A Contribution to the Empirics of Economic Growth
Author(s): N. Gregory Mankiw, David Romer, David N. Weil
Source: *The Quarterly Journal of Economics*, Vol. 107, No. 2 (May, 1992), pp. 407-437
Published by: Oxford University Press
Stable URL: http://www.jstor.org/stable/2118477
Accessed: 11/04/2011 05:37

A CONTRIBUTION TO THE EMPIRICS OF ECONOMIC GROWTH*

N. GREGORY MANKIW
DAVID ROMER
DAVID N. WEIL

This paper examines whether the Solow growth model is consistent with the international variation in the standard of living. It shows that an augmented Solow model that includes accumulation of human as well as physical capital provides an excellent description of the cross-country data. The paper also examines the implications of the Solow model for convergence in standards of living, that is, for whether poor countries tend to grow faster than rich countries. The evidence indicates that, holding population growth and capital accumulation constant, countries converge at about the rate the augmented Solow model predicts.

INTRODUCTION

This paper takes Robert Solow seriously. In his classic 1956 article Solow proposed that we begin the study of economic growth by assuming a standard neoclassical production function with decreasing returns to capital. Taking the rates of saving and population growth as exogenous, he showed that these two variables determine the steady-state level of income per capita. Because saving and population growth rates vary across countries, different countries reach different steady states. Solow's model gives simple testable predictions about how these variables influence the steady-state level of income. The higher the rate of saving, the richer the country. The higher the rate of population growth, the poorer the country.

This paper argues that the predictions of the Solow model are, to a first approximation, consistent with the evidence. Examining recently available data for a large set of countries, we find that saving and population growth affect income in the directions that Solow predicted. Moreover, more than half of the cross-country variation in income per capita can be explained by these two variables alone.

Yet all is not right for the Solow model. Although the model correctly predicts the directions of the effects of saving and

*We are grateful to Karen Dynan for research assistance, to Laurence Ball, Olivier Blanchard, Anne Case, Lawrence Katz, Robert King, Paul Romer, Xavier Sala-i-Martin, Amy Salsbury, Robert Solow, Lawrence Summers, Peter Temin, and the referees for helpful comments, and to the National Science Foundation for financial support.

The Quarterly Journal of Economics, May 1992

population growth, it does not correctly predict the magnitudes. In the data the effects of saving and population growth on income are too large. To understand the relation between saving, population growth, and income, one must go beyond the textbook Solow model.

We therefore augment the Solow model by including accumulation of human as well as physical capital. The exclusion of human capital from the textbook Solow model can potentially explain why the estimated influences of saving and population growth appear too large, for two reasons. First, for any given rate of human-capital accumulation, higher saving or lower population growth leads to a higher level of income and thus a higher level of human capital; hence, accumulation of physical capital and population growth have greater impacts on income when accumulation of human capital is taken into account. Second, human-capital accumulation may be correlated with saving rates and population growth rates; this would imply that omitting human-capital accumulation biases the estimated coefficients on saving and population growth.

To test the augmented Solow model, we include a proxy for human-capital accumulation as an additional explanatory variable in our cross-country regressions. We find that accumulation of human capital is in fact correlated with saving and population growth. Including human-capital accumulation lowers the estimated effects of saving and population growth to roughly the values predicted by the augmented Solow model. Moreover, the augmented model accounts for about 80 percent of the cross-country variation in income. Given the inevitable imperfections in this sort of cross-country data, we consider the fit of this simple model to be remarkable. It appears that the augmented Solow model provides an almost complete explanation of why some countries are rich and other countries are poor.

After developing and testing the augmented Solow model, we examine an issue that has received much attention in recent years: the failure of countries to converge in per capita income. We argue that one should not expect convergence. Rather, the Solow model predicts that countries generally reach different steady states. We examine empirically the set of countries for which nonconvergence has been widely documented in past work. We find that once differences in saving and population growth rates are accounted for, there is convergence at roughly the rate that the model predicts.

Finally, we discuss the predictions of the Solow model for international variation in rates of return and for capital movements. The model predicts that poor countries should tend to have higher rates of return to physical and human capital. We discuss various evidence that one might use to evaluate this prediction. In contrast to many recent authors, we interpret the available evidence on rates of return as generally consistent with the Solow model.

Overall, the findings reported in this paper cast doubt on the recent trend among economists to dismiss the Solow growth model in favor of endogenous-growth models that assume constant or increasing returns to scale in capital. One can explain much of the cross-country variation in income while maintaining the assumption of decreasing returns. This conclusion does not imply, however, that the Solow model is a complete theory of growth: one would like also to understand the determinants of saving, population growth, and worldwide technological change, all of which the Solow model treats as exogenous. Nor does it imply that endogenous-growth models are not important, for they may provide the right explanation of worldwide technological change. Our conclusion does imply, however, that the Solow model gives the right answers to the questions it is designed to address.

I. The Textbook Solow Model

We begin by briefly reviewing the Solow growth model. We focus on the model's implications for cross-country data.

A. The Model

Solow's model takes the rates of saving, population growth, and technological progress as exogenous. There are two inputs, capital and labor, which are paid their marginal products. We assume a Cobb-Douglas production function, so production at time t is given by

$$Y(t) = K(t)^{\alpha}(A(t)L(t))^{1-\alpha} \qquad 0 < \alpha < 1. \tag{1}$$

The notation is standard: Y is output, K capital, L labor, and A the level of technology. L and A are assumed to grow exogenously at rates n and g:

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

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

The number of effective units of labor, $A(t)L(t)$, grows at rate $n + g$.

The model assumes that a constant fraction of output, s, is invested. Defining k as the stock of capital per effective unit of labor, $k = K/AL$, and y as the level of output per effective unit of labor, $y = Y/AL$, the evolution of k is governed by

$$\dot{k}(t) = sy(t) - (n + g + \delta)k(t) = sk(t)^{\alpha} - (n + g + \delta)k(t), \tag{4}$$

where δ is the rate of depreciation. Equation (4) implies that k converges to a steady-state value k^* defined by $sk^{*\alpha} = (n + g + \delta)k^*$, or

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

The steady-state capital-labor ratio is related positively to the rate of saving and negatively to the rate of population growth.

The central predictions of the Solow model concern the impact of saving and population growth on real income. Substituting (5) into the production function and taking logs, we find that steady-state income per capita is

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

Because the model assumes that factors are paid their marginal products, it predicts not only the signs but also the magnitudes of the coefficients on saving and population growth. Specifically, because capital's share in income (α) is roughly one third, the model implies an elasticity of income per capita with respect to the saving rate of approximately 0.5 and an elasticity with respect to $n + g + \delta$ of approximately -0.5.

B. Specification

The natural question to consider is whether the data support the Solow model's predictions concerning the determinants of standards of living. In other words, we want to investigate whether real income is higher in countries with higher saving rates and lower in countries with higher values of $n + g + \delta$.

We assume that g and δ are constant across countries. g reflects primarily the advancement of knowledge, which is not country-specific. And there is neither any strong reason to expect depreciation rates to vary greatly across countries, nor are there any data that would allow us to estimate country-specific depreciation rates. In contrast, the $A(0)$ term reflects not just technology but resource endowments, climate, institutions, and so on; it may therefore differ across countries. We assume that

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

where a is a constant and ϵ is a country-specific shock. Thus, log income per capita at a given time—time 0 for simplicity—is

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

Equation (7) is our basic empirical specification in this section.

We assume that the rates of saving and population growth are independent of country-specific factors shifting the production function. That is, we assume that s and n are independent of ϵ. This assumption implies that we can estimate equation (7) with ordinary least squares (OLS).[1]

There are three reasons for making this assumption of independence. First, this assumption is made not only in the Solow model, but also in many standard models of economic growth. In any model in which saving and population growth are endogenous but preferences are isoelastic, s and n are unaffected by ϵ. In other words, under isoelastic utility, permanent differences in the level of technology do not affect saving rates or population growth rates.

Second, much recent theoretical work on growth has been motivated by informal examinations of the relationships between saving, population growth, and income. Many economists have asserted that the Solow model cannot account for the international differences in income, and this alleged failure of the Solow model has stimulated work on endogenous-growth theory. For example, Romer [1987, 1989a] suggests that saving has too large an influence on growth and takes this to be evidence for positive externalities from capital accumulation. Similarly, Lucas [1988] asserts that variation in population growth cannot account for any substantial variation in real incomes along the lines predicted by the Solow model. By maintaining the identifying assumption that s and n are independent of ϵ, we are able to determine whether systematic examination of the data confirms these informal judgments.

1. If s and n are endogenous and influenced by the level of income, then estimates of equation (7) using ordinary least squares are potentially inconsistent. In this case, to obtain consistent estimates, one needs to find instrumental variables that are correlated with s and n, but uncorrelated with the country-specific shift in the production function ϵ. Finding such instrumental variables is a formidable task, however.

Third, because the model predicts not just the signs but also the magnitudes of the coefficients on saving and population growth, we can gauge whether there are important biases in the estimates obtained with OLS. As described above, data on factor shares imply that, if the model is correct, the elasticities of Y/L with respect to s and $n + g + \delta$ are approximately 0.5 and -0.5. If OLS yields coefficients that are substantially different from these values, then we can reject the joint hypothesis that the Solow model and our identifying assumption are correct.

Another way to evaluate the Solow model would be to *impose* on equation (7) a value of α derived from data on factor shares and then to ask how much of the cross-country variation in income the model can account for. That is, using an approach analogous to "growth accounting," we could compute the fraction of the variance in living standards that is explained by the mechanism identified by the Solow model.[2] In practice, because we do not have exact estimates of factor shares, we do not emphasize this growth-accounting approach. Rather, we estimate equation (7) by OLS and examine the plausibility of the implied factor shares. The fit of this regression shows the result of a growth-accounting exercise performed with the estimated value of α. If the estimated α differs from the value obtained a priori from factor shares, we can compare the fit of the estimated regression with the fit obtained by imposing the a priori value.

C. Data and Samples

The data are from the Real National Accounts recently constructed by Summers and Heston [1988]. The data set includes real income, government and private consumption, investment, and population for almost all of the world other than the centrally planned economies. The data are annual and cover the period 1960–1985. We measure n as the average rate of growth of the working-age population, where working age is defined as 15 to 64.[3] We measure s as the average share of real investment (including

2. In standard growth accounting, factor shares are used to decompose growth over time in a single country into a part explained by growth in factor inputs and an unexplained part—the Solow residual—which is usually attributed to technological change. In this cross-country analogue, factor shares are used to decompose variation in income across countries into a part explained by variation in saving and population growth rates and an unexplained part, which could be attributed to international differences in the level of technology.

3. Data on the fraction of the population of working age are from the World Bank's *World Tables* and the 1988 *World Development Report*.

government investment) in real GDP, and Y/L as real GDP in 1985 divided by the working-age population in that year.

We consider three samples of countries. The most comprehensive consists of all countries for which data are available other than those for which oil production is the dominant industry.[4] This sample consists of 98 countries. We exclude the oil producers because the bulk of recorded GDP for these countries represents the extraction of existing resources, not value added; one should not expect standard growth models to account for measured GDP in these countries.[5]

Our second sample excludes countries whose data receive a grade of "D" from Summers and Heston or whose populations in 1960 were less than one million. Summers and Heston use the "D" grade to identify countries whose real income figures are based on extremely little primary data; measurement error is likely to be a greater problem for these countries. We omit the small countries because the determination of their real income may be dominated by idiosyncratic factors. This sample consists of 75 countries.

The third sample consists of the 22 OECD countries with populations greater than one million. This sample has the advantages that the data appear to be uniformly of high quality and that the variation in omitted country-specific factors is likely to be small. But it has the disadvantages that it is small in size and that it discards much of the variation in the variables of interest.

See the Appendix for the countries in each of the samples and the data.

D. Results

We estimate equation (7) both with and without imposing the constraint that the coefficients on $\ln(s)$ and $\ln(n + g + \delta)$ are equal in magnitude and opposite in sign. We assume that $g + \delta$ is 0.05; reasonable changes in this assumption have little effect on the estimates.[6] Table I reports the results.

4. For purposes of comparability, we restrict the sample to countries that have not only the data used in this section, but also the data on human capital described in Section II.

5. The countries that are excluded on this basis are Bahrain, Gabon, Iran, Iraq, Kuwait, Oman, Saudi Arabia, and the United Arab Emirates. In addition, Lesotho is excluded because the sum of private and government consumption far exceeds GDP in every year of the sample, indicating that labor income from abroad constitutes an extremely large fraction of GNP.

6. We chose this value of $g + \delta$ to match the available data. In U. S. data the capital consumption allowance is about 10 percent of GNP, and the capital-output ratio is about three, which implies that δ is about 0.03; Romer [1989a, p. 60] presents a calculation for a broader sample of countries and concludes that δ is

TABLE I
ESTIMATION OF THE TEXTBOOK SOLOW MODEL

Dependent variable: log GDP per working-age person in 1985			
Sample:	Non-oil	Intermediate	OECD
Observations:	98	75	22
CONSTANT	5.48	5.36	7.97
	(1.59)	(1.55)	(2.48)
ln(I/GDP)	1.42	1.31	0.50
	(0.14)	(0.17)	(0.43)
$\ln(n + g + \delta)$	−1.97	−2.01	−0.76
	(0.56)	(0.53)	(0.84)
$\overline{R}^2$	0.59	0.59	0.01
s.e.e.	0.69	0.61	0.38
Restricted regression:			
CONSTANT	6.87	7.10	8.62
	(0.12)	(0.15)	(0.53)
$\ln(I/GDP) - \ln(n + g + \delta)$	1.48	1.43	0.56
	(0.12)	(0.14)	(0.36)
$\overline{R}^2$	0.59	0.59	0.06
s.e.e.	0.69	0.61	0.37
Test of restriction:			
p-value	0.38	0.26	0.79
Implied α	0.60	0.59	0.36
	(0.02)	(0.02)	(0.15)

Note. Standard errors are in parentheses. The investment and population growth rates are averages for the period 1960–1985. $(g + \delta)$ is assumed to be 0.05.

Three aspects of the results support the Solow model. First, the coefficients on saving and population growth have the predicted signs and, for two of the three samples, are highly significant. Second, the restriction that the coefficients on $\ln(s)$ and $\ln(n + g + \delta)$ are equal in magnitude and opposite in sign is not rejected in any of the samples. Third, and perhaps most important, differences in saving and population growth account for a large fraction of the cross-country variation in income per capita. In the regression for the intermediate sample, for example, the adjusted R^2 is 0.59. In contrast to the common claim that the Solow model "explains" cross-country variation in labor productivity largely by appealing to variations in technologies, the two readily observable

about 0.03 or 0.04. In addition, growth in income per capita has averaged 1.7 percent per year in the United States and 2.2 percent per year in our intermediate sample; this suggests that g is about 0.02.

variables on which the Solow model focuses in fact account for most of the variation in income per capita.

Nonetheless, the model is not completely successful. In particular, the estimated impacts of saving and labor force growth are much larger than the model predicts. The value of α implied by the coefficients should equal capital's share in income, which is roughly one third. The estimates, however, imply an α that is much higher. For example, the α implied by the coefficient in the constrained regression for the intermediate sample is 0.59 (with a standard error of 0.02). Thus, the data strongly contradict the prediction that $\alpha = 1/3$.

Because the estimates imply such a high capital share, it is inappropriate to conclude that the Solow model is successful just because the regressions in Table I can explain a high fraction of the variation in income. For the intermediate sample, for instance, when we employ the "growth-accounting" approach described above and constrain the coefficients to be consistent with an α of one third, the adjusted R^2 falls from 0.59 to 0.28. Although the excellent fit of the simple regressions in Table I is promising for the theory of growth in general—it implies that theories based on easily observable variables may be able to account for most of the cross-country variation in real income—it is not supportive of the textbook Solow model in particular.

II. Adding Human-Capital Accumulation to the Solow Model

Economists have long stressed the importance of human capital to the process of growth. One might expect that ignoring human capital would lead to incorrect conclusions: Kendrick [1976] estimates that over half of the total U. S. capital stock in 1969 was human capital. In this section we explore the effect of adding human-capital accumulation to the Solow growth model.

Including human capital can potentially alter either the theoretical modeling or the empirical analysis of economic growth. At the theoretical level, properly accounting for human capital may change one's view of the nature of the growth process. Lucas [1988], for example, assumes that although there are decreasing returns to physical-capital accumulation when human capital is held constant, the returns to all reproducible capital (human plus physical) are constant. We discuss this possibility in Section III.

At the empirical level, the existence of human capital can alter the analysis of cross-country differences; in the regressions in

Table I human capital is an omitted variable. It is this empirical problem that we pursue in this section. We first expand the Solow model of Section I to include human capital. We show how leaving out human capital affects the coefficients on physical capital investment and population growth. We then run regressions analogous to those in Table I to see whether proxies for human capital can resolve the anomalies found in the first section.[7]

A. The Model

Let the production function be

$$Y(t) = K(t)^{\alpha}H(t)^{\beta}(A(t)L(t))^{1-\alpha-\beta}, \tag{8}$$

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

$$\dot{k}(t) = s_k y(t) - (n + g + \delta)k(t), \tag{9a}$$

$$\dot{h}(t) = s_h y(t) - (n + g + \delta)h(t), \tag{9b}$$

where $y = Y/AL$, $k = K/AL$, and $h = H/AL$ are quantities per effective unit of labor. We are assuming that the same production function applies to human capital, physical capital, and consumption. In other words, one unit of consumption can be transformed costlessly into either one unit of physical capital or one unit of human capital. In addition, we are assuming that human capital depreciates at the same rate as physical capital. Lucas [1988] models the production function for human capital as fundamentally different from that for other goods. We believe that, at least for an initial examination, it is natural to assume that the two types of production functions are similar.

We assume that $\alpha + \beta < 1$, which implies that there are decreasing returns to all capital. (If $\alpha + \beta = 1$, then there are constant returns to scale in the reproducible factors. In this case,

7. Previous authors have provided evidence of the importance of human capital for growth in income. Azariadis and Drazen [1990] find that no country was able to grow quickly during the postwar period without a highly literate labor force. They interpret this as evidence that there is a threshold externality associated with human capital accumulation. Similarly, Rauch [1988] finds that among countries that had achieved 95 percent adult literacy in 1960, there was a strong tendency for income per capita to converge over the period 1950–1985. Romer [1989b] finds that literacy in 1960 helps explain subsequent investment and that, if one corrects for measurement error, literacy has no impact on growth beyond its effect on investment. There is also older work stressing the role of human capital in development; for example, see Krueger [1968] and Easterlin [1981].

there is no steady state for this model. We discuss this possibility in Section III.) Equations (9a) and (9b) imply that the economy converges to a steady state defined by

$$k^* = \left(\frac{s_k^{1-\beta} s_h^{\beta}}{n + g + \delta}\right)^{1/(1-\alpha-\beta)} \tag{10}$$
$$h^* = \left(\frac{s_k^{\alpha} s_h^{1-\alpha}}{n + g + \delta}\right)^{1/(1-\alpha-\beta)}$$

Substituting (10) into the production function and taking logs gives an equation for income per capita similar to equation (6) above:

$$\ln\left[\frac{Y(t)}{L(t)}\right] = \ln A(0) + gt - \frac{\alpha + \beta}{1 - \alpha - \beta}\ln(n + g + \delta) + \frac{\alpha}{1 - \alpha - \beta}\ln(s_k) + \frac{\beta}{1 - \alpha - \beta}\ln(s_h). \tag{11}$$

This equation shows how income per capita depends on population growth and accumulation of physical and human capital.

Like the textbook Solow model, the augmented model predicts coefficients in equation (11) that are functions of the factor shares. As before, α is physical capital's share of income, so we expect a value of α of about one third. Gauging a reasonable value of β, human capital's share, is more difficult. In the United States the minimum wage—roughly the return to labor without human capital—has averaged about 30 to 50 percent of the average wage in manufacturing. This fact suggests that 50 to 70 percent of total labor income represents the return to human capital, or that β is between one third and one half.

Equation (11) makes two predictions about the regressions run in Section I, in which human capital was ignored. First, even if $\ln(s_h)$ is independent of the other right-hand side variables, the coefficient on $\ln(s_k)$ is greater than $\alpha/(1 - \alpha)$. For example, if $\alpha = \beta = 1/3$, then the coefficient on $\ln(s_k)$ would be 1. Because higher saving leads to higher income, it leads to a higher steady-state level of human capital, even if the percentage of income devoted to human-capital accumulation is unchanged. Hence, the presence of human-capital accumulation increases the impact of physical-capital accumulation on income.

Second, the coefficient on $\ln(n + g + \delta)$ is larger in absolute value than the coefficient on $\ln(s_k)$. If $\alpha = \beta = 1/3$, for example, the coefficient on $\ln(n + g + \delta)$ would be -2. In this model high population growth lowers income per capita because the amounts of both physical and human capital must be spread more thinly over the population.

There is an alternative way to express the role of human capital in determining income in this model. Combining (11) with the equation for the steady-state level of human capital given in (10) yields an equation for income as a function of the rate of investment in physical capital, the rate of population growth, and the *level* of human capital:

$$\text{(12)}\quad \ln\left[\frac{Y(t)}{L(t)}\right] = \ln A(0) + gt + \frac{\alpha}{1-\alpha}\ln(s_k) - \frac{\alpha}{1-\alpha}\ln(n+g+\delta) + \frac{\beta}{1-\alpha}\ln(h^*).$$

Equation (12) is almost identical to equation (6) in Section I. In that model the level of human capital is a component of the error term. Because the saving and population growth rates influence h^*, one should expect human capital to be positively correlated with the saving rate and negatively correlated with population growth. Therefore, omitting the human-capital term biases the coefficients on saving and population growth.

The model with human capital suggests two possible ways to modify our previous regressions. One way is to estimate the augmented model's reduced form, that is, equation (11), in which the rate of human-capital accumulation $\ln(s_h)$ is added to the right-hand side. The second way is to estimate equation (12), in which the level of human capital $\ln(h^*)$ is added to the right-hand side. Notice that these alternative regressions predict different coefficients on the saving and population growth terms. When testing the augmented Solow model, a primary question is whether the available data on human capital correspond more closely to the rate of accumulation (s_h) or to the level of human capital (h).

B. Data

To implement the model, we restrict our focus to human-capital investment in the form of education—thus ignoring investment in health, among other things. Despite this narrowed focus, measurement of human capital presents great practical difficulties. Most important, a large part of investment in education takes the form of forgone labor earnings on the part of students.[8] This problem is difficult to overcome because forgone earnings vary with the level of human-capital investment: a worker with little human capital forgoes a low wage in order to accumulate more human capital, whereas a worker with much human capital forgoes a higher wage. In addition, explicit spending on education takes place at all levels of government as well as by the family, which makes spending on education hard to measure. Finally, not all spending on education is intended to yield productive human capital: philosophy, religion, and literature, for example, although serving in part to train the mind, might also be a form of consumption.[9]

We use a proxy for the rate of human-capital accumulation (s_h) that measures approximately the percentage of the working-age population that is in secondary school. We begin with data on the fraction of the eligible population (aged 12 to 17) enrolled in secondary school, which we obtained from the UNESCO yearbook. We then multiply this enrollment rate by the fraction of the working-age population that is of school age (aged 15 to 19). This variable, which we call SCHOOL, is clearly imperfect: the age ranges in the two data series are not exactly the same, the variable does not include the input of teachers, and it completely ignores primary and higher education. Yet if SCHOOL is proportional to s_h, then we can use it to estimate equation (11); the factor of proportionality will affect only the constant term.[10]

This measure indicates that investment in physical capital and population growth may be proxying for human-capital accumulation in the regressions in Table I. The correlation between SCHOOL

8. Kendrick [1976] calculates that for the United States in 1969 total gross investment in education and training was $192.3 billion, of which $92.3 billion took the form of imputed compensation to students (tables A-1 and B-2).

9. An additional problem with implementing the augmented model is that "output" in the model is not the same as that measured in the national income accounts. Much of the expenditure on human capital is forgone wages, and these forgone wages should be included in Y. Yet measured GDP fails to include this component of investment spending.

Back-of-the-envelope calculations suggest that this problem is not quantitatively important, however. If human capital accumulation is completely unmeasured, then measured GDP is $(1 - s_h)y$. One can show that this measurement problem does not affect the elasticity of GDP with respect to physical investment or population growth. The elasticity of measured GDP with respect to human capital accumulation is reduced by $s_h/(1 - s_h)$ compared with the elasticity of true GDP with respect to human capital accumulation. Because the fraction of a nation's resources devoted to human capital accumulation is small, this effect is small. For example, if $\alpha = \beta = 1/3$ and $s_h = 0.1$, then the elasticity will be 0.9 rather than 1.0.

10. Even under the weaker assumption that $\ln(s_h)$ is linear in ln (SCHOOL), we can use the estimated coefficients on $\ln(s_k)$ and $\ln(n + g + \delta)$ to infer values of α and β; in this case, the estimated coefficient on ln (SCHOOL) will not have an interpretation.

and I/GDP is 0.59 for the intermediate sample, and the correlation between SCHOOL and the population growth rate is −0.38. Thus, including human-capital accumulation could alter substantially the estimated impact of physical-capital accumulation and population growth on income per capita.

C. Results

Table II presents regressions of the log of income per capita on the log of the investment rate, the log of $n + g + \delta$, and the log of the percentage of the population in secondary school. The human-capital measure enters significantly in all three samples. It also

TABLE II
ESTIMATION OF THE AUGMENTED SOLOW MODEL

Dependent variable: log GDP per working-age person in 1985			
Sample:	Non-oil	Intermediate	OECD
Observations:	98	75	22
CONSTANT	6.89	7.81	8.63
	(1.17)	(1.19)	(2.19)
ln(I/GDP)	0.69	0.70	0.28
	(0.13)	(0.15)	(0.39)
$\ln(n + g + \delta)$	−1.73	−1.50	−1.07
	(0.41)	(0.40)	(0.75)
ln(SCHOOL)	0.66	0.73	0.76
	(0.07)	(0.10)	(0.29)
$\bar{R}^2$	0.78	0.77	0.24
s.e.e.	0.51	0.45	0.33
Restricted regression:			
CONSTANT	7.86	7.97	8.71
	(0.14)	(0.15)	(0.47)
$\ln(I/GDP) - \ln(n + g + \delta)$	0.73	0.71	0.29
	(0.12)	(0.14)	(0.33)
$\ln(SCHOOL) - \ln(n + g + \delta)$	0.67	0.74	0.76
	(0.07)	(0.09)	(0.28)
$\bar{R}^2$	0.78	0.77	0.28
s.e.e.	0.51	0.45	0.32
Test of restriction:			
p-value	0.41	0.89	0.97
Implied α	0.31	0.29	0.14
	(0.04)	(0.05)	(0.15)
Implied β	0.28	0.30	0.37
	(0.03)	(0.04)	(0.12)

Note. Standard errors are in parentheses. The investment and population growth rates are averages for the period 1960–1985. $(g + \delta)$ is assumed to be 0.05. SCHOOL is the average percentage of the working-age population in secondary school for the period 1960–1985.

greatly reduces the size of the coefficient on physical capital investment and improves the fit of the regression compared with Table I. These three variables explain almost 80 percent of the cross-country variation in income per capita in the non-oil and intermediate samples.

The results in Table II strongly support the augmented Solow model. Equation (11) shows that the augmented model predicts that the coefficients on ln (I/Y), ln (SCHOOL), and ln $(n + g + \delta)$ sum to zero. The bottom half of Table II shows that, for all three samples, this restriction is not rejected. The last lines of the table give the values of α and β implied by the coefficients in the restricted regression. For non-oil and intermediate samples, α and β are about one third and highly significant. The estimates for the OECD alone are less precise. In this sample the coefficients on investment and population growth are not statistically significant; but they are also not significantly different from the estimates obtained in the larger samples.[11]

We conclude that adding human capital to the Solow model improves its performance. Allowing for human capital eliminates the worrisome anomalies—the high coefficients on investment and on population growth in our Table I regressions—that arise when the textbook Solow model is confronted with the data. The parameter estimates seem reasonable. And even using an imprecise proxy for human capital, we are able to dispose of a fairly large part of the model's residual variance.

III. Endogenous Growth and Convergence

Over the past few years economists studying growth have turned increasingly to endogenous-growth models. These models are characterized by the assumption of nondecreasing returns to the set of reproducible factors of production. For example, our model with physical and human capital would become an endogenous-growth model if $\alpha + \beta = 1$. Among the implications of this assumption are that countries that save more grow faster indefinitely and that countries need not converge in income per capita, even if they have the same preferences and technology.

11. As we described in the previous footnote, under the weaker assumption that $\ln(s_h)$ is linear in ln (SCHOOL), estimates of α and β can be inferred from the coefficients on ln(I/GDP) and $\ln(n + g + \delta)$ in the unrestricted regression. When we do this, we obtain estimates of α and β little different from those reported in Table II.

Advocates of endogenous-growth models present them as alternatives to the Solow model and motivate them by an alleged empirical failure of the Solow model to explain cross-country differences. Barro [1989] presents the argument succinctly:

> In neoclassical growth models with diminishing returns, such as Solow (1956), Cass (1965) and Koopmans (1965), a country's per capita growth rate tends to be inversely related to its starting level of income per person. Therefore, in the absence of shocks, poor and rich countries would tend to converge in terms of levels of per capita income. However, this convergence hypothesis seems to be inconsistent with the cross-country evidence, which indicates that per capita growth rates are uncorrelated with the starting level of per capita product.

Our first goal in this section is to reexamine this evidence on convergence to assess whether it contradicts the Solow model.

Our second goal is to generalize our previous results. To implement the Solow model, we have been assuming that countries in 1985 were in their steady states (or, more generally, that the deviations from steady state were random). Yet this assumption is questionable. We therefore examine the predictions of the augmented Solow model for behavior out of the steady state.

A. Theory

The Solow model predicts that countries reach different steady states. In Section II we argued that much of the cross-country differences in income per capita can be traced to differing determinants of the steady state in the Solow growth model: accumulation of human and physical capital and population growth. Thus, the Solow model does *not* predict convergence; it predicts only that income per capita in a given country converges to that country's steady-state value. In other words, the Solow model predicts convergence only after controlling for the determinants of the steady state, a phenomenon that might be called "conditional convergence."

In addition, the Solow model makes quantitative predictions about the speed of convergence to steady state. Let y^* be the steady-state level of income per effective worker given by equation (11), and let $y(t)$ be the actual value at time t. Approximating around the steady state, the speed of convergence is given by

$$\frac{d\ln(y(t))}{dt} = \lambda[\ln(y^*) - \ln(y(t))], \tag{13}$$

where

$$\lambda = (n + g + \delta)(1 - \alpha - \beta).$$

For example, if $\alpha = \beta = 1/3$ and $n + g + \delta = 0.06$, then the convergence rate (λ) would equal 0.02. This implies that the economy moves halfway to steady state in about 35 years. Notice that the textbook Solow model, which excludes human capital, implies much faster convergence. If $\beta = 0$, then λ becomes 0.04, and the economy moves halfway to steady state in about seventeen years.

The model suggests a natural regression to study the rate of convergence. Equation (13) implies that

$$\ln(y(t)) = (1 - e^{-\lambda t}) \ln(y^*) + e^{-\lambda t} \ln(y(0)), \tag{14}$$

where $y(0)$ is income per effective worker at some initial date. Subtracting $\ln(y(0))$ from both sides,

$$\ln(y(t)) - \ln(y(0)) = (1 - e^{-\lambda t}) \ln(y^*) - (1 - e^{-\lambda t}) \ln(y(0)). \tag{15}$$

Finally, substituting for y^*:

$$\begin{aligned} \ln(y(t)) - \ln(y(0)) = {} & (1 - e^{-\lambda t}) \frac{\alpha}{1 - \alpha - \beta} \ln(s_k) \\ & + (1 - e^{-\lambda t}) \frac{\beta}{1 - \alpha - \beta} \ln(s_h) \\ & - (1 - e^{-\lambda t}) \frac{\alpha + \beta}{1 - \alpha - \beta} \ln(n + g + \delta) - (1 - e^{-\lambda t}) \ln(y(0)). \end{aligned} \tag{16}$$

Thus, in the Solow model the growth of income is a function of the determinants of the ultimate steady state and the initial level of income.

Endogenous-growth models make predictions very different from the Solow model regarding convergence among countries. In endogenous-growth models there is no steady-state level of income; differences among countries in income per capita can persist indefinitely, even if the countries have the same saving and population growth rates.[12] Endogenous-growth models with a

12. Although we do not explore the issue here, endogenous-growth models also make quantitative predictions about the impact of saving on growth. The models are typically characterized by constant returns to reproducible factors of production, namely physical and human capital. Our model of Section II with $\alpha + \beta = 1$ and $g = 0$ provides a simple way of analyzing the predictions of models of endogenous growth. With these modifications to the model of Section II, the production function is $Y = AK^{\alpha}H^{1-\alpha}$. In this form the model predicts that the ratio of physical to human capital, K/H, will converge to s_k/s_h, and that K, H, and Y will then all grow at rate $A(s_k)^{\alpha}(s_h)^{1-\alpha}$. The derivative of this "steady-state" growth rate with respect to s_k is then $\alpha A(s_h/s_k)^{1-\alpha} = \alpha/(K/Y)$. The impact of saving on growth depends on the

single sector—those with the "$Y = AK$" production function—predict no convergence of any sort. That is, these simple endogenous-growth models predict a coefficient of zero on $y(0)$ in the regression in (16). As Barro [1989] notes, however, endogenous-growth models with more than one sector may imply convergence if the initial income of a country is correlated with the degree of imbalance among sectors.

Before presenting the results on convergence, we should note the differences between regressions based on equation (16) and those we presented earlier. The regressions in Tables I and II are valid only if countries are in their steady states or if deviations from steady state are random. Equation (16) has the advantage of explicitly taking into account out-of-steady-state dynamics. Yet, implementing equation (16) introduces a new problem. If countries have permanent differences in their production functions—that is, different $A(0)$'s—then these $A(0)$'s would enter as part of the error term and would be positively correlated with initial income. Hence, variation in $A(0)$ would bias the coefficient on initial income toward zero (and would potentially influence the other coefficients as well). In other words, permanent cross-country differences in the production function would lead to differences in initial incomes uncorrelated with subsequent growth rates and, therefore, would bias the results against finding convergence.

B. Results

We now test the convergence predictions of the Solow model. We report regressions of the change in the log of income per capita over the period 1960 to 1985 on the log of income per capita in 1960, with and without controlling for investment, growth of the working-age population, and school enrollment.

In Table III the log of income per capita appears alone on the right-hand side. This table reproduces the results of many previous authors on the failure of incomes to converge [De Long 1988; Romer 1987]. The coefficient on the initial level of income per capita is slightly positive for the non-oil sample and zero for the intermediate sample, and for both regressions the adjusted R^2 is

exponent on capital in the production function, α, and the capital-output ratio. In models in which endogenous growth arises mainly from externalities from physical capital, α is close to one, and the derivative of the growth rate with respect to s_k is approximately $1/(K/Y)$, or about 0.4. In models in which endogenous growth arises largely from human capital accumulation and there are no externalities from physical capital, the derivative would be about $0.3/(K/Y)$, or about 0.12.

TABLE III
TESTS FOR UNCONDITIONAL CONVERGENCE

Dependent variable: log difference GDP per working-age person 1960–1985			
Sample:	Non-oil	Intermediate	OECD
Observations:	98	75	22
CONSTANT	−0.266	0.587	3.69
	(0.380)	(0.433)	(0.68)
ln(Y60)	0.0943	−0.00423	−0.341
	(0.0496)	(0.05484)	(0.079)
$\bar{R}^2$	0.03	−0.01	0.46
s.e.e.	0.44	0.41	0.18
Implied λ	−0.00360	0.00017	0.0167
	(0.00219)	(0.00218)	(0.0023)

Note. Standard errors are in parentheses. Y60 is GDP per working-age person in 1960.

essentially zero. There is no tendency for poor countries to grow faster on average than rich countries.

Table III does show, however, that there is a significant tendency toward convergence in the OECD sample. The coefficient on the initial level of income per capita is significantly negative, and the adjusted R^2 of the regression is 0.46. This result confirms the findings of Dowrick and Nguyen [1989], among others.

Table IV adds our measures of the rates of investment and population growth to the right-hand side of the regression. In all three samples the coefficient on the initial level of income is now significantly negative; that is, there is strong evidence of convergence. Moreover, the inclusion of investment and population growth rates improves substantially the fit of the regression. Table V adds our measure of human capital to the right-hand side of the regression in Table IV. This new variable further lowers the coefficient on the initial level of income, and it again improves the fit of the regression.

Figure I presents a graphical demonstration of the effect of adding measures of population growth and accumulation of human and physical capital to the usual "convergence picture," first presented by Romer [1987]. The top panel presents a scatterplot for our intermediate sample of the average annual growth rate of income per capita from 1960 to 1985 against the log of income per capita in 1960. Clearly, there is no evidence that countries that start off poor tend to grow faster. The second panel of the figure

TABLE IV
TESTS FOR CONDITIONAL CONVERGENCE

Dependent variable: log difference GDP per working-age person 1960–1985			
Sample:	Non-oil	Intermediate	OECD
Observations:	98	75	22
CONSTANT	1.93	2.23	2.19
	(0.83)	(0.86)	(1.17)
ln(Y60)	−0.141	−0.228	−0.351
	(0.052)	(0.057)	(0.066)
ln(I/GDP)	0.647	0.644	0.392
	(0.087)	(0.104)	(0.176)
$\ln(n + g + \delta)$	−0.299	−0.464	−0.753
	(0.304)	(0.307)	(0.341)
$\overline{R}^2$	0.38	0.35	0.62
s.e.e.	0.35	0.33	0.15
Implied λ	0.00606	0.0104	0.0173
	(0.00182)	(0.0019)	(0.0019)

Note. Standard errors are in parentheses. Y60 is GDP per working-age person in 1960. The investment and population growth rates are averages for the period 1960–1985. $(g + \delta)$ is assumed to be 0.05.

TABLE V
TESTS FOR CONDITIONAL CONVERGENCE

Dependent variable: log difference GDP per working-age person 1960–1985			
Sample:	Non-oil	Intermediate	OECD
Observations:	98	75	22
CONSTANT	3.04	3.69	2.81
	(0.83)	(0.91)	(1.19)
ln(Y60)	−0.289	−0.366	−0.398
	(0.062)	(0.067)	(0.070)
ln(I/GDP)	0.524	0.538	0.335
	(0.087)	(0.102)	(0.174)
$\ln(n + g + \delta)$	−0.505	−0.551	−0.844
	(0.288)	(0.288)	(0.334)
ln(SCHOOL)	0.233	0.271	0.223
	(0.060)	(0.081)	(0.144)
$\overline{R}^2$	0.46	0.43	0.65
s.e.e.	0.33	0.30	0.15
Implied λ	0.0137	0.0182	0.0203
	(0.0019)	(0.0020)	(0.0020)

Note. Standard errors are in parentheses. Y60 is GDP per working-age person in 1960. The investment and population growth rates are averages for the period 1960–1985. $(g + \delta)$ is assumed to be 0.05. SCHOOL is the average percentage of the working-age population in secondary school for the period 1960–1985.

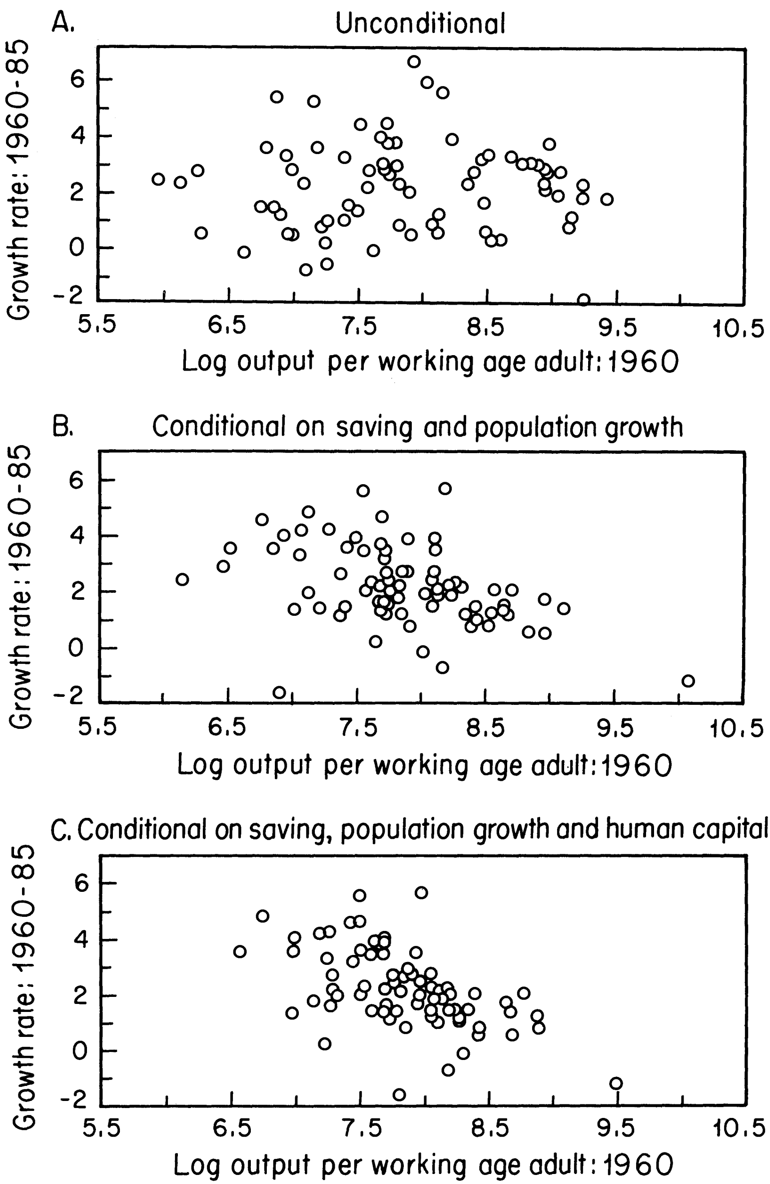

FIGURE I
Unconditional versus Conditional Convergence

partials out the logs of the investment rate and $(n + g + \delta)$ from both the income level and growth rate variables. This figure shows that if countries did not vary in their investment and population growth rates, there would be a strong tendency for poor countries to grow faster than rich ones. The third panel of Figure I partials out our human-capital variable in addition to investment and population growth rates; the tendency toward convergence is now even stronger.

The results in Tables IV and V are notable not only for the finding of convergence, but also for the rate at which convergence occurs. The implied values of λ, the parameter governing the speed of convergence, are derived from the coefficient on ln (Y60). The values in Table IV are much smaller than the textbook Solow model predicts. Yet the estimates in Table V are closer to what the augmented Solow model predicts, for two reasons. First, the augmented model predicts a slower rate of convergence than the model without human capital. Second, the empirical results including human capital imply a faster rate of convergence than the empirical results without human capital. Hence, once again, the inclusion of human capital can help explain some results that appear anomalous from the vantage point of the textbook Solow model.

Table VI presents estimates of equation (16) imposing the restriction that the coefficients on $\ln(s_k)$, $\ln(s_h)$, and $\ln(n + g + \delta)$ sum to zero. We find that this restriction is not rejected and that imposing it has little effect on the coefficients. The last lines in Table VI present the implied values of α and β. The estimates of α range from 0.38 to 0.48, and the estimates of β are 0.23 in all three samples. Compared with the results in Table II, these regressions give a somewhat larger weight to physical capital and a somewhat smaller weight to human capital.

In contrast to the results in Tables I through IV, the results for the OECD sample in Tables V and VI are similar to those for the other samples. An interpretation that reconciles the similarity across samples here and the dissimilarity in the earlier specifications is that departures from steady state represent a larger share of cross-country variation in income per capita for the OECD than for the broader samples. If the OECD countries are far from their steady states, then population growth and capital accumulation have not yet had their full impact on standards of living; hence, we obtain lower estimated coefficients and lower R^2's for the OECD in

TABLE VI
TESTS FOR CONDITIONAL CONVERGENCE, RESTRICTED REGRESSION

Dependent variable: log difference GDP per working-age person 1960–1985			
Sample:	Non-oil	Intermediate	OECD
Observations:	98	75	22
CONSTANT	2.46	3.09	3.55
	(0.48)	(0.53)	(0.63)
ln(Y60)	−0.299	−0.372	−0.402
	(0.061)	(0.067)	(0.069)
$\ln(I/GDP) - \ln(n + g + \delta)$	0.500	0.506	0.396
	(0.082)	(0.095)	(0.152)
$\ln(SCHOOL) - \ln(n + g + \delta)$	0.238	0.266	0.236
	(0.060)	(0.080)	(0.141)
$\overline{R}^2$	0.46	0.44	0.66
s.e.e.	0.33	0.30	0.15
Test of restriction:			
p-value	0.40	0.42	0.47
Implied λ	0.0142	0.0186	0.0206
	(0.0019)	(0.0019)	(0.0020)
Implied α	0.48	0.44	0.38
	(0.07)	(0.07)	(0.13)
Implied β	0.23	0.23	0.23
	(0.05)	(0.06)	(0.11)

Note. Standard errors are in parentheses. Y60 is GDP per working-age person in 1960. The investment and population growth rates are averages for the period 1960–1985. $(g + \delta)$ is assumed to be 0.05. SCHOOL is the average percentage of the working-age population in secondary school for the period 1960–1985.

specifications that do not consider out-of-steady-state dynamics. Similarly, the greater importance of departures from steady state for the OECD would explain the finding of greater unconditional convergence. We find this interpretation plausible: World War II surely caused large departures from the steady state, and it surely had larger effects on the OECD than on the rest of the world. With a value of λ of 0.02, almost half of the departure from steady state in 1945 would have remained by the end of our sample in 1985.

Overall, our interpretation of the evidence on convergence contrasts sharply with that of endogenous-growth advocates. In particular, we believe that the study of convergence does not show a failure of the Solow model. After controlling for those variables that the Solow model says determine the steady state, there is substantial convergence in income per capita. Moreover, convergence occurs at approximately the rate that the model predicts.

IV. Interest Rate Differentials and Capital Movements

Recently, several economists, including Lucas [1988], Barro [1989], and King and Rebelo [1989], have emphasized an objection to the Solow model in addition to those we have addressed so far: they argue that the model fails to explain either rate-of-return differences or international capital flows. In the models of Sections I and II, the steady-state marginal product of capital, net of depreciation, is

$$(17) \qquad MPK - \delta = \alpha(n + g + \delta)/s_k - \delta.$$

Thus, the marginal product of capital varies positively with the population growth rate and negatively with the saving rate. Because the cross-country differences in saving and population growth rates are large, the differences in rates of return should also be large. For example, if $\alpha = 1/3$, $\delta = 0.03$, and $g = 0.02$, then the mean of the steady-state net marginal product is 0.12 in the intermediate sample, and the standard deviation is 0.08.[13]

Two related facts seem inconsistent with these predictions. First, observed differentials in real interest rates appear smaller than the predicted differences in the net marginal product of capital. Second, as Feldstein and Horioka [1980] first documented, countries with high saving rates have high rates of domestic investment rather than large current account surpluses: capital does not flow from high-saving countries to low-saving countries.

Although these two facts indeed present puzzles to be resolved, it is premature to view them as a basis for rejecting the Solow model. The Solow model predicts that the marginal product of capital will be high in low-saving countries, but it does not necessarily predict that real interest rates will also be high. One can infer the marginal product of capital from real interest rates on financial assets only if investors are optimizing and capital markets are perfect. Both of these assumptions are questionable. It is

13. There is an alternative way of obtaining the marginal product of capital, which applies even outside of the steady state but requires an estimate of β and the assumption of no country-specific shifts to the production function. If one assumes that the returns on human and physical capital are equalized within each country, then one can show that the *MPK* is proportional to $y^{(\alpha+\beta-1)/(\alpha+\beta)}$. Therefore, for the textbook Solow model in which $\alpha = 1/3$ and $\beta = 0$, the *MPK* is inversely proportional to the square of output. As King and Rebelo [1989] and others have noted, the implied differences in rates of return across countries are incredibly large. Yet if $\alpha = \beta = 1/3$, then the *MPK* is inversely proportional to the square root of output. In this case, the implied cross-country differences in the *MPK* are much smaller and are similar to those obtained with equation (17).

possible that some of the most productive investments in poor countries are in public capital, and that the behavior of the governments of poor countries is not socially optimal. In addition, it is possible that the marginal product of private capital is also high in poor countries, yet those economic agents who could make the productive investments do not do so because they face financing constraints or because they fear future expropriation.

Some evidence for this interpretation comes from examining international variation in the rate of profit. If capital earns its marginal product, then one can measure the marginal product of capital as

$$MPK = \frac{\alpha}{K/Y}.$$

That is, the return to capital equals capital's share in income (α) divided by the capital-output ratio (K/Y). The available evidence indicates that capital's share is roughly constant across counties. Sachs [1979, Table 3] presents factor shares for the G-7 countries. His figures show that variation in these shares across countries and over time is small.[14] By contrast, capital-output ratios vary substantially across countries: accumulating the investment data from Summers and Heston [1988] to produce estimates of the capital stock, one finds that low-saving countries have capital-output ratios near one and high-saving countries have capital-output ratios near three. Thus, direct measurement of the profit rate suggests that there is large international variation in the return to capital.

The available evidence also indicates that expropriation risk is one reason that capital does not move to eliminate these differences in the profit rate. Williams [1975] examines the experience of foreign investment in developing countries from 1956 to 1972. He reports that, during this period, governments nationalized about 19 percent of foreign capital, and that compensation averaged about 41 percent of book value. It is hard to say precisely how much of the observed differences in profit rates this expropriation risk can explain. Yet, in view of this risk, it would be surprising if the

14. In particular, there is no evidence that rapid capital accumulation raises capital's share. Sachs [1979] reports that Japan's rapid accumulation in the 1960s and 1970s, for example, was associated with a rise in *labor's* share from 69 percent in 1962–1964 to 77 percent in 1975–1978. See also Atkinson [1975, p. 167].

profit rates were not at least somewhat higher in developing countries.

Further evidence on rates of return comes from the large literature on international differences in the return to education. Psacharopoulos [1985] summarizes the results of studies for over 60 countries that analyze the determinants of labor earnings using micro data. Because forgone wages are the primary cost of education, the rate of return is roughly the percentage increase in the wage resulting from an additional year of schooling. He reports that the poorer the country, the larger the return to schooling.

Overall, the evidence on the return to capital appears consistent with the Solow model. Indeed, one might argue that it supports the Solow model against the alternative of endogenous-growth models. Many endogenous-growth models assume constant returns to scale in the reproducible factors of production; they therefore imply that the rate of return should not vary with the level of development. Yet direct measurement of profit rates and returns to schooling indicates that the rate of return is much higher in poor countries.

CONCLUSION

We have suggested that international differences in income per capita are best understood using an augmented Solow growth model. In this model output is produced from physical capital, human capital, and labor, and is used for investment in physical capital, investment in human capital, and consumption. One production function that is consistent with our empirical results is $Y = K^{1/3}H^{1/3}L^{1/3}$.

This model of economic growth has several implications. First, the elasticity of income with respect to the stock of physical capital is not substantially different from capital's share in income. This conclusion indicates, in contrast to Romer's suggestion, that capital receives approximately its social return. In other words, there are not substantial externalities to the accumulation of physical capital.

Second, despite the absence of externalities, the accumulation of physical capital has a larger impact on income per capita than the textbook Solow model implies. A higher saving rate leads to higher income in steady state, which in turn leads to a higher level of human capital, even if the rate of human-capital accumulation is unchanged. Higher saving thus raises total factor productivity as it is usually measured. This difference between the textbook model and the augmented model is quantitatively important. The textbook Solow model with a capital share of one third indicates that the elasticity of income with respect to the saving rate is one half. Our augmented Solow model indicates that this elasticity is one.

Third, population growth also has a larger impact on income per capita than the textbook model indicates. In the textbook model higher population growth lowers income because the available capital must be spread more thinly over the population of workers. In the augmented model human capital also must be spread more thinly, implying that higher population growth lowers measured total factor productivity. Again, this effect is important quantitatively. In the textbook model with a capital share of one third, the elasticity of income per capita with respect to $n + g + \delta$ is $-1/2$. In our augmented model this elasticity is -2.

Fourth, our model has implications for the dynamics of the economy when the economy is not in steady state. In contrast to endogenous-growth models, this model predicts that countries with similar technologies and rates of accumulation and population growth should converge in income per capita. Yet this convergence occurs more slowly than the textbook Solow model suggests. The textbook Solow model implies that the economy reaches halfway to steady state in about 17 years, whereas our augmented Solow model implies that the economy reaches halfway in about 35 years.

More generally, our results indicate that the Solow model is consistent with the international evidence if one acknowledges the importance of human as well as physical capital. The augmented Solow model says that differences in saving, education, and population growth should explain cross-country differences in income per capita. Our examination of the data indicates that these three variables do explain most of the international variation.

Future research should be directed at explaining why the variables taken to be exogenous in the Solow model vary so much from country to country. We expect that differences in tax policies, education policies, tastes for children, and political stability will end up among the ultimate determinants of cross-country differences. We also expect that the Solow model will provide the best framework for understanding how these determinants influence a country's level of economic well-being.

APPENDIX

Number	Country	Sample N	Sample I	Sample O	GDP/adult 1960	GDP/adult 1985	Growth 1960–1985 GDP	Growth 1960–1985 working age pop	I/Y	SCHOOL
1	Algeria	1	1	0	2485	4371	4.8	2.6	24.1	4.5
2	Angola	1	0	0	1588	1171	0.8	2.1	5.8	1.8
3	Benin	1	0	0	1116	1071	2.2	2.4	10.8	1.8
4	Botswana	1	1	0	959	3671	8.6	3.2	28.3	2.9
5	Burkina Faso	1	0	0	529	857	2.9	0.9	12.7	0.4
6	Burundi	1	0	0	755	663	1.2	1.7	5.1	0.4
7	Cameroon	1	1	0	889	2190	5.7	2.1	12.8	3.4
8	Central Afr. Rep.	1	0	0	838	789	1.5	1.7	10.5	1.4
9	Chad	1	0	0	908	462	−0.9	1.9	6.9	0.4
10	Congo, Peop. Rep.	1	0	0	1009	2624	6.2	2.4	28.8	3.8
11	Egypt	1	0	0	907	2160	6.0	2.5	16.3	7.0
12	Ethiopia	1	1	0	533	608	2.8	2.3	5.4	1.1
13	Gabon	0	0	0	1307	5350	7.0	1.4	22.1	2.6
14	Gambia, The	0	0	0	799		3.6		18.1	1.5
15	Ghana	1	0	0	1009	727	1.0	2.3	9.1	4.7
16	Guinea	0	0	0	746	869	2.2	1.6	10.9	
17	Ivory Coast	1	1	0	1386	1704	5.1	4.3	12.4	2.3
18	Kenya	1	1	0	944	1329	4.8	3.4	17.4	2.4
19	Lesotho	0	0	0	431	1483	6.8	1.9	12.6	2.0
20	Liberia	1	0	0	863	944	3.3	3.0	21.5	2.5
21	Madagascar	1	1	0	1194	975	1.4	2.2	7.1	2.6
22	Malawi	1	1	0	455	823	4.8	2.4	13.2	0.6
23	Mali	1	1	0	737	710	2.1	2.2	7.3	1.0
24	Mauritania	1	0	0	777	1038	3.3	2.2	25.6	1.0
25	Mauritius	1	0	0	1973	2967	4.2	2.6	17.1	7.3
26	Morocco	1	1	0	1030	2348	5.8	2.5	8.3	3.6
27	Mozambique	1	0	0	1420	1035	1.4	2.7	6.1	0.7
28	Niger	1	0	0	539	841	4.4	2.6	10.3	0.5
29	Nigeria	1	1	0	1055	1186	2.8	2.4	12.0	2.3
30	Rwanda	1	0	0	460	696	4.5	2.8	7.9	0.4
31	Senegal	1	1	0	1392	1450	2.5	2.3	9.6	1.7
32	Sierra Leone	1	0	0	511	805	3.4	1.6	10.9	1.7
33	Somalia	1	0	0	901	657	1.8	3.1	13.8	1.1
34	S. Africa	1	1	0	4768	7064	3.9	2.3	21.6	3.0
35	Sudan	1	0	0	1254	1038	1.8	2.6	13.2	2.0
36	Swaziland	0	0	0	817		7.2		17.7	3.7
37	Tanzania	1	1	0	383	710	5.3	2.9	18.0	0.5
38	Togo	1	0	0	777	978	3.4	2.5	15.5	2.9
39	Tunisia	1	1	0	1623	3661	5.6	2.4	13.8	4.3
40	Uganda	1	0	0	601	667	3.5	3.1	4.1	1.1
41	Zaire	1	0	0	594	412	0.9	2.4	6.5	3.6
42	Zambia	1	1	0	1410	1217	2.1	2.7	31.7	2.4
43	Zimbabwe	1	1	0	1187	2107	5.1	2.8	21.1	4.4

APPENDIX
(CONTINUED)

		Sample			GDP/ adult		Growth 1960–1985		I/Y	SCHOOL
Number	Country	N	I	O	1960	1985	GDP	working age pop		
44	Afghanistan	0	0	0	1224		1.6		6.9	0.9
45	Bahrain	0	0	0					30.0	12.1
46	Bangladesh	1	1	0	846	1221	4.0	2.6	6.8	3.2
47	Burma	1	1	0	517	1031	4.5	1.7	11.4	3.5
48	Hong Kong	1	1	0	3085	13,372	8.9	3.0	19.9	7.2
49	India	1	1	0	978	1339	3.6	2.4	16.8	5.1
50	Iran	0	0	0	3606	7400	6.3	3.4	18.4	6.5
51	Iraq	0	0	0	4916	5626	3.8	3.2	16.2	7.4
52	Israel	1	1	0	4802	10,450	5.9	2.8	28.5	9.5
53	Japan	1	1	1	3493	13,893	6.8	1.2	36.0	10.9
54	Jordan	1	1	0	2183	4312	5.4	2.7	17.6	10.8
55	Korea, Rep. of	1	1	0	1285	4775	7.9	2.7	22.3	10.2
56	Kuwait	0	0	0	77,881	25,635	2.4	6.8	9.5	9.6
57	Malaysia	1	1	0	2154	5788	7.1	3.2	23.2	7.3
58	Nepal	1	0	0	833	974	2.6	2.0	5.9	2.3
59	Oman	0	0	0		15,584		3.3	15.6	2.7
60	Pakistan	1	1	0	1077	2175	5.8	3.0	12.2	3.0
61	Philippines	1	1	0	1668	2430	4.5	3.0	14.9	10.6
62	Saudi Arabia	0	0	0	6731	11,057	6.1	4.1	12.8	3.1
63	Singapore	1	1	0	2793	14,678	9.2	2.6	32.2	9.0
64	Sri Lanka	1	1	0	1794	2482	3.7	2.4	14.8	8.3
65	Syrian Arab Rep.	1	1	0	2382	6042	6.7	3.0	15.9	8.8
66	Taiwan	0	0	0			8.0		20.7	
67	Thailand	1	1	0	1308	3220	6.7	3.1	18.0	4.4
68	U. Arab Emirates	0	0	0		18,513			26.5	
69	Yemen	0	0	0		1918		2.5	17.2	0.6
70	Austria	1	1	1	5939	13,327	3.6	0.4	23.4	8.0
71	Belgium	1	1	1	6789	14,290	3.5	0.5	23.4	9.3
72	Cyprus	0	0	0	2948		5.2		31.2	8.2
73	Denmark	1	1	1	8551	16,491	3.2	0.6	26.6	10.7
74	Finland	1	1	1	6527	13,779	3.7	0.7	36.9	11.5
75	France	1	1	1	7215	15,027	3.9	1.0	26.2	8.9
76	Germany, Fed. Rep.	1	1	1	7695	15,297	3.3	0.5	28.5	8.4
77	Greece	1	1	1	2257	6868	5.1	0.7	29.3	7.9
78	Iceland	0	0	0	8091		3.9		29.0	10.2
79	Ireland	1	1	1	4411	8675	3.8	1.1	25.9	11.4
80	Italy	1	1	1	4913	11,082	3.8	0.6	24.9	7.1
81	Luxembourg	0	0	0	9015		2.8		26.9	5.0
82	Malta	0	0	0	2293		6.0		30.9	7.1
83	Netherlands	1	1	1	7689	13,177	3.6	1.4	25.8	10.7
84	Norway	1	1	1	7938	19,723	4.3	0.7	29.1	10.0

APPENDIX
(CONTINUED)

		Sample			GDP/ adult		Growth 1960–1985		I/Y	SCHOOL
Number	Country	N	I	O	1960	1985	GDP	working age pop		
85	Portugal	1	1	1	2272	5827	4.4	0.6	22.5	5.8
86	Spain	1	1	1	3766	9903	4.9	1.0	17.7	8.0
87	Sweden	1	1	1	7802	15,237	3.1	0.4	24.5	7.9
88	Switzerland	1	1	1	10,308	15,881	2.5	0.8	29.7	4.8
89	Turkey	1	1	1	2274	4444	5.2	2.5	20.2	5.5
90	United Kingdom	1	1	1	7634	13,331	2.5	0.3	18.4	8.9
91	Barbados	0	0	0	3165		4.8		19.5	12.1
92	Canada	1	1	1	10,286	17,935	4.2	2.0	23.3	10.6
93	Costa Rica	1	1	0	3360	4492	4.7	3.5	14.7	7.0
94	Dominican Rep.	1	1	0	1939	3308	5.1	2.9	17.1	5.8
95	El Salvador	1	1	0	2042	1997	3.3	3.3	8.0	3.9
96	Guatemala	1	1	0	2481	3034	3.9	3.1	8.8	2.4
97	Haiti	1	1	0	1096	1237	1.8	1.3	7.1	1.9
98	Honduras	1	1	0	1430	1822	4.0	3.1	13.8	3.7
99	Jamaica	1	1	0	2726	3080	2.1	1.6	20.6	11.2
100	Mexico	1	1	0	4229	7380	5.5	3.3	19.5	6.6
101	Nicaragua	1	1	0	3195	3978	4.1	3.3	14.5	5.8
102	Panama	1	1	0	2423	5021	5.9	3.0	26.1	11.6
103	Trinidad & Tobago	1	1	0	9253	11,285	2.7	1.9	20.4	8.8
104	United States	1	1	1	12,362	18,988	3.2	1.5	21.1	11.9
105	Argentina	1	1	0	4852	5533	2.1	1.5	25.3	5.0
106	Bolivia	1	1	0	1618	2055	3.3	2.4	13.3	4.9
107	Brazil	1	1	0	1842	5563	7.3	2.9	23.2	4.7
108	Chile	1	1	0	5189	5533	2.6	2.3	29.7	7.7
109	Colombia	1	1	0	2672	4405	5.0	3.0	18.0	6.1
110	Ecuador	1	1	0	2198	4504	5.7	2.8	24.4	7.2
111	Guyana	0	0	0	2761		1.1		32.4	11.7
112	Paraguay	1	1	0	1951	3914	5.5	2.7	11.7	4.4
113	Peru	1	1	0	3310	3775	3.5	2.9	12.0	8.0
114	Surinam	0	0	0	3226		4.5		19.4	8.1
115	Uruguay	1	1	0	5119	5495	0.9	0.6	11.8	7.0
116	Venezuela	1	1	0	10,367	6336	1.9	3.8	11.4	7.0
117	Australia	1	1	1	8440	13,409	3.8	2.0	31.5	9.8
118	Fiji	0	0	0	3634		4.2		20.6	8.1
119	Indonesia	1	1	0	879	2159	5.5	1.9	13.9	4.1
120	New Zealand	1	1	1	9523	12,308	2.7	1.7	22.5	11.9
121	Papua New Guinea	1	0	0	1781	2544	3.5	2.1	16.2	1.5

Note. Growth rates are in percent per year. I/Y is investment as a percentage of GDP, and SCHOOL is the percentage of the working-age population in secondary school, both averaged for the period 1960–1985. N, I, and O denote the non-oil, intermediate, and OECD samples.

HARVARD UNIVERSITY
UNIVERSITY OF CALIFORNIA AT BERKELEY
BROWN UNIVERSITY

REFERENCES

Atkinson, Anthony, *The Economics of Inequality* (Oxford: Clarendon Press, 1975).

Azariadis, Costas, and Allan Drazen, "Threshold Externalities in Economic Development," *Quarterly Journal of Economics*, CV (1990), 501–26.

Barro, Robert J., "Economic Growth in a Cross Section of Countries," NBER Working Paper 3120, September 1989.

De Long, J. Bradford, "Productivity Growth, Convergence, and Welfare: Comment," *American Economic Review*, LXXVIII (1988), 1138–54.

Dowrick, Steve, and Duc-Tho Nguyen, "OECD Comparative Economic Growth 1950–85: Catch-Up and Convergence," *American Economic Review*, LXXIX (1989), 1010–30.

Easterlin, Richard, "Why Isn't the Whole World Developed?" *Journal of Economic History*, XLI (1981), 1–20.

Feldstein, Martin, and Charles Horioka, "Domestic Saving and International Capital Flows," *Economic Journal*, XC (1980), 314–29.

Kendrick, John W., *The Formation and Stocks of Total Capital* (New York: Columbia University for NBER, 1976).

King, Robert G., and Sergio T. Rebelo, "Transitional Dynamics and Economic Growth in the Neoclassical Model," NBER Working Paper 3185, November 1989.

Krueger, Anne O., "Factor Endowments and per Capita Income Differences Among Countries," *Economic Journal*, LXXVIII (1968), 641–59.

Lucas, Robert E. Jr., "On the Mechanics of Economic Development," *Journal of Monetary Economics*, XXII (1988), 3–42.

Psacharopoulos, George, "Returns to Education: A Further International Update and Implications," *Journal of Human Resources*, XX (1985), 583–604.

Rauch, James E., "The Question of International Convergence of per Capita Consumption: An Euler Equation Approach," mimeo, August 1988, University of California at San Diego.

Romer, Paul, "Crazy Explanations for the Productivity Slowdown," *NBER Macroeconomics Annual*, 1987, 163–210.

——, "Capital Accumulation in the Theory of Long Run Growth," *Modern Business Cycle Theory*, Robert J. Barro, ed. (Cambridge, MA: Harvard University Press, 1989a), pp. 51–127.

——, "Human Capital and Growth: Theory and Evidence," NBER Working Paper 3173, November 1989b.

Sachs, Jeffrey D., "Wages, Profit, and Macroeconomic Adjustment: A Comparative Study," *Brookings Papers on Economic Activity* (1979:2), 269–332.

Solow, Robert M., "A Contribution to the Theory of Economic Growth," *Quarterly Journal of Economics*, LXX (1956), 65–94.

Summers, Robert, and Alan Heston, "A New Set of International Comparisons of Real Product and Price Levels Estimates for 130 Countries, 1950–85," *Review of Income and Wealth*, XXXIV (1988), 1–26.

Williams, M. L., "The Extent and Significance of Nationalization of Foreign-owned Assets in Developing Countries, 1956–1972," *Oxford Economic Papers*, XXVII (1975), 260–73.