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TESTS OF THE "CONVERGENCE HYPOTHESIS" : Some further results

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1 This text updates two previous papers: "Test of the Convergence: a critical note" and "Economic growth and the Solow model: some further results", with new World Bank data on capital stocks that were kindly communicated by Vickram Nehru. I thank Esther Duflo for her brilliant research assistance and Guillaume Chalmin and Coralie Mugniot for their earlier work on the data set.

ABSTRACT

TESTS OF THE "CONVERGENCE HYPOTHESIS" :

Some further results

The paper offers new tests of the "convergence hypothesis". It first analyzes the pattern of growth of *measured* inputs (human and physical capital conventionally measured by an inventory method) and shows that these tests sustain the hypothesis. On the other hand, when one analyzes the pattern of growth of *revealed* inputs (physical capital and Solow residual), then one is led to reject the convergence theory. In order to understand what lies at the heart of this discrepancy, I will show that the poor countries failed to catch up to the rich countries not so much because they failed to raise their school enrollments (or the un-conditional convergence of the stock of measured inputs would not hold), but because the law of motion of human capital embodies a "stock of knowledge" which they failed to raise adequately.

RESUME

TESTS DE L'HYPOTHESE DE CONVERGENCE :

DE NOUVEAUX RESULTATS

Ce texte offre de nouveaux tests de l'hypothèse de convergence. Il analyse tout d'abord les sentiers de croissance étudiés par les facteurs de production (capital humain, capital physique) tels qu'ils sont mesurés par les flux. On montre qu'il y a bien "convergence" de ces facteurs de production. D'un autre côté, si on analyse les facteurs de production "révélés" par le résidu de Solow, alors l'hypothèse de convergence est refutée. J'étudie cette différence de résultat en montrant qu'il faut introduire un terme supplémentaire : le "savoir".

Key words: Growth, convergence, human capital, physical capital.
JEL: O4.

1. Introduction

The recent literature on convergence started from the observation by Romer(1986) that the growth rate of an economy appears to exhibit no correlation with the initial value of its per capita income. This was taken as evidence of two things : first, that inequalities across this world show no sign of narrowing down over the years at least on the average ; and second, that the Solow model fails on this count to predict the pattern of growth across the world. The second implication was thought to flow from the first but would soon be shown to be distinct.

Barro (1991) marshalled an impressive battery of regressions showing that a negative correlation between initial income and growth rate could be observed when this correlation was taken conditionally upon a set of variables, the most significant of which was the level of school enrollment. Barro first interpreted this partial correlation as an indication that poor countries could catch up with the rich ones, if only they were initially educated enough. However, that paper did not directly address the question of whether poor countries could indeed get appropriately educated over the years, or whether this was only a rich country's luxury (see Quah, 1993, for a similar critique). In order to investigate this issue, while drawing on Barro's findings, one needs to go beyond one-dimensional tests of the "convergence hypothesis" and analyze a two-dimensional set of differential equations in which physical and human capital would evolve simultaneously (rather than by only one differential equations as in Romer or Barro). Such is the goal of this paper.

We first offer two new tests of the unconditional "convergence hypothesis". In the first of them, we show that the pattern of growth of *measured* inputs (human and physical capital conventionally measured by an inventory method) sustains the "convergence" hypothesis (i.e. rich and poor countries's measured inputs appear to converge). On the other hand, when one analyzes the pattern of growth of *revealed* inputs (physical capital and Solow residual), then one is led to reject the convergence theory, and concur with Romer that poor countries do not catch up with the rich.

In order to understand what lies at the heart of this discrepancy, I get back to analyze the conditional analysis of the pattern of growth of income. As pointed out by Barro and X. Sala-i-Martin (1993) (BX) and Mankiw, Romer and Weil (1993) (MRW) one can re-interpret Barro's finding as evidence of a convergence of each country towards its own steady-state. Specifically, MRW interpret the school enrollment ratio, not as a proxy of the *stock* of human capital accumulated, but instead as a proxy for the *flow* of resources that a country would invest into human capital. In order to preserve the one-dimensional approach of Solow, however, MRW assume that physical and human capital share the same feature and are raised by an investment which amounts, in each case, to a fraction of GDP. But except for its analytical simplicity, there are no compelling reasons to make such an hypothesis. In general, the law of motion of human capital is not written to be proportional to output but to the initial value of human capital itself (as in Lucas and Uzawa), or to a stock of knowledge (an in Azariadis and Drazen). In such models, even with decreasing returns in the production of goods, the endogenous growth result might still be obtained if human capital can grow without bounds. Building upon the two-dimensional approach used in the un-conditional test, I will show that one can indeed reject MRW's formulation and favor an Azariadis-Drazen type of economy, in which human capital accumulation is proportional to an aggregate "knowledge" function that can be written $\Omega = K^{0.2}H^{0.8}$ (under one identifying restriction). I can then demonstrate that the poor countries failed to catch up to the rich countries not so much because they failed to raise their school enrollments (or the un-conditional convergence of the stock of measured inputs would not hold), but because the law of motion of human capital embodies such a stock of knowledge which they failed to raise adequately.

2. Unconditional convergence re-considered

In his abstract to his "cross section" paper, Barro summarized his key finding as follows: "the growth rate of real per capita GDP is positively related to inital human capital (proxied by 1960 school-enrollment rates) and negatively related to the inital (1960) level of real per capita GDP".

However, if one follows Barro and simply interprets the initial school enrollment as a proxy for the initial stock of human capital, the dynamics of the system remain unclear. Grappling with the later requires capturing the law of motion of the stock of human capital over the years. Let us adopt the view that the world is indeed a two-dimensional system in which human and physical capital are endogenously accumulated. Assume further that countries differ only because of different initial endowments. Testing the convergence hypothesis then amounts to testing whether the *unconditional* laws of motions of the two dimensional dynamics are converging. How should we empirically account for these dynamics? One can first measure unambiguously the capital stock that the economy has accumulated. As far as human capital is concerned, new measures of the number of years the working population has spent in school are now available[1]. We can thus first analyze the unconditonal pattern of growth of these two capital stock measures.

2.1 Convergence of measured inputs

Specifically, call h and k the log of human and physical capital per worker. We ran the following regressions:

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[1] The capital and human capital stock data that we shall use throughout this paper are World Bank estimates which are presented in Nehru and Dhareshwar (1993). They are roughly consistent with the data presented in Barro and Lee (1993). In this paper, we focus on secondary school attainments.

$$(1)\quad \begin{cases} \frac{d}{d_t} k_t = a + b\,k_0 + c\,h_0 \\ \\ \frac{d}{d_t} h_t = a' + b'k_0 + c'h_0 \end{cases}$$

in which the left-hand sides are the average growth rates over the years 1960-1985 of the stock of physical and human capital per worker, while the right-hand sides are the corresponding initial 1960 values. The system is then a stable one if and only if $b + c' < 0$ and $b\,c' - b'c > 0$

We get the following results (see sytem (A) in appendix for details):

$$(1')\quad \begin{cases} \frac{d}{d_t} k_t = 0.138 - \underset{(-4.5)}{0.0127}\, k_0 + \underset{(4.5)}{0.0145}\, h_0; \quad R^2=0.23 \\ \\ \frac{d}{d_t} h_t = -0.015 + \underset{(3.31)}{0.0037}\, k_0 - \underset{(-23.6)}{0.0228}\, z_0\ ; \quad R^2=0.89 \text{ (t.statistics)} \end{cases}$$

We then performed a Wald test and got a statistic which supports the hypothesis that the unconditional pattern of growth of human and physical capital are converging.

2.2 Convergence of revealed inputs

Rather than relying on observed inputs, one can follow another line of analysis. If we stick to the view that each economy is a two-dimensional system, we can indeed analyze the two-dimensional sytem (y,k) directly and test whether it is converging or exploding. More generally, any (non-trivial) two-dimensional linear combination of y and k will do. Let us follow MRW and assume that output can be written as:

(2) $Y_t = K_t^{\alpha} H_t^{\beta} (A_t L_t)^{\gamma}$ (with $\alpha + \beta + \gamma = 1$)

in which A is the world stock of knowledge, and H, K and L are respectively the domestic physical and human capital stocks and the labor force. MRW concluded their analysis with the result that $\alpha = \beta = 1/3$. As a (non-essential, at this stage) identifying restriction, let us indeed assume that $\alpha = 1/3$, which amounts to postulating that private and social returns to capital are identical. Whatever the value of β might be, we can then define human capital (in Log of per-worker terms) up to a multiplicative constant. More specifically, let by small letters denote the log of the per-capita block letters variables. We can thus define:

(3) $z_t = 3\, y_t - k_t$ [i.e $y_t = \frac{1}{3}(k_t + z_t)$]

so that z_t and h_t are linearly correlated as follows :

(3') $z_t = \zeta\, h_t + b_t$; where $\zeta = 3\,\beta$ and $b_t = 3\,\gamma\, a_t$.

Given y and k, z is computable, while ζ is an unknown parameter (which, for instance, is worth 1 in MRW's analysis), and b_t is a term which is identical for all countries (and which we consequently neglect in the sequel). We shall sometimes refer to z as a "revealed human capital". In practice, this is just a re-interpreted Solow residual. Now we want to try to determine whether the dynamics of the system (k,z) are converging that we now investigate. (As indicated earlier, this is formally identical to an analysis of the (y,k) system.)

We then estimate the following two-dimensional system :

$$(4)\quad \begin{cases} \dfrac{d}{d_t} k_t = a + b\, k_0 + c\, z_0 \\[2ex] \dfrac{d}{d_t} z_t = a' + b' k_0 + c' z_0 \end{cases}$$

in which, as before, the left-hand sides are the average growth rates over the years 1960-1985, while the right-hand sides are initial 1960 values.

One gets the following results (see system (B) in appendix for details):

$$(4') \quad \begin{cases} \frac{d}{d_t} k_t = \underset{}{0.012} - \underset{(-5.9)}{0.0185} k_0 + \underset{(7.13)}{0.0118} z_0; \quad R^2=0.43 \\ \\ \frac{d}{d_t} z_t = -0.013 + \underset{(2.1)}{0.0128} k_0 - \underset{(-1.4)}{0.00512} z_0; \quad R^2=0.08 \end{cases}$$

Period of estimation: 1960-1985; Sur estimator (White-heteroskedasticity-consistent t statistics in parenthesis).

The sum b + c' is negative, while the determinant of the system, $\Delta = -0.6\ 10^{-4}$, is negative so that the (point-estimate of the) system is actually unstable. We performed a Wald test to see whether the determinant actually was significantly different from zero. Our Wald statistic is 1.57, which leads us to conclude that the system is not exploding. We can then concur that the analysis of the joint laws of motion of the "revealed" stocks of human and physical capital sustains Romer's conclusion about the lack of un-conditional convergence.

3. Conditional convergence re-considered

3.1 The Solow model re-considered

An alternative interpretation of Barro's finding concerning over the conditional convergence result is to interpret the school enrollment variable, not as a proxy for *initial* human capital, but rather as a proxy for the idiosyncratic determinants of the *steady-state* to which the economy might be converging. This view is best exposed in MRW, who claim that the data lend support to the idea that the economies are driven by an augmented Solow model, in which human and physical capital are each endogenously accumulated (but in a country specific way). Let us briefly review their analysis. Assume that production is given by equation (2) above and the write the law of motion of H_t and K_t as :

(5-a) $\dot{K}_t = -dK_t + I_t$

(5-b) $\dot{H}_t = -dH_t + J_t$

in which J_t is the total investment in human capital at time t. In conformity with MRW, we shall assume in the remainder of the paper that the same rate of depreciation holds for physical and human capital. Extending the Solow model to a 2-dimensional framework, MRW also postulate:

(6) $I_t = s_1 Q_t$

(7) $J_t = s_2 Q_t$.

in which s_1 and s_2 are two saving rates taken to be exogenous to the other parameter (but which can vary readily over time). Empirically, s_1 is simply the observed investment rate, while s_2 is (essentially) proxied by the secondary school enrollment ratio .

Let n be the rate of growth of workers and μ the rate of growth of technical progress. We can then log-linearize the law of motion of income per-capita as:

(8) $\frac{d}{dt} y_t = \dot{a}_t + (1-\alpha-\beta)\ (d + n + \mu)\ [\hat{y}_t - y_t]$

in which $\hat{y}$ is:

(9) $\hat{y}_t = (1-\alpha-\beta)\ a_t + \frac{\alpha}{1-\alpha-\beta} \text{ Log } s_1 + \frac{\beta}{1-\alpha-\beta} \text{ Log } s_2$

In MRW's interpretation, (8) is interpreted as the law of convergence of an economy to its steady-state. This would indeed be the case if s_1 and s_2 were to remain constant over the years. One need not make such an assumption, however, in order to derive (8). Indeed equation (8) is simply obtained by differentiating the production function around its *initial* value so that (8) an (9) offer nothing else but a compact form of (2) and (5). Controlling directly or indirectly for $\hat{y}_t$ and estimating equation (8) gives a "universal" coefficient for y_t which is $(1-\alpha-\beta)(d+n+\mu)$ (neglecting, as we shall do throughout the paper, differences of that coefficient over various countries). But this coefficient says little about the actual dynamics of the economy since those can be obtained only by determining know how $s_1 = \frac{I_t}{Q_t}$ and $s_2 = \frac{J_t}{Q_t}$ are actually set. Most importantly, one needs to know how s_1 and s_2 come to depend upon the income of the country. If rich countries can afford to invest more and more as they get richer, then the actual dynamics will be quite different from what a naive interpretation of (8) would imply.

Although apparently innocuous, the law of motion postulated for human capital has strong implications. In particular, by making the law of motion of human and physical capital collinear and proportional to output, MRW impose an equivalence between the fact that $\alpha + \beta < 1$ and the fact that each economy's growth rate is asymptotically set by exogenous technical progress, as in the Solow model. (to the extent that saving rates are- by definition- bounded by one from above). In alternative formulations (such as in Lucas and Uzawa or in Azairadis-Drazen), one can very well have decreasing returns to the production of output and yet maintain the endogenous growth result of unbounded growth, *if* the human capital accumulation can itself grow without bounds. The question that I now want to address is whether the MRW results leave room (empirically) for such alternative formulations.

In order to explore this problem, let us now depart from MRW's formulation and assume instead that the law of motion of human capital must be written as :

(10) $J_t = f(s_2)\ \Omega_t$

in which f(.) is a concave function of the number of hours during which the agents get trained and Ω_t is a stock of "knowledge" on which the training of agents rests (see, e.g., Azariadis and Drazen (1990) or Rosen (1976) for similar formulations). MRW's can be interpreted as the special case where $f(s_2) = s_2$ and $\Omega_t = Q_t$. At the other extreme, the more standard definition (measured as the cumulative stock of years spent at school as in Barro and Lee) simply corresponds to the case where $f(s_2) = s_2$ and $\Omega = H$.

When Ω_t and Q_t are not proportional (and why should they be ?), one can*not* aggregate equations (4) and (5) into a one-dimensional equation such as (8). In order to analyze this new system, let us postulate the following functional forms :

(11) $f(s_2) = s_2^{\varepsilon}$

and $\Omega_t = B \,.\, K_t^{\lambda} H_t^{\nu}(A_t L_t)^{1-\lambda-\nu}$

Call $\omega_t = \text{Log}\, \Omega_t/L_t$. One can then log-linearize (4) and (5) as :

$$(9)\begin{cases} \frac{d}{dt} k_t = \dot{a}_t + (d+n+\mu)\,[\text{Log}\, s_1 + \beta h_t - (1-\alpha)\, k_t] & \text{(9-a)} \\ \frac{d}{dt} h_t = \dot{a}_t + b + (d+n+\mu)\,[\varepsilon\, \text{Log}\, s_2 - (1-\nu)h_t + \lambda k_t] & \text{(9-b)} \end{cases}$$

The determinant of the system is:
$\Delta = (\alpha - \nu)^2 + 4\,\beta\lambda$

and the two eigenvalues are:

$$\gamma = -\frac{[(1-\nu)+(1-\alpha) \pm \sqrt{\Delta}\,]}{2}$$

The system (9) is converging towards a steady-state if and only if the two eigenvalues are negative, i.e, if and only if $\nu < 1 - \frac{\beta\,\lambda}{1-\alpha}$.

In the particular case which is examined by MRW (α=λ, β=ν), the two eigenvalues are $-(d+n+\mu)\,(1-\alpha-\beta)$ and $-(d+n+\mu)$, respectively ; and the corresponding eigenvectors are (1,1) and ($-\beta$,α). In that case, the law of motion of income per-capita is governed only by the first eigenvalue and is the solution to the corresponding one-dimensional differential equation. By contrast, the general case does not yield a one cannot get a one-dimensional differential equation that governs the law of motion of income per-capita (and there is no such thing as *one* speed of convergence). In the (k,z) system one can re-write (9) as:

$$(10)\quad \frac{d}{dt} k_t = C_1 + \theta \ \text{Log}\ s_1 - \theta\ (2/3)\ k_t + \theta\ (1/3)\ z_t$$

$$(11)\quad \frac{d}{dt} z_t = C_2 + \varepsilon\zeta\ \theta\ \ \text{Log}\ s_2 + \theta\ \ \zeta\lambda k_t - \theta\ (1-\nu)\ z_t$$

in which θ=d+n+μ. One immediately sees from (11) how one can recover the value of ν (the weight of human capital in the production of knowledge) from the value of θ.

2.2 Empirical estimates

When we estimate the system (10) and (11) with the same data set as used for equation (3'), we get the following results (see system (C) in appendix for details):

$$(12)\ dk = \ 0.132 + \underset{(13.0)}{0.050\ \text{linv}} - \underset{(-15.5)}{0.0320\ k_0} + \underset{(16.6)}{0.0170\ z_0}\ ;\ R^2 = 0.83$$

$$(13)\ dz = 0.0609 + \underset{(4.25)}{0.0136\ \text{lenr2}} + \underset{(1.69)}{0.00868\ k_0} - \underset{(-2.92)}{0.0091\ z_0}\ ;\ R^2 = 0.32$$

Period of estimation: 1960-85. Sur estimator and White heteroscedastic-consistent t- statistics in parentheses.

We can first analyze the conditional convergence of the system just as we investigated the un-conditional convergence. Our findings show find that the determinant of the system is significantly positive (with a Wald test of 4.33). This dimonstrates that the two eigenvalues are negative and that the conditional sytem is converging. To the extent that linv and lenr2 are the logarithms of two rates which are bounded from above by 100%, we must concur that the economies are converging to a steady-state which depends only upon their propensities to save (no matter what identifying assumptions are made to compute the parameters of the system).

Let us now turn to identifying the model's parameters. The first equation is an over-identified quasi-identity which leads us to reconstruct $\theta = 0.05$. (None of the coefficients of k_0 and z_0 in equation (12) are significantly different from their supposed values, namely $-2/3\ \theta$ and $1/3\ \theta$; because of the discrete-time approximation, however, they do not exactly fit their theoretical value.)

The second equation leads us to reconstruct

$\nu = 0.82$

as the weight of human capital in the production of knowledge. Among the identifying assumptions needed to calculate the other parameters, one can impose, constant returns to scale to the production of output (an assumption which is most often made in two-sector models of endogeneous growth ; e.g., Mulligan and Sala-i-Martin (1991) and the survey by Romer (1989)). In this case we get $\lambda = 0.18$, $\beta = 0.32$ and $\varepsilon = 0.28$. One can then summarize the technology of production through:

$$Q_t = K_t^{0.33} H_t^{0.32} L_t^{0.35}$$

which is essentially identical to MRW, while knowledge would be written:

$$\Omega_t = K_t^{0.2} H_t^{0.8}$$

4. Conditional and un-conditional convergence reconciled

We can now attempt to reconcile the results obtained so far. Let us first compare the lack of unconditional convergence in the (k,z) space to the corresponding conditional convergence result obtained above. There are at least two potential interpretations for this discrepancy. One is that the two saving rates are proxies for idiosyncrasies that the un-conditional test fails to take into account. A second interpretation is that the saving rates are themselves functions of the state of development of the country, so that the rich countries can endogenously manage to save more, which is why the poor contries do not catch up with them[2]. Clearly, if the second interpretation were valid, this would cast doubt on the whole econometric exercises conducted in BX and MRW, as well as in the present contribution. To see more specifically which way the evidence go, we have first run the following decomposition:

$$\text{Log } s_1 = a_1 + b_1 k_0 + c_1 z_0 + \eta_1$$

$$\text{Log } s_2 = a_2 + b_2 k_0 + c_2 z_0 + \eta_2$$

If one takes the view that the lack of unconditonal convergence is due to the unconditional test's failure to account for each country's idiosyncrasies, then one should find that conditioning the laws of motion of the economy by η_1 and η_2 would get the convergence result. By performing these regressions, we obtain:

$$\text{(14-a)}\quad dk = \underset{}{0.011} + \underset{(13.0)}{0.050\,\eta_1} - \underset{(-11.1)}{0.0185\,k_0} + \underset{(13.3)}{0.0118\,z_0}\;;\; R^2 = 0.83$$

$$\text{(14-b)}\quad dz = -\,0.0122 + \underset{(4.25)}{0.0136\,\eta_2} + \underset{(2.50)}{0.00128\,k_0} - \underset{(-1.74)}{0.0051\,z_0}\;;\; R^2 = 0.32$$

A Wald test performed over this system shows that this new conditional analysis does *not* uphold the convergence result. This lends support to the view that the rich countries' endogenous capability to save more explains why the poor countries did not catch up with them. The lack of un-conditional convergence is directly due to that basic fact, rather than a failure to account for idiosyncrasies.

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2 One can think at least to a third interpretation: the "representative" country model is not valid, and one should specify different laws of motion for rich and poor countries.

Let us now turn to interpreting the discrepancy between the unconditional convergence of the set of measured inputs and the lack of unconditional convergence over the set of revealed inputs, a discrepancy which would not be interpretable within the framework of a naive augmented Solow model. What the results obtained in section 3 suggest is the fact that human capital is inappropriately measured when the embodiment of knowledge is not taken into account. Our model suggests that the true saving rate which is relevant to analyze the law of motion of human capital is (in log term):

$$\text{Log } s_2' = \varepsilon \log s_2 + \omega$$

We have then run a new test of conditional convergence, where capital accumulation is conditioned over η_1 as above, while effective human capital z is conditioned over $v_2 = \varepsilon\ \eta_2 + \omega_0$. The results are shown as system (E) in the appendix. Now they do show conditional convergence. This confirms the idea that poor countries are behind not so much because they fail to raise their standard of education, but rather because they fail to raise them enough to compensate for their initial *knowledge* disadvantage.

4. One-dimensional analysis revisited

Let us now return to analyzing the law of motion of income per-capita. One can still pre-multiply (9-a) and (9-b) by α and β respectively, and write :

$$(15)\ \frac{d}{dt} y_t = C + (d+n+\mu)\ [\alpha \text{ Log } s_1 + \beta\ \varepsilon \text{ Log } s_2]$$
$$- (d+n+\mu)\ (1-\alpha-\beta\ \theta_2)\ y_t + \beta\ \theta_1(y_t-k_t)$$

in which $\theta_1 = \frac{\nu\alpha}{\beta} - \lambda$ and $\theta_2 = \lambda + \nu\ \frac{(1-\alpha)}{\beta}$. In the case when $\theta_1 \geq 0$ (which is what we shall obtain empirically below), a country with the same initial income and the same saving rates as a second one will grow *less rapidly* if its initial capital-output ratio is bigger. When $\lambda < \nu\ \frac{\alpha}{\beta}$, a lower productivity of capital implies (*ceteris paribus*) that the country is endowed with a lesser knowledge, hence that it yields a lower growth.

If we initially ignore $(y_t - k_t)$, we get the following result (see appendix for details):

$$(16)\ g = 0.13 + \underset{(2.79)}{0.0194}\ \text{linv} + \underset{(5.68)}{0.0113}\ \text{lenr2} - \underset{(-4.38)}{0.0134}\ y_t \quad : R^2 = 0.44$$

When we run the same regression and add the capital-output ratio as an explanatory variable, we obtain :

$$(17)\ g = 0.175 + \underset{(6.76)}{0.038}\ \text{linv} + \underset{(5.59)}{0.0113}\ \text{lenr2} - \underset{(-3.78)}{0.0130}\ y_t + \underset{(4.10)}{0.0150}\ (y_t - k_t) \quad ; R^2 = 0.54.$$

On the basis of equation (17), we concur that the capital-output ratio, is a significant explanatory variable and add about 10% to the variance explained. An F-test unambiguously leads us to prefer (17) to (16). Furthermore, to the extent that the coefficient of $(y_t - k_t)$ is significantly positive, we can also concur that the weight by which physical capital enters into the production of knowledge is "relatively" lower than its weight in the production of goods ($\lambda < \nu \frac{\alpha}{\beta}$). Using the same identifying assumptions as in section 3, we find a coefficient $\nu = 0.69$, which is essentially identical to the value found in the two-dimensional approach.

5. Conclusion

We have argued in this paper that the lack of unconditional convergence was not due to the failure of the poor countries to build up their stock of physical and human capital (at least when these stocks are naively measured by adding up flows of investment or education).

Instead, we have argued that rich countries stay out of the poor countries' reach by virtue of their combined ability to educate themselves as they grow rich *and* their endogenous ability to accumulate the knowledge upon which these efforts are made. If one nevertheless takes into account the fact that there are limits to the (calendar) time one can spend educating oneself, then our results tend to indicate that the knowledge differential between rich and poor has to narrow down over the years. According to these results, the poor nations, then still have a chance to catch up.

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Current sample:  1 to 72
eq1 DKW=AA+AC*K60W+AD*H60
eq2 DH=BA+BC*K60W+BD*H60
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SEEMINGLY UNRELATED REGRESSION
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Parameter	Estimate	Standard Error	t-statistic
AA	.137506	.024915	5.51907
AC	-.012714	.280341E-02	-4.53519
AD	.012657	.284209E-02	4.45358
BA	.014500	.988969E-02	1.46619
BC	.368345E-02	.111075E-02	3.31619
BD	-.022781	.966207E-03	-23.5777

Standard Errors computed from heteroscedastic-consistent matrix (Robust-White)

Equation EQ1
****

Dependent variable: DKW

Mean of dependent variable	= .034266	Std. error of regression	= .02092
Std. dev. of dependent var.	= .024081	R-squared	= .23441
Sum of squared residuals	= .031522	Durbin-Watson statistic	= 1.9543
Variance of residuals	= .437801E-03		

Equation EQ2
****

Dependent variable: DH

Mean of dependent variable	= .024356
Std. dev. of dependent var.	= .021406
Sum of squared residuals	= .365336E-02
Variance of residuals	= .507411E-04
Std. error of regression	= .712328E-02
R-squared	= .887707
Durbin-Watson statistic	= 2.01157

Parameter	Estimate	Standard Error	t-statistic
delta	.243013E-03	.598537E-04	4.06012

WALD TEST FOR THE HYPOTHESIS THAT THE PARAMETERS OF THE GIVEN SET ARE JOINTLY ZERO :

CHI-SQUARED = 16.484595 WITH 1 DEGREES OF FREEDOM.
P-VALUE = 0.00000000

SYSTEM A : EQUATION (1')

```
Current sample:  1 to 72
  eq1 DKW=AA+AC*K60W+AD*Z60W;
  eq2 DZW=BA+BC*K60W+BD*z60W;
```

Parameter	Estimate	Standard Error	t-statistic
AA	.011602	.018093	.641247
AC	-.018547	.314627E-02	-5.89483
AD	.011757	.164937E-02	7.12833
BA	-.012234	.032406	-.377514
BC	.012821	.611836E-02	2.09557
BD	-.511918E-02	.358126E-02	-1.42943

Standard Errors computed from heteroscedastic-consistent matrix (Robust-White)

```
                    Equation    EQ1
                    ***************
```

Dependent variable: DKW

```
 Mean of dependent variable = .034266      Std. error of regression = .017994
Std. dev. of dependent var. = .024081                     R-squared = .433778
   Sum of squared residuals = .023313      Durbin-Watson statistic = 1.64518
      Variance of residuals = .323792E-03
```

```
                    Equation    EQ2
                    ***************
```

Dependent variable: DZW

```
 Mean of dependent variable = .021395      Std. error of regression = .034941
Std. dev. of dependent var. = .036720                     R-squared = .081808
   Sum of squared residuals = .087902      Durbin-Watson statistic = 2.19524
      Variance of residuals = .122086E-02
```

Parameter	Estimate	Standard Error	t-statistic
delta	-.558007E-04	.445029E-04	-1.25386

WALD TEST FOR THE HYPOTHESIS THAT THE PARAMETERS OF THE GIVEN SET ARE JOINTLY ZERO :

```
CHI-SQUARED =   1.5721772     WITH    1 DEGREES OF FREEDOM.
P-VALUE     =  0.20989120
```

SYSTEM B : EQUATION (4')

```
Current sample:  1 to 72
 eq1 DKW=AA+AB*linv+AC*K60W+AD*Z60W
 eq2 DZW=BA+BB* lnsec+BC*K60W+BD*z60W
```

SEEMINGLY UNRELATED REGRESSION
****

Parameter	Estimate	Standard Error	t-statistic
AA	.131816	.011822	11.1503
AB	.050309	.386347E-02	13.0216
AC	-.032027	.206226E-02	-15.5298
AD	.017024	.102607E-02	16.5914
BA	.060911	.031081	1.95978
BB	.013582	.319342E-02	4.25309
BC	.867808E-02	.514498E-02	1.68671
BD	-.915049E-02	.312797E-02	-2.92538

Standard Errors computed from heteroscedastic-consistent matrix (Robust-White)

Equation EQ1
****

Dependent variable: DKW

```
  Mean of dependent variable = .034266       Std. error of regression = .010091
Std. dev. of dependent var. = .024081                       R-squared = .826801
   Sum of squared residuals = .733222E-02    Durbin-Watson statistic = 2.36105
      Variance of residuals = .101836E-03
```

Equation EQ2
****

Dependent variable: DZW

```
  Mean of dependent variable = .021395       Std. error of regression = .030575
Std. dev. of dependent var. = .036720                       R-squared = .320290
   Sum of squared residuals = .067307        Durbin-Watson statistic = 2.23447
      Variance of residuals = .934819E-03
```

Parameter	Estimate	Standard Error	t-statistic
delta	.145323E-03	.697919E-04	2.08224

WALD TEST FOR THE HYPOTHESIS THAT THE PARAMETERS OF THE GIVEN SET ARE JOINTLY ZERO :

```
CHI-SQUARED =   4.3357102     WITH    1 DEGREES OF FREEDOM.
P-VALUE     =  0.37320708E-01
```

SYSTEM C : EQUATIONS (12) AND (13)

```
Current sample:  1 to 72
eq1 DKW=AA+AB*reslinv+AC*K60W+AD*Z60W;
eq2 DZW=BA+BB*reslnsec+BC*K60W+BD*Z60W;
```

SEEMINGLY UNRELATED REGRESSION
****

Parameter	Estimate	Standard Error	t-statistic
AA	.011602	.817881E-02	1.41853
AB	.050309	.386347E-02	13.0216
AC	-.018547	.167756E-02	-11.0558
AD	.011757	.882573E-03	13.3215
BA	-.012234	.027894	-.438576
BB	.013582	.319342E-02	4.25309
BC	.012821	.514573E-02	2.49167
BD	-.511918E-02	.293430E-02	-1.74460

Standard Errors computed from heteroscedastic-consistent matrix (Robust-White)

Equation EQ1
****

Dependent variable: DKW

```
 Mean of dependent variable = .034266        Std. error of regression = .010091
Std. dev. of dependent var. = .024081                       R-squared = .826801
   Sum of squared residuals = .733222E-02     Durbin-Watson statistic = 2.36105
      Variance of residuals = .101836E-03
```

Equation EQ2
****

Dependent variable: DZW

```
 Mean of dependent variable = .021395        Std. error of regression = .030575
Std. dev. of dependent var. = .036720                       R-squared = .320290
   Sum of squared residuals = .067307         Durbin-Watson statistic = 2.23447
      Variance of residuals = .934819E-03
```

Parameter	Estimate	Standard Error	t-statistic
delta	-.558007E-04	.356392E-04	-1.56571

WALD TEST FOR THE HYPOTHESIS THAT THE PARAMETERS OF THE GIVEN SET ARE JOINTLY ZERO :

```
CHI-SQUARED =   2.4514464     WITH    1 DEGREES OF FREEDOM.
P-VALUE     =  0.11741662
```

SYSTEM D : EQUATIONS (14)

```
Current sample:  1 to 72
 V2=.2*K60w+.8*Z60w+reslnsec
 eq1 DKw=AA+AB*reslinv+AC*K60w+AD*Z60w
 eq2 DZw=BA+BB*V2+BC*K60w+BD*Z60w
```

SEEMINGLY UNRELATED REGRESSION
****

Parameter	Estimate	Standard Error	t-statistic
AA	.011602	.817881E-02	1.41853
AB	.050309	.386347E-02	13.0216
AC	-.018547	.167756E-02	-11.0558
AD	.011757	.882573E-03	13.3215
BA	-.012234	.027894	-.438576
BB	.013582	.319342E-02	4.25309
BC	.010105	.512437E-02	1.97196
BD	-.015985	.398494E-02	-4.01129

Standard Errors computed from heteroscedastic-consistent matrix (Robust-White)

Equation EQ1
****

Dependent variable: DKW

Mean of dependent variable =	.034266	Std. error of regression =	.010091
Std. dev. of dependent var. =	.024081	R-squared =	.826801
Sum of squared residuals =	.733222E-02	Durbin-Watson statistic =	2.36105
Variance of residuals =	.101836E-03		

Equation EQ2
****

Dependent variable: DZW

Mean of dependent variable =	.021395	Std. error of regression =	.030575
Std. dev. of dependent var. =	.036720	R-squared =	.320290
Sum of squared residuals =	.067307	Durbin-Watson statistic =	2.23447
Variance of residuals =	.934819E-03		

Parameter	Estimate	Standard Error	t-statistic
delta	.177657E-03	.683729E-04	2.59835

WALD TEST FOR THE HYPOTHESIS THAT THE PARAMETERS OF THE GIVEN SET ARE JOINTLY ZERO :

CHI-SQUARED = 6.7514198 WITH 1 DEGREES OF FREEDOM.
P-VALUE = 0.93673773E-02

SYSTEM E

LS // Dependent Variable is GW
Date: 29/07/94 / Time: 19:00
SMPL range: 1 - 138
SMPL condition: BRAZIL=0
Observations excluded because of missing data
Number of observations: 80
Heteroskedasticity-Consistent Covariance Matrix

VARIABLE	COEFFICIENT	STD. ERROR	T-STAT.	2-TAIL SIG.
C	0.1298997	0.0269818	4.8143485	0.000
LINV	0.0194173	0.0069541	2.7922027	0.007
LNSEC	0.0113200	0.0019913	5.6846333	0.000
Y60W	-0.0124085	0.0028293	-4.3856858	0.000

R-squared	0.442962	Mean of dependent	0.017536
Adjusted R-squared	0.420974	S.D. of dependent	0.020163
S.E. of regression	0.015343	Sum of squared resid	0.017891
Durbin-Watson stat	2.884718	F-statistic	20.14531
Log likelihood	222.7054		

EQUATION 16

LS // Dependent Variable is GW
Date: 14/07/94 / Time: 13:47
SMPL range: 1 - 138
SMPL condition: BRAZIL=0
Observations excluded because of missing data
Number of observations: 80
Heteroskedasticity-Consistent Covariance Matrix

VARIABLE	COEFFICIENT	STD. ERROR	T-STAT.	2-TAIL SIG.
C	0.1751367	0.0269242	6.5048075	0.000
LINV	0.0377162	0.0055776	6.7620436	0.000
LNSEC	0.0113221	0.0020252	5.5907292	0.000
Y60W	-0.0130841	0.0034586	-3.7830190	0.000
KY60W	-0.0149762	0.0036547	-4.0978124	0.000

R-squared	0.543683	Mean of dependent	0.017536
Adjusted R-squared	0.519346	S.D. of dependent	0.020163
S.E. of regression	0.013979	Sum of squared resid	0.014656
Durbin-Watson stat	2.841332	F-statistic	22.33986
Log likelihood	230.6832		

EQUATION 17