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Testing the Neoclassical Theory of Economic Growth: A Panel Data Approach

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Abstract

Several recent empirical studies have examined determinants of economic growth using country average (cross-section) data. In contrast, this paper employs a technique for using a panel of both cross-section and time-series data for 98 industrial and developing countries over 1960-85 to determine the quantitative importance for economic growth of both country-specific and time-varying factors such as human capital, public investment, and outward-oriented trade policies. The empirical results provide support for the view that these factors exert a positive and significant influence on economic growth. They also provide estimates of the speed at which the gap in real per capita income between rich and poor countries is likely to be reduced over the longer term.

JEL Classification Numbers:

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Contents

I. Introduction

The basic neoclassical model of Solow (1956) and Swan (1956), hereafter S-S, has been the workhorse of economic growth theorists for the past three and a half decades. Its simple assumptions and structure--a single homogenous good, a well-behaved neoclassical production function, exogenous labor-augmenting technical progress, full employment, and exogenous labor force growth--provide an elegant solution to the "knife-edge equilibrium" problem posed by Harrod (1939) and Domar (1946). The "knife-edge" problem derives from the fact that since the output-capital ratio is assumed constant in the Harrod-Domar model, the warranted rate of growth of the capital stock--given by the product of this ratio and the (constant) saving rate--will only equal the constant natural rate of growth of the labor force by coincidence. In contrast, since the S-S model allows for smooth substitution between capital and labor, decreasing returns to capital, and flexible wages and prices, the output-capital ratio declines steadily as the capital-labor ratio rises. This adjustment continues until the warranted rate of growth of capital just matches the constant natural rate of labor-force growth at the full employment level of output (see Hacche, 1979).

The S-S growth model predicts that in steady state equilibrium the level of per capita income will be determined by the prevailing technology as embodied in the production function, as well as the rates of saving, population growth, and technical progress, all three of which are assumed exogenous. Since these rates differ across countries, the S-S model yields testable predictions about the implications of differences in saving rates and population growth rates, for example, for different countries' steady-state levels of per capita income: other things equal, countries that have higher saving rates tend to have higher levels of per capita income, while countries with higher population growth rates tend to have lower levels of per capita income.

Recently, the S-S model has been under attack by the new growth theorists, who dismiss it in favor of "endogenous growth" models that assume constant or increasing returns to capital, alleging that the standard neoclassical model fails to explain observed differences in per capita income across countries. These differences in the implications of the two growth models have led to renewed empirical work in recent years. A major concern of this work has been whether one should expect to see a long-run tendency toward convergence of per capita income levels across countries. "Unconditional convergence" implies that in a cross-country sample the simple correlation between a country's rate of growth of real per capita GDP and the initial level of its per capita GDP is negative; that is, the lower the starting level of per capita real income, the higher its subsequent rate of growth. However, in a recent cross-section study Barro and Sala-i-Martin (1992) find that such a simple correlation is actually positive rather negative, albeit statistically insignificant.

In itself, the empirical evidence against unconditional convergence is not inconsistent with the implications of the neoclassical growth model.

The S-S model does not predict unconditional convergence of per capita incomes across countries; rather, it predicts convergence only after controlling for the determinants of the steady state (that is, it predicts "conditional convergence"). Recent work by Mankiw, Romer and Weil (1992), hereafter M-R-W, using a cross-sectional approach, contends that the S-S model's predictions are indeed consistent with the empirical evidence. However, they also find that if human capital is not taken into account in the model the quantitative effects of saving and population growth rates are biased upward (in absolute value), since human capital is positively correlated with both saving and population growth. Accordingly, in an effort to understand the quantitative relationships among saving, population growth, and income, M-R-W augment the S-S model to include human capital accumulation. They find that this variable is indeed correlated positively with saving and population growth. Relative to estimates based on the textbook model, the estimates of this augmented S-S model yield smaller effects of saving and population growth on per capita income growth, and explain about eighty percent of the cross-country variation in per capita income.

Despite the evidence of the failure of per capita income to converge across countries that has been emphasized by the new growth theorists--the failure of the "unconditional convergence" hypothesis--M-R-W find evidence of conditional convergence at about the rate predicted by the S-S model once cross-country differences in saving and population growth rates are taken into account. Moreover, they interpret the available evidence on cross-country variations in rates of return to capital as being consistent with the S-S growth model. Thus their work provides empirical support for this model, and appears to cast doubt on the new endogenous growth models that invoke constant or increasing returns to capital.

This paper extends the M-R-W model in two directions. First, a panel of time-series cross-section data is used to determine the significance of country-specific effects that are assumed away in the cross-sectional approach employed by Barro and Sala-i-Martin (1992) and M-R-W, as well as nearly all other studies. In order to exploit the additional information contained in these panel data, we extend the econometric analysis by applying an estimation procedure outlined in Chamberlain (1984). Second, we assume that labor-augmenting technical change is influenced by two potentially important factors: (1) the extent to which a country's trade policies are outward-oriented; that is, whether they increase or reduce its openness to international trade (see Edwards, 1992); and (2) the level of social infrastructural capital that is put in place in the domestic economy.

As already noted, our first extension of the model of M-R-W refers to the econometric treatment of the data. In the empirical part of their paper, M-R-W use cross-section data for various groups of countries. Essentially, they take averages of the relevant variables over the period 1960 through 1985. Since only one cross section of countries is used for the entire time period, they are obliged to make some restrictive assumptions about the nature of the shift parameter (technology) in the neoclassical production function and its relation to other variables. Specifically, all unobservable factors that characterize each economy (and are contained in the shift parameter) are assumed to be uncorrelated with the available information; econometrically this means that "country-specific" effects are ruled out by assumption. Our procedure, on the other hand, allows for a more flexible econometric specification of the model by appropriately using panel data to account for these important country-specific effects. This approach yields a number of interesting extensions to the empirical results of M-R-W, particularly when the estimates for the full sample of both industrial 1/ and developing countries are compared with those for a sub-sample that includes only developing countries. Of course, provided the assumptions required for using panel data hold, our approach also improves the efficiency of the estimates by using more information. 2/

Our second, related extension of M-R-W refers to the country-specific variables--trade policies, human capital, and social infrastructure--that we include in the model. The role of policies that foster more openness in a country's international trade regime in stimulating labor-augmenting technological change is twofold. 3/ First, the import-export sector serves as a vehicle for technology transfer through the importation of technologically-advanced capital goods, as elucidated by Bardhan and Lewis (1970), Chen (1979), and Khang (1987); and as a channel for intersectoral external economies via the development of efficient and internationally competitive management, the training of skilled workers, and the spillover consequences of scale expansion (Keesing, 1967; Feder, 1983). Second, rising exports help to relieve the foreign exchange constraint; that is, the country's ability to import technologically-superior capital goods is augmented both directly by rising export receipts and indirectly by the higher flows of foreign credits and direct investment that are induced by the country's increased ability to service domestic debt and equity held by foreigners. 4/

As regards social infrastructure, it is reasonable to assume that an expansion in the amount of public goods and services available for education, health, nutrition and physical infrastructure (transport,

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1/ The individual countries group consists of the 22 industrial countries that are members of the OECD; the developing countries group consists of 76 non-OECD developing countries. See Appendix II.

2/ The panel data set increases the number of observations from 98 to 490; that is, 98 countries multiplied by five time periods of five years each.

3/ See the discussion on the production linkage summarized by Khan and Villanueva (1991). See also Edwards (1992) and Roubini and Sala-i-Martin (1992).

4/ The transfer of efficient technologies and the availability of foreign exchange have featured prominently in recent experiences of rapid economic growth (Thirlwall, 1979).

telecommunications, etc.) will be associated with greater economic efficiency. Empirical studies emphasizing education and health include Diamond (1989), Otani and Villanueva (1990), and Barro (1991), while those focusing on infrastructure include Diamond (1989), Orsmond (1990) and Barro (1991).

The rest of this paper is organized as follows. Section II discusses the extended M-R-W model, derives the steady state and the dynamics around it, and suggests a regression equation for the growth rate of per capita income and its determinants, using a panel data set containing information on a broad group of countries over several time periods. Section III describes the panel data estimation in detail, and presents and interprets the empirical results. Section IV draws several policy implications and offers some concluding remarks.

II. The Model

The model developed by M-R-W, which we also employ, is essentially a version of the neoclassical S-S model that is augmented to account for human capital in the production function and in the savings decisions of the economy.

Consider the following Cobb-Douglas production function:

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

where Y is real output; K is the stock of physical capital, H is the stock of human capital, L is raw labor, and A is a labor-augmenting factor reflecting the level of technology and efficiency of the economy. We assume that $\alpha + \beta < 1$, so that there are constant returns to factor inputs jointly, and decreasing returns separately.

Raw labor and labor-augmenting technology are assumed to grow according to the following functions,

(2) $$L_t = L_o e^{nt}$$

(3) $$A_t = A_o e^{gt} F^{\theta f} P^{\theta p}$$

where n is the exogenous rate of growth of the labor force, g is the exogenous rate of technological progress, F is the degree of openness of the domestic economy to foreign trade, and P is the level of social infrastructure in the economy. (For simplicity, in what follows we normalize L_o

to unity). Thus our efficiency variable A differs from that used by M-R-W in that it depends not only on exogenous technological improvements but also on the degree of openness of the economy and the level of its social infrastructure, as discussed in the preceding section. We believe that this modification is particularly relevant to the empirical study of economic growth in developing countries, where technological improvements tend to be absorbed domestically in conjunction with imports of capital goods, and where the productive sector's efficiency may depend heavily on the level of social infrastructure provided by the government.

As in the S-S model, the savings ratios are assumed to be exogenously determined either by savers' preferences or by government policy. Thus, physical and human capital are accumulated according to the following functions,

$$(4) \quad \frac{dK_t}{dt} = s_k Y_t - \delta K$$

$$(5) \quad \frac{dH_t}{dt} = s_h Y_t - \delta H$$

where s_k and s_h are the fractions of income invested in physical capital and human capital, respectively; and δ is the depreciation rate (assumed, for simplicity, to be the same for both types of capital).

In order to facilitate analysis of the steady state and the behavior around it, we redefine each variable in terms of its value <u>per effective unit of labor</u> by dividing the basic variable by the efficiency-adjusted labor supply. Lower-case letters with a hat represent quantities per effective worker; for instance, output per effective unit of labor ($\hat{y}$) is equal to Y/AL, and so on for the other variables under consideration.

Let us now rewrite the production and accumulation functions in terms of quantities per effective worker:

$$(1a) \quad \hat{y}_t = \hat{k}_t^{\alpha} \hat{h}_t^{\beta}$$

$$(4a) \quad \frac{d\hat{k}_t}{dt} = s_k \hat{y}_t - (n+g+\delta)\hat{k}_t$$

(5a) $$\frac{d\hat{h}_t}{dt} = s_h\hat{y}_t - (n+g+\delta)\hat{h}_t$$

1. The steady state

In the steady state the levels of physical and human capital per effective worker are constant. (Variables in the steady state are represented by a star superscript.) From equations (4a) and (5a), this implies,

(6) $$\hat{k} = \left[\frac{s_k^{1-\beta} s_h^{\beta}}{n+g+\delta}\right]^{\frac{1}{1-\alpha-\beta}}$$

$$\hat{h} = \left[\frac{s_k^{\alpha} s_h^{1-\alpha}}{n+g+\delta}\right]^{\frac{1}{1-\alpha-\beta}}$$

$$\ln\hat{y} = -\left[\frac{\alpha+\beta}{1-\alpha-\beta}\right]\ln(n+g+\delta) + \left[\frac{\alpha}{1-\alpha-\beta}\right]\ln(s_k) + \left[\frac{\beta}{1-\alpha-\beta}\right]\ln(s_h)$$

Furthermore, in the steady state output per worker (y) grows at the constant rate g, which is the exogenous component of the growth rate of the efficiency variable A. This result can be obtained directly from the definition of output per effective worker:

(7) $$\ln\hat{y}_t = \ln Y_t - \ln L_t - \ln A_t$$

$$= \ln y_t - \ln A_o - gt - \theta_f \ln F - \theta_p \ln P$$

Taking time derivatives of both sides of the equation gives:

$$\frac{d\ln\hat{y}_t}{dt} = \frac{d\ln y_t}{dt} - g$$

Therefore, in the steady state, when the growth rate of output per effective worker (which is the left-hand variable in the equation above) is zero, the growth rate of output per worker is equal to g:

$$\frac{d\ln y_t^*}{dt} = g$$

2. <u>Dynamics around the steady state</u>

We do not impose the restriction that the economy is continuously in the steady state. However, we do assume that the economy is sufficiently close to its steady state that a linearization of the transition path around it is appropriate. Such a linearization 1/ produces the following result:

$$(8) \quad \frac{d\ln\hat{y}_t}{dt} = \eta(\ln\hat{y}^* - \ln\hat{y}_t)$$

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

The parameter η defines the speed, per unit of t, of convergence; that is, it determines how fast output per effective worker reaches its steady state. We want to obtain an expression that can be treated as a regression equation for our empirical study. Accordingly, we integrate equation (8) from $t=t_0$ to $t=t_0+r$,

$$\ln\hat{y}_{t_0+r} = (1-e^{-\eta r})\ln\hat{y}^* + e^{-\eta r}\ln\hat{y}_{t_0}$$

1/ The linearization of the transition path around the steady state is derived in Appendix I.

Next, we substitute for $\ln\hat{y}^*_t$,

$$\ln\hat{y}_{t_o+r} = -(1-e^{-\eta r})\left[\frac{\alpha+\beta}{1-\alpha-\beta}\right]\ln(n+g+\delta) + (1-e^{-\eta r})\left[\frac{\alpha}{1-\alpha-\beta}\right]\ln s_k + (1-e^{-\eta r})\left[\frac{\beta}{1-\alpha-\beta}\right]\ln s_h + e^{-\eta r}\ln\hat{y}_{t_o}$$

For purposes of estimation we need an expression in terms of output per worker, rather than output per effective worker. Accordingly, we substitute for $\ln\hat{y}_t$ using equation (7). Finally, we rearrange terms to get the change in the natural logarithm of output as the left hand variable,

$$(9)\quad \ln y_{t_o+r} - \ln y_{t_o} = -(1-e^{-\eta r})\left[\frac{\alpha+\beta}{1-\alpha-\beta}\right]\ln(n+g+\delta) + (1-e^{-\eta r})\left[\frac{\alpha}{1-\alpha-\beta}\right]\ln s_k + (1-e^{-\eta r})\left[\frac{\beta}{1-\alpha-\beta}\right]\ln s_h + (1-e^{-\eta r})\theta_f\ln F + (1-e^{-\eta r})\theta_p\ln P - (1-e^{-\eta r})\ln y_{t_o} + [(1-e^{-\eta r})(t_o+r)g + e^{-\eta r}rg] + (1-e^{-\eta r})\ln A_o$$

Equation (9) provides a useful specification for our empirical study. 1/ We will use it as a guideline but will not apply it literally. The growth effects that we discuss next apply to the transition to the steady state; as noted earlier, in the steady state output per capita grows at the exogenous rate g. If the speed of convergence η is positive (as we expect), we can sign the coefficients in equation (9). The first coefficient indicates that for given α, β, δ, and g the rate of growth of per capita output is negatively related to the growth of the working-age population. The second and third coefficients indicate that the more a country saves and invests in physical and human capital, the more rapidly it grows. The fourth coefficient is positive if θ_f is positive, meaning that greater openness to international trade--by contributing to the efficiency of production--brings about a higher rate of economic growth. A similar analysis holds for the fifth coefficient, which applies to the level of social infrastructure. The sixth term indicates that countries grow faster if they are initially below their steady-growth path; this is what is known

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1/ Note that as t_o goes to infinity, both sides of equation (9) go to the value rg. This is so because in the limit (steady state), the growth of per capita output is equal to g, the exogenous growth rate of technology.

as "conditional convergence" in the growth literature (Barro and Sala-i-Martin, 1992; Mankiw et al., 1990; Loayza, 1992). Next, the term in brackets suggests the presence of a time-specific effect on growth. The last term contains the parameter A_0, which represents all the unobserved (or unaccounted for) elements that determine the efficiency with which the factors of production and the available technology are used to create wealth; of course, the greater is such efficiency, the higher the rate of growth of the economy. This last term suggests the presence of a country-specific effect, which may well be correlated with the other explanatory variables considered in the model.

The above interpretation of equation (9) suggests a natural specification for the regression that can be used to study output growth and its determinants using panel data for a sample of different countries and time periods. Let us write a more general form of equation (9) for a given country i:

$$(10)\quad \ln y_{i,t}-\ln y_{i,t-1} = \theta_1\ln(n_{i,t}+g+\delta)+\theta_2\ln s_{k_{i,t}}+\theta_3\ln s_{h_i}+\theta_4\ln F_i+\theta_5\ln P_i$$
$$+\gamma\ln y_{i,t-1}+\xi_t+\mu_i+\epsilon_{i,t}$$

where ξ_t and μ_i represent, respectively, the time-specific and the country-specific effects; and $\theta_1,\ldots,\theta_5$, and γ are parameters to be estimated.

The use of the time index requires some explanation. First, we have normalized the 'time length' between the first and last observations for each period to equal unity (thus, in equation (9), r = 1). Second, we are indexing the physical capital investment rate s_k by time, to allow it to change from period to period. Notice that the rate of human capital investment s_h, the level of openness F, and the stock of social infrastructure P, may differ from country to country; however, owing to limitations on the availability of data for the estimation work in the next section, their levels in each country are assumed to remain unchanged for all time periods in the sample. 1/ Notice also that neither the value for g nor that for δ is specific to each country. In essence we assume that, conditional on the other variables in the model, the exogenous rate of technological change and the rate of depreciation are equal across countries. 2/

The disturbance term $\epsilon_{i,t}$ is not assumed to be identically and independently distributed. Thus the model does not impose either conditional homoskedasticity across countries or independence over time

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1/ This refers, of course, to those data in our study for which only cross-sectional data are available (mainly, data on F and P).

2/ This assumption corresponds to that in M-R-W. The value for $g+\delta$ that is used in the estimation procedure actually matches the available data.

on the disturbances within each country. We want to allow for serial correlation in the error term because there may be some excluded variables that result in short-run persistence; the μ_i component accounts for long-run persistence in excluded variables that are correlated with the independent regressors.

As indicated in the Introduction, previous empirical studies of long-run growth have made use of cross-sectional data. This forced the use of some rather restrictive assumptions in the econometric specifications. For instance, M-R-W, who take averages of the relevant variables over the period 1960 to 1985, assume that $\ln A_0$ is independent of the investment ratios and the growth rates of the working age population. This amounts to ignoring country-specific effects; for example, their assumption implies that government policies regarding taxation and international trade do not affect domestic investment, or that the endowment of natural resources does not influence fertility. Furthermore, since only one cross section is considered, the time-specific effect becomes irrelevant. Fortunately, panel data are available for most variables of interest. Thus we exploit the additional information contained in panel data to analyze the regression equation (10).

III. Panel Data Estimation

Let us rewrite equation (10) as follows:

$$(10)\quad z_{i,t}-z_{i,t-1} = \theta' v_{i,t}+\gamma z_{i,t-1}+\xi_t+\mu_i+\epsilon_{i,t}$$

where $z_{i,t} = \ln(y_{i,t})$; $v_{i,t} = (\ln(n_{i,t}+g+\delta)\ ,\ \ln(s_{k_{i,t}}),\ \ln(s_{h_i}),\ \ln F_i,$ $\ln P_i)'$; and $\theta = (\theta_1, \ldots, \theta_5)'$. First we need to process the data to eliminate the time effects; we do this by removing the time means from each variable. The ξ_t's can then be ignored and the regression can be estimated without constants (McCurdy 1982).

Taking account of the country-specific effects is not so simple. If the μ_i's are treated as fixed (fixed-effects model), we may be tempted to use the "within" estimator procedure, which is obtained by removing the country means prior to least-squares estimation. 1/ However, this procedure would result in inconsistent estimators because of the presence of a lagged dependent variable in the right-hand side of the regression equation.

1/ References on the "within" estimator include Mundlak (1978) and Greene (1990, Chapter 16).

The "within" regression equation is,

$$(11) \quad (z_{i,t}-z_{i,t-1})-\overline{(z_{i,t}-z_{i,t-1})} = \theta'(v_{i,t}-\overline{v}_i)+\gamma(z_{i,t-1}-\overline{z}_i)+(\epsilon_{i,t}-\overline{\epsilon}_i)$$

However, the "within" estimator is inconsistent because $COV(\overline{z}_i,\overline{\epsilon}_i) \neq 0$.

Nor can we use the "difference" estimator. If we apply first differences to equation (10):

$$(12) \quad (z_{i,t}-z_{i,t-1})-(z_{i,t-1}-z_{i,t-2}) = \theta'(v_{i,t}-v_{i,t-1})+\gamma(z_{i,t-1}-z_{i,t-2})+(\epsilon_{i,t}-\epsilon_{i,t-1})$$

The difference estimator is also inconsistent because $COV(z_{i,t-1},\epsilon_{i,t-1}) \neq 0$.

Taking differences of lengths greater than one period may seem to solve the problem of correlation between one of the regressors and the error term. However, if the disturbances $\{\epsilon_t\}$ follow an autocorrelation process then taking differences of lengths 2, 3, and so on is also inappropriate. Consider the following model with differences two periods apart:

$$(13) \quad (z_{i,t}-z_{i,t-1})-(z_{i,t-2}-z_{i,t-3}) = \theta'(v_{i,t}-v_{i,t-2})+\gamma(z_{i,t-1}-z_{i,t-3})+(\epsilon_{i,t}-\epsilon_{i,t-2})$$

$$COV(\epsilon_t,\epsilon_s) \neq 0, \quad s \neq t$$

The two-periods-apart difference estimator is inconsistent because $COV(z_{i,t-1},\epsilon_{i,t-2}) \neq 0$; this is so because $COV(\epsilon_{i,t-1},\epsilon_{i,t-2}) \neq 0$.

Our chosen estimation method is the Π matrix approach outlined in Chamberlain (1984). Chamberlain's Π matrix procedure consists of two steps. In the first step, we estimate the parameters of the reduced-form regressions for the endogenous variable in each period in terms of the exogenous variables in all periods; thus, we estimate a multivariate regression system with as many regressions as periods for the endogenous variables we consider. Since we allow for heteroskedasticity and correlation between the errors of all regressions, we use the seemingly unrelated regression (SUR) estimator. As a result of this first step we obtain estimates of the parameters of the reduced-form regressions (these are the elements of the Π matrix) and the robust (White's heteroskedasticity-consistent) variance-covariance matrix of these parameters.

The specific model we are working with implies some restrictions on the elements of the Π matrix; in other words, the parameters of interest are functions of the elements of the Π matrix. This takes us to the second step of the procedure: we estimate the parameters of interest by means of a minimum distance estimator using the robust variance-covariance of the estimated Π as the weighting matrix:

$$Min(Vec\Pi - f(\psi))' \, \Omega \, (Vec\Pi - f(\psi))$$

where ψ is the set of parameters of interest, and Ω is the robust variance-covariance of the Π matrix. Chamberlain (1982) shows that this procedure obtains asymptotically efficient estimates.

In order to use this method we need to make explicit the restrictions that our model imposes on the Π matrix. After removing the time means, our basic model in equation (10) can be written as

$$(14) \qquad z_{i,t}-z_{i,t-1} = \theta' v_{i,t} + \gamma z_{i,t-1} + \mu_i + \epsilon_{i,t}$$

At this point it is necessary that we distinguish the two kinds of variables contained in the vector $v_{i,t}$; namely, those that are both country- and time-specific ($\ln(n_{i,t}+g+\delta)$ and $\ln(s_{k_{i,t}})$) and those that are only country-specific ($\ln(s_{h_i})$, $\ln F_i$ and $\ln P_i$). Then we rewrite equation (14) as follows:

$$(15) \qquad z_{i,t}-z_{i,t-1} = \theta_a' x_{i,t} + \theta_b' w_i + \gamma z_{i,t-1} + \mu_i + \epsilon_{i,t}$$

where $x_{i,t} = (\ln(n_{i,t}+g+\delta),\ \ln(s_{k_{i,t}}))'$, $w_i = (\ln(s_{h_i}),\ \ln F_i,\ \ln P_i)'$, $\theta_a = (\theta_1,\ \theta_2)'$, and $\theta_b = (\theta_3,\ \theta_4,\ \theta_5)'$.

By recursive substitution of the z_{t-1} term in each regression equation, we have: 1/

$$z_{i,1}-z_{i,0} = \theta_a' x_{i,1} + \theta_b' w_i + \gamma z_{i,0} + \mu_i + \omega_{i,1}$$

$$z_{i,2}-z_{i,1} = \gamma\theta_a' x_{i,1} + \theta_a' x_{i,2} + (1+\gamma)\theta_b' w_i + \gamma(1+\gamma) z_{i,0} + (1+\gamma)\mu_i + \omega_{i,2}$$

$$z_{i,3}-z_{i,2} = \gamma(1+\gamma)\theta_a' x_{i,1} + \gamma\theta_a' x_{i,2} + \theta_a' x_{i,3} + (1+\gamma)^2\theta_b' w_i + \gamma(1+\gamma)^2 z_{i,0} + (1+\gamma)^2\mu_i + \omega_{i,3}$$

$$\vdots$$

$$z_{i,T}-z_{i,T-1} = \gamma(1+\gamma)^{T-2}\theta_a' x_{i,1} + \gamma(1+\gamma)^{T-3}\theta_a' x_{i,2} + \ldots + \gamma(1+\gamma)\theta_a' x_{i,T-2} + \gamma\theta_a' x_{i,T-1}$$
$$+ \theta_a' x_T + (1+\gamma)^{T-1}\theta_b' w_i + \gamma(1+\gamma)^{T-1} z_{i,0} + (1+\gamma)^{T-1}\mu_i + \omega_{i,T}$$

$$E^*(\omega_{i,t} \mid x_{i,1}, \ldots, x_{i,T}, w_i) = 0 \qquad (t=1, \ldots, T)$$

Chamberlain (1984) proposes to deal with the correlated country-specific effect μ_i and the initial condition $z_{i,o}$ by replacing them with their linear predictors:

$$E^*(\mu_i \mid x_{i,1}, x_{i,2}, \ldots x_{i,T}, w_i) = \tau_1' x_{i,1} + \tau_2' x_{i,2} + \ldots + \tau_T' x_{i,T} + \tau_w' w_i$$

$$E^*(z_{i,0} \mid x_{i,1}, x_{i,2}, \ldots x_{i,T}, w_i) = \lambda_1' x_{i,1} + \lambda_2' x_{i,2} + \ldots + \lambda_T' x_{i,T} + \lambda_w' w_i$$

1/ In the term z_{t-1} the index "1" refers to 5 years.

In order to identify the coefficients of the variables for which we only have cross-sectional data (s_{h_i}, F_i, and P_i), it is necessary to assume that $\tau'_w = 0$. This is not a very restrictive assumption if one believes that the partial correlation between w_i and μ_i is low, given that the panel data variables $x_{i,t}$ are accounted for.

As Chamberlain points out, assuming that the variances are finite and that the distribution of ($x_{i,1}, \ldots, x_{i,T}, w_i, \mu_i$) does not depend on i, then the use of the linear predictors does not impose any additional restrictions. However, using the linear predictors does not account completely for the presence of country-specific effects when the correct specification contains interactive terms (that is, nonlinear terms including products of the observed variables and the country-specific factors). Of course, we assumed away such a possibility when we declared that equation (10) represented our maintained model.

We now write the Π matrix implied by our model. As will be seen in the next section, our panel data consist of five cross sections for the variables ($z_{i,t}-z_{i,t-1}$) and $x_{i,t}$, six cross sections for the variable $z_{i,t}$ (of course, the additional cross section is the initial condition $z_{i,o}$), and one cross section for the variables w_i. Thus the multivariate regression implied by our model is:

$$(16) \qquad \begin{bmatrix} z_{i,0} \\ z_{i,1}-z_{i,0} \\ z_{i,2}-z_{i,1} \\ z_{i,3}-z_{i,2} \\ z_{i,4}-z_{i,3} \\ z_{i,5}-z_{i,4} \end{bmatrix} = \Pi \begin{bmatrix} x_{i,1} \\ x_{i,2} \\ x_{i,3} \\ x_{i,4} \\ x_{i,5} \\ w_i \end{bmatrix}$$

$$\Pi = [B + \psi\lambda' + \phi\tau']$$

where,

$$B = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ \theta_a' & 0 & 0 & 0 & 0 & \theta_b' \\ \gamma\theta_a' & \theta_a' & 0 & 0 & 0 & (1+\gamma)\theta_b' \\ \gamma(1+\gamma)\theta_a' & \gamma\theta_a' & \theta_a' & 0 & 0 & (1+\gamma)^2\theta_b' \\ \gamma(1+\gamma)^2\theta_a' & \gamma(1+\gamma)\theta_a' & \gamma\theta_a' & \theta_a' & 0 & (1+\gamma)^3\theta_b' \\ \gamma(1+\gamma)^3\theta_a' & \gamma(1+\gamma)^2\theta_a' & \gamma(1+\gamma)\theta_a' & \gamma\theta_a' & \theta_a' & (1+\gamma)^4\theta_b' \end{bmatrix}$$

$$\psi\lambda' = \begin{bmatrix} 1 \\ \gamma \\ \gamma(1+\gamma) \\ \gamma(1+\gamma)^2 \\ \gamma(1+\gamma)^3 \\ \gamma(1+\gamma)^4 \end{bmatrix} \begin{bmatrix} \lambda_1' & \lambda_2' & \lambda_3' & \lambda_4' & \lambda_5' & \lambda_w' \end{bmatrix}$$

$$\phi\tau' = \begin{bmatrix} 0 \\ 1 \\ (1+\gamma) \\ (1+\gamma)^2 \\ (1+\gamma)^3 \\ (1+\gamma)^4 \end{bmatrix} \begin{bmatrix} \tau_1' & \tau_2' & \tau_3' & \tau_4' & \tau_5' & \tau_w' \end{bmatrix}$$

IV. Data and Results

Three different growth models are considered in our econometric analysis. The first is a simple S-S model; the second is an augmented version of the S-S model that includes investment in human capital; and the third, which has been presented in Section II, is an augmented version that includes human capital investment, openness to foreign trade, and a variable that represents the stock of public infrastructure. The first two models can, of course, be obtained by applying appropriate exclusion restrictions to the third model.

Thus the basic S-S model is obtained from equation (9) by setting $\beta = \theta_f = \theta_p = 0$; its corresponding regression equation is,

$$(10a)\ \ln y_{i,t} - \ln y_{i,t-1} = \theta_1' \ln(n_{i,t}+g+\delta) + \theta_2 \ln s_{k_{i,t}} + \gamma \ln y_{i,t-1} + \xi_t + \mu_i + \epsilon_{i,t}$$

The second model can also be obtained from equation (9) by setting $\theta_f = \theta_p = 0$; its regression equation is,

$$(10b)\ \ln y_{i,t} - \ln y_{i,t-1} = \theta_1' \ln(n_{i,t}+g+\delta) + \theta_2 \ln s_{k_{i,t}} + \theta_3 \ln s_{h_i} + \gamma \ln y_{i,t-1} + \xi_t + \mu_i + \epsilon_{i,t}$$

We will consider an alternative specification for this second model in which panel data, rather than cross-sectional data, are used as a proxy for the ratio of human capital investment to GDP. The regression equation for this alternative model is the same as equation (10b), except that the investment ratio for human capital is also indexed by time.

The definitions and sources of the data for estimation are described in Appendix II. Our sample covers a broad group of industrial and developing countries and extends over the period from 1960 to 1985. We work with regular non-overlapping intervals of five years each. Thus, our five cross sections correspond to the years 1965, 1970, 1975, 1980, and 1985. For some of the variables--y_t and s_{h_t}--the observations for each cross section correspond exactly to the year of the cross section. For others--such as n_t and s_{k_t}--such observations correspond to averages over the previous five years. For the variables s_h and P, the observations correspond to averages over the whole period 1960 to 1985; while for the openness variable F, the observation for each country is taken from various years in the first part of the 1980s.

Each of the variables under consideration will now be explained in more detail. The dependent variable is the five-year difference in the natural logarithm of real GDP per worker; that is, $(\ln(y_{i,65}) - \ln(y_{i,60}))$, ..., $(\ln(y_{i,85}) - \ln(y_{i,80}))$. As noted above, the most general model considers six explanatory variables. The first is the natural logarithm of the average growth rate of the working-age population plus $(g+\delta)$; we follow M-R-W in assuming that $(g+\delta) = 0.05$. The average growth rate of the working age population is taken over the previous five-year interval. Thus we also have five observations of this variable for each country; that is, $\ln(n_{i,65}+0.05)$, ..., $\ln(n_{i,85}+0.05)$.

The second explanatory variable is the natural logarithm of the average ratio of real investment (including government investment) to real GDP. These averages are also taken over the previous five-year interval, so that we have five observations for each country; that is, $\log(s_{ki,65})$, ..., $\log(s_{ki,85})$.

The third explanatory variable is a proxy for the ratio of human capital investment to GDP. Specifically, following M-R-W we use the percentage of the working age population that is enrolled in secondary school, a measure that is approximated by the gross secondary-school enrollment ratio multiplied by the fraction of the working-age population that is of secondary-school age (i.e., aged 15 to 19). 1/ In the main specifications of the second and third models we use cross-sectional data for this variable; that is, we use its average over the whole period from 1960 to 1985. In the alternative specification of the second model we use panel data for the proxy of the human capital investment ratio; that is, for each country we have five observations; namely, $\ln(s_{hi,65})$, ..., $\ln(s_{hi,85})$.

The fourth variable, lnF, is a proxy for the restrictiveness of the economy's international trade system: it is a weighted average of the country's tariff rates on intermediate and capital goods. The weights are the respective import shares, and each tariff rate is calculated as the percentage ad valorem import charge. Thus the larger the value of this variable, the less open is the domestic economy. We obtain the data from Lee (1992). This measure of openness is used because we are interested in the relation between the availability of foreign technology (embodied in intermediate and capital goods) and the efficiency factor in the production function. Lee points out that there are some problems with this measure of the weighted average tariff rate, the most important of which is that the data refer to various years in the first part of the 1980s and thus may not be representative of our entire sample period (1960 to 1985). 2/ Nevertheless, we believe that this simple proxy is likely to be inversely correlated with openness of trade regimes in the majority of countries under consideration during our sample period.

The fifth variable, lnP, is a proxy for the level of public infrastructure; it is defined as the average ratio of general government fixed investment (central government plus public enterprises) to GDP in each five-year period. There are obvious problems in using this flow variable as a proxy for the stock of public infrastructure. It does not account for the initial level of public infrastructure (in our case the 1960 level). Nor does it allow for country-specific differences in depreciation rates, or in the quality of investment expenditures. Nevertheless, it is likely that our

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1/ For a discussion on the appropriateness of this proxy, see M-R-W (1992).

2/ Another well-known shortcoming is that the use of import shares tends to under weight the effects of the tariff structure on relatively price elastic goods and neglects the effects of prohibitive tariffs.

proxy is positively correlated with the level of public infrastructure, and the omitted factors discussed above will be reflected in the country-specific constants.

The sixth explanatory variable is the natural logarithm of real GDP per worker, lagged one 'period' (that is, five years back); therefore, the observations for each country are, $\ln(y_{i,60})$, ..., $\ln(y_{i,80})$.

Appendix II lists the countries used to obtain the empirical estimates for each of the three models of interest. The sample includes all industrial and developing countries for which data are available and for which petroleum production is not the primary economic activity. 1/ Excluding the countries for which data are not available may create sample selectivity problems, particularly since these countries are frequently the poorest ones. Thus it is not appropriate to assume that the results obtained here could be extrapolated to the economies that have to be excluded from the sample owing to data problems, most of which are also in the lowest-income category. We estimate each of the models using two samples of countries. The first is the full sample of both industrial countries and developing countries, while the second consists of the developing countries only. Hence a second aspect of the empirical work is that of comparing the estimated coefficients obtained from these two samples. In all models, time-specific and country-specific effects are dealt with using the methodology outlined in Section III above.

Before presenting the results, we need to clarify the meaning of the "country-specific effects" in each of the estimated models. All empirical growth models implicitly assume that the excluded variables can be grouped into a single factor that affects the included variables in a given uniform way. This is rather restrictive, since each unobserved variable may affect the included variables in a different way. Thus, grouping them together introduces biases and inefficiencies. Much is gained by identifying and obtaining information on the different components of the country-specific factor. This is precisely our intention when we go from the first to the second and third models. In a sense, adding information on human capital, public infrastructure, and openness to the simple S-S model may be viewed as an attempt to disaggregate the components of the all-inclusive country-specific factor assumed in the first model. Specifically, in the second model we identify the human-capital component of the country-specific factor, while in the third model we add proxies for public infrastructure and openness to further disaggregate the country-specific effects.

We begin with the simple S-S model (regression equation (10a)). Results for this specification are reported in Table 1. Using a Cobb-Douglas production function in the Solow growth model, we expect the

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1/ It is well known that standard growth models do not account for growth in economies that are heavily concentrated in the extraction of depletable resources (see Sala-i-Martin, 1990).

Table 1. Simple Solow-Swan Model

SAMPLE	All countries	Developing Countries
No. of Countries:	98	76
VARIABLE	COEFFICIENT	COEFFICIENT
$\ln(y_{t-1})$ 1/	-.268576 (-5.90)	-.270720 (-6.47)
$\ln(n_t+0.05)$ 2/	-.122014 (-4.90)	-.147418 (-6.64)
$\ln(s_{k_t})$ 3/	.148905 (8.36)	.118404 (7.03)
Implied η 4/	.0626 (5.03)	.0631 (5.50)
Wald test for uncorrelated effects	164.53	167.21
p-value	.00000	.00000
Wald test for $\theta_1=-\theta_2$ in equation (10')	.798	1.093
p-value	.3718	.2959

1/ Real GDP per worker lagged one 'period' (that is, five years back).
2/ Average growth rate of the working-age population plus sum of rates of technological progress and depreciation.
3/ Average ratio of real investment (including government investment) to real GDP.
4/ Speed of convergence, per year.

estimated values of γ to be negative, θ_1, negative, and θ_2, positive; furthermore, we expect θ_1 and θ_2 to have approximately the same absolute value. As can be seen from Table 1, all these predictions of the S-S model hold true for the sample that includes all countries, as well as for that for developing countries only.

Moreover, our estimated values for the speed of convergence η are 0.0626 and 0.0631 per year for the sample containing all 98 countries and for that of developing countries, respectively, implying that the economy moves half way to the steady state in about 11 years. 1/ These estimates are much larger than those reported in Barro (1991b) and M-R-W, but similar to the predicted value of the simple S-S model (see the formula for η in equation (8), setting β=0 and using sensible values for n, g, and δ). M-R-W find that the implied estimate for the speed of convergence of the model to its steady state growth path is 0.0137 per year. Barro (1991b), using variables such as school enrollment ratios, the government consumption expenditure ratio, proxies for political stability and a measure of market distortions, finds an estimated speed of convergence equal to 0.0184 per year. These estimates correspond to a half life for the logarithm of output per effective worker of between 37 and 50 years. 2/ We believe that the large difference between these earlier estimates and the ones we report here can be explained by the fact that the Barro and M-R-W studies do not account for the correlation between the country-specific effects and the independent variables in the model, thus producing biased coefficients. When country-specific effects are ignored, the coefficient on lagged output is biased toward zero because there is a positive correlation between country-specific effects (defined to be positive) and the initial levels of income in each interval (lagged output).

We can in fact test for the presence of such a correlation. Let us consider the null hypothesis of "uncorrelated effects," which means that the country-specific effects have no correlation with the independent variables. From the equation for the linear predictor of μ_i and equation (16) it is evident that the null hypothesis of uncorrelated effects, in the framework of our maintained model, is equivalent to H_0: $\lambda'_1 = \ldots = \lambda'_5 = 0$. As can be seen in Table 1, the Wald test strongly rejects the null hypothesis of uncorrelated effects.

In Table 2 we report the results of the estimation assuming that the coefficients on $\ln(n_t + 0.05)$ and $\ln(s_{k_{t-1}})$ are the same in absolute value, but opposite in sign ($\theta_1 = -\theta_2$). We do this in order to obtain estimates for the implied capital share, α, in the Cobb-Douglas production function. The estimates for α are 0.335 and 0.326 for all countries and for developing countries, respectively. These estimated capital shares are very close to

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1/ Note that in the estimating equation (9) the parameters η and r appear on both sides; we set r = 5 years in our panel data regressions.

2/ The half-life formula is T = (ln 2)/η, where T is number of years.

Table 2. Simple Restricted Solow-Swan Model
(Cobb-Douglas Assumption: $-\theta_1 = \theta_2$)

SAMPLE	All countries	Developing Countries
No. of Countries:	98	76
VARIABLE	COEFFICIENT (T-RATIO)	COEFFICIENT (T-RATIO)
$\ln(y_{t-1})$ 1/	-.278212	-.266049
	(-6.37)	(-6.63)
$-\ln(n_t+0.05)$ 2/	.140136	.128487
and $\ln(s_{k_t})$ 3/	(9.52)	(9.55)
Implied η 4/	.0652	.0619
	(5.39)	(5.66)
Implied α 5/	.335	.326

1/ Real GDP per worker lagged one 'period' (that is, five years back).
2/ Average growth rate of the working-age population plus sum of rates of technological progress and depreciation.
3/ Average ratio of real investment (including government investment) to real GDP.
4/ Speed of convergence, per year.
5/ Income share accruing to non-human capital.

the value of 0.350 that Maddison (1987) obtains for the share of non-human capital in production. Our estimated non-human capital shares imply that diminishing returns set in quickly, which explains the rapid convergence predicted by the model.

Let us return to Table 1 to examine the differences in the estimated coefficients obtained using the two samples. For the sample of developing countries, the absolute value of the coefficient of population growth is larger than that for the sample of all countries. This can be explained by the fact that the developed industrial countries have tended to grow relatively steadily in per capita terms over the sample period, while experiencing relatively low rates of population growth. Accordingly, when they are excluded from the sample the estimated effect of population growth is larger. Our estimates also suggest that investment in physical capital is less productive for the developing countries than for the industrial countries. The fact that we do not obtain the same parameter estimates using the two different samples has to do with sampling error and with the inability to control completely for the country-specific effects. 1/

Table 3 presents the econometric estimates for the second version of the S-S model (regression equation (10b)). As might be expected, the inclusion of a proxy for the ratio of human capital investment to GDP has the effect of lowering the absolute value of the estimated coefficients on the other variables in both the total and the developing-country samples. However the changes are relatively small, apparently because most of the effect of human capital investment has already been captured by the country-specific effects in the estimates of the first model. As also expected, the coefficient on the proxy for the human capital investment ratio is significantly positive. In this second model, a Cobb-Douglas production function implies that $-\theta_1 = \theta_2 + \theta_3$ in equation (10b). This restriction, however, is rejected by the data on the basis of the Wald test. This result may be due to the fact that education is more closely related to the efficiency variable than to human capital proper as an accumulatable factor of production; of course, the reason this assumption does not appear to be consistent with the sample data could be that the aggregate production function is in fact more complex than the Cobb-Douglas form allows. It is also interesting to note that, for both samples, the speed of convergence is now estimated to be lower than that in the first model. We believe this is due to higher returns to total capital, broadly defined to include human capital. In fact, as already noted, when only physical capital is accumu-

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1/ There are two basic reasons for this imperfection. The first has to do with the fact that we are grouping together all unobservable factors into the country-specific effects; thus if an unobserved variable affects the two samples differently, we obtain sharper estimates by separating the two samples. The second reason may be the presence of nonlinear interactions between physical capital investment and the variables that are left out of the first model, such as education, public infrastructure, and openness to trade (linear interactions are accounted for by our methodology).

Table 3. Solow-Swan Model Augmented to include Human Capital Investment

SAMPLE	All countries	Developing Countries
No. of Countries:	98	76
VARIABLE	COEFFICIENT (T-RATIO)	COEFFICIENT (T-RATIO)
$\ln(y_{t-1})$ 1/	-.177514 (-3.41)	-.209543 (-4.27)
$\ln(n_t+0.05)$ 2/	-.087278 (-3.02)	-.100729 (-3.86)
$\ln(s_{k_t})$ 3/	.106143 (6.60)	.084423 (5.54)
$\ln(s_{h_t})$ 4/	.106425 (4.91)	.099510 (5.38)
Implied η	.0391 (3.09)	.0470 (3.79)
Wald test for uncorrelated effects	87.91	178.85
p-value	.00000	.00000
Wald test for $\theta_1=-\theta_2+\theta_3$ in equation (10')	12.31	5.16
p-value	.00000	.02317

1/ Real GDP per worker lagged one 'period' (that is, five years back).

2/ Average growth rate of the working-age population plus sum of rates of technological progress and depreciation.

3/ Average ratio of real investment (including government investment) to real GDP.

4/ Ratio of human capital investment to GDP, proxied by the product of gross secondary-school enrollment ratio times the fraction of the working population aged 15 to 19.

lated its marginal productivity decreases rapidly. Thus the steady state is achieved more quickly, but at a lower per capita output level (see the definition of η in equation (8), and set the share of human capital β at a positive level).

Table 4 reports the results of the second model when panel data for the human capital proxy, rather than only cross-sectional data, are used to estimate the effect of this variable. We find that the estimated coefficient on this proxy is now significantly *negative* for both samples. 1/ This result is at first surprising. Why does the addition of the time-series dimension in data for the proxy of human capital alter the *sign* of its effect on growth? Our explanation for this result is that when we incorporate time series data on education for each country, we are now using not only the cross-country differences in the relation between education and growth but also the effect of *changes* in the human capital proxy within each country over time. This temporal relationship has in fact been negative over the years, especially for developing countries (see Tilak, 1989; and Fredriksen, 1991). In other words, adjusted secondary school enrollment ratios rose steadily in most developing countries over 1960-1985, sometimes by large amounts, while the rate of output growth remained stable or even fell. Apparently this time-series relation is strong enough to override the cross-sectional effects in the estimation. This empirical result points to the possibility that the adjusted secondary school enrollment ratio may not be a good proxy for the ratio of human capital investment to GDP when relatively short intervals (in our case five-year intervals) are compared. The length of the interval is important for the quality of such a proxy because there is a considerable lag between the completion of education and its appropriate use as a factor of production (see Psacharopoulos and Ariagada, 1986b). Therefore, cross-sectional data (that is, data where the observation for each country is an average of its respective time-series observations) may be the preferred proxy in estimating the growth effects of human capital investment. The implication is that when the secondary school enrolment ratio is used as the proxy, we can obtain reasonably good estimates of cross-country differences in human capital investment, but not of *changes* in the rate of human capital investment within a country over time.

Table 5 reports the results for the third augmented version of the S-S model presented in Section II. Its corresponding regression is represented by equation (10). Considerations of data availability obliged us to restrict the sample of countries used in this last estimation (see Appendix II). Therefore, one would have to be particularly cautious about extrapolating the results described below to countries that are not included in the sample. The negative sign of the coefficient on lagged output indicates "conditional convergence," which means that--controlling for the determinants of the steady state across countries--poor countries would tend

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1/ De Gregorio (1992) reports similar results for a sample of Latin American countries.

Table 4. Solow-Swan Model Augmented to Include Human Capital Investment, Using Panel Data for the Proxy for Human-Capital Investment Ratio

SAMPLE	All countries	Developing Countries
No. of Countries:	96	75
VARIABLE	COEFFICIENT (T-RATIO)	COEFFICIENT (T-RATIO)
$\ln(y_{t-1})$ 1/	-1.038294 (-34.55)	-1.29606 (-95.73)
$\ln(n_t+0.05)$ 2/	-.038919 (-5.25)	-.011380 (1.45)
$\ln(s_{k_t})$ 3/	.023293 (1.61)	.104808 (10.16)
$\ln(s_{h_t})$ 4/	-.065204 (-5.09)	-.110844 (-13.26)
Wald test for uncorrelated effects	3249.00	60274.42
p-value	.00000	.00000
Wald test for $\theta_1=-\theta_2+\theta_3$ in equation (10')	12.23	0.07
p-value	.00000	.79737

1/ Real GDP per worker lagged one 'period' (that is, five years back).
2/ Average growth rate of the working-age population plus sum of rates of technological progress and depreciation.
3/ Average ratio of real investment (including government investment) to real GDP.
4/ Ratio of human capital investment to GDP, proxied by the product of gross secondary-school enrollment ratio times the fraction of the working population aged 15 to 19.

Table 5. Solow-Swan Model Augmented to Include Human Capital Investment, Openness to Foreign Trade, and Public Infrastructure

SAMPLE	All countries	Developing Countries
No. of Countries:	81	59
VARIABLE	COEFFICIENT (T-RATIO)	COEFFICIENT (T-RATIO)
$\ln(y_{t-1})$ 1/	-.220766 (-9.45)	-.683584 (-17.75)
$\ln(n_t+0.05)$ 2/	-.147034 (-12.52)	-.176006 (-9.01)
$\ln(s_{k_t})$ 3/	.201278 (18.17)	.205703 (14.24)
$\ln(s_{h_t})$ 4/	.094480 (8.18)	.319660 (18.15)
ln(F) 5/	-0.065026 (-11.76)	-0.081973 (-15.97)
ln(P) 6/	.012753 (.78)	.097803 (6.47)
Implied η	.0499 (8.32)	.2301 (9.45)
Wald test for uncorrelated effects	526.03	5596.77
p-value	.00000	.00000
Wald test for $\theta_1=-\theta_2+\theta_3$ in equation (10)	61.76	238.19
p-value	.00000	.00000

1/ Real GDP per worker lagged one 'period' (that is, five years back).
2/ Average growth rate of the working-age population plus sum of rates of technological progress and depreciation.
3/ Average ratio of real investment (including government investment) to real GDP.
4/ Ratio of human capital investment to GDP, proxied by the product of gross secondary-school enrollment ratio times the fraction of the working population aged 15 to 19.
5/ "Closedness" of the economy, proxied by the weighted average of tariff rates on imported intermediate and capital goods.
6/ Ratio of public infrastructure to GDP, proxied by the average ratio of general government fixed investment (central government plus public enterprises) to GDP.

to grow faster than rich ones (see Barro and Sala-i-Martin, 1992). By including the investment ratios as well as the proxies for openness and public infrastructure in the regression equation, we appropriately condition for different preferences and technologies.

The growth rate of the labor force is estimated to be negatively related to per capita output growth, especially when the estimates come from the sample that includes developing countries only. Investments in both physical capital and human capital are strongly and positively correlated with growth. When proxies for openness and public infrastructure are included in the model, the estimated coefficient of the rate of investment in physical capital becomes twice as large as it was in the second model, for both samples. This seems to indicate that the *quality* of physical investment improves when the international transfer of technology is allowed and when better public infrastructure is provided. We believe that this has to do with the fact that greater openness and better public services create a market environment where allocative efficiency is enhanced. In addition, the estimated effect of the rate of investment in human capital becomes much stronger in the case of the developing country sample when the aforementioned proxies are included.

The variable F, defined as the weighted average of tariffs on intermediate and capital goods, has a significant negative effect on output growth. This measure of openness (probably "closedness" is a better term given the way this variable is defined) affects growth not only through the investment ratios, as indicated above, but also through the efficiency term, which accounts for technological improvement. The evidence of such an independent role for openness, combined with the fact that the absolute value of the coefficient's point estimate is larger for the developing countries, lends support to the view that for many countries, particularly developing ones, a liberal trade regime enhances growth by providing a source of technological progress via the freedom to import sophisticated goods from the most technologically-advanced nations. At a broader level, this result provides a measure of empirical confirmation for the familiar argument that outward-oriented trade strategies tend to promote economic growth in developing countries.

The ratio of government investment to GDP (the variable P) has a positive coefficient for both samples, but this coefficient is statistically significant at the 95 percent level only for the developing country sample. The statistical insignificance of this coefficient in the full sample may be due to the fact that our proxy for public infrastructure is based on flow data that do not take into account the initial level of the associated stock. This is especially important for the industrial countries, which by 1960 had accumulated substantial stocks of public infrastructure relative to those in developing countries. In that sense, our proxy is better suited to developing countries, and this may explain why we find a much larger and highly significant coefficient in the sample for the latter group. As in the case of the openness variable it is interesting to note that, at least for the latter sample, the proxy for public infrastructure has an independent role in economic growth even when physical and human capital are already included.

V. Concluding Remarks

This paper has extended the work of Mankiw, Romer and Weil (1992), in two directions. Unlike their model, which relies exclusively on cross-sectional data, we find evidence of significant country-specific effects, which our panel data estimation procedure is able to detect. One important consequence of obtaining estimates from panel data is the faster rate of conditional convergence that we have estimated in our model, relative to that estimated by M-R-W and Barro (1991b). We surmise that this difference occurs because the latter studies do not take into account the correlation between country-specific effects and the independent variables in their estimates of the growth equation. The other new result is that overall economic efficiency is influenced significantly and positively by the extent of openness to international trade and by the level of social infrastructure in the domestic economy.

Like M-R-W, we find that the Solow-Swan growth model's predictions are consistent with the evidence. These include the positive effects of saving ratios and the negative effects of population growth on the steady-state level as well as the transitional growth path of per capita GDP. We also find (conditional) convergence at approximately the rate predicted by the S-S model. We estimate the share of capital at about a third, which is close to the value estimated by Maddison (1987) for the share of non-human capital in GDP. Our estimated capital shares imply that diminishing returns to physical capital set in quickly; this explains the rapid convergence predicted by our model.

Comparing the results between the two samples of industrial and developing countries, we find that the absolute value of the estimated coefficient on population growth is larger when we restrict our sample to developing countries alone, reflecting the fact that many countries in this group have tended to exhibit slow growth in per capita while experiencing rapid rates of population growth. Moreover, there is evidence that investment in physical capital has been less productive for those developing countries that have had lower initial stocks of human capital and social infrastructure, as well as higher rates of effective protection, all of which have tended to reduce the overall efficiency of physical investment.

Our results on the growth effects of a country's openness to international trade and on social infrastructure deserve some further elaboration. When openness and the level of public infrastructure are taken into account in the estimates, physical investment becomes quantitatively more important in the growth process, implying that a better quality of investment is encouraged by a more liberal international trade regime and more social infrastructure. Particularly for the developing countries, investment in human capital also becomes more quantitatively important when a more open trading environment and a better public infrastructure are in place.

There are two channels through which the negative impact on growth of a restrictive trade system (proxied by the weighted average of tariffs on intermediate and capital goods) is transmitted, particularly in developing countries where the capital goods industries are in their infancy or non-existent: via the rate of investment and its efficiency. High tariffs, particularly on capital goods, discourage imports of the sophisticated goods that are an important factor in the international transfer of technology. The strong statistical significance of our proxy for "closedness" in the growth equation provides evidence that outward-oriented development strategies have a positive impact on economic growth.

The public infrastructure variable is statistically and positively significant only for the developing countries, and appropriately so. This can be explained by the failure of our proxy to account for the initial level of public infrastructure; for the industrial-country group, the level of public infrastructure in 1960 was a large multiple of the level in the developing-country group. As in the case of the outward orientation of development strategies, better provision of public infrastructure exerts an independent influence on the rate of economic growth.

Linearization of the Transition Path Around the Steady State

We apply a Taylor series approximation. The variable in question is $\ln \hat{y}$, and the function to be approximated is its derivative with respect to time, namely, $d(\ln \hat{y})/dt$. The linear approximation is centered around the steady state value of the natural logarithm of adjusted output, that is, $\ln \hat{y}*$.

$$(1a)\quad d(\ln \hat{y}_t)/dt \simeq d(\ln \hat{y}_t)/dt\Big|_{\ln \hat{y}*} + (\ln \hat{y}_t - \ln \hat{y}*)\, d(d\ln \hat{y}_t/dt)/d\ln \hat{y}_t\Big|_{\ln \hat{y}*}$$

Since in the steady state, the growth rate of $\hat{y}$ is zero, the first term of the right-hand side of (1a) drops out. Concentrating on the second term of the right-hand side, we obtain from text equation (1'):

$$\ln \hat{y}_t = \alpha \ln \hat{k}_t + \beta \ln \hat{h}_t.$$

Therefore,

$$(2a)\quad d(\ln \hat{y}_t)/dt = -(\alpha+\beta)(n+g+\delta) + \alpha s_k(\hat{y}_t/\hat{k}_t) + \beta s_h(\hat{y}_t/\hat{h}_t).$$

Taking derivatives with respect to $\ln \hat{y}_t$ yields,

$$d(d\ln \hat{y}_t/dt)/d\ln \hat{y}_t = d(\alpha s_k(\hat{y}_t/\hat{k}_t))/d\ \ln\hat{y}_t + d(\beta s_h(\hat{y}_t/\hat{h}_t)/d\ \ln\hat{y}_t,$$

$$= \alpha s_k(\hat{y}_t/\hat{k}_t) + \beta s_h(\hat{y}_t/\hat{h}_t) - [\alpha s_k(\hat{y}_t{}^2/\hat{k}_t{}^2)(d\hat{k}_t/d\hat{y}_t) + \beta s_h(\hat{y}_t{}^2/\hat{k}_t{}^2)(d\hat{h}_t/d\hat{y}_t)],$$

$$= \alpha s_k(\hat{y}_t/\hat{k}_t) + \beta s_h(\hat{y}_t/\hat{h}_t) - s_k(\hat{y}_t/\hat{k}_t) + [s_k(\hat{y}_t/\hat{k}_t) - s_h(\hat{y}_t/\hat{h}_t)]\beta d(\ln\hat{h}_t)/d(\ln\hat{y}_t).$$

Before we evaluate the derivative at the steady state, consider the following steady-state relations (which are obtained from text equation (6)):

$$\hat{y}_t*/\hat{k}_t* = (n+g+\delta)/s_k;$$

$$\hat{y}_t*/\hat{h}_t* = (n+g+\delta)/s_k.$$

Using these relations, we can now evaluate the derivative,

$$d(d\ln \hat{y}_t/dt)/d\ln \hat{y}_t\Big|_{\ln \hat{y}*} =$$

$$\alpha s_k(\hat{y}*/\hat{k}*) + \beta s_h(\hat{y}*/\hat{h}*) - s_k(\hat{y}*/\hat{k}*) + \beta[s_k(\hat{y}*/\hat{k}*) - s_h(\hat{y}*/\hat{h}*)]d(\ln\hat{h}_t)/d(\ln\hat{y}_t)\Big|_{\ln \hat{y}*}$$

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

Therefore, equation (1a) becomes,

$$d(\ln\hat{y}_t)/dt \simeq -\eta\,(\ln \hat{y}* - \ln \hat{y}_t),$$

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

Data Sources and Definitions, and Sample of Countries

Data Sources:

The basic data used in this study are annual observations for the period 1960 to 1985. The following variables were taken from Summers and Heston (1991), Penn World Tables:

y : real GDP per worker

s_k : real investment to GDP ratio (five-year average)

n : growth rate of number of workers (five-year average)

The following variable was taken from Mankiw, Romer and Weil (1992):

s_h : Percent of working age population enrolled in secondary school (average for the period 1960-85). Panel data were obtained from the UNESCO Statistical Yearbook (1991) and were adjusted for age using population data from UN Population Division (1990).

Data on tariffs was taken from Jong-Wha Lee (1992):

F : Import-share weighted average of tariffs on intermediate and capital goods (from various years in the early 1980s).

The DEC Analytical Database from the World Bank, International Economics Department (1991) was used to obtain a proxy for public infrastructure:

P : average ratio of general government fixed investment to GDP.

Composition of Samples

1. Industrial (OECD Member) Countries

1. Canada
2. U.S.A.
3. Japan
4. Austria
5. Belgium
6. Denmark
7. Finland
8. France
9. Germany, West
10. Greece
11. Ireland
12. Italy
13. Netherlands
14. Norway
15. Portugal
16. Spain
17. Sweden
18. Switzerland
19. Turkey
20. U.K.
21. Australia
22. New Zealand

2. Developing (Non-OECD) Countries

1. Algeria
2. Angola
3. Benin
4. Botswana
5. Burkina Faso
6. Burundi
7. Cameroon
8. Central Africa Republic
9. Chad
10. Congo
11. Egypt
12. Ethiopia
13. Ghana
14. Cote d'Ivoire
15. Kenya
16. Liberia
17. Madagascar
18. Malawi
19. Mali
20. Mauritania
21. Mauritius
22. Morocco
23. Mozambique
24. Niger
25. Nigeria
26. Rwanda
27. Senegal
28. Sierra Leone
29. Somalia
30. South Africa
31. Sudan
32. Tanzania
33. Togo
34. Tunisia
35. Uganda
36. Zaire
37. Zambia
38. Zimbabwe
39. Costa Rica
40. Dominican Republic
41. El Salvador
42. Guatemala
43. Haiti
44. Honduras
45. Jamaica
46. Mexico
47. Nicaragua
48. Panama
49. Trinidad & Tobago
50. Argentina
51. Bolivia
52. Brazil
53. Chile
54. Colombia
55. Ecuador
56. Paraguay
57. Peru
58. Uruguay
59. Venezuela
60. Bangladesh
61. Myanmar
62. Hong Kong
63. India
64. Indonesia
65. Israel
66. Jordan
67. Korea, South
68. Malaysia
69. Nepal
70. Pakistan
71. Philippines
72. Singapore
73. Sri Lanka
74. Syria
75. Thailand
76. Papua N. Guinea

Tables 1, 2, and 3: The sample for the estimates presented in these tables covers all of the 98 industrial and developing countries listed above.

Table 4 (96 Countries): The sample for the estimates in this Table is the same as that for Tables 1-3, except that South Africa and Switzerland have been dropped due to unavailability of data.

Table 5 (81 Countries): In the sample for the estimates in this Table, the following countries have been dropped from the sample of Tables 1-3 for the same reason: Botswana, Cameroon, Central African Republic, Chad, Cote d'Ivoire, Liberia, Mali, Mauritania, Mozambique, Niger, South Africa, Togo, Dominican Republic, Honduras, Panama, Myanmar, Israel.

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