4 614	2.1	10.3	3.4	2.28	.	.	0.08	.
Central African Rep.	D	1 408	1.7	8.5	1.4	1.28	.	.	0.05	.
Congo	D+	7 024	2.4	14.5	3.8	3.14	.	.	0.21	.
Egypt	D+	7 161	2.5	6.2	7.0	3.22	2.4	.	0.31	0.42
Ethiopia	D+	716	2.3	4.7	1.1	.	6.0	.	.	0.02
Ghana	D+	2 166	2.3	7.8	4.7	2.94	.	.	0.24	.
Kenya	C	2 050	3.4	14.5	2.4	2.60	3.5	1 300	0.10	0.07
Liberia	D	2 542	3.0	29.5	2.5	1.68	.	.	.	.
Malawi	D+	1 378	2.4	12.6	0.6	2.33	.	.	0.02	.
Mali	D+	1 382	2.2	6.3	1.0	0.79	.	.	0.25	.
Mauritius	D+	9 823	2.6	11.8	7.3	4.56	.	.	0.20	.
Morocco	C-	6 670	2.5	8.5	3.6	.	2.9	.	.	0.32
Mozambique	D	1 494	2.7	12.8	0.7	0.99	1.2	.	0.04	0.04
Niger	D	1 247	2.6	9.1	0.5	0.55	.	.	0.11	.
Rwanda	D+	1 438	2.8	4.3	0.4	1.33	.	.	0.08	.
Senegal	C-	2 620	2.3	7.3	1.7	2.12	.	.	0.06	.
Sierra Leone	D+	2 751	1.6	2.3	1.7	1.72	.	.	0.20	.
South Africa	C-	12 855	2.3	26.2	3.0	4.95	.	.	.	.
Sudan	D	2 952	2.6	1.8	2.0	0.91	.	.	0.03	.
Tanzania	C-	978	2.9	19.3	0.5	2.28	.	.	0.02	.
Togo	D	1 624	2.5	16.8	2.9	2.08	.	.	0.16	.
Tunisia	C-	10 134	2.4	15.6	4.3	2.50	4.8	.	0.45	0.23
Uganda	D	895	3.1	4.0	1.1	1.58	.	.	0.06	.
Zaire	D	942	2.4	9.2	3.6	2.24	.	.	0.19	.
Zambia	D+	2 279	2.7	30.2	2.4	3.91	.	.	0.06	.
Zimbabwe	C-	3 535	2.8	18.0	4.4	2.55	.	1 997	0.20	.
Canada	A-	29 947	2.0	22.5	10.6	10.37	12.4	39 491	.	.
Costa Rica	C	9 942	3.5	13.8	7.0	5.35	.	.	0.09	.
Dominican Rep.	C	7 240	2.9	14.0	5.8	4.35	.	5 294	0.15	.
El Salvador	C	4 596	3.3	7.8	3.9	3.52	.	.	.	.
Guatemala	C	7 748	3.1	8.6	2.4	2.50	.	3 281	.	.
Haiti	D	1 939	1.3	6.6	1.9	1.64	1.6	.	0.15	0.15
Honduras	C	4 171	3.1	13.4	3.7	3.56	4.5	.	.	.
Jamaica	C	5 079	1.6	22.3	11.2	4.21	.	.	0.16	.
Mexico	C	16 054	3.3	20.1	6.6	4.09	.	.	0.30	.
Nicaragua	D	6 228	3.3	18.4	5.8	3.13	.	.	0.13	.
Panama	C	10 484	3.0	25.0	11.6	6.31	.	.	0.14	.
Trinidad and Tobago	C	19 692	1.9	19.6	8.8	6.50	6.6	.	0.17	0.16
USA	A	34 374	1.5	17.0	11.9	11.78	13.0	31 041	0.08	0.07
Argentina	C	11 097	1.5	12.2	5.0	6.61	.	10 141	0.13	.
Bolivia	C	5 021	2.4	17.7	4.9	4.28	.	.	.	.
Brazil	C-	10 910	2.9	20.1	4.7	3.48	6.4	.	.	.
Chile	C	10 667	2.3	13.4	7.7	6.25	8.1	7 768	.	.
Colombia	C	10 199	3.0	17.5	6.1	4.56	.	9 108	0.17	.
Ecuador	C	9 167	2.8	25.3	7.2	5.67	6.5	.	0.21	0.18
Paraguay	C	7 081	2.7	11.1	4.4	4.80	.	.	.	.
Peru	C	8 529	2.9	16.0	8.0	5.74	7.0	.	0.19	0.16
Uruguay	C-	11 351	0.6	15.9	7.0	6.58	.	.	.	.
Venezuela	C	16 695	3.8	16.7	7.0	5.37	.	.	.	.
Afghanistan	D	2 606	1.6	6.4	0.9	0.97	.	.	0.12	.
Bangladesh	C-	2 441	2.6	5.9	3.2	2.04	2.4	.	0.19	0.16
Burma (Myanmar)	D	1 458	1.7	11.6	3.5	2.04	.	.	.	.
Hong Kong	B-	19 385	3.0	21.2	7.2	7.51	9.1	.	0.08	0.07
India	C	1 816	2.4	16.6	5.1	3.36	1.9	1 519	0.22	0.38
Indonesia	C	4 423	1.9	17.5	4.1	3.56	5.0	.	.	.
Israel	B	24 433	2.8	27.2	9.5	9.30	11.3	20 095	.	.
Japan	A	21 780	1.2	31.1	10.9	8.34	.	45 354	.	.
Jordan	D	11 984	2.7	16.4	10.8	4.04	5.9	.	0.53	0.36
Korea, Rep. of	B-	9 434	2.7	24.3	10.2	7.85	8.0	14 520	0.08	0.08
Malaysia	C	12 073	3.2	28.4	7.3	5.02	7.0	.	0.18	0.13
Nepal	D+	1 771	2.0	9.9	2.3	0.62	.	.	0.25	.

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Table A1 (continued)

Country	Quality rating	Y/L	n	s_k	s_h	$h(BL)$	$h(PA)$	k	$a_H(BL)$	$a_H(PA)$
Pakistan	C-	4 686	3.0	16.4	3.0	1.92	.	.	0.28	.
Philippines	C	4 912	3.0	19.7	10.6	6.50	7.0	2 942	.	.
Singapore	C	21 735	2.6	29.2	9.0	4.65	.	.	0.15	.
Sri Lanka	C-	5 249	2.4	21.0	8.3	5.46	4.5	.	.	.
Taiwan	D-	11 387	3.0	22.9	.	7.00	9.0	.	.	.
Thailand	C-	4 878	3.1	15.0	4.4	4.87	.	2 792	0.08	.
Austria	A-	22 189	0.4	27.2	8.0	5.79	12.9	27 320	0.25	0.11
Belgium	A	25 194	0.5	23.2	9.3	9.11	10.5	41 964	.	.
Denmark	A-	22 006	0.6	28.4	10.7	10.38	8.6	29 309	0.13	0.16
Finland	A-	22 143	0.7	34.7	11.5	9.54	8.5	44 367	.	.
France	A	25 472	1.0	26.1	8.9	6.54	6.2	37 040	.	.
Germany, Fed. Rep.	A	24 175	0.5	27.2	8.4	8.61	10.4	36 600	0.14	0.12
Greece	A-	14 989	0.7	26.3	7.9	6.64	7.9	15 305	0.17	0.14
Ireland	A-	15 475	1.1	26.9	11.4	7.84	.	23 484	0.19	.
Italy	A	26 569	0.6	28.3	7.1	5.78	10.2	32 260	0.26	0.15
Netherlands	A	27 041	1.4	24.5	10.7	8.60	11.0	.	0.11	0.08
Norway	A-	27 486	0.7	33.0	10.0	10.31	11.0	48 175	.	.
Portugal	A-	10 095	0.6	23.7	5.8	3.70	9.5	.	0.29	0.11
Spain	A-	18 056	1.0	26.5	8.0	5.58	10.4	25 114	0.21	0.11
Sweden	A-	24 402	0.4	22.9	7.9	9.33	12.4	24 498	.	.
Switzerland	B+	29 351	0.8	29.8	4.8	7.98	12.7	.	.	.
Turkey	C	7 538	2.5	20.8	5.5	3.18	.	.	0.14	.
United Kingdom	A	22 041	0.3	18.0	8.9	8.51	12.2	21 633	0.14	0.10
Australia	A-	26 855	2.0	28.5	9.8	10.22	12.3	29 436	0.14	0.12
New Zealand	A-	22 578	1.7	21.8	11.9	11.21	11.7	.	0.11	0.11
Papua New Guinea	D	3 478	2.1	24.2	1.5	1.38	.	.	0.09	.

Note. Y/L is real GDP per worker in 1985; n is the annualized growth rate of the working age population in percent for the period 1960-85; s_k is investment as a percentage of GDP, and s_h is the percentage of the working-age population in secondary school, both averaged for the period 1960-1985. h is average years of schooling, for 1985 taken from Barro and Lee [1993] ($h(BL)$), and for 1980-88 taken from Psacharopoulos and Arriagada [1992] ($a_H(PA)$). k is real (physical) capital per worker in 1985. a_H is the percentage of total teaching staff at general secondary education in 1985 in the total stock of human capital, computed from UNESCO Statistical Yearbook and from Barro and Lee ($a_H(BL)$) or from Psacharopoulos and Arriagada ($a_H(PA)$). Y/L, s_k , and k are taken from Summers and Heston [1991], n and s_h are taken from Mankiw et al. [1992].

Table A2 - IV Estimation of Equation (5)

Dependent variable: $\ln(Y/L)$

List of instruments: $CONSTANT, \ln(s_k), \ln(n+g+\delta), \ln(s_h)$

Sample:	All countries		D countries excluded	
Observations:	87	44	61	38
CONSTANT	5.28 (1.35)	6.73 (2.16)	6.18 (1.41)	5.01 (1.41)
$\ln(s_k)$	-0.02	0.03	0.18	-0.04
	(0.16)	(0.40)	(0.23)	(0.32)
$\ln(n+g+\delta)$	-0.67	0.27	-0.42	-0.49
	(0.52)	(0.93)	(0.54)	(0.61)
$\ln(h)$	1.32	1.78	1.37	1.53
	(0.16)	(0.46)	(0.25)	(0.36)
$\overline{R}^2$	0.71	0.63	0.66	0.78
s.e.e.	0.57	0.66	0.48	0.38
Restricted regression:				
CONSTANT	7.06 (0.15)	5.95 (0.55)	6.76 (0.28)	6.30 (0.43)
$\ln(s_k)-\ln(n+g+\delta)$	0.04	-0.03	0.23	0.08
	(0.16)	(0.41)	(0.21)	(0.32)
$\ln(h)$	1.33	1.79	1.37	1.53
	(0.16)	(0.47)	(0.24)	(0.36)
$\overline{R}^2$	0.71	0.63	0.67	0.78
s.e.e.	0.57	0.66	0.48	0.38
Test of restriction:				
p-value	0.15	0.49	0.64	0.36
Implied a	0.04 (0.15)	-0.03 (0.43)	0.19 (0.14)	0.07 (0.27)
Implied ζ	1.28 (0.33)	1.84 (1.22)	1.17 (0.37)	1.41 (0.73)

Note. Standard errors in parentheses. Y/L is real GDP per worker in 1985. s_k and n are averages for the period 1960-1985. ($g+\delta$) is assumed to be 0.05. s_h is the percentage of the working-age population in secondary school in 1985. h is average years of schooling. Average years of schooling in the first and third column are taken from Barro and Lee [1993], and in the second and forth column from Psacharopoulos and Arriagada [1992].