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Testing the Neoclassical Theory of Economic Growth

A Panel Data Approach

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Recent empirical studies have examined the determinants of economic growth using country-average (cross-sectional) data. By contrast, this paper employs a technique for using a panel of cross-sectional and time series data for 98 countries over the 1960–85 period 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 support the view that these factors exert a positive and significant influence on growth. They also provide estimates of the speed at which the gap between the real per capita incomes of rich and poor countries is likely to be reduced over the longer term. [JEL O41, C23]

THE BASIC neoclassical model of Solow (1956) and Swan (1956) 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

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exogenous labor force growth—provide an elegant solution to the "knife-edge" problem posed by Harrod (1939) and Domar (1946) and ensure the attainment of a balanced equilibrium growth path (Hacche (1979)).

The Solow-Swan 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, and by the rates of saving, population growth, and technical progress, all three of which are assumed exogenous. Since these rates differ across countries, the Solow-Swan model yields testable predictions about how differing saving rates and population growth rates, for example, might affect different countries' steady-state levels of per capita income: other things being equal, countries that have higher saving rates tend to have higher levels of per capita income, and countries with higher population growth rates tend to have lower levels of per capita income.

Recently, the Solow-Swan model has come under attack by the new growth theorists, who dismiss it in favor of "endogenous growth" models that assume constant or increasing returns to capital. These critics allege that the standard neoclassical model fails to explain observed differences in per capita income across countries. The different 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 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 the growth rate of real per capita GDP and the initial level of real per capita GDP is negative. In other words, the lower the starting level of real per capita income, the higher is its subsequent rate of growth. In a recent cross-section study, however, Barro and Sala-i-Martin (1992) find that this simple correlation is positive rather than negative, albeit statistically insignificant.

In itself, the empirical evidence against unconditional convergence is not inconsistent with the implications of the neoclassical growth model. The Solow-Swan model does not predict unconditional convergence of per capita income 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) contends, using a cross-sectional approach, that the Solow-Swan model's predictions are indeed consistent with the empirical evidence. They also find, however, that if human capital is not accounted for in the model the quantitative implications of different 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, Mankiw, Romer, and Weil augment the Solow-Swan 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, this augmented Solow-Swan model implies smaller effects of saving and population growth on per capita income growth and explains about 80 percent of the cross-country variation in per capita income.

Despite the evidence on the failure of per capita income to converge across countries—the failure of the "unconditional convergence" hypothesis—Mankiw, Romer, and Weil find evidence of conditional convergence at about the rate predicted by the Solow-Swan 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 the rates of return to capital as being consistent with the Solow-Swan growth model. Thus, their work provides empirical support for the model and casts doubt on the new endogenous growth models that invoke constant or increasing returns to capital.

This paper extends the Mankiw, Romer, and Weil analysis in two directions. First, a panel of time series cross-sectional 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 Mankiw, Romer, and Weil (1992), 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—whether they increase or decrease its openness to international trade (see Edwards (1992)); and (2) the stock of public infrastructure in the domestic economy.

As already noted, our first extension of the Mankiw, Romer, and Weil analysis refers to the econometric treatment of the data. In the empirical part of their paper, they use cross-sectional data for various groups of countries. Essentially, they take averages of the relevant variables over the whole period, 1960–85. 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 general econometric specification of the model by appropriately using panel data to account for important country-specific effects. This approach yields a number of interesting extensions to the empirical results of Mankiw, Romer, and Weil, particularly when the estimates for the full sample of both industrial and developing countries are compared with those for developing countries only.[1] Provided the assumptions required for using the panel data hold, our approach also improves the efficiency of the estimates by using more information.[2]

Our second, related, extension of Mankiw, Romer, and Weil's empirical analysis refers to the country-specific variables—trade policies, human capital, and government fixed investment—that we include in the model. Policies that foster more openness in a country's international trade regime help to stimulate labor-augmenting technological change in two ways.[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 through the development of efficient and internationally competitive management, the training of skilled workers, and the spillover consequences of scale expansion (Keesing (1967) and Feder (1983)). Second, rising exports help to relieve the foreign exchange constraint—that is, a country's ability to import technologically superior capital goods is augmented directly by rising export receipts and indirectly by the higher flows of foreign credits and direct investment caused by the country's increased ability to service debt and equity held by foreigners.[4]

As regards government fixed investment, it is reasonable to assume that an expansion in the amount of public goods concentrated in physical infrastructure (such as transport and telecommunications) will be associated with greater economic efficiency. Empirical studies that emphasize

[1] Our sample of industrial countries consists of the 21 developed countries that are members of the OECD; our sample of developing countries consists of 76 non-OECD developing countries. See the appendix.

[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), Roubini and Sala-i-Martin (1992), and Villanueva (1993).

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

other productive public expenditures, such as education and health spending, include Diamond (1989), Otani and Villanueva (1990), and Barro (1991); those that focus on fixed investment include Diamond (1989), Orsmond (1990), and Barro (1991).

I. The Model

The Mankiw, Romer, and Weil model is an augmented neoclassical Solow-Swan model that accounts for human capital in the production function and saving decisions of the economy.

Consider the following Cobb-Douglas production function:

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

where Y is real output, K is the stock of physical capital, H is the stock of human capital, L is raw labor, A is a labor-augmenting factor reflecting the level of technology and efficiency in the economy, and t refers to time in years. 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,

$$L_t = L_0 e^{nt}, \tag{2}$$

$$A_t = A_0 e^{gt} F^{\theta_f} P^{\theta_p}, \tag{3}$$

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 government fixed investment in the economy. (For simplicity, we normalize L_0 to unity.) Thus, our efficiency variable A differs from that used by Mankiw, Romer, and Weil in that it depends not only on exogenous technological improvements but also on the degree of openness of the economy (with elasticity θ_f) and on the level of government fixed investment (with elasticity θ_p). 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 through imports of capital goods and where the productive sector's efficiency may depend heavily on the level of fixed investment undertaken by the government.

As in the Solow-Swan 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,

$$\frac{dK_t}{dt} = s_k Y_t - \delta K, \tag{4}$$

$$\frac{dH_t}{dt} = s_h Y_t - \delta H, \tag{5}$$

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

To facilitate analysis of the steady state and the behavior around it, we redefine each variable in terms of its value *per effective unit of labor*, by dividing each 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.

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

$$\hat{y}_t = \hat{k}_t^{\alpha} \hat{h}_t^{\beta}, \tag{1'}$$

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

and

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

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 (4′) and (5′), this assumption implies

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

$$\hat{h}^* = \left(\frac{s_k^{\alpha} s_h^{1-\alpha}}{n + g + \delta}\right)^{1/1-\alpha-\beta}, \tag{6}$$

and

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

Furthermore, in the steady state, output per worker (y) grows at the constant rate g (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:

$$\begin{aligned}\ln \hat{y}_t &= \ln Y_t - \ln L_t - \ln A_t \\ &= \ln y_t - \ln A_0 - gt - \theta_f \ln F - \theta_p \ln P. \qquad (7)\end{aligned}$$

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 is zero, the growth rate of output per worker is equal to g:

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

Dynamics Around the Steady State

Following Mankiw, Romer, and Weil, 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 produces the following result:[5]

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

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

The parameter η defines the speed of convergence: 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 $t = t_0 + r$:

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

[5]The linearization of the transition path around the steady state is derived in Appendix I of our original working paper (Knight, Loayza, and Villanueva (1992)).

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

$$\ln \hat{y}_{t_0+r} = -(1 - e^{-\eta r})\left(\frac{\alpha + \beta}{1 - \alpha - \beta}\right) \ln(n + g + \delta) + (1 - e^{-\eta r})\left(\frac{\alpha}{1 - \alpha - \beta}\right) \ln s_k + (1 - e^{-\eta r})\left(\frac{\beta}{1 - \alpha - \beta}\right) \ln s_h + e^{-\eta r} \ln \hat{y}_{t_0}.$$

For purposes of estimation, we need an expression in terms of output per worker rather than output per effective worker. Accordingly, following Mankiw, Romer, and Weil, 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:

$$\begin{aligned} \ln y_{t_0+r} - \ln y_{t_0} = {} & -(1 - e^{-\eta r})\left(\frac{\alpha + \beta}{1 - \alpha - \beta}\right) \ln(n + g + \delta) \\ & + (1 - e^{-\eta r})\left(\frac{\alpha}{1 - \alpha - \beta}\right) \ln s_k \\ & + (1 - e^{-\eta r})\left(\frac{\beta}{1 - \alpha - \beta}\right) \ln s_h \\ & + (1 - e^{-\eta r})\theta_f \ln F + (1 - e^{-\eta r})\theta_p \ln P \\ & - (1 - e^{-\eta r}) \ln y_{t_0} + [(1 - e^{-\eta r})(t_0 + r)g \\ & + e^{-\eta r} rg] + (1 - e^{-\eta r}) \ln A_0. \end{aligned} \tag{9}$$

Equation (9) provides a useful specification for our empirical study.[6] We will use it as a guide but not apply it literally.

The growth effects that we next discuss 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 predict the sign of 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

[6] Note that as t_0 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.

greater openness to international trade—by contributing to the efficiency of production—raises the rate of economic growth. A similar analysis holds for the fifth coefficient, which applies to the level of government fixed investment. The sixth term indicates that countries grow faster if they are initially below their steady-state growth path, what is known as "conditional convergence" in the growth literature (Barro and Sala-i-Martin (1992), Mankiw, Romer, and Weil (1992), and Loayza (1992)). Next, the term in brackets suggests the presence of a time-specific effect on growth. The last term contains A_0, which represents all the unobserved 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 growth rate 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:

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

where ξ_t and μ_i represent time-specific and country-specific effects and where $\theta_1, \ldots, \theta_5$ 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 (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 government fixed investment P may differ from country to country, but owing to the limited availability of data their levels in each country are assumed to remain unchanged for all time periods in the sample.[7] 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 exoge-

[7]This refers to those data in our study for which only cross-sectional data are available.

nous rate of technological change and the rate of depreciation are equal across countries.[8]

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 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.

II. Panel Data Estimation

As we have noted, previous empirical studies of long-run growth have made use of cross-sectional data. This practice forced the use of some rather restrictive assumptions in the econometric specifications. For instance, Mankiw, Romer, and Weil, 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 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 and 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 the panel data to analyze regression equation (10), using a technique suggested by Chamberlain (1983).

We rewrite equation (10) as follows:

$$z_{i,t} - z_{i,t-1} = \theta' \mathbf{v}_{i,t} + \gamma z_{i,t-1} + \xi_t + \mu_i + \epsilon_{i,t} \qquad (10')$$

where $z_{i,t} = \ln(y_{i,t})$; $\mathbf{v}_{i,t} = [\ln(n_{i,t} + g + \delta), \ln(s_{k_{i,t}}), \ln(s_{h_{i,t}}), \ln F_i, \ln P_i]'$; and $\theta = (\theta_1, \ldots, \theta_5)'$. First, we need to process the data to eliminate the time effects, which we do 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

[8]This assumption corresponds to that in Mankiw, Romer, and Weil. The value for $g + \delta$ that is used in the estimation procedure actually matched the available data.

μ_i's are treated as fixed (as in a 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.[9] 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. The inconsistency comes from the fact that the error term obtained after removing the country means is correlated with lagged output.

Our chosen estimation method is the $\mathbf{\Pi}$ matrix approach outlined in Chamberlain (1983). Chamberlain's $\mathbf{\Pi}$ 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 (the elements of the $\mathbf{\Pi}$ matrix) and the robust (White's (1980) heteroskedasticity-consistent) variance-covariance matrix of such parameters.

The specific model we are working with implies some restrictions on the elements of the $\mathbf{\Pi}$ matrix: the parameters of interest are functions of the $\mathbf{\Pi}$ matrix. This takes us to the second step in the procedure: we estimate the parameters of interest by means of a minimum-distance estimator using the robust variance-covariance of the estimated $\mathbf{\Pi}$ as the weighting matrix:

$$\min[\text{vec}\,\mathbf{\Pi} - f(\mathbf{\Psi})]'\mathbf{\Omega}[\text{vec}\,\mathbf{\Pi} - f(\mathbf{\Psi})],$$

where ψ is the set of parameters of interest and $\mathbf{\Omega}$ is the robust variance-covariance of the $\mathbf{\Pi}$ 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 $\mathbf{\Pi}$ matrix. After removing the time means, our basic model in equation (10′) can be written as

$$z_{i,t} - z_{i,t-1} = \boldsymbol{\theta}'\mathbf{v}_{i,t} + \gamma z_{i,t-1} + \mu_i + \epsilon_{i,t}. \tag{11}$$

At this point it is necessary that we distinguish the two kinds of variables contained in the vector $\mathbf{v}_{i,t}$: those that are both country and time specific ($\ln[n_{i,t} + g + \delta]$ and $\ln[s_{ki,t}]$) and those that are only country

[9] References on the "within" estimator include Mundlak (1978) and Greene (1990, chapter 16).

specific ($\ln[s_{h_i}]$, $\ln[F_i]$ and $\ln[P_i]$). Then we rewrite equation (11) as follows:

$$z_{i,t} - z_{i,t-1} = \theta_a' \mathbf{x}_{i,t} + \theta_b' \mathbf{w}_i + \gamma z_{i,t-1} + \mu_i + \epsilon_{i,t}, \tag{12}$$

where $\mathbf{x}_{i,t} = [\ln(n_{i,t} + g + \delta),\ \ln(s_{k_{i,t}})]'$, $\mathbf{w}_i = [\ln(s_{h_i}),\ \ln\ F_i,\ \ln\ P_i]'$, $\theta_a=(\theta_1, \theta_2)'$, and $\theta_b = (\theta_3, \theta_4, \theta_5)'$.

By recursive substitution of the z_{t-1} term in each regression equation, we have[10]

$$\begin{aligned}
z_{i,1} - z_{i,0} &= \theta_a' \mathbf{x}_{i,1} + \theta_b' \mathbf{w}_i + \gamma z_{i,0} + \mu_i + \omega_{i,1},\\
z_{i,2} - z_{i,1} &= \gamma\theta_a' \mathbf{x}_{i,1} + \theta_a' \mathbf{x}_{i,2} + (1 + \gamma)\theta_b' \mathbf{w}_i + \gamma(1 + \gamma) z_{i,0}\\
&\quad + (1 + \gamma)\mu_i + \omega_{i,2},\\
z_{i,3} - z_{i,2} &= \gamma(1 + \gamma)\theta_a' \mathbf{x}_{i,1} + \gamma\theta_a' \mathbf{x}_{i,2} + \theta_a' \mathbf{x}_{i,3} + (1 + \gamma)^2 \theta_b' \mathbf{w}_i\\
&\quad + \gamma(1 + \gamma)^2 z_{i,0} + (1 + \gamma)^2 \mu_i + \omega_{i,3},\\
&\ \ \vdots\\
z_{i,T} - z_{i,T-1} &= \gamma(1 + \gamma)^{T-2} \theta_a' \mathbf{x}_{i,1} + \gamma(1 + \gamma)^{T-3} \theta_a' \mathbf{x}_{i,2} + \cdots\\
&\quad + \gamma(1 + \gamma)\theta_a' \mathbf{x}_{i,T-2} + \gamma\theta_a' \mathbf{x}_{i,T-1}\\
&\quad + \theta_a' \mathbf{x}_T + (1 + \gamma)^{T-1} \theta_b' \mathbf{w}_i + \gamma(1 + \gamma)^{T-1} z_{i,0}\\
&\quad + (1 + \gamma)^{T-1} \mu_i + \omega_{i,T},
\end{aligned}$$

$$E^*(\omega_{i,t} \mid \mathbf{x}_{i,1}, \ldots, \mathbf{x}_{i,T}, \mathbf{w}_i) = 0, \qquad \text{for } t = 1, \ldots, T.$$

Chamberlain (1983) proposes to deal with the correlated country-specific effect μ_i and the initial condition $z_{i,0}$ by replacing them by their linear predictors:

$$\begin{aligned}
E^*(\mu_i \mid \mathbf{x}_{i,1}, \mathbf{x}_{i,2}, \ldots, \mathbf{x}_{i,T}, \mathbf{w}_i) &= \tau_1' \mathbf{x}_{i,1} + \tau_2' \mathbf{x}_{i,2} + \cdots\\
&\quad + \tau_T' \mathbf{x}_{i,T} + \tau_w' \mathbf{w}_i;\\
E^*(z_{i,0} \mid \mathbf{x}_{i,1}, \mathbf{x}_{i,2}, \ldots, \mathbf{x}_{i,T}, \mathbf{w}_i) &= \lambda_1' \mathbf{x}_{i,1} + \lambda_2' \mathbf{x}_{i,2} + \cdots\\
&\quad + \lambda_T' \mathbf{x}_{i,T} + \lambda_w' \mathbf{w}_i.
\end{aligned}$$

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

As Chamberlain points out, assuming that the variances are finite and

[10]In the term z_{t-1}, the index "1" refers to five years.

that the distribution of $(\mathbf{x}_{i,1}, \ldots, \mathbf{x}_{i,T}, \mathbf{w}_i, \mu_{\cdot i})$ 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 includes 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 $\mathbf{\Pi}$ 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 $\mathbf{x}_{i,t}$, six cross-sections for the variable $z_{i,t}$ (the additional cross-section being the initial condition $z_{i,0}$), and one cross-section for the variables $\mathbf{w}_i$. Thus, the multivariate regression implied by our model is

$$\begin{bmatrix} z_{i,0} \\ z_{i,1} - z_{i,0} \\ z_{i,2} - z_{i,1} \\ z_{i,3} - z_{i,2} \\ z_{i,4} - z_{i,3} \\ z_{i,5} - z_{i,4} \end{bmatrix} = \mathbf{\Pi} \begin{bmatrix} \mathbf{x}_{i,1} \\ \mathbf{x}_{i,2} \\ \mathbf{x}_{i,3} \\ \mathbf{x}_{i,4} \\ \mathbf{x}_{i,5} \\ \mathbf{w}_i \end{bmatrix}, \tag{13}$$

$$\mathbf{\Pi} = [\mathbf{B} + \mathbf{\Psi}\boldsymbol{\lambda}' + \boldsymbol{\phi}\boldsymbol{\tau}'],$$

$$\mathbf{B} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ \boldsymbol{\theta}_a' & 0 & 0 & 0 & 0 & \boldsymbol{\theta}_b' \\ \gamma\boldsymbol{\theta}_a' & \boldsymbol{\theta}_a' & 0 & 0 & 0 & (1+\gamma)\boldsymbol{\theta}_b' \\ \gamma(1+\gamma)\boldsymbol{\theta}_a' & \gamma\boldsymbol{\theta}_a' & \boldsymbol{\theta}_a' & 0 & 0 & (1+\gamma)^2\boldsymbol{\theta}_b' \\ \gamma(1+\gamma)^2\boldsymbol{\theta}_a' & \gamma(1+\gamma)\boldsymbol{\theta}_a' & \gamma\boldsymbol{\theta}_a' & \boldsymbol{\theta}_a' & 0 & (1+\gamma)^3\boldsymbol{\theta}_b' \\ \gamma(1+\gamma)^3\boldsymbol{\theta}_a' & \gamma(1+\gamma)^2\boldsymbol{\theta}_a' & \gamma(1+\gamma)\boldsymbol{\theta}_a' & \gamma\boldsymbol{\theta}_a' & \boldsymbol{\theta}_a' & (1+\gamma)^4\boldsymbol{\theta}_b' \end{bmatrix},$$

$$\mathbf{\Psi}\boldsymbol{\lambda}' = \begin{bmatrix} 1 \\ \gamma \\ \gamma(1+\gamma) \\ \gamma(1+\gamma)^2 \\ \gamma(1+\gamma)^3 \\ \gamma(1+\gamma)^4 \end{bmatrix} [\boldsymbol{\lambda}_1' \; \boldsymbol{\lambda}_2' \; \boldsymbol{\lambda}_3' \; \boldsymbol{\lambda}_4' \; \boldsymbol{\lambda}_5' \; \boldsymbol{\lambda}_w'],$$

$$\boldsymbol{\phi}\boldsymbol{\tau}' = \begin{bmatrix} 0 \\ 1 \\ (1+\gamma) \\ (1+\gamma)^2 \\ (1+\gamma)^3 \\ (1+\gamma)^4 \end{bmatrix} [\boldsymbol{\tau}_1' \; \boldsymbol{\tau}_2' \; \boldsymbol{\tau}_3' \; \boldsymbol{\tau}_4' \; \boldsymbol{\tau}_5' \; \boldsymbol{\tau}_w'].$$

III. Data and Results

We consider three different specifications of the growth model in our econometric analysis. The first is a simple Solow-Swan model; the second is a version of the Solow-Swan model that includes investment in human capital; and the third, which was presented in Section I, is a version that includes human capital investment, openness to foreign trade, and the stock of public infrastructure. The first two models can be obtained by applying appropriate exclusion restrictions to the third model. Thus, the basic Solow-Swan model is obtained from equation (9) by setting $\beta = \theta_f = \theta_p = 0$. Its corresponding regression equation is

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

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

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

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 (10‴), except that the investment ratio for human capital is also indexed by time.

The definitions and sources of the data used for estimation are described in the appendix. Our sample extends over the period from 1960 to 1985. We work with regular nonoverlapping intervals of five years. Thus, our five cross-sections correspond to the years 1965, 1970, 1975, 1980, and 1985. For 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. 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 is now explained in more detail. The dependent variable is the five-year difference in the natural logarithm of real GDP per worker—that is, $\ln(y_{i,65}) - \ln(y_{i,60}), \ldots, \ln(y_{i,85}) - \ln(y_{i,80})$. 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 Mankiw, Romer, and Weil in assuming that $(g + \delta) = 0.05$. The average growth rate of the working-age population is taken over the preceding five-year interval. Thus, we also have five observations of this variable for each country—that is, $\ln(n_{i,65} + 0.05), \ldots, \ln(n_{i,85} + 0.05)$.

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 preceding five-year intervals, so that we have five observations for each country—that is, $\log(s_{k_i,65}), \ldots, \log(s_{k_i,85})$.

The third explanatory variable is a proxy for the ratio of human capital investment to GDP. Specifically, following Mankiw, Romer, and Weil (1992), we use the percentage of the working-age population that is enrolled in secondary school, a measure that is approximated by the product of the gross secondary-school enrollment ratio times the fraction of the working-age population that is of secondary-school age (aged 15 to 19).[11] In the main specifications of the second and third models, we use cross-sectional data for this variable: 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 $\ln(s_{h_i,65}), \ldots, \ln(s_{h_i,85})$.

The fourth variable, $\ln F$, is a proxy for the restrictiveness of the economy's foreign trade regime: it is a weighted average of 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 (1993). This measure of openness to trade is used because we are interested in the relation between the availability of foreign technology (embodied in intermediate and capital goods) and the efficiency parameter 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). Nevertheless, we believe that this simple proxy is likely to be inversely correlated with openness for the majority of countries under consideration during our sample period.

The fifth variable, $\ln P$, is a proxy for the level of the public capital stock; it is defined as the average level of the ratio of general government fixed investment (central government plus public enterprises) to GDP in

[11] For a discussion of the appropriateness of this proxy, see Mankiw, Romer, and Weil (1992).

each five-year period. There are obvious problems in using this flow variable as a proxy for the stock of public capital. It does not account for the initial level of public capital (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 proxy is positively correlated with the level of public capital, 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). The observations for each country are therefore $\ln(y_{i,60}), \ldots, \ln(y_{i,80})$.

The appendix 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.[12] 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 could be extrapolated to those economies that had 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 98 countries (22 industrial OECD-member countries and 76 developing countries), and the second consists of the 76 developing countries only. Hence, a second aspect of the empirical work is a comparison of the estimated coefficients obtained from the two samples. Our main results are presented in Tables 1, 2, and 3. In all models, time-specific and country-specific effects are dealt with using the methodology outlined in Section II 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

[12] It is well known that standard growth models do not account for growth in economies that specialize in the extraction of depletable resources (see Sala-i-Martin (1990)).

Table 1. *Two Versions of the Solow-Swan Model*

Variable[a]	Simple Solow-Swan model: All countries ($n = 98$)	Simple Solow-Swan model: Developing countries ($n = 76$)	Simple restricted Solow-Swan model[b]: All countries ($n = 98$)	Simple restricted Solow-Swan model[b]: Developing countries ($n = 76$)
$\ln(y_{t-1})$	−0.2686	−0.2707	−0.2782	−0.266[illegible]
	(−5.90)	(−6.47)	(−6.37)	(−6.63)
$\ln(n_t + 0.05)$	−0.1220	−0.1474	−0.1401	−0.1285
	(−4.90)	(−6.64)	(−9.52)	(−9.55)
$\ln(s_{k_t})$	0.1489	0.1184	0.1401	0.1285
	(8.36)	(7.03)	(9.52)	(9.55)
Implied η	0.0626	0.0631	0.0652	0.0619
	(5.03)	(5.50)	(5.39)	(5.66)
Implied α	...	...	0.335	0.326
Wald test for uncorrelated effects	164.53	167.21	...	...
(P-value)	0.0000	0.0000		
Wald test for $\theta_1 = -\theta_2$ in equation (10')	0.798	1.093	...	...
(P-value)	0.3718	0.2959		

[a] $\text{Ln}(y_{t-1})$ is the logarithm of real GDP per worker lagged one period (five years). $\text{Ln}(n_t + 0.05)$ is the logarithm of the average growth rate of the working-age population plus the sum of technological progress and depreciation. $\text{Ln}(s_{k_t})$ is the logarithm of the average ratio of real investment to real GDP. Implied η is the speed of convergence per year. T-ratios are in parentheses. Implied α is the income share accruing to nonhuman capital.

[b] These estimates are obtained by imposing the restriction implied by the Cobb-Douglas assumption—namely, that $-\theta_1 = \theta_2$.

human capital, public capital, and openness to the simple Solow-Swan 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 capital and openness to disaggregate the country-specific effects further.

We begin with the simple Solow-Swan model (regression equation (10″)). Results for this specification are reported in Table 1. Using a Cobb-Douglas production function in the Solow growth model, we expect the estimated values of γ to be negative, those for θ_1 to be negative, and those for θ_2 to be 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 Solow-Swan model hold true for the sample that includes all countries, as well as for that including developing countries only.

Moreover, our estimated values for the speed of convergence η are 0.0626 a year for the sample containing all 98 countries and 0.0631 for that containing developing countries, implying that the economy moves halfway to the steady state in about 11 years.[13] These estimates are much larger than those reported in Barro (1991) and Mankiw, Romer, and Weil (1992), but similar to the predicted value of the simple Solow-Swan model (see the formula for η in equation (8), setting $\beta = 0$ and using sensible values for n, g, and δ). Mankiw, Romer, and Weil find that the implied estimate for the speed of convergence to its steady-state growth path is 0.0137 a year. Barro (1991), 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 a year. These estimates correspond to a half-life for the logarithm of output per effective worker of between 37 and 50 years.[14] We believe that the large difference between their estimates and ours can be explained by the fact that their studies do not account for the correlation between the country-specific effects and the independent variables in the model, thus producing biased coefficients. Specifically, 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 every interval (lagged output).

[13] 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.
[14] The half-life formula is $T = \ln(2)/\eta$, where T is number of years.

Table 2. *Solow-Swan Model Augmented to Include Human Capital Investment*

Variable[a]	Using cross-sectional data for human capital investment: All countries ($n = 98$)	Using cross-sectional data for human capital investment: Developing countries ($n = 76$)	Using panel data for human capital investment: All countries ($n = 96$)	Using panel data for human capital investment: Developing countries ($n = 75$)
$\ln(y_{t-1})$	−0.1775	−0.2095	−1.0383	−1.2961
	(−3.41)	(−4.27)	(−34.55)	(−95.73)
$\ln(n_t + 0.05)$	−0.0873	−0.1007	−0.0389	−0.0114
	(−3.02)	(−3.86)	(−5.25)	(1.45)
$\ln(s_{k_t})$	0.1061	0.0844	0.0233	0.1048
	(6.60)	(5.54)	(1.61)	(10.16)
$\ln(s_h)$	0.1064	0.0995	...	...
	(4.91)	(5.38)		
$\ln(s_{h_t})$	...	...	−0.0652	−0.1108
			(−5.09)	(−13.26)
Implied η	0.0391	0.0470	...	...
	(3.09)	(3.79)		
Wald test for uncorrelated effects	87.91	178.85	3249.00	60274.42
(P-value)	0.0000	0.0000	0.0000	0.0000
Wald test for $\theta_1 = -(\theta_2 + \theta_3)$ in equation (10'')	12.31	5.16	12.23	0.07
(P-value)	0.0000	0.02317	0.0000	0.7974

[a] $\text{Ln}(y_{t-1})$ is the logarithm of real GDP per worker lagged one period (five years). $\text{Ln}(n_t + 0.05)$ is the logarithm of the average growth rate of the working-age population plus the sum of technological progress and depreciation. $\text{Ln}(s_{k_t})$ is the logarithm of the average ratio of real investment to real GDP. $\text{Ln}(s_{h_t})$ is the logarithm of the ratio of human capital investment to GDP, proxied by the product of gross secondary-school enrollment ratio times the fraction of the working-age population aged 15 to 19. T-ratios are in parentheses.

We can test for the presence of such a correlation. 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: $\boldsymbol{\lambda}_1' = \cdots = \boldsymbol{\lambda}_5' = 0$. As can be seen in Table 1, the Wald test strongly rejects the null hypothesis of uncorrelated effects.

In Table 1, we also report the results of an estimation that assumes 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 for all countries and 0.326 for developing countries.[15] These estimated capital shares are very close to the value of 0.350 that Maddison (1987) obtains for the share of nonhuman capital in production. Our estimated nonhuman capital shares imply that diminishing returns set in quickly, which explains the rapid convergence predicted by the model.

Table 1 also allows us 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 on 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 show relatively steady per capita growth over the sample period while experiencing relatively low 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 developing countries than for developed 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.[16]

Table 2 presents the econometric estimates for the second version of

[15] Somehow contradicting our finding that the capital share in production is approximately the same for both industrial and developing countries, De Gregorio (1992) finds an estimate for the capital share of about 0.5 for a sample of Latin American economies.

[16] 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).

the Solow-Swan model (regression equation (10‴)). 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 full sample and the developing country subsample. 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 tbis second model, a Cobb-Douglas production function implies that $-\theta_1 = \theta_2 + \theta_3$ in equation (10‴). 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. The reason why this assumption does not appear to be consistent with the sample data could be that the aggregate production function is 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 in the first model. We believe this is due to higher returns to capital broadly defined to include human capital. In fact, when only physical capital is accumulated 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 2 also reports the results of the second model when panel data for the human capital proxy, rather than only cross-sectional data, are used. We find that the estimated coefficient on this proxy is now significantly negative for both samples.[17] This result is at first surprising. Why does the addition of the time series dimension to the proxy for human capital change 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 use not only the cross-country differences in the relation between education and growth but also the effect of *changes* in the human capital proxy over time in each country. This temporal relationship has been negative over the years, especially in developing countries (see Tilak (1989) and Fredriksen (1991)). In other words, adjusted secondary-school enrollment ratios rose steadily in most developing countries during 1960–85, sometimes by large amounts, while output growth remained

[17] De Gregorio (1992) reports similar results for a sample of Latin American countries.

stable or 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 (1986)). Therefore, cross-sectional data (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 enrollment ratio is used as the proxy, we can obtain 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 3 reports the results for the third augmented version of the Solow-Swan model. 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 the appendix). 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 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 only developing countries. Investments in both physical capital and human capital are strongly and positively correlated with growth. When proxies for openness and public capital are included in the model, the coefficient on 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 increases when the international transfer of technology is allowed and when better public capital 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 rate of investment in human capital becomes much stronger in the case

Table 3. *Solow-Swan Model Augmented to Include Human Capital Investment, Openness to Foreign Trade, and Public Infrastructure*

Variable[a]	All countries (n = 81)	Developing countries (n = 59)
$\ln(y_{t-1})$	−0.2208	−0.6836
	(−9.45)	(−17.75)
$\ln(n_t + 0.05)$	−0.1470	−0.1760
	(−12.52)	(−9.01)
$\ln(s_{k_t})$	0.2013	0.2057
	(18.17)	(14.24)
$\ln(s_{h_t})$	0.0945	0.3197
	(8.18)	(18.15)
$\ln(F)$	−0.0650	−0.0820
	(−11.76)	(−15.97)
$\ln(P)$	0.0128	0.0978
	(0.78)	(6.47)
Implied η	0.0499	0.2301
	(8.32)	(9.45)
Wald test for		
uncorrelated effects	526.03	5596.77
(P-value)	0.0000	0.0000
Wald test for $\theta_1 = -(\theta_2 + \theta_3)$		
in equation (10)	61.76	238.19
(P-value)	0.0000	0.0000

[a] $\text{Ln}(y_{t-1})$ is the logarithm of real GDP per worker lagged one period (five years). $\text{Ln}(n_t + 0.05)$ is the logarithm of the average growth rate of the working-age population plus the sum of technological progress and depreciation. $\text{Ln}(s_{k_t})$ is the logarithm of the average ratio of real investment to real GDP. $\text{Ln}(s_{h_t})$ is the logarithm of the ratio of human capital investment to GDP, proxied by the product of gross secondary-school enrollment ratio times the fraction of the working-age population aged 15 to 19. $\text{Ln}(F)$ is the logarithm of the "closedness" of the economy, proxied by the weighted average of tariff rates on imported intermediate and capital goods. $\text{Ln}(P)$ is the logarithm of the ratio of public infrastructure to GDP, proxied by the average ratio of general government fixed investment (central government plus public enterprises) to GDP. T-ratios are in parentheses.

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 ("closedness" may be a better term given how 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, liberal trade regimes provide 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 fixed 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 capital is based on flow data that do not account for the initial level of the associated stock. This is especially important for the industrial countries, which by 1960 had accumulated substantial stocks of public capital, relative to those in developing countries. In that sense, our proxy is better suited to developing countries, which 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 capital has an independent role in economic growth, even when physical and human capital are already included.

IV. Concluding Remarks

This paper has extended the work of Mankiw, Romer, and Weil (1992) in two directions. Unlike their analysis, 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 this result is the faster rate of conditional convergence that we find in our model, relative to that estimated by Mankiw, Romer, and Weil and by Barro (1991). 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 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 government fixed investment in the domestic economy.

Like Mankiw, Romer, and Weil, we find that the Solow-Swan 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 and on the transitional growth path of per capita GDP. We also find (conditional) convergence to be approximately the rate predicted by the Solow-Swan model. We estimate the share of capital at about one-third, which is close to the value estimated by Maddison (1987) for the share of nonhuman capital in GDP. Our estimated capital shares imply that diminishing returns to physical capital set in quickly, explaining 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 for our sample of developing countries alone, reflecting the fact that many countries in this group have tended to exhibit slow growth in per capita terms 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 of government fixed investment 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 government fixed investment deserve some elaboration. When openness and the level of public infrastructure are taken into account, 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 by more government fixed investment. 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 nonexistent: through the rate of investment and through its efficiency. A high tariff structure discourages imports of capital goods and leads to less technology transfer, and thus to less technological improvement. The strong statistical significance of the proxy for "closedness" provides evidence that outward-oriented development strategies have a positive impact on economic growth.

The government fixed investment variable is statistically and positively significant only in the developing countries, and appropriately so. This can be explained by the failure of our proxy for public infrastructure to account for its initial level. Among 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. This may mean that the government is in a better position to provide infrastructure than the private sector. In other words, either the private sector, if it had the resources, would tend to underinvest in infrastructure or the marginal productivity of public sector resources devoted to infrastructure is higher than that of private sector resources (presumably owing to significant externalities).

APPENDIX

Data Sources, Definitions, and the Sample of Countries

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

y = real GDP per worker;

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

n = growth rate of the 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 1960–85 period).

Panel data for the proxy of human capital investment were obtained from the UNESCO *Statistical Yearbook 1991* and were adjusted for age using population data from UN Population Division (1991). Data on tariffs were taken from Lee (1992):

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

The DEC Analytical data base from the World Bank (1991) was used to obtain a proxy for public infrastructure:

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

The sample of countries was as follows.

Industrial countries

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

Developing countries

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

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

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

Table 5 (81 countries): In the sample 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, Côte d'Ivoire, Dominican Republic, Honduras, Israel, Liberia, Mali, Mauritania, Mozambique, Myanmar, Niger, Panama, South Africa, and Togo.

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