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HUMAN CAPITAL ACCUMULATION AND ECONOMIC GROWTH

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This paper examines how human capital affects growth, considering the reverse impact or causation of growth on human capital accumulation. To analyze this simultaneity, we estimate the dynamic system that describes the behavior of the economy. We obtain the parameters of the aggregate production function and those characterizing the process of human capital accumulation. The joint estimation of the dynamic equations provides evidence about the level effect of education on economic growth. When we do not consider the joint estimation, the outcome changes in the opposite direction.

Key words: Economic growth, human capital accumulation, simultaneous relation, empirical evidence.

(*JEL* O40, 050)

1. Introduction

The role of education (or in general, of the formation of human capital) in the growth process has been extensively analyzed in the theoretical literature (see Nelson and Phelps, 1966, Welch, 1970, Lucas, 1988, Azariadis and Drazen, 1990 and Romer, 1990, among others). This literature identifies two ways in which educational investment can contribute to growth. First, human capital can directly participate in production as a productive factor. In this sense, the accumulation of human capital would directly generate the growth of output. This is the so-called level effect. Second, human capital can contribute to raising technical progress since education eases the innovation, diffusion and adoption of new technologies. In this way, the level of human

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capital affects productivity growth. This second effect is the so-called rate effect.

A number of studies have tested the empirical relevance of these theories. However, the evidence they provide is mixed. While most papers find a positive correlation between educational attainment levels and productivity growth, other studies find that the coefficient of the educational variable does not enter significatively in a growth accounting regression. Therefore, the empirical evidence suggests that human capital contributes to growth through the rate effect, but there is no clear evidence of the level effect. The central concern of this paper is to give new empirical conclusions on the relationship between human capital and economic growth. To that aim, we propose to analyze not only the contribution of human capital to output growth (the level effect), but also the effect of the level of income on human capital accumulation. Previous studies have only estimated the one-side effect of human capital in the growth of income.

The level effect of human capital on economic growth has mainly been investigated through the convergence analysis proposed by Barro and Sala-i-Martin (1992).[1] In this sense, Mankiw, Romer and Weil (1992), (MRW, henceforth), extends the Solow growth model by incorporating an explicit process of human capital accumulation. In this framework, they derive a convergence equation relating the increments of output to the investment rates for both physical and human capital. This specification allows them to analyze the direct participation of human capital as an input in aggregate production by using flow data for both types of capital. In particular, they take the proportion of working-age population that is still studying as a proxy of the investment rate in human capital. Thus, running a single cross-country regression, they obtain evidence that would confirm the existence of a direct effect of human capital on economic growth.

Following the framework introduced by MRW, other articles have studied the effect of human capital in income growth by modifying some aspects of this analysis. This has generated opposing results on the significance of the level effect of human capital. Nonneman and Van-

[1] Kyriacou (1991) and Benhabib and Spiegel (1994) also analyze the relationship between human capital and economic growth running the Cobb-Douglas production function in differences where human capital is one of the productive factors. Their results show that the estimated coefficients for human capital are not significantly different from zero, and in some cases they are even negative.

houdt (1996) suggest an augmentation of the MRW model by introducing also the accumulation of technological know-how. Moreover, they use as a proxy of human capital the share of GDP invested in education. Their results show that the estimated coefficient of human capital is not statistically significant. However, Murthy and Chien (1997) demonstrate that this result is radically changed when a new comprehensive measure for human capital is used. More precisely, they take a weighted average of the population enrolled in higher, secondary and primary education, as proxy for human capital. Hence, they conclude that human capital has a direct role in explaining economic growth. As the original MRW analysis, both articles are based on single cross-country regressions. Regarding this, Islam (1995) considers the convergence equation originally derived by MRW and examines how the results change with the adoption of a panel data approach. Moreover, he takes from Barro and Lee (1993) the average schooling years in the total population over age 25 as a proxy of the stock level of human capital. He finds that the role of human capital in the growth process is non-significant under these two modifications in the MRW analysis.[2]

As a conclusion of the previous overview, one may state that the sources for these puzzling results seem to be the use of different measures of human capital and different estimation approaches. Thus, the choice of the proxy of human capital could be introducing a measurement error problem. Moreover, one objection to all of these analyses is that they do not take into account a possible reverse impact of growth on human capital accumulation. The absence of this feedback effect is a consequence of the process for human capital accumulation they assume. All previous studies consider that physical and human capital are both accumulated by means of similar investment technology, which exhibits the same depreciation rate. The present paper proposes a new interpretation for the process of human capital accumulation. We assume that the level of income achieved by the economy determines the accumulation of human capital by increasing the desire of individuals to augment their level of education. This new interpretation allows us to analyze the contribution of human capital to growth of income considering simultaneously the effect that the level of income has on the

[2] In the same line, Gorostiaga (1999) uses Spanish regional data to estimate, by a panel approach and the instrumental variable technique, a convergence equation based on this framework. She finds that the estimated coefficient of human capital is negative and significant.

process of human capital accumulation. For that purpose, we jointly estimate the dynamic system that describes the evolution of income and human capital.[3] The relevance of this joint estimation technique, using instrumental variables, is that it adjusts the possible existence of the measurement error problem. Thus, the estimation of this simultaneous system confirms that human capital has a positive and significant effect on the growth rate of income. Furthermore, if we do not contemplate the simultaneity, and we isolate the estimation of the dynamic equation of income without the corresponding instrumental variable, then the outcome changes in the opposite direction.

The outline of the paper is as follows. In Section 2, we present the theoretical model from which we derive the econometric specification used in the empirical analysis. Section 3 details the different sources of data, and it presents the empirical results. Finally, a summary and some concluding remarks are presented in Section 4.

2. The growth model

This section presents the benchmark model which is closely related to the one proposed by MRW. We consider a standard economy where the aggregate production function is represented by Cobb-Douglas technology with constant returns to scale. More precisely, in each period t the production is given by

$$Y_t = K_t^{\alpha} H_t^{\beta} (A_t L_t)^{1-\alpha-\beta} \qquad [1]$$

where Y_t is aggregate output, K_t is the stock of physical capital, H_t is the stock of human capital, A_t is a technical efficiency index that grows at a constant and exogenous rate, g, and L_t is labor. We assume that population grows at an exogenous and constant rate. In each period this new population is incorporated to the labor market, and at the same time, a part of the current labor force retires and therefore they will not participate in the next production process. Thus, considering this retirement process and the growth rate of population, we suppose that labor force, L_t, grows at a constant and exogenous rate n.

Output may be either used for consumption or investment in physical capital. Therefore, the law of motion for physical capital stock is

[3] Issues on simultaneity and endogeneity have also been studied by Cho (1996). In particular, this paper analyzes how the endogeneity of the investment to GDP ratio and the population growth rate affects the conditional convergence result.

determined by the constant rate of investment in physical capital, s_k, and its depreciation rate, δ:

$$\overset{\bullet}{K}_t = s_k Y_t - \delta K_t. \quad [2]$$

In our economy individuals also accumulate human capital through their schooling formation. This process must not be interpreted in the same way as the law of motion for physical capital stock. While physical capital accumulation is an investment decision of each individual, people accumulate human capital spending time in schooling. In this sense, it is possible to refute the usefulness of the assumptions that human capital evolves as physical capital and that it has the same depreciation rate. More precisely, we assume that the evolution of human capital, i.e., the growth rate of the average educational attainment, depends on two variables, the average level of output and the present level of human capital. The initial conjecture, that we will confirm in section 3, is that this process positively depends on actual output, because it determines the willingness of individuals to increase their educational level. However, the evolution of education is negatively affected by the present stock of human capital. That is because the educational attainment achieved by the old workers, who will retire, will not be used in the next period.

To describe human capital accumulation we assume, for simplicity, a lineal form. Denoting by $\tilde{Y}_t = Y_t/L_t$ and $\tilde{H}_t = H_t/L_t$, the evolution of human capital is given by the following reduced form:

$$\overset{\bullet}{\tilde{H}}_t = \gamma \tilde{Y}_t - (\eta + n)\tilde{H}_t, \quad [3]$$

where $\tilde{H}_t$ indicates the average of the educational attainment achieved by the labor force. Note that this process must not be interpreted as a saving function. Thus, the parameter γ does not tell us how much income individuals spend on accumulating human capital. It actually shows how the economy translates the achieved level of income per worker into an increase in the schooling of the labor force. Parameter γ is a kind of "elasticity of human capital accumulation with respect to aggregate income" that determines the demand for new human capital. In this sense, countries with higher income will accumulate a larger amount of human capital. Parameter η represents the demographic mechanism of the "retirement effect". Note that both parameters γ and η are not quantified in monetary units and they are not directly observable and so, their values should simultaneously be estimated with the other technological parameters.

In this model, economic growth is exclusively driven by labor in efficiency units, which grows at a constant rate $n+g$. For this reason, we can now normalize all variables in efficiency units of labor to characterize the steady-state equilibrium and the dynamics. More precisely, defining $k_t = K_t/A_tL_t$, $h_t = H_t/A_tL_t$, and $y_t = Y_t/A_tL_t$, the dynamic equations of the normalized variables are given by

$$\overset{\bullet}{k_t} = s_k k_t^{\alpha} h_t^{\beta} - (n+g+\delta)k_t, \qquad [4]$$

$$\overset{\bullet}{h_t} = \gamma k_t^{\alpha} h_t^{\beta} - (n+g+\eta)h_t. \qquad [5]$$

This dynamic system is locally stable. Hence, given any initial stock of both types of capital, the variables k_t and h_t converge to their steady-state values. Therefore, by making $\dot{k}_t = 0$ and $\dot{h}_t = 0$, we obtain the steady-state value of output in efficiency units of labor:

$$Y = \left[\left(\frac{\gamma}{n+g+\eta}\right)^{\beta}\left(\frac{s_k}{n+g+\delta}\right)^{\alpha}\right]^{1/1-\alpha-\beta}. \qquad [6]$$

The long-run level of income is determined by the technological parameters α and β, the exogenous investment rate s_k, the parameters defining human capital accumulation γ and η, the depreciation rate of physical capital δ, and the long-run growth rate $n+g$. Thus, those countries with a larger physical capital investment rate, a larger "propensity" to accumulate human capital and a smaller growth rate of efficiency units of labor will reach a larger steady-state level of output in efficiency units of labor. Note that an identical value of parameters γ and η for all countries is compatible with different short-run schooling rates across them. These differences in schooling rates would derive from differences in the short-run level of income and human capital per worker.

We are also interested in describing the dynamic behavior of output in efficiency units of labor. Accordingly, in Appendix A1, we obtain the following log-linear approximation of this path in a neighborhood of the steady state:

$$\begin{aligned}\overset{\bullet}{\ln y_t} &= \alpha[-(1-\alpha)(n+g+\delta)+\beta(n+g+\eta)](\ln k_t - \overline{\ln k}) \\ &\quad +\beta[\alpha(n+g+\delta)-(1-\beta)(n+g+\eta)](\ln h_t - \overline{\ln h}). \qquad [7]\end{aligned}$$

At this stage, we should be able to use the theoretical model to estimate the relationship between output and human capital. Unlike all related papers (see, e.g., MRW, Litchenberg, 1992, Nonneman and Vanhoudt, 1996), we will not make use of the solution of a convergence equation. With such equation we could only obtain the dependence of output on human capital, but not the converse relationship. We need to find some complete system of simultaneous equations defining the evolution of these variables. We derive this dynamic system in Appendix A as follows:

$$\overset{\bullet}{\ln h_t} = (n+g+\eta)(\ln y_t - \ln h_t) + (n+g+\eta) \ln\left(\frac{\gamma}{n+g+\eta}\right), \quad [8]$$

$$\overset{\bullet}{\ln y_t} = \beta \overset{\bullet}{\ln h_t} + (n+g+\delta)\beta \ln h_t + \alpha(n+g+\delta) \ln\left(\frac{s_k}{n+g+\delta}\right) - [(1-\alpha)(n+g+\delta)] \ln y_t. \quad [9]$$

While system [8]/[9] is expressed in efficiency units of labor, only information on per worker units is available. Hence, we must isolate technical progress by substituting the level of technical progress $A_0 e^{gt}$ for A_t. Therefore, after simple manipulation, and considering that $\tilde{y}_t = \ln(Y_t/L_t)$ and $\tilde{h}_t = \ln(H_t/L_t)$, we can write the following econometric specification:[4]

$$\frac{\tilde{h}_{t+\tau} - \tilde{h}_t}{\tau} = g + (n+g+\eta)(\tilde{y}_t - \tilde{h}_t) + (n+g+\eta) \ln\left(\frac{\gamma}{n+g+\eta}\right) + \varepsilon_{ht+\tau}, \quad [10]$$

$$\frac{\tilde{y}_{t+\tau} - \tilde{y}_t}{\tau} = \beta\frac{\tilde{h}_{t+\tau} - \tilde{h}_t}{\tau} + \beta(n+g+\delta)\tilde{h}_t - (1-\alpha)(n+g+\delta)\tilde{y}_t + \alpha(n+g+\delta)\ln\left(\frac{s_k}{n+g+\delta}\right) + g(1-\beta) + (1-\alpha-\beta)(n+g+\delta)(\ln(A_0)+gt) + \varepsilon_{yt+\tau}. \quad [11]$$

This econometric specification permits us not only to obtain the estimated coefficients of α and β, but also the estimated values of γ and

[4]Note that we directly estimate the log-linear approximation to the original system, instead of its solution. Since we will use short periods, five-years span data, we can propose this direct estimation of the law of motion of the system.

η. Thus, we can simultaneously obtain the double direction in the relationship between output and human capital.

3. Data and estimation results

The estimation will be done using pooled data for different samples of countries during the period 1960-1990. This sample period is subdivided into five-year intervals. Thus we use six observations, since the endogenous variables are expressed in variation rates. Following MRW and Islam (1995), the sample is divided into three subsamples: NONOIL (72 countries), where we exclude the oil producer countries; INTER (65 countries), where we exclude small countries and those which Summers and Heston identify as countries whose real income data are based on extremely little data; and OECD, which is made up of the 22 OECD countries with population greater than one million.[5]

Regarding the source of the data, we obtain the figures for income, population, labor force and investment rates from the Summers-Heston (1996) data set. These data are expressed in real terms and are corrected for differences in purchasing power. Concerning the information on the human capital stock, we consider the revised data set constructed by Barro and Lee (1996). The information of human capital that we use is the estimated educational attainment of the population aged 25 and above. In particular, we will take the average years of schooling as an index of the level of human capital achieved by each country. The investment rate, s_k, and the growth rate of the labor force, n, are both computed for each country as the average of their respective annual values, i.e., $s_k = \frac{1}{5}\sum_{t=1}^{5}(I_t/Y_t)$ and $n_t = \frac{1}{5}\ln(L_{t+5}/L_t)$. Finally, we assume that the depreciation rate of physical capital is 0.05 and the growth rate of technical progress is 0.02.

As was pointed in the previous section, we will use these data to estimate equations [10] and [11]. These equations constitute a triangular system of simultaneous equations. Since the random perturbations may be correlated, we must use a joint estimation method to obtain consistent and efficient estimators. We choose the two-stage non-linear least squares method.[6] Joint estimation of system [10]/[11] provide the

[5] The number of countries in our subsamples differs from MRW's because we do not have human capital data available for all countries over the whole period.

[6] We have estimated the first equation of system [10]/[11] and then we used these estimated coefficients to compute the instrumental variable for the endogenous regressor of the second equation. However, note that the standard errors obtained with the estimation of the second equation are associated to the instrumental

estimated values of parameters γ and β. The first value gives us the effect of output on human capital accumulation, whereas the second provides us with the effect of human capital on the growth rate of output, i.e., the level effect of human capital.

TABLE 1
Estimation of the human capital equation in the dynamic system

$$\frac{\tilde{h}_{t+\tau}-\tilde{h}_t}{\tau} = g+(n+g+\eta)(\tilde{y}_t-\tilde{h}_t)+(n+g+\eta)\ln\left(\frac{\gamma}{(n+g+\eta)}\right)+\varepsilon_{ht+\tau}$$

	NONOIL		INTER		OECD
η	0.064 (0.005)	0.064 (0.004)	0.064 (0.006)	0.064 (0.006)	0.066 (0.008)
γ	1.12E-08 (1.06E-09)	1.15E-08 (4.4E-09)	4.6E-08 (9.1E-10)	4.99E-09 (9.13E-10)	4.4E-09 (6.7E-10)
t.d.	yes	no	yes	no	yes
c.d.	no	yes	no	yes	no

Notes. There are six observations for each country Sample period for estimation is 1960-1990 The NONOIL sample has a total of 432 observations, the INTER sample has a total of 390 observations, and the OECD sample has a total of 132 observations.
t.d indicates whether the estimation includes "time dummies"
c.d. indicates whether the estimation includes "continent dummies"
Standard errors are in parenthesis.

Table 1 shows the estimated values of parameters γ and η that determine the evolution of human capital. These results are obtained from the estimation of equation [10]. First, we observe that output has a positive and significant effect on the accumulation of human capital. Remember that γ is neither a rate of investment nor does it represent how much money people must invest to accumulate human capital. These positive values of γ should be interpreted as follows. Each one thousand dollars of annual income per worker achieved by the economy generates in each period t an increase of 0.0000115 years in schooling investment of the labor force for the NONOIL sample of countries. In both samples, most of the countries come from Africa and Asia, where the levels of schooling are very low. This means that the results of Table 1 could be conditioned due to the presence of many developing countries. In order to test for this problem, we have also included dummies to distinguish between countries from the OECD,

variable, while we are interested in the true standard errors corresponding to the observed variable. Therefore, we have had to calculate the true standard errors which are different (but they hardly change) from the ones given by the equation by equation estimation procedure. See Hamilton (1994, chap. 14) for more details.

Africa, Asia, and Latin-America. The estimated values of parameters γ and η hardly change by introducing these variables. Nevertheless, since the estimated coefficients of these dummies are significatively different from zero, we still maintain them to control for differences in the steady state of each group of countries.

Undoubtedly, the estimation with fixed effects for each country would be very interesting because we would be able to obtain different values of γ and η for each country. Moreover, we could then directly compare our results with the outcomes obtained by Islam (1995). However, the introduction of more coefficients would make the joint estimation of the system extremely difficult. Since the main aim of the paper is to analyze how this joint estimation affects the results on β, we have only considered dummies to distinguish between continents.

On the other hand, the estimated value for η is about 0.06 for all samples. This positive value confirms that the law of human capital accumulation will not explode. This result is very reasonable since the used human capital variable is bounded from above.

After the estimation of the parameters that determine human capital accumulation, we must estimate the value of α and β. To this end, we estimate equation [11]. According our estimation method, we use the predicted value obtained from the regression of the equation in [10] as an instrumental variable for the variation of human capital. Table 2, in its first and second columns, shows the outcomes of this joint estimation for three samples. We present estimates for time and continent dummies because their estimated coefficients are significatively different from zero. Moreover, we have checked that the significance of the human capital coefficient does not depend on the presence of the dummies, and the estimated coefficients are similar. The value of β is always positive and significant. This result allows us to conclude that there exists a direct empirical relationship between human capital per worker and economic growth when the simultaneity is considered.

To facilitate the comparison of our results, Table 2 also reports the results obtained by Islam (1995). As expected, the estimation with instrumental variables gives us outcomes that are contrary to those given by Islam (1995). Below, we present a detailed discussion of the consequences that the omission of the simultaneity can generate in the estimation results.

To complete our study, we now ignore the simultaneity and we directly use the actual series of human capital instead of its predicted value.

TABLE 2
Estimation of the output per worker equation in the dynamic system

$$\frac{\tilde{y}_{t+\tau}-\tilde{y}_t}{\tau}=\beta\frac{\tilde{h}_{t+\tau}-\tilde{h}_t}{\tau}+\beta(n+g+\delta)\tilde{h}_t-(1-\alpha)(n+g+\delta)y_t+$$
$$+\alpha(n+g+\delta)\ln\left(\frac{s_k}{n+g+\delta}\right)+g(1-\beta)+(1-\alpha-\beta)(n+g+\delta)(\ln(A_0)+gt)+\varepsilon_{yt+\tau}$$

	With instrumental variable	With instrumental variable	Without instrumental variable	Without instrumental variable	Islam (1995)
			NONOIL		
Constant	29.0 (2.381)	35.0 (7.464)	8.0 (0.548)	9.0 (0.574)	
α	0.38 (0.155)	0.35 (0.021)	0.64 (0.012)	0.58 (0.020)	0.80 (0.053)
β	0.39 (0.067)	0.40 (0.034)	0.01 (0.012)	0.02 (0.013)	0.05 (0.102)
t.d./c.d.	yes/no	no/yes	yes/no	no/yes	no/no
λ_1 / λ_2	0.022/0.09	0.024/0.09			0.0069
N	432	432	432	432	480
			INTER		
Constant	38.0 (12.61)	32.0 (9.962)	8.3 (0.622)	9.2 (0.666)	
α	0.39 (0.058)	0.43 (0.054)	0.68 (0.014)	0.64 (0.021)	0.78 (0.006)
β	0.38 (0.029)	0.33 (0.030)	0.02 (0.001)	0.03 (0.012)	-0.007 (0.129)
t.d./c.d.	yes/no	no/yes	yes/no	no/yes	no/no
λ_1 / λ_2	0.022/0.09	0.024/0.09			0.0079
N	390	390	390	390	370
			OECD		
Constant	21 (25.26)		5.7 (0.798)		
α	0.49 (0.058)		0.70 (0.032)		0.60 (0.101)
β	0.21 (0.056)		-0.02 (0.012)		0.017 (0.180)
t.d./c.d.	yes/no		yes/no		no/no
λ_1 / λ_2	0.025/0.09				0.016
N	132		132	432	110

Notes: There are six observations for each country. Sample period for estimation is 1960-1990 The NONOIL sample has a total of 432 observations, the INTER sample has a total of 390 observations, and the OECD sample has a total of 132 observations.
t.d. indicates whether the estimation includes "time dummies"
c.d. indicates whether the estimation includes "continent dummies".
Standard errors are in parenthesis.

In other words, we also estimate equation [11] without using the instrumental variable for the variation of human capital. Table 2 shows the results in the third and fourth columns. We can observe that the estimated coefficient of human capital is not always significant. This outcome is similar in spirit to that found by Islam (1995) in his pooled regression.[7] However, if the reverse relationship between human capital and income exists, estimates without the instrumental variable are biased because simultaneity produces correlation between the perturbation $\varepsilon_{yt+\tau}$ and the endogenous human capital variable.

More precisely, correlation of the human capital variable with $\varepsilon_{yt+\tau}$ arises from several sources. One is the dependence of the variation of human capital on income, which is controlled by parameter γ. The estimation of the equation [10] confirms the existence of this positive correlation. Another source could be the existence of a positive correlation between the disturbances of the two equations, $\varepsilon_{ht+\tau}$ and $\varepsilon_{yt+\tau}$. Thus, we could presume that countries with larger human capital accumulation would tend to be those countries that also had larger output per worker growth in the second equation of the system. The use of the instrumental variable would solve the overestimation problem that these positive correlations could generate. However, our results show that the estimated value of human capital increases when the instrumental variable is used. This apparent contradiction can be explained as follows. One must note that, due to the particular feature of the human capital idea, the choice of its proxy can introduce a measurement error problem. This measurement error generates an underestimation of the coefficients. The use of the instrumental variable proposed to solve the simultaneity would also avoid this problem. Therefore, the difference between the magnitudes of the estimations with or without the instrumental variable indicates that this negative correlation arising from the measurement error is larger than those positive correlations.[8]

Finally, we investigate whether the inclusion of the simultaneity affects the process of convergence to the steady state. Although we have not developed a convergence analysis, we can still use our estima-

[7] The values of our estimated coefficients are different to those obtained by Islam (1995) because our specification is not the same that he estimates.

[8] Hall and Jones (1999) present a similar argumentation to motivate the use of instrumental variables to estimate the effect of a change in social infrastructure on the log of output per worker. They also obtain that the instrumental variable estimate is substantially larger than the OLS estimate.

tion results to approximate the speed of convergence of the economy. In MRW and Islam (1995), physical and human capital have the same investment technology with the same depreciation rate and, as a consequence, the dynamics of income are given by a unique dynamic equation. Therefore, their speed of convergence is given by the unique negative eigenvalue associated to this equation. However, the new interpretation of human capital accumulation gives up the assumption that physical and human capital investments are substitutes. For this reason, in our model the dynamic evolution of the economy is defined by a system composed of two dynamic equations. Moreover, the steady state is locally stable, i.e., the Jacobian matrix associated to the linearized system has two negative eigenvalues, denoted by λ_1 and λ_2, that determine the process of convergence. Hence, unlike MRW or Islam (1995), we do not have a direct measure of the speed of convergence. However, in order to compare the convergence predictions of our model with the ones obtained by Islam (1995), we can compute how much time the economy needs to reach one half of the distance from the departure point to the steady state. By using the estimated values of the negative eigenvalues given in Table 2, Appendix 2 develops the procedure for this computation. We get that the economy spends between 30 and 36 years, depending on the sample we use, in covering this distance. Therefore, we conclude that the speed of convergence in our model would be similar to the one estimated by MRW and Barro and Sala-i-Martin (1992).

4. Conclusion

This paper has analyzed the empirical relationship between human capital and economic growth across countries. In particular, we have probed the empirical evidence on the so-called level effect, through the simultaneous dependence between human capital and income.

The joint estimation of the dynamic equations that describe the behavior of human capital and output per worker provides evidence about the level effect of education on economic growth. Moreover, this estimation also allows us to conclude that the level of income has a positive and significant effect on the process of human capital accumulation. We consider that our results are superior to the previous ones based on a convergence equation expressing the growth rate of income as a function of human capital and other variables, because these analyses do not take into account the dependence of human capital on income.

Thus, we have also investigated what happens when this simultaneity is not considered. That is, we have only estimated the equation of output without the instrumental variable, and the result is that the level effect of education on economic growth seems not to be clear cut.

Finally, an extension of the paper could be to analyze how the introduction of the rate effect of human capital affects the results. Our conjecture is that the significance of the level effect will not change. Future research should confirm it.

Appendix A.1. The system of simultaneous equations for output and human capital

For the purposes of this Appendix, we will log-linearly approximate the behavior of the economy in a local neighborhood of the steady state. The steady-state values of the log-variables are:

$$\begin{aligned}\overline{\ln k} &= \frac{\beta}{1-\alpha-\beta}\ln\left(\frac{\gamma}{n+g+\eta}\right) \\ &+\frac{1-\beta}{1-\alpha-\beta}\ln\left(\frac{s_k}{n+g+\delta}\right), \qquad [A1.1]\end{aligned}$$

$$\begin{aligned}\overline{\ln h} &= \frac{1-\alpha}{1-\alpha-\beta}\ln\left(\frac{\gamma}{n+g+\eta}\right) \\ &+\frac{\alpha}{1-\alpha-\beta}\ln\left(\frac{s_k}{n+g+\delta}\right), \qquad [A1.2]\end{aligned}$$

$$\begin{aligned}\overline{\ln y} &= \frac{\beta}{1-\alpha-\beta}\ln\left(\frac{\gamma}{n+g+\eta}\right) \\ &+\frac{\alpha}{1-\alpha-\beta}\ln\left(\frac{s_k}{n+g+\delta}\right). \qquad [A1.3]\end{aligned}$$

With this log-transformation, dynamic system [4]/[5] is rewritten as

$$\dot{\overbrace{\ln k_t}} = s_k \exp\{(\alpha-1)\ln k_t + \beta \ln h_t\} - (n+g+\delta), \qquad [A1.4]$$

$$\dot{\overbrace{\ln h_t}} = \gamma \exp\{\alpha \ln k_t + (\beta-1)\ln h_t\} - (n+g+\delta), \qquad [A1.5]$$

We now linearize the previous system around the steady state [A1.1]-[A1.3]. In this way, we obtain

$$\begin{aligned}\dot{\overbrace{\ln k_t}} &= -(1-\alpha)(n+g+\delta)(\ln k_t - \overline{\ln k}) \\ &+\beta(n+g+\delta)(\ln h_t - \overline{\ln h}), \qquad [A1.6]\end{aligned}$$

$$\begin{aligned}\dot{\overbrace{\ln h_t}} &= \alpha(n+g+\delta)(\ln k_t - \overline{\ln k}\} \\ &-(1-\beta)(n+g+\delta)(\ln h_t - \overline{\ln h}), \qquad [A1.7]\end{aligned}$$

Moreover, knowing that $\ln \dot{y}_t = \alpha \ln \dot{k}_t + \beta \ln \dot{h}_t$, we obtain from [A1.6]/[A1.7] the equation [7]. At this point, we derive a system describing the simultaneous evolution of $\ln y_t$ and $\ln h_t$ by introducing $\alpha(\ln k_t - \overline{\ln k}) = (\ln y_t - \overline{\ln y}) - \beta(\ln h_t - \overline{\ln h})$ into [A1.7] and [7]. Hence, we obtain

$$\begin{aligned} \ln \overset{\bullet}{h}_t &= (n+g+\eta)(\ln y_t - \overline{\ln y}) - (n+g+\eta) \\ &\quad (\ln h_t - \overline{\ln h}), \qquad [A1.8] \\ \ln \overset{\bullet}{y}_t &= -[(1-\alpha)(n+g+\delta) - \beta(n+g+\eta)](\ln y_t - \overline{\ln y}) \\ &\quad +\beta(\delta-\eta)(\ln h_t - \overline{\ln h}). \qquad [A1.9] \end{aligned}$$

Using steady-state values from [A1.1]/[A1.2]/[A1.3], system [A1.8] can be rewritten as follows:

$$\ln \overset{\bullet}{h}_t = (n+g+\eta)(\ln y_t - \ln h_t) + (n+g+\eta)\ln\left(\frac{\gamma}{n+g+\eta}\right), \quad [A1.10]$$

$$\begin{aligned} \ln \overset{\bullet}{y}_t &= -[(1-\alpha)(n+g+\delta) - \beta(n+g+\eta)]\ln y_t + \beta(\delta-\eta)\ln h_t \\ &\quad +\alpha(n+g+\delta)\ln\left(\frac{s_k}{n+g+\delta}\right) \qquad [A1.11] \\ &\quad +\beta(n+g+\eta)\ln\left(\frac{\gamma}{n+g+\eta}\right). \end{aligned}$$

Finally, manipulating [A1.11] with [A1.10] we obtain system [8]/[9].

Appendix A2. Speed of convergence

In order to compute the speed of convergence as was defined in the main text, we first write the general solution of the dynamic system [A1.10]/[A1.11]:

$$\begin{aligned} \ln y_t - \overline{\ln y} &= c_1 e_{11}\exp\{\lambda_1 t\} + c_2 e_{21}\exp\{\lambda_2 t\}, \qquad [A2.1] \\ \ln h_t - \overline{\ln h} &= c_1 e_{12}\exp\{\lambda_1 t\} + c_2 e_{22}\exp\{\lambda_2 t\}, \qquad [A2.2] \end{aligned}$$

where c_1 and c_2 are arbitrary constants, λ_1 and λ_2 are the stable eigenvalues of the dynamic system, and e_{ij} is j component of eigenvector associated to eigenvalue λ_i. At this point, we assume for convenience that the speed of convergence is the same for all countries. Thus, we must consider that n is constant across both countries and years. Therefore, we first take the average value during the period 1960-90 for each country, and then we calculate the average among countries.

Given initial values q_0 and u_0, we compute from [A2.1]/[A.2.2] the constants c_1 and c_2 as follows

$$c_1 = \frac{e_{22}(\ln y_0 - \overline{\ln y}) - e_{21}(\ln h_0 - \overline{\ln h})}{e_{11}e_{22} - e_{12}e_{21}} \qquad [A2.3]$$

$$c_2 = \frac{e_{11}(\ln h_0 - \overline{\ln h}) - e_{12}(\ln y_0 - \overline{\ln y})}{e_{11}e_{22} - e_{12}e_{21}} \qquad [A2.4]$$

Thus, the speed of convergence in our model is given by two existing eigenvalues. In order to compare the convergence predictions, we must then compute the years that output takes to reach the halfway distance from its initial state to its steady-state value. Thus, denoting by H these years, we know that $\ln y_H - \overline{\ln y} = (\ln y_0 - \overline{\ln_y})/2$. Therefore, we implicitly obtain H from [A2.1]/[A2.2] as follows:

$$\frac{\ln y_0 - \overline{\ln y}}{2} = c_1 e_{11} \exp\{\lambda_1 H\} + c_2 e_{21} \exp\{\lambda_2 H\}. \qquad [A2.5]$$

Solving this equation [A2.5] we obtain the value of H. Note that we need to know the initial value of income in efficient units of labor, i.e., $\ln y_0$. However, the value of A_0 is empirically unknown, so that $\ln y_0$ cannot be computed. Therefore, in order to compute H we have to assume some initial point $\ln y_0$. In particular, we take half of the steady state value, i.e., $\ln y_0 = \overline{\ln y}/2$. Moreover, this steady state value is numerically computed using the results presented in Tables 1 and 2.

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Resumen

Este trabajo estudia cómo el capital humano afecta al crecimiento económico teniendo en cuenta que la renta determina a su vez la acumulación de capital humano. Para analizar esta simultaneidad, estimamos el sistema de ecuaciones dinámicas que describen el comportamiento de la economía. Con ello se obtienen tanto los parámetros de la función de producción como aquellos que caracterizan la acumulación de capital humano. La estimación conjunta del sistema dinámico revela evidencia a favor de la existencia del llamado efecto nivel de la educación en el crecimiento económico. El resultado cambia cuando no se considera la estimación conjunta.

Palabras clave: Crecimiento económico, acumulación de capital humano, relación de simultaneidad, evidencia empírica.

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