A REASSESSMENT OF THE PROXIMATE DETERMINANTS OF INCOME LEVELS AND GROWTH OF NATIONS

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Abstract

This paper provides further evidence of the inconsistency of the Solow growth model with the observed cross-country variation in income levels and growth rates. We relax the assumption made by Mankiw, Romer, Weil (1992) of identical technical progress rates across countries by estimating country-specific rates of technological progress using growth accounting. We document the varied technological progress rates across countries and show that the testable predictions of the Solow model are often not fulfilled with the model performing better when testing the out of steady-state dynamics than when assessing the determinants of the steady-state income levels. Similar results are obtained when considering different data sources, other country samples and time periods. Our findings suggest that the usual investigations of the proximate determinants of income levels and growth across countries should be supplemented by a thorough analysis of the fundamentals.

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1. INTRODUCTION

In their seminal paper, Mankiw, Romer and Weil (1992) (henceforth MRW) suggested a simple framework to test the predictions of the Solow (1956) growth model and thus its consistency with the observed variation of cross sectional levels and growth rates of income. MRW showed that the textbook model (physical capital and labor being the only production factors) accounted for more than half of the cross-country variation of the steady-state GDP per working-age population in 1985 for two of the three samples tested (nonoil with 98 countries, intermediate with 76 countries and OECD with 22 countries). The only drawback of their test was a larger than expected share of physical capital in income. This finding led them to consider a variant of the Solow model in which human capital enters the production function as an additional production factor. Doing so, the explanatory power of the model rose to about 80% and the shares of physical and human capital in income were of the expected magnitudes (about one third apiece). The authors also addressed the issue of out of steady-state dynamics and convergence and found that the observed cross-country growth over the period 1960-1985 lends support to the conditional convergence hypothesis at an average convergence speed of about two percent per annum. Overall, MRW conclude that differences in population growth, savings and educational attainment explain most of the international variation of income per capita and growth rates. Furthermore, they affirmed that the model “gives the right answers to the questions it is designed to address”.

Variations of the MRW framework have been widely used by researchers to assess the impact of many policy measures on the level and growth of output and recommend some policies to promote growth. Examples include, among many others, Kumar and Pacheco (2012), and Dunne and Nikolaidou (2012). Bayraktar-Saglam and Yetkiner (2014) provide an excellent recent overview of the literature pertaining to the determinants of growth and speed of convergence of nations.

In their analysis MRW make two crucial assumptions. First, despite acknowledging that countries may differ in their initial technology level, resource endowments and institutions, they chose to relegate these differences to a constant and the error term of their regressions. This is very likely to create an omitted variable bias for the regressions results (Islam, 1995). Additionally, it is plausible that the error term containing country-specific elements is correlated with the explanatory variables (population growth, savings and education). Second, they assume that all countries share the same rate of technological advancement and thus identical growth rates in steady-state. More specifically, they assume it to be 0.02 per annum which is roughly the long-run growth rate of the GDP per capita of the United States. The above assumptions deem the results of MRW biased or at best questionable.

The MRW settings and assumptions, especially regarding the common technology, have been criticized and reexamined by many subsequent papers. The vast majority addressed only the initial level of technology through the use of panel data techniques (Knight et al., 1993; Loayza, 1994; Islam, 1995; and Caselli et al., 1996 among others). The only papers we are aware of that addressed both problems are those of Lee et al. (1997) and Felipe and McCombie (2005). The former introduces a stochastic Solow model that allows for country-specific level and growth of A as well as of the speed of convergence for a panel of 102 countries over the period 1960-1989. The latter attribute their exceptionally high explanatory power when the model is applied for the OECD countries to its resemblance of the income accounting identity.[1]

We contribute to the extensive critique of the Solow growth model and its ability to explain the observed cross-country variations in income and growth rates by relaxing the assumption of strict parametric homogeneity maintained by MRW by assigning country-specific growth rates of technology, *A*, applying the growth accounting methodology (Solow, 1957 and Hall and Jones, 1999). Our analysis can be extended to deal with the implied assumption of equal initial technology levels by using panel data techniques; however, we chose to examine the implications of relaxing only the assumption of identical TFP growth while maintaining the other assumption of identical initial levels of technology.

Although it has been extensively criticized, the growth accounting approach is widely used by bureaus of statistics and central banks all over the world to obtain measures of total factor productivity. Thus, such estimates constitute fairly reliable measures of the growth of *A*.

Our departure point is the construction of series of physical capital stock using the perpetual inventory method. As in Bernanke and Gürkaynak (2001), the growth of *A* is then obtained as the residual after accounting for the weighted contributions of physical capital, labor and human capital. In our calculations of the growth of *A* we employ two alternative assumptions regarding the returns to a year of schooling (7% and 12%) which is our measure of human capital.

By allowing for parameter heterogeneity across countries, we correct for one of the deficiencies of the MRW settings that came under attack by subsequent works. We test the predictions of the Solow growth model for both the steady-state level of the GDP per worker

[1] Notice that while MRW's fit for OECD countries was very low, the specification of Felipe and McCombie (2005) with country-specific level and growth of technology produced a very high fit.

and its transitory growth rates using both the original MRW dataset as well as more recent ones. Furthermore, several specifications of country samples and time periods are considered.

The remainder of the paper is organized as follows. Section 2 introduces the MRW framework for testing the Solow model and surveys the previous empirical evidence. A description of the data used is provided in section 3. Our results are presented in section 4. Section 5 wraps up with a summary and some policy implications.

2. THE MRW FRAMEWORK

The Solow growth model (1956) departs from a standard Cobb-Douglas production function with constant returns to scale:

$$Y_t = K_t^{\alpha}(A_t L_t)^{1-\alpha}\,; \quad 0 < \alpha < 1 \tag{1}$$

where Y is output, K physical capital stock, L labor, A level of technology, and α and ($1\text{-}\alpha$) are the output elasticities with respect to capital and labor, respectively. Labor and technology are assumed to grow exogenously at the rates n and g, respectively. Moreover, it is assumed that a constant fraction of Y, s, is saved and invested in accumulation of physical capital. Combining the production function and the evolution of the capital stock, it is easy to show that the steady-state of income per capita is given by:

$$y^* = A_t \left(\frac{s}{n+g+\delta}\right)^{\frac{\alpha}{1-\alpha}} \tag{2}$$

where δ is the depreciation rate. Acknowledging that $A_0 = A_t e^{gt}$, we can substitute for A and take logs to obtain:

$$\ln(y) = \ln(A_0) + gt + \frac{\alpha}{1-\alpha}\ln(s) - \frac{\alpha}{1-\alpha}\ln(n + g + \delta) \tag{3}$$

MRW assume that the term A_0 reflects not just technology, but resource endowments, climate, and institutions therefore it is expected to differ across countries. Thus, they assumed that $\ln(A_0) = a + \varepsilon$ where a is a constant and ε is a country-specific shock which is independent of s and n. Moreover, they postulated that g and δ are fixed across countries and their sum equals roughly 0.05. Under these assumptions, MRW's specification for cross-country data is given by:

$$\ln(y) = a + \frac{\alpha}{1-\alpha}\ln(s) - \frac{\alpha}{1-\alpha}\ln(n + 0.05) + \varepsilon \quad (4)$$

Equation (4) specifies both the signs and the magnitudes of the coefficients of *s* and *n* and it is used by MRW to explain the variation of *y* across countries and, thus, the consistency of the Solow model with the observed variation. In addition, an identifying restriction of the model emerges; the coefficients of *s* and *n* are equal in their absolute value.

When human capital is introduced into the production function, equation (1) becomes:

$$Y_t = K_t^{\alpha} H_t^{\beta} (A_t L_t)^{1-\alpha-\beta}\ ;\ 0 < \alpha, \beta < 1 \quad (5)$$

where *H* is the stock of human capital, and β is the elasticity of output with respect to *H*. MRW maintain the assumption of decreasing returns to all capital (i.e. $\alpha + \beta < 1$**).** Assuming that the evolution of human capital is similar to that of physical capital and that fixed shares of income, s_k and s_h, are invested in physical capital and human capital, respectively, MRW express the equation that describes the factors determining the GDP per capita in steady-state for the augmented Solow model:

$$\ln(y) = a + \frac{\alpha}{1-\alpha-\beta}\ln(s_k) + \frac{\beta}{1-\alpha-\beta}\ln(s_h) - \frac{\alpha+\beta}{1-\alpha-\beta}\ln(n + 0.05) + \varepsilon \quad (6)$$

Like the textbook model, equation (6) predicts the signs and magnitude of the coefficients, in addition to the identifying restriction that the sum of the coefficients equals zero. Assuming that countries are in their steady-state, the equation can be used to test how different rates of investments in physical and human capital and rates of growth of the labor force can explain the variation of income levels across countries.

MRW provide another test of the Solow model. They examine the predictions of the model out of steady-state. The model predicts conditional convergence, i.e. convergence among countries after controlling for the determinants of steady-state. By approximating around the steady-state, the growth of per capita income for the augmented model can be expressed as:[2]

$$\frac{d\ln(y_t)}{dt} = \lambda[\ln(y^*) - \ln(y_t)] \quad (7)$$

where $\lambda = (n + g + \delta)(1 - \alpha - \beta)$ is the speed of convergence. By substituting for y^* we get the equation describing the out of steady-state growth determinants:

$$\ln(y_t) - \ln(y_0) = (1 - e^{-\lambda t})[\ln(A_0) + gt] + (1 - e^{-\lambda t})\frac{\alpha}{1-\alpha-\beta}\ln(s_k) + (1 - e^{-\lambda t})\frac{\beta}{1-\alpha-\beta}\ln(s_h) - (1 - e^{-\lambda t})\frac{\alpha+\beta}{1-\alpha-\beta}\ln(n + g + \delta) - (1 - e^{-\lambda t})\ln(y_0) \quad (8)$$

Once again, the initial level of A, A_0, is dropped and dumped into a constant and an error term and g is assumed to be fixed at 0.02:

$$\ln(y_t) - \ln(y_0) = a + (1 - e^{-\lambda t})\frac{\alpha}{1-\alpha-\beta}\ln(s_k) + (1 - e^{-\lambda t})\frac{\beta}{1-\alpha-\beta}\ln(s_h) - (1 - e^{-\lambda t})\frac{\alpha+\beta}{1-\alpha-\beta}\ln(n + 0.05) - (1 - e^{-\lambda t})\ln(y_0) + \varepsilon \quad (9)$$

The coefficient on the initial income per capita, y_0, is the key factor in determining whether the underlying cross-section data exhibit conditional convergence or not. A significant negative coefficient implies conditional convergence at the average rate of λ.

MRW work has been replicated, further augmented, and criticized by a number of subsequent papers. Some papers addressed the assumption of a common initial technology using panel data techniques. Knight et al. (1993) assumed that the technology level is affected by the extent of openness to international trade and by the level of government fixed investment.[3] When applying the Π matrix procedure, they found evidence of country-specific

[2] The textbook version is rather a similar expression with the due changes.

[3] Dinopoulos and Thompson (1999) adopt a similar approach by taking the level of technology as a function of human capital.

effects and of faster rates of convergence compared to those estimated by MRW. They attributed the higher convergence rates to the mistreatment of the correlation between the country-specific effects and the independent variables. Similar results were obtained by Loayza (1994) and Islam (1995) with the latter reporting lower than expected share of capital in income.

In addition to the mistreatment of the country-specific effects that represent differences in technology, Caselli et al. (1996) address the endogenous nature of the regression independent variables. To correct for the two shortcomings they suggest a dynamic panel data GMM estimator. Their estimation results in a convergence at the speed of 10% that far exceeds the widely accepted convergence at the speed of 2%.

Some researchers have chosen to further augment the Solow growth model and thus add relevant variables that were left not accounted for by MRW. Knowles and Owen (1995) augmented the MRW setting with health capital proxied by life expectancy and uncovered a stronger and more robust relationship between growth and health capital than between growth and educational human capital. Nonneman and Vanhoudt (1996) augmented with the accumulation of technological know-how proxied by expenditures on research and development. Augmenting with R&D results in a very high fit of the OECD sample. However, when testing for convergence, they detected an insignificant effect of human capital. Park and Prat (1996) advance further by considering the spillover effects of R&D. They succeed to explain a large fraction of the variation of income per capita of the OECD sample.

Bernanke and Gürkaynak (2001) suggest that MRW's specification is "broadly consistent with any growth model that admits a balanced growth path – a category that includes virtually all the growth models in the literature" and its good fit cannot be attributed to Solow's formulation. Furthermore, they find that using recent data and longer period of investigation results in rejection of the parameter restrictions proposed by MRW.

Another strand of the literature focuses on the econometric issues related to the MRW settings. Temple (1998) applies some robustness tests, mainly least trimmed squares and uses dummy variables for Africa, Latin America, East Asia and industrialized countries to account for the individual country effects. He finds that MRW results stand fairly well with the exception of the OECD sample (including the R&D augmented model). Conversely, he casts doubt on the reliability of the convergence speed suggested by MRW.

Two studies that addressed both the level and growth heterogeneity of A are those of Lee et al. (1997) and Felipe and McCombie (2005). Lee et al. (1997) question the deterministic Solow growth model and the notion of convergence and offer an empirical version of a stochastic Solow model. Focusing on the growth dynamics of the Solow model rather than on the level of output per capita in steady-state, they strongly reject the hypothesis of a common technology growth across countries. The authors find that when relaxing the assumption of homogeneity in the level and growth of A, the average convergence speed rises from about 2% to around 30%. Nonetheless, Lee et al. (1997) call for extra caution when interpreting convergence and affirm that their convergence measures are informative only about the within country output movements.

Felipe and McCombie (2005) employ measures of the initial and growth rates of productivity that are based on the dual of the production function for OECD members. Using data on the average growth rates of wage and profit rates they obtained measures of the country-specific initial and growth rates of the technical progress and included them in the MRW-type regressions. Their estimation yielded a very high fit of the OECD sample that they attribute to the fact that the MRW specification resembles the income accounting identity that relates output to the sum of total wages and profits. Thus, they explain why "the coefficients in the estimated equation must take a given value and sign, irrespective of whether the neoclassical assumptions hold" and why "if Solow's augmented growth model were specified correctly it would yield a very high statistical fit, potentially with an R^2 equal to unity".

3. DATA

The data for the replication of MRW's results are extracted from their paper. Their main source is version 4.0 of Penn World Tables (PWT). We follow their way and obtain our data mainly from the online PWT version 6.1 of Heston, Summers and Aten (2002). This version provides purchasing power parity and national income accounts converted to international prices for 168 countries for some or all of the years 1950-2000. All monetary values are expressed in international Dollars at 1996 prices. The raw data includes PPP-adjusted series of GDP per capita, GDP per worker, investments/GDP ratio, and population. These series serve us to compute series of GDP, investments and labor force. Unlike the original MRW data that used working-age population, we opt to use labor force that is easily calculated from PWT 6.1.

Data on the rate of human capital accumulation, namely the average percentage of working age population enrolled in secondary school (the school variable in MRW setting) is taken from the data set of Bernanke and Gürkaynak (2001) and supplemented by data from the online databases of World Development Indicators and the United Nations' World Population Prospects.

We follow many others in confining human capital to schooling attainment weighted by the relative earnings. More specifically, our measure of human capital is:

$$H_t = \sum_{i=1}^{7} W_{it} P_{it} \qquad (10)$$

where P_{it} represents the share of the working age population that completed the level of education *i* (no schooling, attended/completed primary, secondary or higher education). The shares are obtained from an online update of Barro and Lee (2001) school attainment dataset. W_{it} is the weight for the relative earnings of the schooling group *i* (100 for the group with no schooling) that is based on Bernanke and Gürkaynak (2001) and Psacharopoulos (1994).

Labor shares are obtained from Bernanke and Gürkaynak (2001) according to the availability of the following measures; first, taking into account actual labor earnings of unincorporated enterprises so the labor share is calculated as the ratio of corporate employee compensation to GDP net of indirect taxes and private surplus of private unincorporated enterprises (OSPUE). Second, using imputed rather than actual measures of OSPUE and using the same formula as in the first measure. Third, assuming that corporate and non-corporate workers receive the same compensation on average, the labor share is calculated as the ratio of corporate labor compensation to the product of the share of corporate workers in labor force, and GDP net of indirect taxes. Fourth, a naïve labor share that is defined as the ratio of corporate employee compensation to GDP net of indirect taxes. Finally, the conventional share of 0.65 would be used for countries having none of the above country-specific labor shares.

The classification of countries to nonoil, inter and OECD follows the original MRW data. Countries that were not included in the original sample are disregarded.

4. MRW SPECIFICATION WITH COUNTRY-SPECIFIC TECHNOLOGY

To allow for country-specific growth of technology we resort to the growth accounting methodology due to Solow (1957) and Hall and Jones (1999). The latter focused on the levels of productivity rather than the growth rates while the former addressed both. In order to perform the exercises, data on output, labor force, physical capital stock, and human capital is needed. We use the perpetual inventory method in which the capital stock is expressed as accumulation of past investments net of depreciation:

$$K_t = K_{t-1}(1-\delta) + I_t \qquad (11)$$

The initial capital stock is estimated based on Harberger (1978):[4]

$$K_0 = \frac{I_1}{g_Y + \delta}; \quad g_Y = \frac{\Delta Y}{Y} \tag{12}$$

where unlike many researchers who take a simple arithmetic growth of output, we estimate g_Y utilizing all the observations available: $\ln(Y_t) = a_0 + \hat{g}_Y t + \varepsilon$. Doing so, we avoid relying on few observations that are prone to the volatility of business cycles. Since the effect of errors in K_0 fades as time passes, our capital stock series starts in 1950 while our used observations cover the period 1960-2000.

Following Hall and Jones (1999) we adopt a human capital augmented Cobb-Douglass production function:

$$Y_t = A_t K_t^{\alpha} (L_t H_t)^{1-\propto-\beta} \tag{13}$$

With data on *Y*, *K*, *L*, *H* and the share of labor in income we calculate the growth of TFP of each country in our sample as the residual in the traditional growth accounting methodology:

$$\frac{\Delta A}{A} = \frac{\Delta y}{y} - \propto \frac{\Delta k}{k} - (1 - \propto) \frac{\Delta H}{H} \tag{14}$$

Since the share of capital in income, α, plays a crucial role in the estimates of productivity levels and growth we use shares that are based on the national accounts. A brief description of the measures of α is presented in section 3. All the growth rates in equation (14) are calculated as the time coefficient of a regression of the log of the respective variable on an intercept and time. This is very crucial to avoid relying on only two observations (initial and last periods) as it is the case of geometric growth rates.

A quick glance at our estimates of productivity growth as they stem from Table 1 and Figures 1 and 2 emphasizes the inappropriateness of a fixed *g*. Table 1 summarizes the mean growth rates of TFP for several samples over two periods, 1960-85 and 1960-2000 and shows that the average growth rate of TFP is much lower than the presumed rate of 0.02 used by

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[4] There are other methods for estimating the initial capital stock. However, this method has been the most popular among researchers.

MRW and many others. The hypothesis of *g=0.02* is rejected for all samples and periods. A further support for our view is provided in figures 1 and 2. The figures depict the estimates of TFP under two assumptions regarding human capital. The first is zero return to schooling which is equivalent to no human capital in the production function. The second alternative is 7% return for a year of schooling. We attempted a 12% return of schooling as well but we don't present the results to conserve space. According to the figures, not only that the estimates of most the countries are below 0.02 but most significantly, they vary greatly across countries.[5] The estimates of the OECD sample are the closest to MRW's figure and when the members of OECD are excluded from the other samples our estimates of TFP growth drop far below the 0.02 mark.

Our specifications for the steady-state income per worker that incorporates heterogeneous growth of *A* for the textbook and the augmented models, respectively, are:

$$\ln(y) = c_0 + \frac{\alpha}{1-\alpha}\ln(s_k) - \frac{\alpha}{1-\alpha}\ln(n+g+0.03) + \varepsilon \qquad (15)$$

$$\ln(y) = c_0 + \frac{\alpha}{1-\alpha-\beta}\ln(s_k) + \frac{\beta}{1-\alpha-\beta}\ln(s_h) - \frac{\alpha+\beta}{1-\alpha-\beta}\ln(n+g+0.03) + \varepsilon \qquad (16)$$

In addition, our specifications for the out of steady-state growth are:

$$\ln(y_t) - \ln(y_0) = c_0 + \left(1-e^{-\lambda t}\right)\frac{\alpha}{1-\alpha}\ln(s_k) - \left(1-e^{-\lambda t}\right)\frac{\alpha}{1-\alpha}\ln(n+g+0.03) - \left(1-e^{-\lambda t}\right)\ln(y_0) + \varepsilon \qquad (17)$$

$$\ln(y_t) - \ln(y_0) = c_0 + \left(1-e^{-\lambda t}\right)\frac{\alpha}{1-\alpha-\beta}\ln(s_k) + \left(1-e^{-\lambda t}\right)\frac{\beta}{1-\alpha-\beta}\ln(s_h) - \left(1-e^{-\lambda t}\right)\frac{\alpha+\beta}{1-\alpha-\beta}\ln(n+g+0.03) - \left(1-e^{-\lambda t}\right)\ln(y_0) + \varepsilon \qquad (18)$$

[5] The higher the schooling return, the lower the estimates of TFP growth.

The results of the estimation of these equations are exposed in the following sub sections.

4.1 Steady-state regressions estimates

Assuming that all countries in our samples are in their steady-states, we show our estimation results for the original MRW sample spanning 1960-85, PWT 6.1 data for the same period and for 1960-2000 in tables 2-3, 4-5, and 6-7, respectively.

The replication of MRW's results for the textbook Solow growth model under their assumptions of homogenous technologies is presented in columns 1-3 of Table 2. We succeed in exact replication of their results for the three samples. Table 2 depicts the estimation results of equation (15); when TFP is calculated without human capital as a production factor (columns 4-6) we observe that the coefficients of $n+g$ are highly insignificant and even with the opposite sign for the nonoil sample. Furthermore, contrary to the predictions of the model and to the original MRW regressions reported in columns 1-3, the sum of the coefficients of s_k and $n+g$ is different from zero, except for the OECD sample. Moreover, the explanatory power of our regressions is lower than those of MRW. Our results are kept intact when considering a 7% return to every schooling year (columns 7-9 of Table 2).

When estimating the augmented model (Table 3), the results obtained are relatively more in harmony with those of MRW; the coefficients of physical and human investment are significant and of the expected sign. However, the restriction imposed by the model is rejected in the cases of nonoil and inter samples. Unlike the textbook model, the coefficient of $n+g$ for the inter sample is negative and statistically significant. Once again, assuming a 7% schooling return does not alter our results. Our estimates of the shares of α and β deem irrelevant since the restriction imposed by the model was rejected in most cases.

To test for the robustness of our findings, we also obtained estimates for MRW sample period, 1960-1985, using PWT, 6.1. The estimation results are reported in Table 4 for the textbook model and in Table 5 for the augmented version. Columns 1-3 of both tables present the results under MRW specification, i.e. *g*=0.02. When compared to the original MRW results presented in columns 1-3 of Tables 2 and 3 the following remarks emerge; first, the coefficients of n is negative but insignificant in all samples of the textbook model, and becomes significant for the non-oil and inter samples when the model is augmented. Second, the explanatory power of the textbook model is much lower (0.41 compared with 0.59 and 0.29 against 0.59 for the nonoil and inter samples, respectively). However, the fit of the model is comparable to the original one for the augmented case. Interestingly, the OECD sample exhibits an adjusted R^2 of 0.41 compared to 0.24 in the regression that is based on MRW data. Third, we couldn't reject the restriction of the coefficients' sum equaling zero. Fourth, our implied value of the share of capital falls close to expectations in the textbook version (0.30 and 0.25 for nonoil and inter, respectively). This finding contrasts MRW's who obtained estimates of the magnitude of 0.60.

When considering the augmented model, however, our implied share of physical capital drops drastically to 0.05-0.07 and the implied share of human capital soars to 0.42-0.47. Thus, despite the good fit of the model, the results do not meet MRW’s expectations.

The same tests are carried out for the period 1960-1985 under our assumptions of country-specific technical change. The tests are shown in columns 4-9 of Tables 4 and 5. The picture that emerges from our regressions differs from what we just outlined. Looking at the textbook setting, the coefficient of $n+g$ is significant but has the opposite sign, the over-identifying restriction is rejected, and the explanatory power is higher. It seems that the results are highly fragile; they depend on the specification of the regression and the sample and augmenting (Table 5) does not result in major changes.

To further assess the robustness of the model and see whether our findings hold for the most updated data, we consider the period 1960-2000. Our dependent variable is the log of the GDP per worker in 2000, assuming that countries are in their steady-state. Tables 6 and 7 present our estimation results under the assumption of g=0.02 as well as our country-specific measures of TFP. Our main findings are summarized as follows. First, when considering the assumption of homogenous technical change (columns 1-3 of both tables) the signs of the coefficients are according to our expectations, however, the restriction is rejected in the largest sample (nonoil) for both the textbook and augmented models. Second, when assuming heterogeneous technical change (columns 4-9 of Tables 6 and 7) the signs of $n+g$ take the opposite sign or become insignificant. Moreover, the parameter restriction is rejected in most cases. This result is in tandem with the findings reported by Bernanke and Gürkaynak (2001) who maintained the assumption of identical g across countries. Third, in general, the models have comparable high explanatory power to the original MRW regressions.

Overall, our results cast heavy doubts on the consistency of the Solow model with the observed income levels across countries. When performing some sensitivity analysis checks, the model fails to stand modifications such as the choice of data source, sample, time period or assumptions regarding the rate of technical progress. Table 8 summarizes our various robustness tests and clearly shows that deviating from the original setup of MRW (their original sample coupled with their assumption of identical technical progress across countries) leads to failing to meet all the empirical predictions of the Solow model. In fact, in none of the attempted specifications we succeed to obtain all of the four predictions. Thus, sticking to the Solow model that takes into account only the proximate determinants of income across countries is insufficient and researchers should dig deep into the fundamental determinants of income in order to provide some suitable policy suggestions for countries trying to catch up with the rest of the world.

4.2 Tests of out of steady-state dynamics

The other application of the MRW setting is testing for convergence among countries. Focusing on the dynamics around the steady-state is less stringent than assuming steady-state at a certain time. Table 9 reports the results of tests of absolute convergence carried out on MRW original data as well as on PWT 6.1 for the periods 1960-1985 and 1960-2000. Predictably, the absolute convergence is rejected for the large samples but not for the homogenous sample of the OECD countries. Thus, we conclude that countries do not converge to a single steady-state but rather to their own steady-states.

We proceed by examining the conditional convergence hypothesis for a variety of samples, data sources and measures of TFP growth. First, we replicate MRW results for the textbook and the augmented models (columns 1-3 of Tables 10 and 11). They find that the coefficients of the model take the expected signs; however, the coefficients of $n+g$ are insignificant for the textbook model, and turn to be marginally significant when augmenting with human capital. Once again, the fit of the model is the highest for the OECD sample. In addition, the speed of convergence rises as the sample becomes more homogenous. Their convergence rates range from 0.6% to 1.7% for the textbook model and from 1.4 to 2% for the augmented model with the highest rate corresponding to the OECD sample.

Our next step is assessing the robustness of MRW's findings under different alternatives of g and time periods. When using the original data of MRW but with country-specific rates of technical change (columns 4-9 of Tables 10 and 11) we find remarkable similarities between our results and the results that are based on g=0.02. The coefficients for both the textbook and the augmented models take the "right" signs with the exception of the coefficients of $n+g$ that are mostly insignificant. In addition, the fit of the models and the implied speed of convergence are slightly lower than those of MRW. Thus, considering alternative measures of g other than the presumed 0.02 do not seem to alter the results of MRW drastically when sticking to the original data.

Testing the model over the period, 1960-1985, using the updated PWT 6.1 dataset leads to entirely different outcomes. Our estimation is reported in Tables 12 and 13. Maintaining the assumption of identical *g* across countries (columns 1-3 of both tables), we find that the fit of the models is extremely low for the nonoil and inter samples when the textbook model is estimated (0.05 and 0.04, respectively). The explanatory power rises (0.34 and 0.22, respectively) when augmenting; however, it is outstandingly lower than the original MRW values. With respect to the signs of coefficients and speed of convergence, the augmented model yields similar results to those obtained using MRW original data. Unlike the large samples of countries, the OECD sample performs especially well; its fit exceeds 0.80, all the coefficients are significant and of the expected signs, and the speed convergence ranges from 2.2% in the textbook model to 2.8% in the augmented model.

Assigning country-specific measures of TFP drawn from our growth accounting exercise alters our findings considerably. First, the fit of the models increases compared with the case in which *g* is identical across countries, indicating that *g* is a relevant variable that ought to be incorporated in the model specification rather than assuming it to be fixed. Second, surprisingly, the sign of $g+n$, including for the OECD sample, is positive and significant which contrasts the predictions of the model. Third, the speed of convergence is lower than in the case of g=0.02 but higher than the ones obtained when using the original data set of MRW. The augmented model features convergence rates of 1.2%, 1.2%, and 2.8% for the nonoil, inter and OECD samples respectively.

Another dimension of sensitivity analysis that we explore is a different period. Tables 14 and 15 present the results of the estimation of the convergence tests over the period 1960-2000. We focus on the augmented model (Table 15), being the one more likely to resemble the observed variation in economic growth across economies. Under the assumption of g=0.02 the model seems to yield relatively good fit (0.57, 0.54, and 0.81 for nonoil, inter, and

OECD, respectively), and significant coefficients of the right sign. Furthermore, the implied speed of convergence is high and compares to the originally reported rates by MRW. However, as we consider heterogeneous technical progress (columns 4-9 of table 15) our results change considerably. Now, the coefficients of $n+g$ are positive, but mostly insignificant, the fit of the models is modest (around 0.45 for the large samples), and the speed of convergence is lower than when g=0.02. Interestingly, the OECD sample remains the one that performs relatively well under the different settings.

Table 16 summarizes our findings of the speed of convergence under the various specifications that we considered. We clearly notice that the conditional convergence hypothesis is verified in most of the cases and that the speed of convergence varies across specifications and samples. However, we find that the speed of convergence is relatively low. This finding can be possibly attributed to the misspecified determinants of income that we highlighted earlier. Adding fundamentals to the growth regressions is needed to supplement the analysis of the proximate determinants of income.

To sum up, testing the predictions of the Solow model out of the steady-state under different settings of samples, time periods, and assumptions regarding the rate of technical progress seems to yield fairly better results than when assessing the determinants of GDP per worker in steady-state. This outcome can be attributed to the fact that the assumption of all countries at their respective steady-states in 1985 or 2000 is a strict one that has little or no support.

5. SUMMARY, CONCLUSIONS, AND POLICY IMPLICATIONS

In this paper we reexamine the seminal work of Mankiw, Romer, and Weil (1992) along several dimensions. First, we challenge their assumption of homogenous rate of technical change. We propose country-specific measures of the growth of productivity that are based on the widely used growth accounting methodology. Series of physical capital stock are constructed for a large sample of countries using the perpetual inventory method. Furthermore, we adopt measures of human capital that incorporate returns to schooling. Our estimates of TFP differ greatly across countries and are found to be significantly lower than the 2% that was assumed by MRW to be fixed across countries. Second, we use a more recent version of PWT over the same time period, 1960-1985. A third dimension of sensitivity analysis is investigating the period 1960-2000 rather than the original period.

We find it hard to come up with clear conclusions regarding the consistency of the Solow growth model with the observed levels and growth rates of output across countries. Often, the estimated coefficients of the variables of the steady-state regressions are inconsistent with the predicted ones. Most importantly, the over-identifying restriction is rejected in the majority of the cases. When performing some sensitivity analysis checks the model fails to stand modifications such as the choice of data source, sample, time period or assumptions regarding the rate of technical progress.

When testing the predictions of the Solow model out of the steady-state under different settings of samples, time periods, and assumptions regarding the rate of technical progress, our estimation seems to yield fairly better results than when assessing the determinants of GDP per worker in steady-state. This outcome can be attributed to the fact that the assumption of all countries at their respective steady-states be it 1985 or 2000 is a strict one that has little or no solid support.

Overall, we question the robustness of the Solow growth model and its ability to explain the cross-country variations in income levels and growth rates when one takes into account the varied levels of technical progress across economies and/or when considering different samples and time periods.

Our findings cast heavy doubts on the relevance of Solow growth model-based policy recommendations. Hundreds of articles have advocated the use of the neoclassical framework to assess the impact of a multitude of variables and policy measures on economic growth and consequently come up with some policy suggestions to promote growth and close the observed gaps between economies. Based on our findings, these recommendations have to be taken with a grain of salt and caution should be exercised. We suggest digging deep into the fundamental determinants of income and growth rates of nations. Prior to asking what is the impact of a certain policy on income and growth, one should adequately specify his model in order to firstly account for the fundamentals and then engage in the effects of specific policies on income levels and growth rates.

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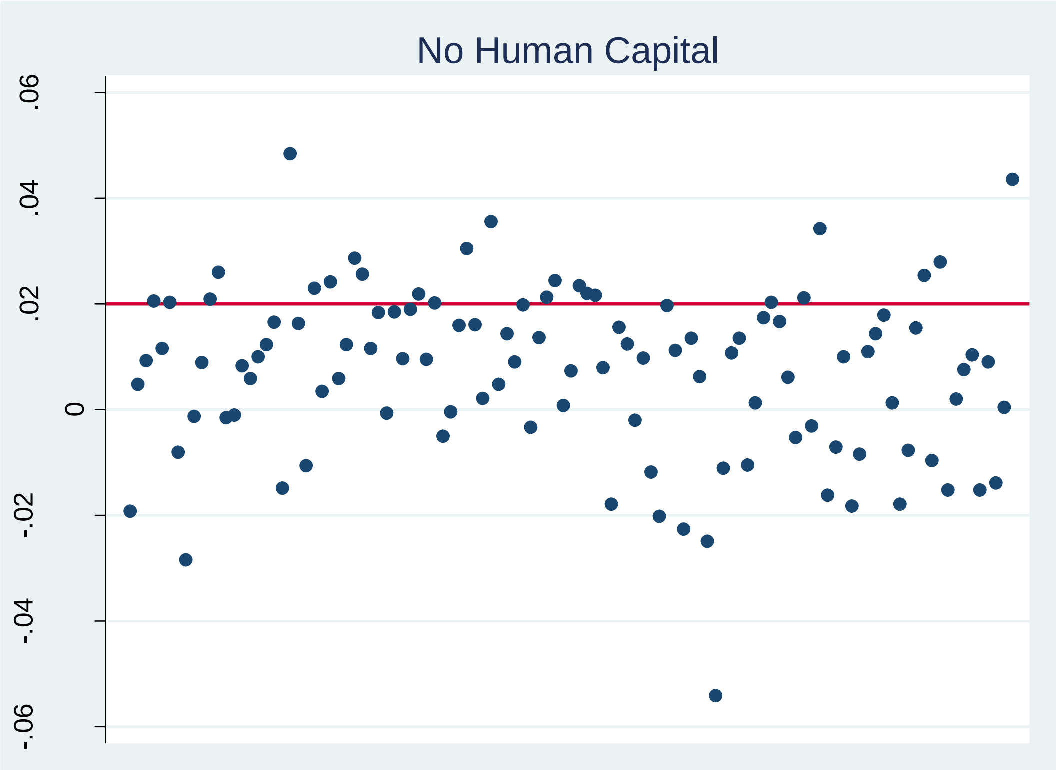

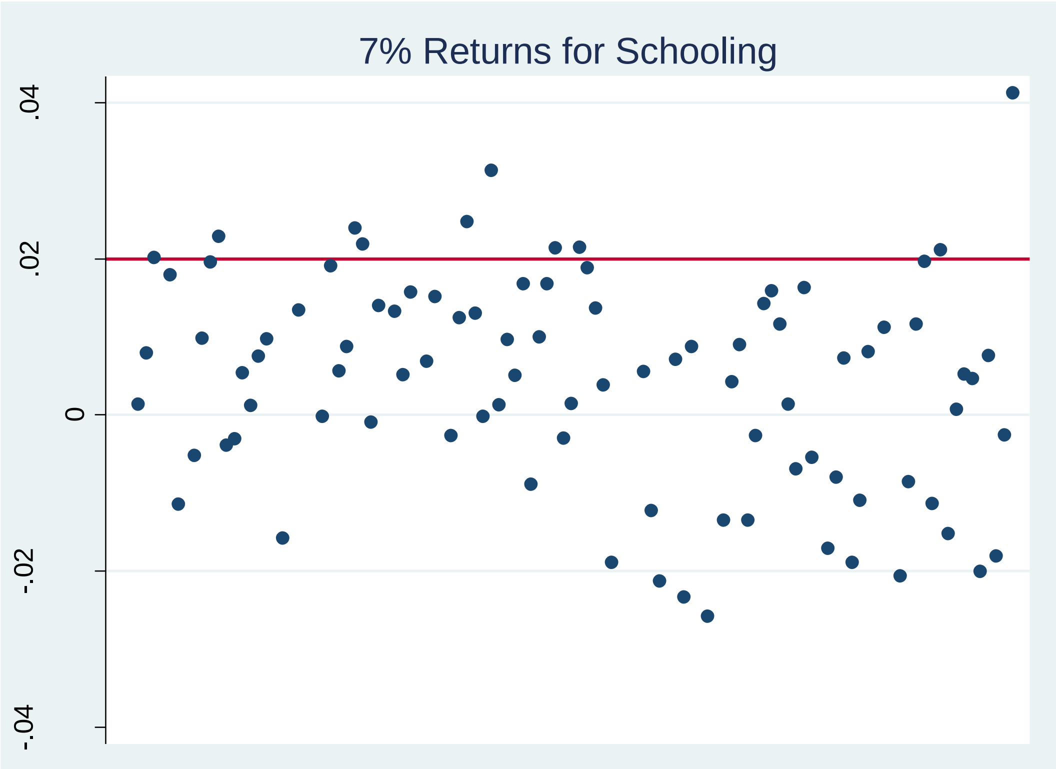

Figure 1 – Average TFP growth, 1960-85

Figure 2 – Average TFP Growth, 1960-2000

Table 1 – Mean TFP Growth Rates (%)

Sample	All countries		Nonoil		Inter		OECD
		excluding OECD		excluding OECD		excluding OECD	
1960-85							
No human capital	0.71	0.55	0.64	0.41	0.89	0.69	1.38
	(0.15)	(0.18)	(0.17)	(0.21)	(0.17)	(0.23)	(0.20)
7% return	0.42	0.24	0.39	0.17	0.68	0.51	1.05
to schooling	(0.14)	(0.17)	(0.15)	(0.19)	(0.15)	(0.20)	(0.20)
1960-2000							
No human capital	0.49	0.34	0.38	0.15	0.65	0.44	1.15
	(0.13)	(0.15)	(0.14)	(0.17)	(0.13)	(0.17)	(0.16)
7% return	0.24	0.08	0.19	-0.02	0.40	0.22	0.80
to schooling	(0.13)	(0.16)	(0.14)	(0.17)	(0.12)	(0.16)	(0.15)

Notes:
Figures in parentheses are the standard errors.
The hypothesis g=0.02 is rejected for all samples at the 1% significance level.

Table 2 – The Textbook Solow Growth Model, 1960-85, MRW Data

	1	2	3	4	5	6	7	8	9
	Dependent variable: log GDP per worker in 1985								
	g=0.02			**g=tfp; no return for education**			**g=tfp; 7% return for education**		
Sample	**Non-oil**	**Inter**	**OECD**	**Non-oil**	**Inter**	**OECD**	**Non-oil**	**Inter**	**OECD**
Obs.	98	75	22	91	71	21	81	67	21
Constant	5.43	5.35	8.02	11.50	10.43	8.13	11.64	10.10	8.13
	(1.58)***	(1.54)***	(2.52)***	(0.66)***	(0.97)***	(1.77)***	(0.84)***	(1.05)***	(1.76)***
ln(I/GDP)	1.42	1.32	0.50	1.51	1.50	0.67	1.62	1.48	0.67
	(0.14)***	(0.17)***	(0.43)	(0.15)***	(0.19)***	(0.46)	(0.17)***	(0.22)***	(0.46)
ln(n+g+δ)	-1.99	-2.02	-0.74	0.21	-0.21	-0.76	0.18	-0.31	-0.74
	(0.56)***	(0.53)***	(0.85)	(0.24)	(0.34)	(0.63)	(0.30)	(0.36)	(0.61)
$\bar{R}^2$	0.59	0.59	0.01	0.56	0.47	0.04	0.56	0.4	0.04
<u>Restricted</u>									
Constant	6.87	7.09	8.62	6.90	7.07	8.34	6.71	7.08	8.30
	(0.12)***	(0.15)***	(0.53)***	(0.21)***	(0.22)***	(0.64)***	(0.24)***	(0.27)***	(0.66)***
ln(I/GDP)-ln(n+g+δ)	1.49	1.43	0.55	1.16	1.25	0.70	1.35	1.20	0.69
	(0.12)***	(0.14)***	(0.37)	(0.18)***	(0.19)***	(0.41)	(0.20)***	(0.21)***	(0.40)
$\bar{R}^2$	0.59	0.59	0.06	0.31	0.39	0.09	0.36	0.33	0.09
p-value of restriction	0.363	0.259	0.809	0.000	0.001	0.902	0.000	0.004	0.914
Implied α	0.598	0.589	0.356	0.538	0.555	0.411	0.574	0.545	0.408
	(0.020)	(0.024)	(0.151)	(0.039)	(0.037)	(0.143)	(0.036)	(0.043)	(0.142)

Notes:
Standard errors are in parentheses.
*, **, and *** indicate significance at the 10%, 5% and 1% levels, respectively.

Table 3 – The Augmented Solow Growth Model, 1960-85, MRW Data

	1	2	3	4	5	6	7	8	9
	Dependent variable: log GDP per worker in 1985								
	g=0.02			**g=tfp; no return for education**			**g=tfp; 7% return for education**		
Sample	**Non-oil**	**Inter**	**OECD**	**Non-oil**	**Inter**	**OECD**	**Non-oil**	**Inter**	**OECD**
Obs.	98	75	22	91	71	21	81	67	21
Constant	6.84	7.79	8.64	10.82	10.53	9.05	11.00	10.41	9.03
	(1.18)***	(1.19)***	(2.21)***	(0.50)***	(0.69)***	(1.54)***	(0.67)***	(0.75)***	(1.52)***
ln(I/GDP)	0.70	0.70	0.28	0.84	0.79	0.50	0.97	0.81	0.50
	(0.13)***	(0.15)***	(0.39)	(0.14)***	(0.16)***	(0.40)	(0.17)***	(0.18)***	(0.39)
ln(n+g+δ)	-1.75	-1.50	-1.08	-0.36	-0.60	-1.03	-0.35	-0.64	-1.02
	(0.42)***	(0.40)***	(0.76)	(0.19)*	(0.25)**	(0.55)*	(0.25)	(0.26)**	(0.53)*
ln(school)	0.65	0.73	0.77	0.69	0.83	0.81	0.67	0.83	0.81
	(0.07)***	(0.10)***	(0.29)**	(0.08)***	(0.10)***	(0.29)**	(0.10)***	(0.10)***	(0.29)**
$\bar{R}^2$	0.78	0.77	0.24	0.75	0.73	0.30	0.72	0.7	0.31
Restricted									
Constant	7.85	7.97	8.72	7.91	7.93	8.35	7.62	7.85	8.30
	(0.14)***	(0.15)***	(0.47)***	(0.18)***	(0.19)***	(0.55)***	(0.22)***	(0.22)***	(0.56)***
ln(I/GDP)-ln(n+g+δ)	0.74	0.71	0.28	0.46	0.55	0.43	0.65	0.55	0.42
	(0.12)***	(0.14)***	(0.33)	(0.15)***	(0.16)***	(0.36)	(0.18)***	(0.17)***	(0.36)
ln(school)-ln(n+g+δ)	0.66	0.73	0.77	0.87	0.88	0.78	0.83	0.85	0.78
	(0.07)***	(0.09)***	(0.28)**	(0.09)***	(0.11)***	(0.27)**	(0.11)***	(0.11)***	(0.27)**
$\bar{R}^2$	0.78	0.77	0.28	0.65	0.68	0.33	0.63	0.64	0.34
p-value of restriction	0.390	0.883	0.971	0.000	0.000	0.634	0.000	0.001	0.612
Implied α	0.308	0.290	0.138	0.197	0.226	0.196	0.262	0.229	0.191
	(0.043)	(0.048)	(0.147)	(0.056)	(0.057)	(0.140)	(0.060)	(0.062)	(0.140)
Implied β	0.274	0.300	0.375	0.372	0.362	0.351	0.334	0.355	0.355
	(0.033)	(0.040)	(0.120)	(0.042)	(0.046)	(0.110)	(0.046)	(0.048)	(0.111)

Notes:
Standard errors are in parentheses.
*, **, and *** indicate significance at the 10%, 5% and 1% levels, respectively.

Table 4 – The Textbook Solow Growth Model, 1960-85, PWT 6.1 Data

	1	2	3	4	5	6	7	8	9
	Dependent variable: log GDP per worker in 1985								
	g=0.02			**g=tfp; no return for education**			**g=tfp; 7% return for education**		
Sample	**Non-oil**	**Inter**	**OECD**	**Non-oil**	**Inter**	**OECD**	**Non-oil**	**Inter**	**OECD**
Obs.	92	72	21	91	71	21	81	67	21
Constant	5.81	4.61	9.64	10.29	10.03	11.93	10.72	9.85	11.68
	(1.93)***	(1.97)**	(1.92)***	(0.86)***	(1.15)***	(1.45)***	(1.01)***	(1.13)***	(1.47)***
ln(I/GDP)	0.43	0.30	0.08	0.40	0.34	0.07	0.37	0.31	0.07
	(0.06)***	(0.07)***	(0.06)	(0.05)***	(0.06)***	(0.06)	(0.06)***	(0.06)***	(0.06)
$\ln(n+g+\delta)$	-0.52	-1.28	-0.09	1.01	0.78	0.67	1.07	0.64	0.57
	(0.75)	(0.79)	(0.66)	(0.26)***	(0.38)**	(0.46)	(0.31)***	(0.37)*	(0.46)
$\bar{R}^2$	0.41	0.29	-0.01	0.50	0.32	0.10	0.47	0.30	0.07
<u>Restricted</u>									
Constant	6.03	6.90	9.67	6.10	7.00	9.77	6.33	7.27	9.75
	(0.40)***	(0.48)***	(0.55)***	(0.46)***	(0.52)***	(0.57)***	(0.49)***	(0.50)***	(0.57)***
$\ln(I/GDP)-\ln(n+g+\delta)$	0.44	0.34	0.08	0.41	0.32	0.07	0.39	0.29	0.07
	(0.05)***	(0.06)***	(0.06)	(0.06)***	(0.07)***	(0.06)	(0.06)***	(0.06)***	(0.06)
$\bar{R}^2$	0.42	0.29	0.05	0.34	0.25	0.02	0.32	0.24	0.02
p-value of restriction	0.908	0.235	0.987	0.000	0.005	0.124	0.000	0.014	0.176
Implied α	0.304	0.253	0.077	0.293	0.243	0.067	0.281	0.227	0.068
	(0.026)	(0.035)	(0.051)	(0.030)	(0.038)	(0.053)	(0.032)	(0.037)	(0.053)

Notes:
Standard errors are in parentheses.
*, **, and *** indicate significance at the 10%, 5% and 1% levels, respectively.

Table 5 – The Augmented Solow Growth Model, 1960-85, PWT 6.1 Data

	1	2	3	4	5	6	7	8	9
	Dependent variable: log GDP per worker in 1985								
	g=0.02			**g=tfp; no return for education**			**g=tfp; 7% return for education**		
Sample	**Non-oil**	**Inter**	**OECD**	**Non-oil**	**Inter**	**OECD**	**Non-oil**	**Inter**	**OECD**
Obs.	92	72	21	91	71	21	81	67	21
Constant	8.49	9.25	10.86	11.02	11.48	12.69	11.47	11.31	12.49
	(1.28)***	(1.34)***	(1.50)***	(0.62)***	(0.78)***	(1.21)***	(0.72)***	(0.80)***	(1.22)***
ln(I/GDP)	0.14	0.10	0.07	0.18	0.14	0.06	0.16	0.14	0.06
	(0.05)***	(0.05)**	(0.05)	(0.05)***	(0.05)***	(0.05)	(0.05)***	(0.05)***	(0.05)
ln(n+g+δ)	-1.02	-0.98	-0.48	0.03	-0.06	0.23	0.08	-0.08	0.15
	(0.49)**	(0.50)*	(0.52)	(0.22)	(0.27)	(0.40)	(0.24)	(0.27)	(0.40)
ln(school)	0.84	0.98	0.93	0.81	0.98	0.83	0.88	0.93	0.85
	(0.08)***	(0.10)***	(0.25)***	(0.09)***	(0.11)***	(0.26)***	(0.10)***	(0.11)***	(0.26)***
$\bar{R}^2$	0.75	0.71	0.41	0.74	0.70	0.40	0.74	0.67	0.39
Restricted									
Constant	8.58	8.99	9.46	8.27	8.63	9.49	8.20	8.62	9.44
	(0.35)***	(0.36)***	(0.43)***	(0.40)***	(0.42)***	(0.54)***	(0.41)***	(0.41)***	(0.54)***
ln(I/GDP)-ln(n+g+δ)	0.14	0.10	0.07	0.16	0.12	0.07	0.16	0.12	0.07
	(0.04)***	(0.05)**	(0.05)	(0.05)***	(0.05)**	(0.06)	(0.05)***	(0.05)**	(0.06)
ln(school)-ln(n+g+δ)	0.84	0.98	0.86	0.92	0.99	0.59	0.97	0.92	0.61
	(0.08)***	(0.09)***	(0.24)***	(0.10)***	(0.12)***	(0.30)*	(0.11)***	(0.12)***	(0.29)**
$\bar{R}^2$	0.75	0.72	0.41	0.66	0.62	0.15	0.65	0.60	0.17
p-value of restriction	0.939	0.839	0.341	0.000	0.000	0.011	0.000	0.000	0.015
Implied α	0.072	0.048	0.036	0.076	0.058	0.042	0.075	0.058	0.041
	(0.022)	(0.022)	(0.024)	(0.025)	(0.025)	(0.034)	(0.025)	(0.025)	(0.033)
Implied β	0.423	0.471	0.446	0.441	0.468	0.356	0.455	0.453	0.364
	(0.029)	(0.031)	(0.070)	(0.034)	(0.037)	(0.115)	(0.036)	(0.039)	(0.110)

Notes:
Standard errors are in parentheses.
*, **, and *** indicate significance at the 10%, 5% and 1% levels, respectively.

Table 6 – The Textbook Solow Growth Model, 1960-2000, PWT 6.1 Data

	1	2	3	4	5	6	7	8	9
	Dependent variable: log GDP per worker in 2000								
	g=0.02			**g=tfp; no return for education**			**g=tfp; 7% return for education**		
Sample	**Non-oil**	**Inter**	**OECD**	**Non-oil**	**Inter**	**OECD**	**Non-oil**	**Inter**	**OECD**
Obs.	84	70	21	84	70	21	76	65	21
Constant	0.49	-0.56	8.22	9.59	9.21	15.22	8.28	6.75	15.35
	(2.00)	(1.99)	(2.21)***	(1.22)***	(1.58)***	(1.72)***	(1.31)***	(1.62)***	(1.81)***
ln(I/GDP)	0.43	0.29	0.04	0.50	0.44	0.02	0.48	0.40	0.01
	(0.06)***	(0.07)***	(0.06)	(0.06)***	(0.07)***	(0.05)	(0.06)***	(0.07)***	(0.05)
ln(n+g+δ)	-2.54	-3.27	-0.80	0.95	0.68	1.56	0.41	-0.28	1.56
	(0.80)***	(0.82)***	(0.77)	(0.39)**	(0.53)	(0.56)**	(0.43)	(0.55)	(0.57)**
$\bar{R}^2$	0.52	0.47	-0.03	0.50	0.36	0.24	0.46	0.35	0.23
<u>Restricted</u>									
Constant	5.42	6.14	10.36	5.40	6.18	10.51	5.74	6.41	10.51
	(0.45)***	(0.53)***	(0.55)***	(0.52)***	(0.59)***	(0.57)***	(0.50)***	(0.55)***	(0.57)***
ln(I/GDP)-ln(n+g+δ)	0.52	0.44	0.04	0.50	0.42	0.02	0.47	0.40	0.02
	(0.06)***	(0.07)***	(0.06)	(0.06)***	(0.07)***	(0.06)	(0.06)***	(0.07)***	(0.06)
$\bar{R}^2$	0.49	0.38	-0.03	0.42	0.33	-0.04	0.43	0.36	-0.04
p-value of restriction	0.014	0.001	0.331	0.000	0.042	0.011	0.040	0.826	0.012
Implied α	0.340	0.304	0.038	0.334	0.296	0.022	0.320	0.286	0.023
	(0.025)	(0.032)	(0.054)	(0.029)	(0.035)	(0.056)	(0.029)	(0.033)	(0.056)

Notes:
Standard errors are in parentheses.
*, **, and *** indicate significance at the 10%, 5% and 1% levels, respectively.

Table 7 – The Augmented Solow Growth Model, 1960-2000, PWT 6.1 Data

	1	2	3	4	5	6	7	8	9
	Dependent variable: log GDP per worker in 2000								
	g=0.02			**g=tfp; no return for education**			**g=tfp; 7% return for education**		
Sample	**Non-oil**	**Inter**	**OECD**	**Non-oil**	**Inter**	**OECD**	**Non-oil**	**Inter**	**OECD**
Obs.	84	70	21	84	70	21	76	65	21
Constant	4.79	6.56	10.44	10.22	11.98	15.17	9.65	10.56	15.14
	(1.25)***	(1.37)***	(1.62)***	(0.83)***	(1.01)***	(1.47)***	(0.87)***	(1.12)***	(1.54)***
ln(I/GDP)	0.16	0.13	0.04	0.24	0.21	0.02	0.25	0.22	0.02
	(0.04)***	(0.05)***	(0.04)	(0.05)***	(0.05)***	(0.04)	(0.05)***	(0.05)***	(0.04)
ln(n+g+δ)	-2.57	-2.16	-1.08	-0.39	-0.04	0.80	-0.62	-0.44	0.75
	(0.48)***	(0.50)***	(0.54)*	(0.30)	(0.34)	(0.55)	(0.30)**	(0.36)	(0.57)
ln(school)	1.03	1.22	1.27	1.10	1.32	0.95	1.14	1.22	0.96
	(0.09)***	(0.11)***	(0.28)***	(0.11)***	(0.13)***	(0.34)**	(0.12)***	(0.13)***	(0.35)**
$\bar{R}^2$	0.83	0.81	0.50	0.77	0.75	0.45	0.77	0.73	0.44
<u>Restricted</u>									
Constant	8.11	8.49	9.84	7.63	7.86	10.01	7.48	7.75	9.89
	(0.35)***	(0.36)***	(0.39)***	(0.41)***	(0.45)***	(0.61)***	(0.38)***	(0.41)***	(0.64)***
ln(I/GDP)-ln(n+g+δ)	0.20	0.16	0.04	0.22	0.20	0.03	0.24	0.21	0.03
	(0.04)***	(0.04)***	(0.04)	(0.05)***	(0.06)***	(0.06)	(0.05)***	(0.05)***	(0.06)
ln(school)-ln(n+g+δ)	1.06	1.28	1.23	1.17	1.26	0.77	1.15	1.13	0.81
	(0.09)***	(0.11)***	(0.26)***	(0.12)***	(0.14)***	(0.44)*	(0.12)***	(0.13)***	(0.44)*
$\bar{R}^2$	0.81	0.80	0.52	0.74	0.68	0.06	0.75	0.70	0.07
p-value of restriction	0.007	0.149	0.708	0.001	0.000	0.002	0.008	0.010	0.002
Implied α	0.090	0.065	0.016	0.094	0.080	0.015	0.099	0.089	0.017
	(0.020)	(0.018)	(0.017)	(0.022)	(0.023)	(0.031)	(0.021)	(0.022)	(0.030)
Implied β	0.468	0.524	0.542	0.489	0.513	0.430	0.483	0.483	0.440
	(0.027)	(0.027)	(0.053)	(0.032)	(0.035)	(0.140)	(0.032)	(0.035)	(0.135)

Notes:
Standard errors are in parentheses.
*, **, and *** indicate significance at the 10%, 5% and 1% levels, respectively.

Table 8 – Number of predictions met (out of the four detailed below)

	Identical technology			Country-specific technology and no return for education			Country-specific technology and 7% return for education		
	Non-oil	**Inter**	**OECD**	**Non-oil**	**Inter**	**OECD**	**Non-oil**	**Inter**	**OECD**
Textbook Solow									
1960-1985 (MRW)	3	3	2	1	1	2	1	1	2
1960-1985 (PWT)	3	2	1	2	2	1	2	1	1
1960-2000 (PWT)	3	3	1	2	2	0	3	3	0
Augmented Solow									
1960-1985 (MRW)	4	4	1	2	2	2	1	2	2
1960-1985 (PWT)	3	3	2	1	1	1	1	1	1
1960-2000 (PWT)	2	3	2	1	1	1	2	1	1

Notes:
Predictions derived from the Solow model: 1) significant right sign of coefficients, 2) sum of coefficients equals zero, 3) implied elasticities are according to expectations, 4) high explanatory power of model
Shaded cells indicate the original findings of MRW.

Table 9 – Absolute Convergence

	1	2	3	4	5	6	7	8	9
	Dependent variable: log difference GDP per worker 1960-1985						**log difference GDP per worker 1960-2000**		
	MRW data			**PWT 6.1**			**PWT 6.1**		
Sample	**Non-oil**	**Inter**	**OECD**	**Non-oil**	**Inter**	**OECD**	**Non-oil**	**Inter**	**OECD**
Obs.	98	75	22	90	71	21	83	69	21
Constant	-0.27	0.59	3.69	0.37	1.00	5.10	-0.07	0.44	6.67
	(0.38)	(0.43)	(0.68)***	(0.41)	(0.46)**	(0.75)***	(0.56)	(0.69)	(1.00)***
ln(Y60)	0.09	-0.00	-0.34	0.02	-0.05	-0.45	0.08	0.03	-0.58
	(0.05)*	(0.05)	(0.08)***	(0.05)	(0.05)	(0.08)***	(0.06)	(0.08)	(0.10)***
$\bar{R}^2$	0.03	-0.01	0.46	-0.01	0.00	0.63	0.01	-0.01	0.61
Implied λ	-0.004	0.000	0.017	-0.001	0.002	0.024	-0.002	-0.001	0.022
	(0.002)	(0.002)	(0.005)	(0.002)	(0.002)	(0.006)	(0.001)	(0.002)	(0.006)

Notes:
Standard errors are in parentheses.
*, **, and *** indicate significance at the 10%, 5% and 1% levels, respectively.

Table 10 – Conditional Convergence, Textbook Model, 1960-85, MRW Data

	1	2	3	4	5	6	7	8	9
	Dependent variable: log difference GDP per worker 1960-1985								
	g=0.02			**g=tfp; no return for education**			**g=tfp; 7% return for education**		
Sample	**Non-oil**	**Inter**	**OECD**	**Non-oil**	**Inter**	**OECD**	**Non-oil**	**Inter**	**OECD**
Obs.	98	75	22	91	71	21	81	67	21
Constant	1.92	2.25	2.14	3.33	3.77	4.98	3.76	3.76	5.04
	(0.83)**	(0.85)**	(1.18)*	(0.57)***	(0.67)***	(0.88)***	(0.63)***	(0.67)***	(0.86)***
ln(Y60)	-0.14	-0.23	-0.35	-0.15	-0.18	-0.31	-0.17	-0.18	-0.30
	(0.05)***	(0.06)***	(0.07)***	(0.05)***	(0.06)***	(0.08)***	(0.05)***	(0.06)***	(0.08)***
ln(I/GDP)	0.65	0.65	0.39	0.65	0.62	0.33	0.66	0.63	0.32
	(0.09)***	(0.10)***	(0.18)**	(0.09)***	(0.11)***	(0.21)	(0.10)***	(0.12)***	(0.21)
ln(n+g+δ)	-0.30	-0.46	-0.77	0.17	0.25	0.38	0.26	0.25	0.42
	(0.30)	(0.31)	(0.35)**	(0.11)	(0.17)	(0.31)	(0.14)*	(0.18)	(0.30)
$\bar{R}^2$	0.38	0.35	0.62	0.43	0.34	0.55	0.41	0.32	0.57
Implied λ	0.006	0.010	0.017	0.007	0.008	0.015	0.007	0.008	0.014
	(0.002)	(0.003)	(0.004)	(0.002)	(0.003)	(0.005)	(0.002)	(0.003)	(0.005)

Notes:
Standard errors are in parentheses.
*, **, and *** indicate significance at the 10%, 5% and 1% levels, respectively.

Table 11 – Conditional Convergence, Augmented Model, 1960-85, MRW Data

	1	2	3	4	5	6	7	8	9
	Dependent variable: log difference GDP per worker 1960-1985								
	g=0.02			**g=tfp; no return for education**			**g=tfp; 7% return for education**		
Sample	**Non-oil**	**Inter**	**OECD**	**Non-oil**	**Inter**	**OECD**	**Non-oil**	**Inter**	**OECD**
Obs.	98	75	22	91	71	21	81	67	21
Constant	3.02	3.71	2.76	4.17	4.90	5.21	4.24	4.82	5.22
	(0.83)***	(0.91)***	(1.20)**	(0.63)***	(0.77)***	(1.02)***	(0.69)***	(0.78)***	(1.00)***
ln(Y60)	-0.29	-0.37	-0.40	-0.26	-0.32	-0.34	-0.23	-0.30	-0.32
	(0.06)***	(0.07)***	(0.07)***	(0.06)***	(0.07)***	(0.10)***	(0.06)***	(0.08)***	(0.10)***
ln(I/GDP)	0.52	0.54	0.33	0.58	0.56	0.32	0.62	0.58	0.31
	(0.09)***	(0.10)***	(0.17)*	(0.09)***	(0.11)***	(0.22)	(0.10)***	(0.12)***	(0.21)
ln(n+g+δ)	-0.51	-0.54	-0.86	0.03	0.06	0.31	0.17	0.07	0.36
	(0.29)*	(0.29)*	(0.34)**	(0.12)	(0.18)	(0.36)	(0.16)	(0.19)	(0.35)
ln(school)	0.23	0.27	0.23	0.18	0.24	0.09	0.11	0.23	0.07
	(0.06)***	(0.08)***	(0.15)	(0.07)***	(0.09)**	(0.19)	(0.07)	(0.09)**	(0.19)
$\bar{R}^2$	0.46	0.43	0.65	0.47	0.39	0.53	0.42	0.37	0.54
Implied λ	0.014	0.018	0.020	0.012	0.015	0.016	0.011	0.015	0.016
	(0.003)	(0.004)	(0.005)	(0.003)	(0.004)	(0.006)	(0.003)	(0.004)	(0.006)

Notes:
Standard errors are in parentheses.
*, **, and *** indicate significance at the 10%, 5% and 1% levels, respectively.

Table 12 – Conditional Convergence, Textbook Model, 1960-85, PWT 6.1 Data

	1	2	3	4	5	6	7	8	9
	Dependent variable: log difference GDP per worker 1960-1985								
	g=0.02			**g=tfp; no return for education**			**g=tfp; 7% return for education**		
Sample	**Non-oil**	**Inter**	**OECD**	**Non-oil**	**Inter**	**OECD**	**Non-oil**	**Inter**	**OECD**
Obs.	90	71	21	89	70	21	79	66	21
Constant	1.11	0.96	2.12	3.53	3.27	6.90	3.61	3.49	6.79
	(1.03)	(0.98)	(1.19)*	(0.55)***	(0.65)***	(0.84)***	(0.63)***	(0.66)***	(0.84)***
ln(Y60)	-0.07	-0.11	-0.42	-0.12	-0.13	-0.47	-0.12	-0.16	-0.46
	(0.06)	(0.06)*	(0.07)***	(0.05)**	(0.05)**	(0.06)***	(0.05)**	(0.05)***	(0.06)***
ln(I/GDP)	0.10	0.08	0.06	0.08	0.08	0.04	0.08	0.08	0.04
	(0.04)***	(0.04)**	(0.03)*	(0.03)**	(0.03)**	(0.03)	(0.03)***	(0.03)**	(0.03)
$\ln(n+g+\delta)$	0.15	-0.09	-0.82	0.81	0.67	0.65	0.81	0.63	0.63
	(0.39)	(0.39)	(0.30)**	(0.13)***	(0.17)***	(0.20)***	(0.15)***	(0.17)***	(0.20)***
$\bar{R}^2$	0.05	0.04	0.76	0.36	0.23	0.78	0.34	0.25	0.78
Implied λ	0.003	0.005	0.022	0.005	0.006	0.026	0.005	0.007	0.025
	(0.003)	(0.003)	(0.004)	(0.002)	(0.002)	(0.004)	(0.002)	(0.003)	(0.004)

Notes:
Standard errors are in parentheses.
*, **, and *** indicate significance at the 10%, 5% and 1% levels, respectively.

Table 13 – Conditional Convergence, Augmented Model, 1960-85, PWT 6.1 Data

	1	2	3	4	5	6	7	8	9
	Dependent variable: log difference GDP per worker 1960-1985								
	g=0.02			**g=tfp; no return for education**			**g=tfp; 7% return for education**		
Sample	**Non-oil**	**Inter**	**OECD**	**Non-oil**	**Inter**	**OECD**	**Non-oil**	**Inter**	**OECD**
Obs.	90	71	21	89	70	21	79	66	21
Constant	3.59	3.64	3.72	4.72	4.67	7.35	4.92	4.84	7.24
	(0.94)***	(1.10)***	(1.26)***	(0.62)***	(0.84)***	(1.04)***	(0.71)***	(0.82)***	(1.04)***
ln(Y60)	-0.32	-0.33	-0.51	-0.25	-0.27	-0.51	-0.26	-0.29	-0.50
	(0.06)***	(0.08)***	(0.07)***	(0.06)***	(0.07)***	(0.07)***	(0.06)***	(0.07)***	(0.08)***
ln(I/GDP)	0.05	0.06	0.05	0.06	0.07	0.04	0.07	0.07	0.04
	(0.03)	(0.03)	(0.02)**	(0.03)**	(0.03)**	(0.03)	(0.03)**	(0.03)**	(0.03)
ln(n+g+δ)	-0.28	-0.27	-0.86	0.53	0.46	0.58	0.54	0.43	0.56
	(0.33)	(0.35)	(0.27)***	(0.14)***	(0.18)**	(0.22)**	(0.16)***	(0.18)**	(0.22)**
ln(school)	0.40	0.38	0.35	0.24	0.25	0.13	0.27	0.25	0.13
	(0.06)***	(0.09)***	(0.15)**	(0.07)***	(0.10)**	(0.18)	(0.08)***	(0.10)**	(0.18)
$\bar{R}^2$	0.34	0.22	0.81	0.44	0.29	0.78	0.42	0.31	0.77
Implied λ	0.015	0.016	0.028	0.012	0.012	0.028	0.012	0.014	0.028
	(0.004)	(0.005)	(0.006)	(0.003)	(0.004)	(0.006)	(0.003)	(0.004)	(0.006)

Notes:
Standard errors are in parentheses.
*, **, and *** indicate significance at the 10%, 5% and 1% levels, respectively.

Table 14 – Conditional Convergence, Textbook Model, 1960-2000, PWT 6.1 Data

	1	2	3	4	5	6	7	8	9
	Dependent variable: log difference GDP per worker 1960-2000								
	g=0.02			**g=tfp; no return for education**			**g=tfp; 7% return for education**		
Sample	**Non-oil**	**Inter**	**OECD**	**Non-oil**	**Inter**	**OECD**	**Non-oil**	**Inter**	**OECD**
Obs.	83	69	21	83	69	21	75	64	21
Constant	-2.40	-2.69	2.23	3.51	3.82	11.13	3.50	3.35	11.23
	(1.19)**	(1.20)**	(1.88)	(0.76)***	(0.90)***	(1.37)***	(0.80)***	(0.97)***	(1.45)***
ln(Y60)	-0.15	-0.20	-0.54	-0.11	-0.08	-0.60	-0.12	-0.12	-0.61
	(0.07)**	(0.07)***	(0.09)***	(0.06)*	(0.07)	(0.08)***	(0.07)*	(0.08)	(0.08)***
ln(I/GDP)	0.18	0.16	0.03	0.19	0.20	0.01	0.19	0.21	0.00
	(0.04)***	(0.05)***	(0.04)	(0.04)***	(0.04)***	(0.03)	(0.04)***	(0.04)***	(0.03)
ln(n+g+δ)	-1.32	-1.62	-1.35	0.99	1.21	1.46	0.92	0.90	1.44
	(0.48)***	(0.51)***	(0.51)**	(0.21)***	(0.28)***	(0.36)***	(0.24)***	(0.33)***	(0.37)***
$\bar{R}^2$	0.29	0.33	0.69	0.40	0.40	0.78	0.37	0.34	0.77
Implied λ	0.004	0.005	0.019	0.003	0.002	0.023	0.003	0.003	0.023
	(0.002)	(0.002)	(0.005)	(0.002)	(0.002)	(0.005)	(0.002)	(0.002)	(0.005)

Notes:
Standard errors are in parentheses.
*, **, and *** indicate significance at the 10%, 5% and 1% levels, respectively.

Table 15 – Conditional Convergence, Augmented Model, 1960-2000, PWT 6.1 Data

	1	2	3	4	5	6	7	8	9
	Dependent variable: log difference GDP per worker 1960-2000								
	g=0.02			**g=tfp; no return for education**			**g=tfp; 7% return for education**		
Sample	**Non-oil**	**Inter**	**OECD**	**Non-oil**	**Inter**	**OECD**	**Non-oil**	**Inter**	**OECD**
Obs.	83	69	21	83	69	21	75	64	21
Constant	1.18	2.20	5.44	5.08	6.34	11.68	5.34	6.05	11.74
	(1.05)	(1.33)	(1.75)***	(0.85)***	(1.11)***	(1.44)***	(0.86)***	(1.14)***	(1.51)***
ln(Y60)	-0.47	-0.51	-0.67	-0.31	-0.33	-0.66	-0.36	-0.39	-0.66
	(0.07)***	(0.08)***	(0.08)***	(0.08)***	(0.09)***	(0.09)***	(0.08)***	(0.10)***	(0.09)***
ln(I/GDP)	0.11	0.12	0.03	0.16	0.18	0.01	0.17	0.18	0.01
	(0.03)***	(0.04)***	(0.03)	(0.04)***	(0.04)***	(0.03)	(0.04)***	(0.04)***	(0.03)
ln(n+g+δ)	-1.81	-1.65	-1.37	0.48	0.77	1.21	0.33	0.45	1.17
	(0.38)***	(0.42)***	(0.40)***	(0.24)*	(0.29)***	(0.43)**	(0.26)	(0.32)	(0.45)**
ln(school)	0.61	0.70	0.82	0.40	0.52	0.34	0.49	0.55	0.35
	(0.08)***	(0.13)***	(0.24)***	(0.11)***	(0.15)***	(0.30)	(0.12)***	(0.15)***	(0.31)
$\bar{R}^2$	0.57	0.54	0.81	0.47	0.48	0.78	0.48	0.46	0.77
Implied λ	0.016	0.018	0.028	0.009	0.010	0.027	0.011	0.012	0.027
	(0.003)	(0.004)	(0.006)	(0.003)	(0.004)	(0.007)	(0.003)	(0.004)	(0.007)

Notes:
Standard errors are in parentheses.
*, **, and *** indicate significance at the 10%, 5% and 1% levels, respectively.

Table 16 – Evidence of Conditional Convergence (at the 5% significance level) and its Speed

	Identical technology			Country-specific technology and no return for education			Country-specific technology and 7% return for education		
	Non-oil	**Inter**	**OECD**	**Non-oil**	**Inter**	**OECD**	**Non-oil**	**Inter**	**OECD**
Textbook Solow									
1960-1985 (MRW)	Y (0.6%)	Y (1.0%)	Y (1.7%)	Y (0.7%)	Y (0.8%)	Y (1.5%)	Y (0.7%)	Y (0.8%)	Y (1.4%)
1960-1985 (PWT)	N	N	Y (2.2%)	Y (0.5%)	Y (0.6%)	Y (2.6%)	Y (0.5%)	Y (0.7%)	Y (2.5%)
1960-2000 (PWT)	Y (0.4%)	Y (0.5%)	Y (1.9%)	N	N	Y (2.3%)	N	N	Y (2.3%)
Augmented Solow									
1960-1985 (MRW)	Y (1.4%)	Y (1.8%)	Y (2.0%)	Y (1.2%)	Y (1.5%)	Y (1.6%)	Y (1.1%)	Y (1.5%)	Y (1.6%)
1960-1985 (PWT)	Y (1.5%)	Y (1.6%)	Y (2.8%)	Y (1.2%)	Y (1.2%)	Y (2.8%)	Y (1.2%)	Y (1.4%)	Y (2.8%)
1960-2000 (PWT)	Y (1.6%)	Y (1.8%)	Y (2.8%)	Y (0.9%)	Y (1.0%)	Y (2.7%)	Y (1.1%)	Y (1.2%)	Y (2.7%)

Notes:
Y – indicates significant coefficient of the initial income in the growth regressions at the 5% while N indicates insignificant coefficient.
Speed of convergence is in parenthesis.
Shaded cells indicate the original findings of MRW.