THE ROLE OF HUMAN CAPITAL IN ECONOMIC GROWTH: A CASE STUDY

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Abstract

The Solow growth model does an unsatisfactory job in explaining income disparity across countries with rates of saving and population growth as the only determinants. An important branch of empirical macroeconomic literature examines international income differences and the trend of convergence by including human capital in the Solow growth model, and clearly establishes that human capital plays a very important role in the growth process. However, allowing for differences in the aggregate production function across countries with a panel data approach, Islam (1995) finds that human capital fails to enter significantly. This paper re-examines the role of human capital in the growth equation, applying the same approach as Islam's. A sensitivity analysis is also conducted to test the sensitivity of the results to a variety of specification alterations such as different measures of variables and different time periods.

Dedication

谨献给我亲爱的父母和姐姐

To My Parents and Sister

Acknowledgements

I offer my enduring gratitude to the faculty, staff and my fellow students at the SFU Department of Economics, who have combined to create a stimulating synergy for research in our field. I owe particular thanks to Professor Peter Kennedy, whose penetrating questions taught me to question more deeply.

Special thanks are owed to my parents and my elder sister, whose support throughout my education years has been unbroken, and multi-faceted.

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1. Introduction

Considerable empirical work has been done to account for international variation in the standard of living and cross-country growth. Robert Solow presents his study of economic growth in his classic 1956 article. He starts by assuming a standard neoclassical production function with decreasing returns to physical capital, and concludes that the steady-state level of income per capita is determined by the exogenous rates of saving and population growth. He predicts that a higher rate of saving makes a country richer, while a higher rate of population growth makes a country poorer. These predictions about the directions of the impact of saving rate and population growth on income conform with cross-country data.

Unfortunately, the Solow growth model fails to predict the magnitudes precisely. Based on the Solow growth model, a doubling of the saving rate increases income by a factor of less than 1.5, but empirical data shows that income will differ by a factor of 20. Romer (1987, 1989a) comments that saving rates have too large an impact on growth, and interprets this as evidence of positive externalities from capital accumulation. In addition, Lucas (1988) also proves that population growth cannot substantially explain income difference across countries.

The failure of the Solow model in explaining income disparity is the incentive for me to go beyond the standard Solow model. Except for the trend among economists to discard the Solow growth model in favor of endogenous growth models, which assume constant or increasing returns to the set of reproducible factors of production, several approaches have been implemented to augment the standard Solow growth model. Inclusion of human capital comes naturally as more and more evidence suggests the importance of human capital in economic growth. Kendrick (1976) estimates that over half of the total U.S. capital stock in 1969 was human capital. Azariadis and Drazen (1990) find that without a highly literate labor force, no country was able to experience fast growth during the postwar period. The exclusion of human capital can potentially explain the unsatisfactory performance of the standard Solow growth model by overestimating the influences of saving and population growth. The economic intuition is that higher saving rate or lower population growth results in higher income and further creates a higher level of human capital. In other words, physical capital and population growth have greater effects on the level of income when accumulation of human capital is considered. Moreover, human capital accumulation might be correlated with saving and population growth. As a result, omitting human capital variables leads to biased estimated coefficients of the above two independent variables (Mankiw, Romer, and Weil (1992)). Lucas (1988) even asserts that although the returns to physical capital accumulation are decreasing when human capital is constant, the returns to both physical and human capital as a whole might be constant.

Now the question is, how does human capital affect production and growth? The first approach is to treat human capital as an ordinary input in the production function, as proposed by Mankiw, Romer, and Weil (1992). They find that the human capital variable enters significantly in explaining income differences. It also decreases the influence of saving rates and population growth as predicted by empirical evidence, and improves the fit of the regression significantly. They conclude that the augmented Solow model provides a better explanation of the cross-country data. They also show that much of the income disparity across counties can be traced to the difference in the determinants of the steady state, which include saving, population growth, and capital accumulation. After these variables are controlled for, income per capita of a given country converges to its steady-state level. This is called "conditional convergence." The finding of convergence has been thought of as support for the Solow growth model, and has been a major focus of recent work on growth empirics.

Islam (1995) extends Mankiw, Romer, and Weil's (1992) study by introducing a panel data approach. He chooses the same country sets, and analyses the data for the period 1960-1985. He finds better evidence of convergence in a panel data scenario, but fails in showing the significance of human capital in the model. My study begins by replicating Islam (1995) using a sample of the 22 OECD countries.[1] Due to the limitations of the data, the empirical work focuses on the convergence model. The estimates of the human capital variable are insignificant in two of the three estimations. The inclusion of human capital does not significantly improve the estimates of the structural parameters either. In addition, a sensitivity analysis is conducted to test the fragility of the results to a variety of specification alterations such as different measures of variables and different time periods. There is no fundamental change in the results that can convince us of the importance of human capital in economic growth.

[1] The 22 OECD countries are: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Japan, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, United Kingdom, and United States.

Empirical work has established the importance of human capital in economic growth, but why my exercise tells a different story? Many studies cast doubt on the traditional role given to human capital as merely a factor of production. Now the question is, how exactly does human capital affect economic growth? Romer (1990a) suggests that human capital may directly affect productivity by enhancing the capacity of countries to create new technologies. Nelson and Phelps (1966) suggest that the ability of a country to import and use new technologies from abroad is also a function of the country's human capital stock. Benhabib and Spiegel (1994) adapt the Nelson and Phelps (1966) framework to analyze the effect of human capital on the speed of technological catch-up and diffusion, and examine how these changes influence growth. The alternative model indicates a more positive role for human capital in determining per capita income. This inspires us to develop a more comprehensive model to account for the complex and influential role human capital plays in economic growth.

This paper is organized into 6 sections. The following section will be an introduction of the standard Solow model and the augmented Solow growth model with the inclusion of human capital. The models are designed to account for the issue of conditional convergence with the panel data approach. Section 3 is about data and estimation. In Section 4, I conduct sensitivity analyses to test for the robustness of my results to a variety of specification alterations such as different measures of variables and different time periods. A possible improvement of the model is discussed in Section 5. Section 6 concludes.

2. The Model

2.1 The Standard Solow Growth Model

Islam (1995) bases his empirical studies on the work of Mankiw, Romer, and Weil (1992). M-R-W starts with the standard Solow growth model and assume a Cobb-Douglas production function with a labor-augmenting technological progress. Production at time t is:

$$(1)\ Y(t) = K(t)^{\alpha}(A(t)L(t))^{1-\alpha} \quad 0 < \alpha < 1,$$

where Y is output, K capital, L labor, and A the level of technology. Assume that L and A grow exogenously at rates n and g:

$$(2)\ L(t) = L(0)e^{nt}$$

$$(3)\ A(t) = A(0)e^{gt}.$$

Assume that a constant fraction of output, s, is invested. Define $\hat{y} = Y / AL$ and $\hat{k} = K / AL$ as output and stock of physical capital per unit of effective labor. The change of $\hat{k}$ is governed by

$$(4)\ \dot{\hat{k}} = s\hat{y}(t) - (n + g + \delta)\hat{k}(t)$$

$$= s\hat{k}(t)^{\alpha} - (n + g + \delta)\hat{k}(t),$$

where δ is the rate of depreciation. As determined by the above equation, the steady state $\hat{k}$ is:

$$(5)\ \hat{k}^{*} = [s/(n + g + \delta)]^{1/(1-\alpha)}.$$

Substituting this to the production function, the steady-state income per capita is:

$$(6)\ \ln\left[\frac{Y(t)}{L(t)}\right] = \ln A(0) + gt + \frac{\alpha}{1-\alpha}\ln(s) - \frac{\alpha}{1-\alpha}\ln(n+g+\delta)$$

As factors are assumed to be paid their marginal products, the model allows us to estimate the signs and magnitudes of the coefficients on saving rates and population growth. Physical capital's share in income (α) is around one third. If the model is correctly specified, there should not be substantial externalities to physical capital. In another word, the elasticity of income with respect to the stock of physical capital should be almost the same as capital's share in income. Therefore, the elasticity of income per capita with respect to the saving rate should be 0.5, and elasticity with respect to $n+g+\delta$ is -0.5.

M-R-W assumes decreasing returns to scale. If, however, $\alpha = 1$, which means that there are constant returns to scale in the reproducible factor, there will be no steady state for this model. Countries that save more will grow faster indefinitely. Countries need not converge in income per capita, even if they have the same technologies and preferences. This is what endogenous-growth models advocate. It is presented as an alternative to the Solow model, motivated by the empirical failure of the Solow model to explain cross-country difference. M-R-W argues that the Solow model predicts convergence after controlling for the determinants of the steady state, which is called "conditional convergence." It predicts that income per capita of a country converges to its respective steady state. Furthermore, the Solow model predicts quantitatively the speed of convergence. We can verify the validity of convergence by empirical estimation.

M-R-W assumes g and δ to be constant across countries, but $A(0)$ may differ, as it reflects the variety between countries in technologies, resource endowments, climate, institutions, and so on. Therefore, they assume that:

$$\ln A(0) = a + \varepsilon ,$$

where a is a constant, and ε is the country-specific shock term. M-R-W assumes g to be constant across countries, because it reflects the advancement of technology, which is not country specific. As t is also a fixed number for a cross section regression, we can incorporate gt into the constant term. Substituting this into the above equation, the log of the steady-state income per capita is:

$$(7)\ \ln\left(\frac{Y}{L}\right) = a + \frac{\alpha}{1-\alpha}\ln(s) - \frac{\alpha}{1-\alpha}\ln(n+g+\delta) + \varepsilon$$

M-R-W estimates the equation above with ordinary least squares (OLS) basing on the assumption that s and n are independent of ε. They provide three reasons for making this assumption. First, this assumption is commonly made in many standard growth models, not just in the Solow model. Also, in models in which saving and population growth are endogenous but preferences are isoelastic, s and n are unaffected by ε [2]. Second, regarding the relationship between income, saving, and population growth, this assumption makes it possible to test various informal hypotheses that have been made. Third, the model above predicts both the signs and the magnitudes of the coefficients on saving and population growth. If the model is correctly specified, the elasticities of Y/L with respect to s and $n+g+\delta$ are approximately 0.5 and -0.5. If the values of OLS estimates are significantly different from these predictions, or insignificant estimates are

[2] Mankiw, Romer, and Weil (1992) Page 411.

obtained in the restricted model where we assume the parameters of s and $n+g+\delta$ are equal in magnitude but opposite in sign, we can reject the joint hypothesis of the validity of the Solow model and the identifying assumption.

Among the three reasons, Islam points out that the first is the most important. M-R-W explains that under isoelastic utility, permanent differences in technologies do not affect s and n. Islam argues that assumption of isoelastic preference represents an additional restriction. Moreover, $A(0)$ is defined broadly, including resource endowments, institutions, etc. It seems likely that the country-specific technology shift term ε is correlated with the saving rate and population growth experienced by that country. Applying a single cross-section regression using OLS will create omitted variable bias. We can try to find an instrumental variable that is correlated with s and n, but uncorrelated with ε. However, due to the nature and the scope of $A(0)$, finding such a variable will be extremely hard.

Therefore, Islam advocates that a panel data framework provides a better control for the difference in technology. This is made evident by considering the equation describing out of steady-state problem, such as the issue of convergence. Let $\hat{y}^*$ be the steady-state level of income per effective worker given by equation (6), and $\hat{y}(t)$ the actual value at any time t. Approximating around the steady state using a first-order Taylor-series, the pace of convergence is given by

$$(8)\ \frac{d\ln\hat{y}(t)}{dt}=\lambda[\ln(\hat{y}^*)-\ln\hat{y}(t)].$$

λ represents the rate of convergence, which equals to $(n+g+\delta)(1-\alpha)$[3]. Equation (8) implies that:

$$(9)\ \ln \hat{y}(t_2) = (1-e^{-\lambda\tau})\ln \hat{y}^* + e^{-\lambda\tau}\ln \hat{y}(t_1),$$

where $\hat{y}(t_1)$ is income per effective worker at some initial point of time, and $\tau = (t_2 - t_1)$. Subtracting $\ln \hat{y}(t_1)$ from both sides yields

$$(10)\ \ln \hat{y}(t_2) - \ln \hat{y}(t_1) = (1-e^{-\lambda\tau})\ln \hat{y}^* - (1-e^{-\lambda\tau})\ln \hat{y}(t_1).$$

Substituting for $\hat{y}^*$ gives:

$$(11)\ \ln \hat{y}(t_2) - \ln \hat{y}(t_1) = (1-e^{-\lambda\tau})\frac{\alpha}{1-\alpha}\ln(s) - (1-e^{-\lambda\tau})\frac{\alpha}{1-\alpha}\ln(n+g+\delta)$$
$$-(1-e^{-\lambda\tau})\ln \hat{y}(t_1).$$

The issue of correlation between the unobservable $A(0)$ and the observed included variables is hidden since it is formulated in terms of income per effective worker. Let $y(t)$ be the per capita income. We can reformulate equation (11) in terms of income per capita:

$$(12)\ \ln y(t_2) = (1-e^{-\lambda\tau})\frac{\alpha}{1-\alpha}\ln(s) - (1-e^{-\lambda\tau})\frac{\alpha}{1-\alpha}\ln(n+g+\delta)$$
$$+e^{-\lambda\tau}\ln y(t_1) + (1-e^{-\lambda\tau})\ln A(0) + g(t_2 - e^{-\lambda\tau}t_1).$$

Equation (12) represents a dynamic panel data model with $(1-e^{-\lambda\tau})\ln A(0)$ as the time-invariant individual country-effect term.

[3] The derivation of the speed of convergence is presented in Romer, David "Advanced Macroeconomics", second edition, Page 24-25.

As pointed out by Islam, this panel data formulation is obtained by moving from a single cross-section covering the entire period to cross sections of the several shorter time spans that constitute it. The assumptions in a single cross-section regression that the formulation is based on approximation around steady state and that s and n are constant for the entire period, are both valid for shorter periods. The panel data approach allows us to investigate the process of convergence over several consecutive time intervals after controlling for the individual country effects.

Equation (7) is valid only if countries are in their steady states, or if derivation from the steady states is random. However, equation (12) is based on approximation around the steady state, and able to capture the dynamic toward the steady state. If the OECD countries are not at their steady states, population growth and capital investments may not have their full impact on income. M-R-W shows that the departure from steady states explains a larger share of income difference across countries for OECD sample than broader samples. As the convergence model accounts for out-of-steady-state dynamics, in my empirical studies I will focus on the convergence problem only.

2.2 Augmented Solow Model with the Inclusion of Human Capital

Economists have been emphasizing the role of human capital in the process of growth for a long time. In this section, I will explore the effect of human capital on economic growth.

At the empirical level, human capital can change the analysis of cross-section differences. In the equations M-R-W introduces above, human capital is an omitted variable. Now we can modify our model by including human capital as a factor of production.

M-R-W redefines the production function as

$$(13)\ Y(t) = K(t)^{\alpha} H(t)^{\varphi} (A(t)L(t))^{1-\alpha-\varphi},$$

where H is the stock of human capital, and all other variables are the same as defined before. Let s_k be the fraction of income invested in physical capital and s_h be the fraction of investment in human capital. Therefore, the evolution of the economy is determined by

$$(14a)\ \dot{k}(t) = s_k y(t) - (n + g + \delta)k(t),$$

$$(14b)\ \dot{h}(t) = s_h y(t) - (n + g + \delta)h(t),$$

where $y = Y/AL, k = K/AL$, and $h = H/AL$ are quantities per effective unit of labor. This is a very simple model with human capital. M-R-W assumes that the same production function applies to human capital, physical capital and consumption, which implies that one unit of consumption can be transformed into either one unit of physical capital or the same amount of human capital. Moreover, human capital is assumed to depreciate at the same rate as physical capital. M-R-W claims that these simple specifications are natural for an initial examination. I will discover the problems of these simple specifications in section 5.

They also assume decreasing returns to all capital, or more formally $\alpha + \varphi < 1$. By assuming the existence of a steady state, the economy converges to:

$$(15a)\ k^* = \left(\frac{s_k^{1-\varphi} s_h^{\varphi}}{n + g + \delta} \right)^{1/(1-\alpha-\varphi)},$$

$$\text{(15b)}\quad h^* = \left(\frac{s_k^{\alpha} s_h^{1-\alpha}}{n+g+\delta} \right)^{1/(1-\alpha-\varphi)} .$$

Substituting this back into the production function and taking logs produces:

$$\text{(16)}\quad \ln\left[\frac{Y(t)}{L(t)}\right] = \ln A(0) + gt - \frac{\alpha+\varphi}{1-\alpha-\varphi}\ln(n+g+\delta) + \frac{\alpha}{1-\alpha-\varphi}\ln(s_k) + \frac{\varphi}{1-\alpha-\varphi}\ln(s_h).$$

This shows that steady-state income per capita depends on the accumulation of human capital, physical capital, and population growth. α is expected to be around one third, and φ between one third and one half.

Based on the above equation, M-R-W states that human capital influences growth through two mechanisms. First, the coefficient of $\ln(s_k)$ is greater than $\alpha/(1-\alpha)$, whether $\ln(s_h)$ independent of the other right-hand side variables or not. The reason is that even if the percentage of human capital investment remains constant, a higher saving rate creates higher income, which leads to a higher steady-state level of human capital. Consequently, human capital increases the effect of physical capital on income per capita. Second, the coefficient of $\ln(n+g+\delta)$ is larger in absolute value than that of $\ln(s_k)$. Higher population growth decreases per capita income because human capital and physical capital must be spread more sparsely over the population.

In addition, the augmented Solow model with human capital predicts a slower rate of convergence than the standard model, because $\lambda = (n+g+\delta)(1-\alpha-\varphi)$ instead of $\lambda = (n+g+\delta)(1-\alpha)$. For example, if $\alpha = \varphi = 1/3$, and $n+g+\delta = 0.06$, the convergence rate would equal 0.02 in the former case, while 0.04 in the later. Basing on the rule of 72, in the former case, it takes around 35 years for an economy to move halfway to steady state, and only 17 years in the later.

Substituting equation (15b) into (16), we can express steady-state income per capita as a function of the steady-state level of human capital:

$$(17)\ \ln\left[\frac{Y(t)}{L(t)}\right] = \ln A(0) + gt - \frac{\alpha}{1-\alpha}\ln(n+g+\delta) + \frac{\alpha}{1-\alpha}\ln(s_k) + \frac{\varphi}{1-\alpha}\ln(h^*).$$

Comparing this model with the one without human capital, we can see that human capital is a component of the error term if not specified clearly as a variable in the model. If human capital is correlated with saving rates and population growth as we expect, omitting the human capital will bias the coefficients of saving rates and population growth.

Similar to M-R-W, Islam augments his panel data model by including human capital. The model he uses is as follows:

$$(18)\ \ln y(t_2) = (1-e^{-\lambda\tau})\frac{\alpha}{1-\alpha}[\ln(s_k) - \ln(n+g+\delta)] + (1-e^{-\lambda\tau})\frac{\varphi}{1-\alpha}\ln(h^*)$$

$$+e^{-\lambda\tau}\ln y(t_1) + (1-e^{-\lambda\tau})\ln A(0) + g(t_2 - e^{-\lambda\tau}t_1).$$

To calculate the structural parameters, in equation (18), he imposes the restriction that the coefficients of saving and population growth rate are equal in magnitude but opposite in sign. The rate of conditional convergence λ is calculated from the estimated coefficient of $\ln y(t_1)$, physical capital's share α from the coefficient of the restricted term, and human capital's share φ from the coefficient of $\ln(h^*)$.

In my empirical work, I focus on testing whether human capital enters significantly in my model, and after I control for human capital, whether the augmented model renders better estimates of the structural parameters, λ, α, and φ.

3. Estimation Issues And Data

Islam uses two panel data estimators in his paper: Least Squares with Dummy Variables (LSDV) estimator, and Minimum Distance (MD) estimator. The former is based on the fixed-effects assumption made earlier in the paper. One problem with LSDV is the lagged dependent variable on the right-hand side of equation. The existence of the lagged term makes the estimator inconstant, when consider the asymptotics in the direction of $N \to \infty$. Fortunately, when consider the asymptotic properties in the direction of T, LSDV proves to be consistent. Islam conducted Monte Carlo study to show that LSDV estimator performs very well. Moreover, since both estimations render similar results, I use LSDV in my experiments.

However, bear in mind that fixed effects removes unique features that could be used to explain growth. A major drawback of fixed effects estimation is that the transformation involved in this estimation process wipes out all explanatory variables that do not vary within a unit. This means that any time invariant explanatory variable disappears, so we are not able to estimate a slope coefficient for that variable. Although panel data approach corrects the mistake of the cross section, it creates a problem of its own.

3.1 Data

Summers-Heston data set makes a panel data approach possible for economic growth issues because it includes various measures of national accounts for different countries over several decades. Islam's exercise bases on Summers-Heston (1988), or PWT 4, which covers the period 1950-1985. As this data set is no longer available, in my replication, I use PWT 5 instead. Due to the merit of data integrity, I choose OECD sample for this paper. The sample consists of 22 OECD countries whose population is greater than one million.

In M-R-W, Y/L is real GDP divided by the working-age population in that year, and n the average rate of growth of the working-age population. Because of the difficulty in acquiring panel data on working-age population, Islam computes the population growth rate from the total population, and uses GDP per capita to measure Y/L. To be consistent with M-R-W, he makes $(g+\delta)$ equal to 0.05 and assumes this value to be constant for all countries over all years.[4] s_k is the investment as a percentage of GDP. I follow Islam's measures of variables in the initial replication, but use alternative measures in the sensitivity analysis.

In measuring the level of human capital, Barro and Lee (1993) construct a human capital variable, which gives the average schooling years in the total population over age 25. Islam adopts this measure. To be consistent with him, I use this measure in my initial replications as well, and use the variables of the end points of time for the respective time spans.

Figure 1 and 2 present the extent to which this measure varies across countries. Figure 1 shows the average of the values for each country over 1960 to 1985. New

[4] M-R-W makes reasonable changes to this value, but the estimates do not differ markedly.

Zealand has the highest value, which is 10.91. Portugal is the lowest, with a value of 2.42.

Figure 1: Average Years of Schooling for Each Country 1960-1985

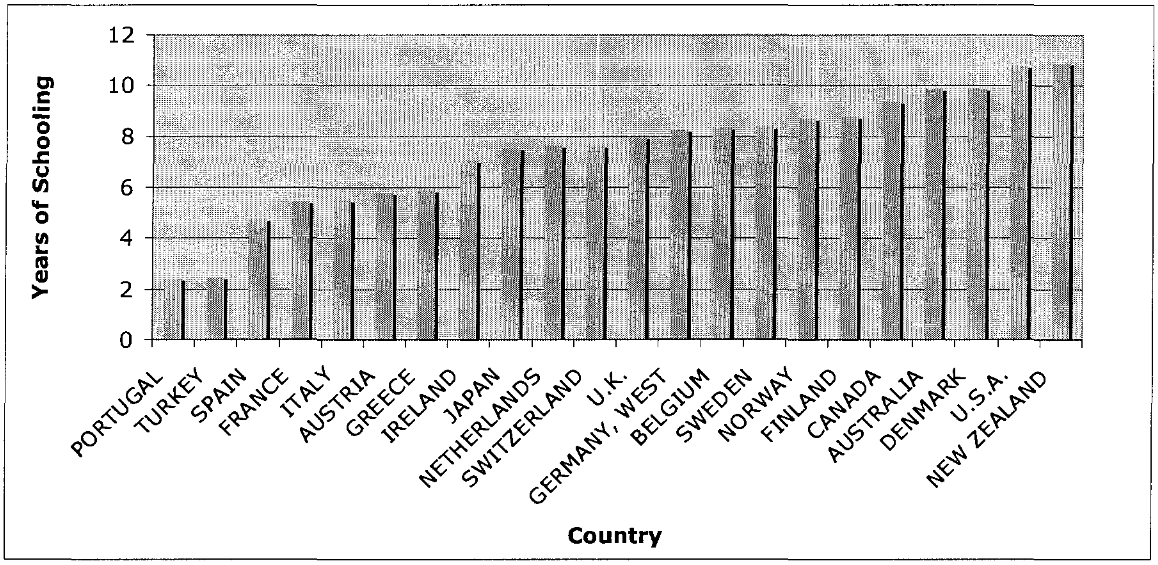
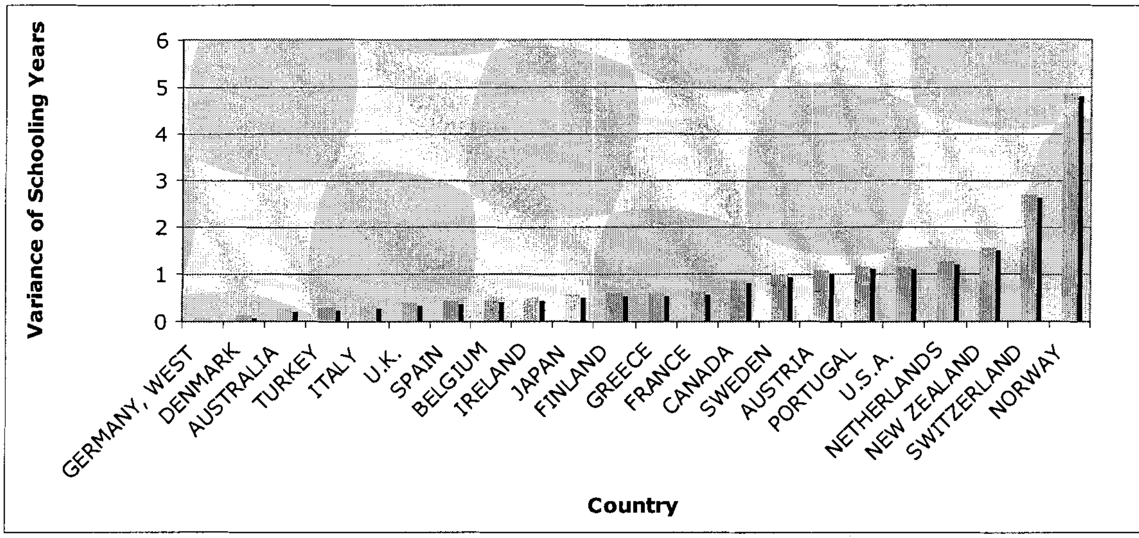


Figure 2 shows the variance of the measures for each country over the years. Most of the countries had very stable average years of schooling over the 25 years. The only exception is Norway, with a variance as large as 4.87. [5]

[5] Norway may be an unrepresentative outlier because of its oil. Experiments are conducted to drop it out. This change has little effect on the estimates.

Figure 2: Variance of Schooling Years for Each Country 1960-1985



The small variance of this measure shows that panel data, especially the fixed effects, may not be a perfect approach. It helps explain why M-R-W obtains significant human capital in the results while Islam does not. The fixed effects use variation across time within each cross-sectional unit, ignoring variation between units. In contrast, cross section uses variation across countries. The change in average years of schooling across time within a country is basically no more than one year, compared to cross-country difference, which can be as large as 10 years. The tiny variation of this measure can potentially contribute to the insignificant role human capital plays in Islam's equation.

3.2 Estimation Results

In order to see how much my results differ from those of Islam's because of differences in data set, in my first replications, I run single cross-section, pool data, and panel data regressions analogous to those conducted by him.

3.2.1. Single Cross-Section Regression

In the single cross-section regression, y_{it} is the log of per capita GDP for 1985, and $y_{i,t-1}$ the log of per capita GDP for 1960. s and n are averages of saving and population growth rates for the period 1960-1985. In order to obtain the estimates of the structural parameters, convergence rate λ, and physical capital's share α, I estimate the equations with the restriction that the coefficients of the saving and population growth variables are equal in magnitude but opposite in sign. The results are shown in Table I. For the purpose of comparison, Islam's results are also presented. The results of all the unrestricted models are presented in the appendices.

Table 1: Single Cross-Section Results (Restricted), 1960-1985: Dependent Variable is $\ln(y85)$

	Restricted	
Variable	Islam (1995)	Replication
Constant	2.6689 (0.5715)	0.2502 (1.0802)
$\ln(y60)$	0.6817 (0.0678)	0.7143 (0.0618)
$\ln(s) - \ln(n+g+\delta)$	0.4847 (0.1602)	0.4775 (0.1507)
$\overline{R}^2$	0.8524	0.8805
Implied λ	0.015327	0.013458
Implied α	0.6036	0.6257

Such a comparison shows that the results are very similar. The estimates of the coefficients of the initial GDP, saving rate, and implied physical capital's share α are especially close.

The λ estimated from the restricted estimation is almost the same as that estimated from the unrestricted estimation. The low estimates of λ shows the low rate of convergence. However, the estimate of physical capital's share α is unpleasantly high, almost double our expectation. This result suggests us to understand capital in the production function in a broader sense. The unsatisfactory estimates of the structural parameters serve as the main reason for M-R-W to go beyond the standard Solow model and add human capital into the equation.

3.2.2. Pooled Estimation

In the panel framework, Islam divides the total period into several shorter time spans. He opts for five-year time intervals. For period 1960-1985, he has five data points for each country: 1985, 1980, 1975, 1970, and 1965. For example, when $t = 1965$, $t-1 = 1960$. Saving and population growth are averages over 1961-1965.

To test whether dividing the growth period into five-year spans has any significant effect, Islam implements a pooled regression on the five-year-span data using OLS. His results and my replication results of the restricted model are listed in Table II.

Table 2: Pooled Regression From a Panel of Five-Year Span Data (Restricted): Dependent Variable is $\ln(y_{it})$

	Restricted	
Variable	Islam (1995)	Replication
$\ln(y_{i,t-1})$	0.9248 (0.0147)	0.8923 (0.0139)
$\ln(s)$ - $\ln(n+g+\delta)$	0.1184 (0.0286)	0.1172 (0.0302)
$\overline{R}^2$	0.9901	0.9752
Implied λ	0.0156	0.0228
Implied α	0.6150	0.5211

As the value of τ is different, the coefficients of this table are not directly comparable with those of Table I. We need to look at the implied values of the structural parameters, rate of convergence λ and physical capital's share α. Islam's results are very close to the corresponding estimates in Table I, but my results show slightly pleasant improvements: λ almost doubles, and α decreases.

Islam wants to use the results of the pooled regression to show "that dividing the period into shorter spans and considering the growth process over shorter consecutive intervals does not affect the results."[6] On the contrary, my results do show the difference. One possible explanation is that when we divide the period into shorter time spans, short-term disturbances may loom large. The results are more likely to be affected by business cycle fluctuations. In addition, more updated data is not necessarily more accurate. I would not cast doubt on Islam's statement impetuously because our data sets are different.

Despite the noticeable improvement, the estimated rate of conditional convergence is still very low, and the capital's share very high.

3.2.3. LSDV: Estimation with Fixed Effects

The results of the LSDV estimation are shown in Table III. Again, I focus on the estimates of the structural parameters.

[6] Islam (1995) page 1143.

Table 3: LSDV Estimation with Fixed Effects (Restricted): Dependent Variable is $\ln(y_{it})$

	Restricted	
Variable	Islam (1995)	Replication
$\ln(y_{i,t-1})$	0.6294 (0.0495)	0.7548 (0.0203)
$\ln(s) - \ln(n+g+\delta)$	0.0954 (0.0581)	0.1298 (0.0576)
$\overline{R}^2$	0.9642	0.9885
Implied λ	0.0926	0.0563
Implied α	0.2047	0.3462

Islam's LSDV estimates for the OECD sample differ from the corresponding MD estimates. He explains that the direction in which they differ accentuates the qualitative properties of panel data estimation results. My results are quite similar to Islam's MD estimates. Again, a possible reason is the difference in the source of data. However, my results show significant improvements over pooled estimation. I obtain much higher rate of convergence, and the estimate of the physical capital's share is more in conformity with its commonly accepted empirical value. From this finding, we can conclude that panel approach helps to render better results.

3.2.4. Estimation with Human Capital

Results obtained from inclusion of the human capital variable in the single cross-section, pooled regression, and panel estimation are in table IV.

Table 4: Estimation with Human Capital

	Single Cross Section		**Pooled Regression**		**Panel Estimation**	
	Islam	Replication	Islam	Replication	Islam	Replication
$\ln(h)$	0.0864 (0.1551)	0.1846 (0.1421)	0.0034 (0.0268)	0.0616 (0.0266)	-0.0208 (0.0449)	0.0154 (0.0530)
Implied λ	0.0187	0.0207	0.0162	0.0328	0.0913	0.0580
Implied α	0.5416	0.5073	0.6016	0.4190	0.2074	0.3400
Implied φ	0.1062	0.2251	0.0174	0.2365	-0.0450	0.0403

Comparing the results of the first columns with the ones I obtain from the standard Solow model, we can see that the augmented Solow model does provide higher rates of convergence, and lower value of physical capital's share. However, human capital variable fails to enter significantly. Even in M-R-W's work, when they try to determine the convergence rate, human capital is insignificant. My estimates of implied φ, the exponent for the human capital, are close to what is estimated by M-R-W.

In the pooled estimation, human capital proves to be significant. I also obtain higher rate of convergence, and more empirically plausible estimates of physical capital's share α, and human capital's share φ. My results differ significantly from what Islam obtains, which are similar to what he gets from single cross-section estimation without the human capital. He mentions that "incorporation of the time dimension of the human capital variable into the analysis annihilates the effect that the cross-sectional variation in human capital had on the regression results."[7] My findings contradict his conjecture. My results suggest that pooled regression does render better estimates of parameters, and inclusion of human capital does improve the performance of the Solow model. Similar to our previous discussion about the variation within and between units, pooled data is an unweighted average of the within and between estimators. It represents some of the cross-sectional difference in human capital, which improves the significance of human capital in economic growth.

However, in the panel estimation, human capital variable loses its significance. The estimate of human capital's share is negligible too. However, I attain better estimates of the convergence rate and physical capital's share. Despite the insignificance of the

[7] Islam (1995) page 1152.

human capital variable, the effect of controlling for the difference in the technology term remains robust.

4. Sensitivity Analysis

In the following sections, I will test the robustness of my estimates when I use alternative measures of variables to estimate, or extend the observation period.

4.1 Alternative measure of Y/L

L represents labor force instead of the whole population in the model. Changes in the labor force may be the result of changes of population happening 15 years ago. The asynchronous movements and the difference in magnitude of these two variables show that using per capita GDP to gauge Y/L is questionable, even though how it changes the result is to be discovered. M-R-W uses real GDP divided by the working-age population in that year to measure Y/L, which we think should be more accurate. Summers and Heston data set provides data for real GDP per worker. I use real GDP per worker to run all the regressions again, and see how my new results differ from what I obtain before. The results from the restricted regressions are presented in Table V.

Table 5: Results of the Restricted Regressions When Real GDP per Worker was Used

	Table I	Table II	Table III	Table IV		
Restricted				Single	Pool	Panel
Constant	1.7533 (1.0524)					
$\ln(y_{i,t-1})$	0.5930 (0.0567)	0.8517 (0.0149)	0.6962 (0.0211)			
$\ln(s)$ - $\ln(n+g+\delta)$	0.4446 (0.1428)	0.1105 (0.0315)	0.1072 (0.0581)			
$\ln(h)$				0.1394 (0.1395)	0.0431 (0.0269)	-0.0469 (0.0504)
$\overline{R}^2$	0.8578	0.9687	0.9865	0.8653	0.9694	0.9867
Implied λ	0.0209	0.0321	0.0724	0.0273	0.0394	0.0668
Implied α	0.5221	0.4269	0.2608	0.4425	0.3663	0.2731
Implied φ				0.1572	0.1526	-0.1201

Real GDP per worker does show some advantages over per capita GDP, but in a very small order. For table I, the convergence rate is higher, and capital's share smaller. The convergence rates attain from unrestricted model and restricted model are very close. The same is true for all the other tables. For Table IV, the human capital variable loses its significant in pooled regression. It even appears with a wrong sign in the panel regression. As a result, human capital's share φ enters negatively too. This is similar to what Islam gets.

Notice that even though we might expect labor force estimate to be a superior measure of the labor force of a country than population as a proxy, the accuracy of this measure is suspicious, especially in less developed countries where workers in agriculture sector may not be included in labor force. We would not be surprised if this measure does not provide us with better results.

4.2 Extending the Observation Period

Islam chooses the period 1960-1985. As more updated data set, which is PWT6, is available, I extend my empirical work to 1960-2000. The results can be seen in Table VI.

Table 6: Results of the Restricted Regressions when Period is extended to 1960-2000

	Table I	Table II	Table III	Table IV		
Restricted				Single	Pool	Panel
Constant	2.7818 (1.3385)					
$\ln(y_{i,t-1})$	0.5314 (0.1111)	0.8916 (0.0117)	0.8661 (0.0167)			
$\ln(s)$ - $\ln(n+g+\delta)$	0.3876 (0.2061)	0.1248 (0.0220)	0.1264 (0.0431)			
$\ln(h)$				0.5518 (0.2555)	0.0720 (0.0267)	0.1095 (0.0627)
$\overline{R}^2$	0.6652	0.9739	0.9789	0.7373	0.9748	0.9791
Implied λ	0.0253	0.0229	0.0287	0.0741	0.0335	0.0398
Implied α	0.4527	0.5353	0.4856	0.3150	0.4471	0.4015
Implied φ				0.4482	0.2581	0.3636

Surprisingly, estimated rates of convergence are very stable for the first three tables. The implied physical capital's share α does not differ much either. Panel data approach seems to lose its advantage here. When I include human capital in the model, appealing results are found. I achieved statistical significance on the coefficients of human capital variable in both the single cross-section and the pooled regression. t-statistics for the panel data is also able to reach 1.74. This is quite surprising since few of the results I acquire so far suggests the significance of human capital in economic growth. Moreover, the single cross-section regression renders very good results: the convergence rate is very high, and the physical and human capital's shares are exactly what we expect. The estimates of the structural parameters in the last regression are not as good. Even though, the estimated human capital's share φ is still significant in magnitude, and close to our expectation.

The above results are obtained by using per capita GDP as Y/L. I also use GDP per worker as Y/L to compare. The results are presented in the Appendix. The estimates are better than what I obtain here, but there is no notable difference. Moreover, in the augmented model, human capital variable enters insignificantly in all three estimations.

4.3 Alternative Measure of Human Capital

As pointed out by Hanushek and Kimko(2000), one problem with human capital measured by average years of schooling comes from the lack of adjustment for schooling quality. It is not reasonable to assume that a year of secondary schooling in the United States is equivalent to a year at the same grade level in Egypt. Alternative measures of human capital should be suggested and implemented.

In the following experiment, I use education expenditure as percentage of GNI (formerly GNP) as the measure of human capital. The data is estimated by World Bank staff using data from the United Nations Statistics Division's Statistical Yearbook, and the UNESCO Institute for Statistics online database. Since this is a measure of human capital accumulation, we need to revise equation (18) to express income per capita in terms of human capital accumulation instead of the level of human capital. Substituting equation (15b) into (18), the revision is demonstrated in equation (19).

$$(19)\ \ln y(t_2) = (1-e^{-\lambda\tau})\frac{\alpha}{1-\alpha-\varphi}\ln(s_k) - (1-e^{-\lambda\tau})\frac{\alpha+\varphi}{1-\alpha-\varphi}\ln(n+g+\delta)]$$

$$+(1-e^{-\lambda\tau})\frac{\varphi}{1-\alpha-\varphi}\ln(s_h) + e^{-\lambda\tau}\ln y(t_1) + (1-e^{-\lambda\tau})\ln A(0) + g(t_2 - e^{-\lambda\tau}t_1).$$

Equation (19) is a panel data version of equation (16), in the same way that equation (18) is the panel version of (17). Equation (18) and equation (19) are interchangeable. In our empirical work, we only need to care whether the available data is more closely related to the rate of accumulation or the level of human capital. However, notice that the coefficients of the variables are different. Structural parameters are once again our focus of interest.

To calculate the structural parameters, I run the following restricted regression:

$$(20)\ \ln y(t_2) = (1-e^{-\lambda\tau})\frac{\alpha}{1-\alpha-\varphi}[\ln(s_k) - \ln(n+g+\delta)]$$

$$+(1-e^{-\lambda\tau})\frac{\varphi}{1-\alpha-\varphi}[\ln(s_h) - \ln(n+g+\delta)]$$

$$+e^{-\lambda\tau}\ln y(t_1) + (1-e^{-\lambda\tau})\ln A(0) + g(t_2 - e^{-\lambda\tau}t_1).$$

As older data is not available, I estimate the equation using the data from 1970 to 2000. Another change from the previous replication is the use of the averages of human capital for the respective time spans, instead of the values of the end points of time. The results are presented in Table VII.

Table 7: Results of Regressions When Human Capital Investment is used

	Single Cross-Section	Pooled Estimation	Panel Estimation
$\ln(s_h)$	0.4542 (0.1322)	0.04252 (0.0202)	-0.0075 (0.0368)
Implied λ	0.0543	0.0177	0.0045
Implied α	0.3072	0.4329	0.8647
Implied φ	0.2629	0.1898	0.0681

The new variable improves the significance of the human capital variable in the single cross-section regression. The estimates of the structural parameters are satisfactory too. The estimated rate of convergence is high, and capital's shares are plausible. The results I obtain from pooled estimation are less appealing, but still, human capital investment variable is statistically significant. Again, when I include human capital variables in my model, panel estimation seems to be powerless. The estimate of the parameter of human capital investment is negative in sign, and all structural parameters take unreasonable values.

The incorporation of the temporal dimension of human capital variables into growth regression always renders anomalous results. Earlier in his paper, I try to explain this phenomenon by focusing on the drawbacks of the panel data estimation and human capital measured by average years of schooling. Another possible explanation is brought out by Islam. He explains that measured by education expenditure, or rates such as enrollment rates, many countries, especially less developed countries, have made great progress, but the true level of human capital may not improve as much. The negative temporal relationship between human capital variable and economic growth in these countries outweigh the positive cross-sectional relationship.

This reminds us of the difference between the theoretical human capital variable and the actual variable used in regression. Traditional proxies of human capital are in the form of education. Measuring education investment is not as easy as we expect because spending on education takes place at all levels of economic subjects. Moreover, not all spending on education can yield productive human capital, such as philosophy, and literature. Problems exist in other measures of human capital too. Hanushek and Kimko(2000) construct new measures of quality based on student cognitive performance on some international exams of academic achievement in mathematics and science. They believe that employing direct cognitive skill measures has the significant advantage of permitting quality differences to arise from factors outside of formal schools. However they admit that important aspects of the relevant human capital are only partially measured by cognitive tests. Human capital has also been proxied in the literature by literacy. Using literacy as a proxy for human capital stock will trigger empirical problems too. For example, the OECD sample consists mostly of developed countries. Developed countries tend to have literacy rates close to unity. Quality of measurement differs across countries as well. Overall, measurement of human capital shows great empirical difficulties, thus leads to potential inaccuracy of estimation. Unless we can find a comprehensive measure that perfectly represents human capital, it is unlikely that we can achieve better results by simply sticking to the augmented Solow model.

5. One Possible Improvement

The "anomalous" results attained above shed some doubt on the role of human capital in economic growth. Nelson and Phelps (1996) point out that we may misspecify the role of human capital by simply treating it as another factor of production. Therefore, one possible improvement is a better specification of the production function with respect to human capital. Endogenous growth theory models technological progress as a function of the level of education since education is believed to help the labor force create, adopt, and implement new technologies. Benhabib and Spiegel (1994) make a very good attempt in this direction.

They use estimates of human and physical capital stocks to analyze cross-country evidence on the determinants of economic growth. Similar to Islam (1995), they start from a standard Cobb-Douglas production function. They find that human capital growth has insignificant, and sometimes even negative impact on determining income growth. To test the robustness of the results, they experiment with both alternative data, such as human capital variables from Kyriacou (1991), Barro and Lee (1993), and literacy data, and alterative samples. Human capital enters insignificantly and with the wrong sign in all experiments. The results also exhibit stability with respect to the inclusion of a variety of ancillary variables.

As a result, Benhabib and Spiegel adopt an alternative model. The model allows human capital to influence technological progress through two channels: by directly affecting the ability of countries to innovate new technologies, and by affecting technological catch-up and diffusion between countries.

They also propose a specific model. They assume a Cobb-Douglas technology, $Y_t = A_t(H_t)K_t^{\alpha}L_t^{\beta}$, and take log difference. The relationship for long-term growth from time 0 to T is:

$$(21)\ (\log Y_T - \log Y_0) = [\log A_T(H_t) - \log A_0(H_t)] + \alpha(\log K_T - \log K_0)$$
$$+\beta(\log L_T - \log L_0) + (\log \varepsilon_T - \log \varepsilon_0)$$

Basing on their assumption, the technological growth can be specified as:

$$(22)\ [\log A_T(H_t) - \log A_0(H_t)]_i = c + gH_i + mH_i[(Y_{\max} - Y_i)/Y_i],$$

where c represents exogenous technological progress, gH_i represents endogenous technological progress associated with the capability of a country to innovate new technologies domestically, which is a function of human capital, and $mH_i[Y_{\max} - Y_i)/Y_i]$ represents the diffusion of technology from technology leader, which is also a function of human capital. The "domestic innovation" term shows that human capital independently accelerates technology, while the "catch-up" term indicates that keeping human capital levels constant, countries starting with low levels of productivity will experience faster rates of growth of technology. (This is different from the concept of convergence in the standard Solow model.) Substituting Equation (22) into Equation (21), they estimate the following model:

$$(23)\ (\log Y_T - \log Y_0) = c + (g - m)H_i + mH_i(Y_{\max}/Y_i) + \alpha(\log K_T - \log K_0)$$
$$+\beta(\log L_T - \log L_0) + (\log \varepsilon_T - \log \varepsilon_0).$$

The results confirm that per capita income growth depends positively on human capital, and assign a positive role to the level of human capital in economic growth. However, they also mention that the relative importance of the "catch-up" term $[H(Y_{max}/Y)]$ and the "domestic innovation" term H may change with the relative position of the countries. For technologically advanced countries, innovation of domestic technology may be more effective than technology imported from abroad. They divide the samples basing on per capita income, and find out that for the richest countries, "domestic innovation" term H enters positively and significantly, but the "catch-up" term $[H(Y_{max}/Y)]$ is relatively less important, entering insignificantly, and with an estimated coefficient close to zero. The "catch-up" term is the main difference between the previously introduced model and this one. As OECD countries are comparatively rich and technologically advanced countries, I am not going to use my sample to estimate this model. I would not expect the "catch-up" term to provide me with appealing results. Moreover, Y_{max}/Y may not be too much different from one, H and $[H(Y_{max}/Y)]$ might be highly correlated. It will be dangerous to run a regression like that.

Suggested by Benhabib and Spiegel, another role that human capital may play is as an agent in attracting other production factors, such as physical capital. Lucas (1990) shows that the relatively poor endowments of human capital in poor countries inhibit physical capital from flowing to these countries. Benhabib and Spiegel verify the role for human capital as an engine in attracting physical capital by showing that the stocks of human capital and physical capital are positively correlated for all specifications.

Overall, Benhabib and Spiegel present a very promising model to analyze the role of human capital in economic growth. We can conclude that when better specification of the model is developed, we can empirically prove the influential role human capital plays in growth.

6. Conclusion

Human capital has long been considered an important factor in economic growth. I believe that the inclusion of human capital may help the Solow model explain international income differences, as well as the issue of convergence. However, how it affects economic development is not yet clear.

My first experiment includes the human capital variable in the standard Solow growth model as a factor of production. The results show that the human capital variable enters insignificantly. When I employ a panel data approach to correct the potential mistakes that OLS might have, the coefficient of the human capital variable appears with the wrong sign. However, the effect of accounting for the difference in the $A(0)$ term is robust. The estimates of the structural parameters succeed to present better values: I obtain higher estimated rates of convergence and empirically more plausible values of capital's shares.

Further experiments employ sensitivity analyses to test the robustness of the results to a variety of specification alterations such as different measures of variables and different time periods. Similar results are attained.

As a result, I introduce an alternative model, where human capital influences economic growth through two channels: first, it directly affects the rate of domestic technology innovation, and second, it affects the speed of technology adoption from abroad. Empirical work shows more positive role for human capital in this model.

Human capital affects economic growth through several channels. Only when we discover most of these channels and specify better models to describe them, can we verify the empirical significance of human capital in influencing growth.

Appendices

Appendix A: Results from the Unrestricted Restricted Regressions

Single Cross-Section Results, 1960-1985: Dependent Variable is $\ln(y85)$

	Unrestricted	
Variable	Islam (1995)	Replication
Constant	1.7433 (1.2655)	0.0840 (1.2440)
$\ln(y60)$	0.6722 (0.0694)	0.7103 (0.0648)
$\ln(s)$	0.4114 (0.1845)	0.4423 (0.1957)
$\ln(n+g+\delta)$	-0.8021 (0.4187)	-0.5878 (0.4069)
$\overline{R}^2$	0.8499	0.8810
Implied λ	0.015887	0.013683

Pooled Regression from a Panel of Five-Year Span Data: Dependent Variable is $\ln(y_{it})$

	Unrestricted	
Variable	Islam (1995)	Replication
$\ln(y_{i,t-1})$	0.9228 (0.0147)	0.8951 (0.0144)
$\ln(s)$	0.1047 (0.0313)	0.1294 (0.0349)
$\ln(n+g+\delta)$	-0.1799 (0.0653)	-0.0731 (0.0696)
$\overline{R}^2$	0.9807	0.9753
Implied λ	0.0161	0.0221

LSDV Estimation with Fixed Effects: Dependent Variable is $\ln(y_{it})$

	Unrestricted	
Variable	Islam (1995)	Replication
$\ln(y_{i,t-1})$	0.5864 (0.0532)	0.753415 (0.022177)
$\ln(s)$	0.1215 (0.0586)	0.127957 (0.059065)
$\ln(n+g+\delta)$	-0.0698 (0.1007)	-0.143744 (0.103398)
$\overline{R}^2$	0.9659	0.988530
Implied λ	0.1067	0.0566

Appendix B: Results from Sensitivity Analysis

Results of the Unrestricted Regressions When Real GDP per Worker was Used

Restricted	Table I	Table II	Table III
Constant	1.5952 (1.1993)		
$\ln(y_{i,t-1})$	0.5892 (0.0594)	0.8570 (0.0154)	0.7080 (0.0223)
$\ln(s)$	0.4101 (0.1857)	0.1336 (0.0362)	0.1235 (0.0587)
$\ln(n+g+\delta)$	-0.5517 (0.3840)	-0.0279 (0.0720)	0.0186 (0.1019)
$\overline{R}^2$	0.8585	0.9692	0.9869
Implied λ	0.0212	0.0309	0.0691

Results of the Unrestricted Regressions when Period is extended to 1960-2000

Unrestricted	Table I	Table II	Table III
Constant	1.5735 (1.7198)		
$\ln(y_{i,t-1})$	0.5387 (0.1106)	0.8939 (0.0123)	0.8724 (0.0192)
$\ln(s)$	0.1639 (0.2875)	0.1329 (0.0255)	0.1351 (0.0451)
$\ln(n+g+\delta)$	-1.0393 (0.6227)	-0.0904 (0.0593)	-0.0672 (0.0984)
$\overline{R}^2$	0.6877	0.9740	0.9789
Implied λ	0.0247	0.0224	0.0273

Results of the Regressions when Period is Extended to 1960-2000, and Y/L as real GDP per worker

	Table I	Table II	Table III	Table IV		
Unrestricted				Single	Pool	Panel
Constant	2.6085 (1.8229)					
$\ln(y_{i,t-1})$	0.4283 (0.1173)	0.8620 (0.0139)	0.8353 (0.0215)			
$\ln(s)$	-0.0379 (0.3048)	0.1234 (0.0270)	0.1274 (0.0466)			
$\ln(n+g+\delta)$	-1.5162 (0.6601)	-0.1280 (0.0639)	-0.0304 (0.1036)			
$\overline{R}^2$	0.5921	0.9656	0.9730			
Implied λ	0.0339	0.0297	0.0360			
Restricted						
Constant	4.1154 (1.4226)					
$\ln(y_{i,t-1})$	0.4333 (0.1066)	0.8623 (0.0132)	0.8261 (0.0190)			
$\ln(s)$ - $\ln(n+g+\delta)$	0.3764 (0.2090)	0.1242 (0.0232)	0.1164 (0.0451)			
$\ln(h)$				0.2392 (0.2438)	0.0339 (0.0260)	0.1216 (0.0624)
$\overline{R}^2$	0.5865	0.9656	0.9729	0.6089	0.9657	0.9734
Implied λ	0.0335	0.0296	0.0382	0.0491	0.0348	0.0519
Implied α	0.3991	0.4743	0.4010	0.3339	0.4354	0.3306
Implied φ				0.2253	0.1199	0.3563

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