OCCASIONAL PAPERS
Number 46

# ECONOMIC GROWTH AND CONVERGENCE

Robert J. Barro

INTERNATIONAL CENTER FOR ECONOMIC GROWTH

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# Economic Growth and Convergence

Robert J. Barro

An International Center for Economic Growth Publication

ICS PRESS
San Francisco, California

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Publication of this Occasional Paper was funded by the United States Agency for International Development (AID).

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**Library of Congress Cataloging-in-Publication Data**

Barro, Robert J.
Economic growth and convergence / Robert J. Barro.
p. cm. — (Occasional papers ; 46)
Includes bibliographical references.
ISBN 1-55815-283-0 (pbk.)
1. Economic development. I. Title. II. Series: Occasional papers (International Center for Economic Growth) ; 46.
HD75.B366 1993
338.9—dc20 93-31955
CIP

# PREFACE

We are pleased to publish *Economic Growth and Convergence* as the forty-sixth in our series of Occasional Papers, which present perspectives on development issues by noted scholars and policy makers.

In this paper, Robert Barro examines the futures and limitations of the theory of economic convergence. The theory holds that less developed countries or regions develop at a greater rate in per capita terms than their richer or more developed counterparts, causing a tendency toward "convergence" in their per capita incomes. The theory is borne out mainly in regions with similar economic and political structures.

After presenting the empirical data supporting convergence theory, Dr. Barro descusses the possibility of isolating the variables that impact on a country's growth rate—such as openness to international trade, political stability, and the educational attainment of the labor force. When these variables are held constant, the estimated rate of convergence for real per capita GDP in the less developed nations turns out to be highly significant statistically and a magnitude only slightly below that found among the U.S. states and the regions of Europe and Japan. There is, essentially, an inverse relationship between a country's starting point and its rate of economic growth.

Dr. Barro points out that absolute convergence—that is, poor countries literally catching up to the richer countries of the world—depends on whether the tendency toward convergence applies to government policy and other determinants of long-run target positions. Counterproductive economic and social policies hinder growth by creating disincentives to technological innovation and by limiting trade.

Less developed countries that are unable to reform harmful policies limit their opportunities for convergence.

We at the International Center for Economic Growth hope that Dr. Barro's contribution will help developing and postsocialist countries to avoid past mistakes and meet the challenges of the new world economic environment. He has gained considerable recognition for his theoretical and empirical contributions to the understanding of economic growth and its causes. His essay represents a significant contribution to our mission to promote adoption of appropriate policies advancing human welfare and helping support emerging democracies throughout the world.

Nicolás Ardito-Barletta
General Director
International Center for Economic Growth

January 1994
Panama City, Panama

ROBERT J. BARRO

# Economic Growth and Convergence

A key issue in economic development is whether economies that start out behind tend to grow faster in per capita terms and thereby converge toward those that began ahead. This convergence property seems to apply empirically for economies that have similar underlying structures—such as the regions of the major developed countries or among the OECD countries—but not for a heterogeneous collection of countries that includes the poor nations of Africa, South Asia, and Latin America. One reason for the failure of convergence in this broad context is that countries are effectively heading toward different long-run targets for per capita income. These targets depend on government policies in areas such as taxation, protection of property rights, and provision of infrastructure services and education. The targets can also vary due to factors that governments cannot readily influence, such as the underlying attitudes about saving, work effort, and fertility, and the availability of natural resources.

For a given long-run target—determined by government policies and other factors—the convergence tendency depends on the speed with which an economy approaches this target. This speed turns out empirically to be similar across economies, such as a broad cross section of countries, that differ greatly in other respects. Conceptually,

This paper is an extension of the material contained in "Human Capital and Economic Growth," in Federal Reserve Bank of Kansas City *Policies for Long-Run Economic Growth*, August 1992; and "Economic Growth, Convergence, and Government Policies," forthcoming from the Milken Institute.

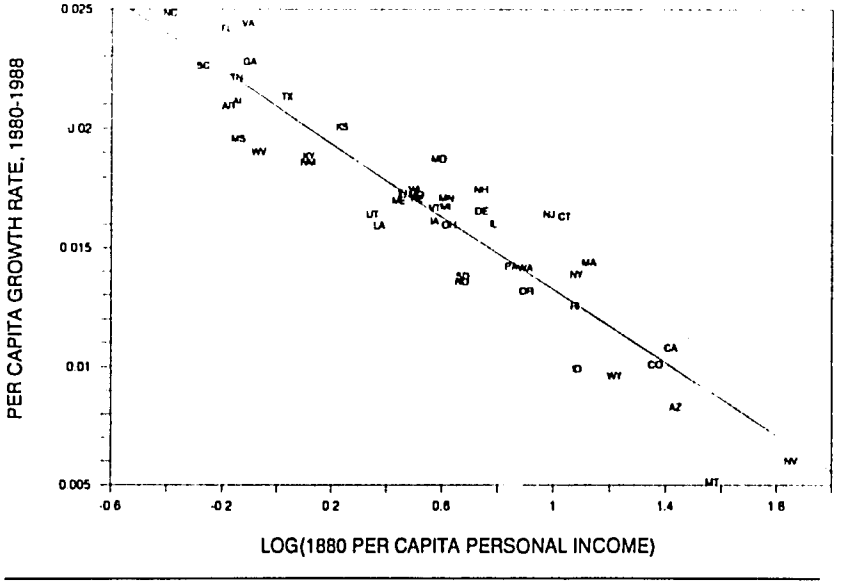
the speed of convergence depends on issues like diminishing returns to capital, the behavior of saving, the mobility of capital and labor, and the diffusion of technology from leaders to followers.

I begin with a discussion of some empirical evidence on economic growth, especially as it pertains to the convergence question. Then I relate these facts to theories of economic growth and make inferences for the role of government policies.

## Some Empirical Evidence on Convergence

**Regional data.** Figures 1–4 relate to regional economies: the U.S. states and the regions of some major countries in western Europe. Figure 1, which applies to 47 continental U.S. states or territories,[1] plots the average annual growth rate of per capita personal income

FIGURE 1. Convergence of Personal Income across U.S. States: 1880 Income and Income Growth from 1880 to 1988




Log of 1880 per capita personal income

(exclusive of transfer payments) from 1880 to 1988 against the logarithm of per capita personal income in 1880. The figure shows a striking inverse relationship, that is, the places that were poorer in 1880 grew significantly faster in per capita terms over the subsequent 108 years. Thus, the behavior of growth rates across the U.S. states is consistent with convergence, in the sense of the poor places growing faster than the rich ones.

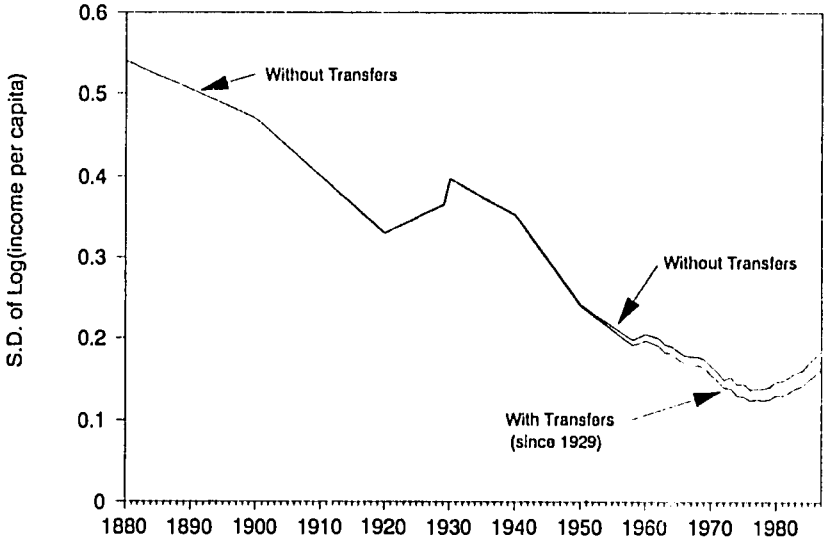
Part of the story that underlies Figure 1 is the catching-up of the southern states to the initially richer eastern and western states. But the convergence pattern applies equally well within regions as across regions; for example, the initially poor eastern states, such as Maine and Vermont, tended to grow faster than the initially rich eastern states, such as Massachusetts and New York.

The data shown in Figure 1 turn out to imply that the rate of convergence is roughly 2 percent per year. (See Barro and Sala-i-Martin (1992a) for the details.) In other words, about 2 percent of the gap between a rich and a poor economy tends to be eliminated in one year. This rate of convergence implies a half life of about 35 years, that is, it takes 35 years on average for half of an initial spread to vanish. Furthermore, it takes 70 and 115 years, respectively, to eliminate 75 percent and 90 percent of the gap. These numbers accord with the period of roughly a century after 1880 that it took for the per capita income of the typical southern state to come close to that in the typical northern state.

Figure 2 shows a measure of the dispersion of per capita income (the standard deviation of the logarithm of per capita personal income) across the U.S. states from 1880 to 1988. (Personal income is measured exclusive of transfer payments until 1929 and is shown with and without transfers thereafter.) The dispersion declined steadily from 1880 until 1920, then rose in the 1920s because of the sharp fall in real incomes originating in agriculture. The effect of the agricultural shock was pronounced because the agricultural states had lower than average levels of per capita income prior to the shock. The dispersion declined from the 1930s until the late 1970s but increased during the 1980s back to the levels of the early 1960s. (Recent data show that dispersion declined again after 1988.)

In the early 1980s, the rise in dispersion reflected the oil shock of

FIGURE 2. Dispersion of Personal Income across U.S. States, 1880–1988



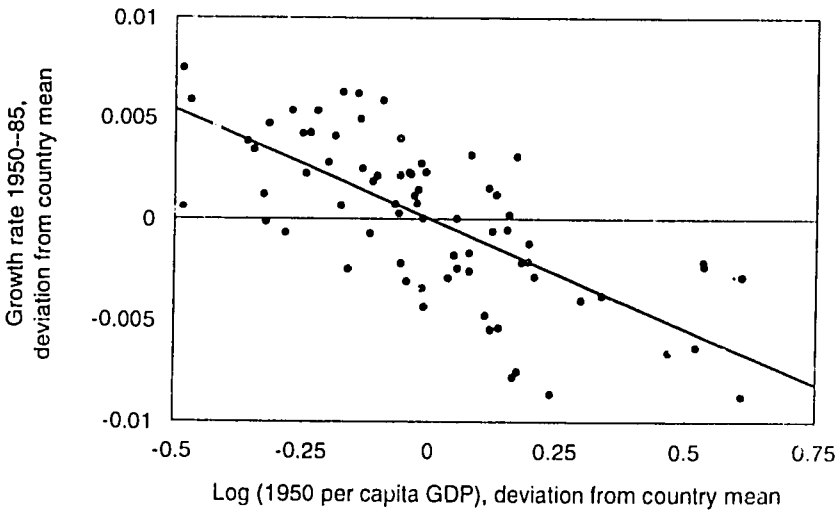

a. Income dispersion is measured by the unweighted cross-sectional standard deviation of the log of per capita personal income.

b. Data on the dispersion of per capita personal income inclusive of government transfer payments are included since 1929, although the effect of including transfer payments is negligible before 1950.

1979–80, an effect that was pronounced because the oil states already had above average levels of per capita income. The behavior of oil prices does not seem, however, to account for the continuing rise in dispersion in the late 1980s. This recent behavior resembles the pattern for measures of inequality for the incomes of individuals and families. The rise in dispersion at the state level may therefore reflect elements that have been cited in studies of the increased income inequality for families: the changing technological mix and the increased returns to education.

Figures 3 and 4 describe the behavior of per capita gross domestic product (GDP) from 1950 to 1985 for 73 regions of 7 European countries (11 in Germany, 11 in the United Kingdom, 20 in Italy, 21 in France, 4 in the Netherlands, 3 in Belgium, and 3 in Denmark). Figure 3 plots the regional growth rate of per capita GDP from 1950 to 1985 (expressed relative to the mean growth rate for the respective country)

FIGURE 3. Growth Rate versus Initial Level of Per Capita GDP for 73 European Regions



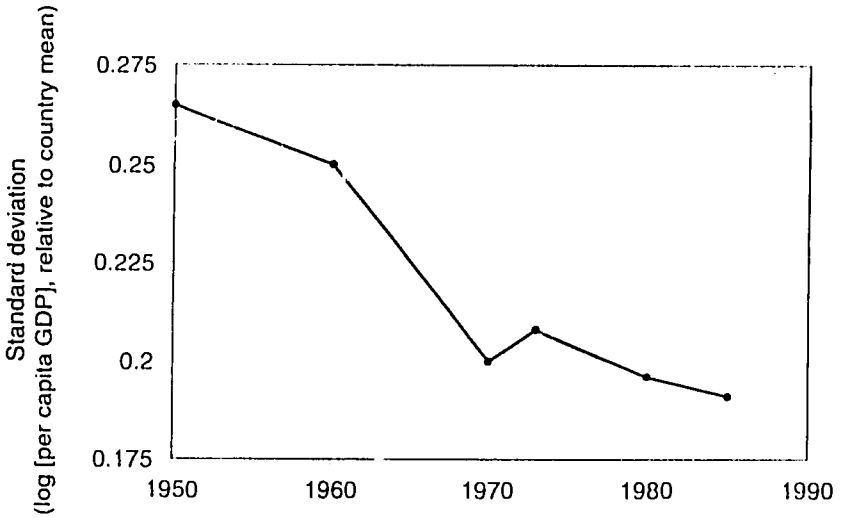

Log (1950 per capital GDP), deviation from country mean

versus the logarithm of per capita GDP in 1950 (again measured relative to the mean for each country).[2] Although the relation is less striking than that shown in Figure 1, the inverse association between the initial position and the subsequent growth rate is statistically highly significant. The results turn out quantitatively to imply a speed of convergence that is again about 2 percent per year (see Barro and Sala-i-Martin 1991). Similar behavior also shows up for the provinces of Japan (Barro and Sala-i-Martin 1992c), although in this case, the estimated rate of convergence is about 3 percent per year.

Figure 4 shows the dispersion across the 63 European regions from the 4 larger countries—Germany, the United Kingdom, Italy, and France. The dispersion of per capita GDP declined from 1950 to 1970, but then changed little on net from 1970 to 1985.

**Evidence from a broad sample of countries.** Figures 5 and 6 provide information about convergence for 114 countries, roughly all of the significant countries that exist except for the formerly centrally

FIGURE 4. Dispersion of Per Capita GDP across 63 Regions of 4 Major European Countries




planned economies. Figure 5 plots the average growth rate of real per capita GDP from 1960 to 1985 against the logarithm of real per capita GDP in 1960.[3] In contrast to the clear inverse relationships that showed up in Figures 1 and 3, the growth rate and initial level are essentially uncorrelated in Figure 5; the association is actually slightly positive. The cross-country data therefore do not reveal convergence: the poor countries did not tend to grow faster per capita than the rich, and, hence, the typical poor country did not tend to catch up to the typical rich country (see Romer 1990a for a discussion of this evidence).

The convergence behavior found for regions in Figures 1 and 3 shows up across countries if the sample is restricted to a relatively homogeneous group of well-off places (see Baumol 1986, DeLong 1988, and Dowrick and Nguyen 1989). If one looks, for example, at the twenty countries that were members of the OECD in 1960, then the initially poorer countries tended to grow faster per capita. The estimated rate of convergence in this sample turns out, however, to be only about 1 percent per year.

FIGURE 5. Growth versus Initial Level of Real Per Capita GDP for 114 Countries

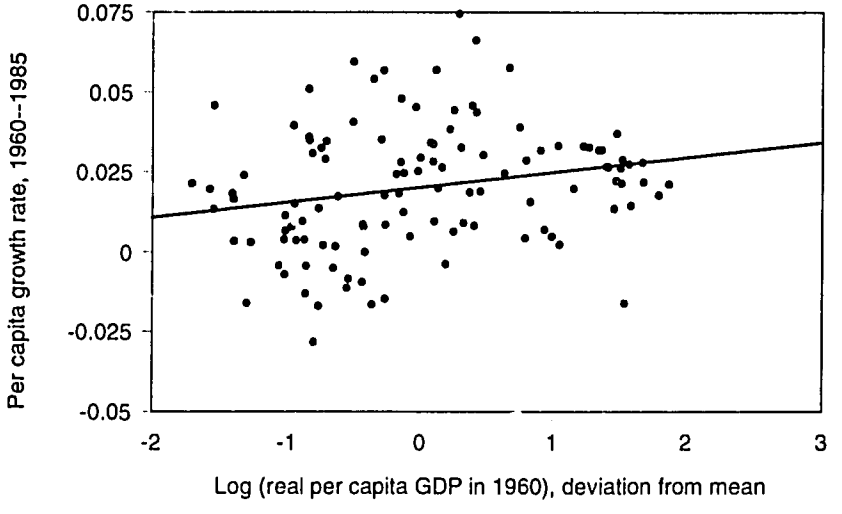
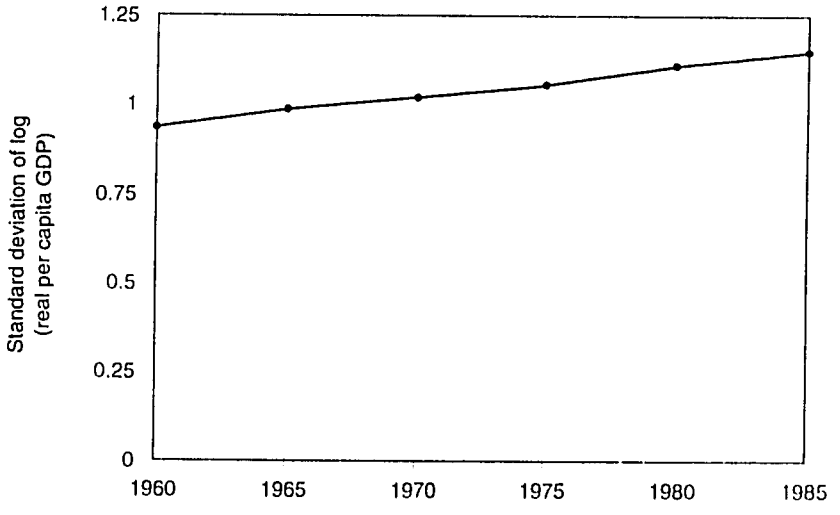



Figure 6 shows the time path from 1960 to 1985 for the dispersion of per capita real GDP for the 114 countries. (The data are plotted at five-year intervals.) The dispersion rose moderately but steadily over the sample. Figure 7 shows that this pattern also applied since 1950 for the sixty countries that have the earlier data.

## Theoretical Perspectives on the Empirical Evidence

One framework for studying convergence is the neoclassical growth model developed for a closed economy by Ramsey (1928), Solow (1956), Swan (1956), Cass (1965), and Koopmans (1965). In this model, the force toward convergence involves the accumulation of capital through domestic savings in a context of diminishing returns. As an economy accumulates capital and thereby develops, the falling rate of return on capital tends to reduce the rate of growth. Thus, poor

FIGURE 6. Dispersion of Logarithm of Real Per Capita GDP for 114 Countries

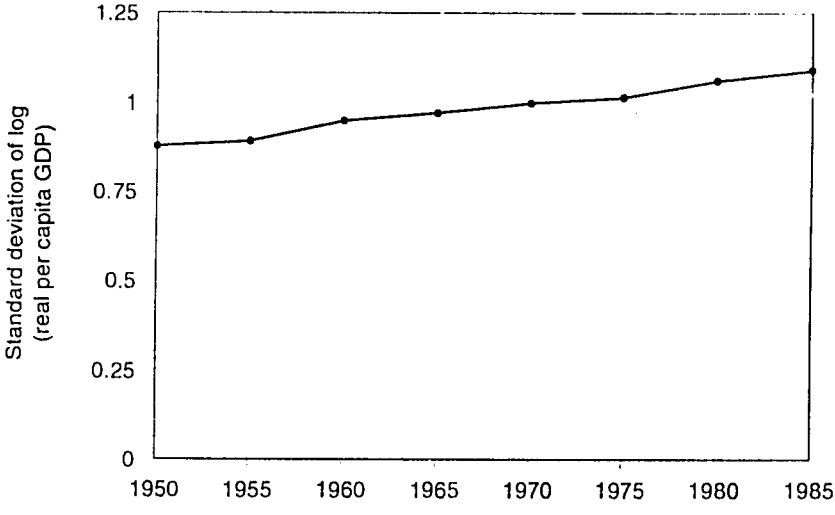



countries tend to grow faster because they have a higher rate of return on capital.

If different economies—say, countries or regions of countries—have the same underlying technology, preferences, and government policies, then the standard growth model predicts an *absolute* form of convergence. Economies with lower starting levels of income and product per person tend to grow faster in per capita terms because the smaller level of per capita product translates into a higher productivity of capital. This prediction accords with the regional data considered in Figures 1 and 3.

Quantitatively, the empirical estimate that regional convergence occurs at about 2 percent per year turns out to accord with the underlying growth model only if the diminishing returns to capital—the source of convergence in that model—set in slowly (see Barro and Sala-i-Martin 1992a). We have to take a broad view of capital to include human capital—educational attainment, work experience, and health—so that the rate of return on capital does not fall rapidly as

FIGURE 7. Dispersion of Logarithm of Real Per Capita GDP for 60 Countries




capital is accumulated. To fit the empirical estimate of the convergence rate, the share of capital income in total income has to be roughly three-quarters. This high capital share is reasonable, however, if we include human capital as part of the total capital stock.

If we try to apply the theory to the heterogeneous group of over one hundred countries, then we have to allow for differences in underlying conditions. These elements include not only the level of technology and attitudes about saving, work, and fertility, but also government policies in regard to taxation, maintenance of property rights, and provision of infrastructure services. Economies may differ substantially in some of these respects and may accordingly be converging to different long-run paths of per capita income.

Let $y_i$ be the current level of per capita income for economy $i$ and $y_i^*$ be the long-run target that the economy is approaching. If economies have different long-run values, $y_i^*$, then the standard growth model predicts a *conditional* form of convergence. An economy grows faster if its starting level of per capita income, $y_i$, is further away from its

own long-run value, $y_i^*$. This conclusion follows because the private return from investment—net of taxation and risk of expropriation—depends inversely on the gap between $y_i$ and $y_i^*$.

The results for the broad sample of countries shown in Figure 5 can fit with the standard growth model if the countries vary substantially in their target values, $y_i^*$. These variations could plausibly be large because of differences in government policies that affect the incentives to invest and operate efficiently; the countries differ in their openness to international trade and domestic competition, in effective tax rates on market activity, and in political stability and other factors that influence property rights. Since the sample comprises considerable heterogeneity with regard to cultural histories, the countries may also vary significantly in respect to their underlying preferences about saving, fertility, and work effort.

The interpretation offered by the standard growth theory is therefore that the variations across the 114 countries in per capita GDP, $y_i$, reflect mainly the variations in the long-run targets, $y_i^*$, and are accordingly essentially uncorrelated with the gaps from the targets, $y_i - y_i^*$. Since the underlying theory predicts an inverse relation between the growth rate and this gap, this interpretation is consistent with the absence of a significant relation between the growth rate and the initial level, $y_i$. In contrast, for the U.S. states and the regions of European countries and Japan, the interpretation was that the $y_i^*$ were roughly equal, and, hence, that the variations in $y_i$ reflected mainly differences in the gaps, $y_i - y_i^*$. The growth rate was therefore inversely related to the initial level in these samples.

**The role of human capital.** Extensions of the neoclassical growth model have distinguished the sector that produces goods—consumables and physical capital—from an education sector that produces new human capital (see, for example, Uzawa 1964, Lucas 1988, and Mulligan and Sala-i-Martin 1992). The assumption in these models is that the education sector is relatively intensive in human capital: it takes human capital embodied in teachers to produce human capital in students.

One finding stressed by Mulligan and Sala-i-Martin (1992) concerns imbalances between human and physical capital, that is,

departures of the ratio of human to physical capital from the ratio that prevails in the long run. The key result is that a higher ratio of human to physical capital, and, hence, a higher ratio of human capital to output, raises the growth rate. A country with an abundance of human capital tends also to focus its investment on physical capital; that is, a high ratio of human to physical capital results in a high ratio of physical investment to GDP.

The conclusions about imbalances between human and physical capital are reinforced if the accumulation of human capital involves adjustment costs that are much higher than those applicable to physical capital. (Machines and buildings can be assembled quickly, but people cannot be educated rapidly without encountering a sharp drop-off in the rate of return to investment.) An economy with a high ratio of human to physical capital is then like an economy that is described by the transitional dynamics of the usual neoclassical growth model. The economy effectively starts with a quantity of physical capital per worker that is substantially below its steady-state position, that is, far below the amount that matches the large quantity of human capital. The usual convergence effect implies that the growth rate of output exceeds its steady-state value in this situation.

A high ratio of human to physical capital applies, as an example, after a war that destroys large amounts of physical capital, but that leaves human capital relatively intact. Japan and Germany after World War II are illustrative cases. The theory accords with the empirical observation that countries in this situation tend to recover rapidly.[4]

In the standard neoclassical growth model, a higher rate of population growth reduces the steady-state value of capital per worker and thereby lowers the steady-state value of per capita income, $y_i^*$. The decrease in $y_i^*$ implies that the economy grows in the transition (for a given value of $y_i$) at a slower rate. The rate of population growth is exogenous in this model, and the effect on the steady-state level of capital per worker involves the flow of new capital that has to be provided to accompany the flow of new workers.

Richer theories, such as the one by Becker, Murphy, and Tamura (1990), include the resources expended on children and allow fertility to be a choice variable of families. A key result is that a larger stock of human capital per person raises the wage rate and therefore the time

cost of raising children. (The assumption is that the productivity in the sector that raises children does not rise as fast as that in the sectors that produce goods and new human capital.) A higher stock of human capital motivates families to choose a lower fertility rate and to raise the investment in human capital for each child (that is, to substitute quality for quantity in children). These responses of population growth and human capital investment tend to raise the growth rate of output. This model therefore provides another channel through which a larger stock of human capital results in a higher subsequent rate of economic growth.

## Empirical Analysis

In a recent study (Barro 1991) and in ongoing research (Barro and Lee 1993), I have attempted to isolate observable variables that serve as proxies for the long-run targets, $y_i^*$. If these targets can satisfactorily be held constant, then the theory predicts that an inverse relation between a country's growth rate and its starting position, $y_i$, would emerge. This result does, in fact, obtain if one holds constant variables like the share of government consumption in GDP, measures of openness to international trade (such as tariff rates and the black-market premium on foreign exchange), indicators of political stability (such as the frequency of revolutions and coups), and measures of initial human capital (such as the values at the start of the sample of educational attainment and life expectancy). If these kinds of variables are held constant, then the estimated rate of convergence for real per capita GDP turns out to be statistically highly significant and of a magnitude, about 1.5 percent per year, that is only slightly below that found for the U.S. states and the regions of Europe and Japan. These results are therefore consistent with the conditional convergence predicted by the standard growth model. In particular, the typical country is converging to its own long-run target at nearly the same rate at which the typical U.S. state or region of Europe and Japan is converging to its target.

Tables 1 and 2 contain a sample of this empirical research. Table 1 shows regression equations for the growth rate of real per capita GDP. (The data on GDP are the values adjusted for differences in

TABLE 1 Panel Regressions for Growth Rate of Real Per Capita GDP, Five-year Intervals, 1960 to 1985

| Independent variable | Estimated coefficients and standard errors | | | |
|---|---|---|---|---|
| Log(initial GDP)[b] | −.0167 | −.0196 | −.0202 | −.0217 |
| | (.0027)[a] | (.0024) | (.0026) | (.0023) |
| Log(school)[c] | .0232 | .0109 | .0193 | .0092 |
| | (.0041) | (.0041) | (.0039) | (.0038) |
| $(G/Y)$[d] | −.140 | −.159 | −.074 | −.091 |
| | (.031) | (.027) | (.031) | (.027) |
| Openness[e] · log(1 + tariff rate)[f] | −.201 | −.050 | −.239 | −.145 |
| | (.101) | (.085) | (.091) | (.078) |
| Log(1 + black-market premium)[g] | −.0226 | −.0208 | −.0246 | −.0235 |
| | (.0054) | (.0049) | (.0051) | (.0047) |
| Frequency of revolutions and coups[h] | −.0147 | −.0107 | −.0127 | −.0092 |
| | (.0074) | (.0062) | (.0066) | (.0055) |
| $I/Y$[i] | — | .120 | — | .121 |
| | | (.021) | | (.019) |
| Fertility rate[j] | — | −.0037 | — | −.0019 |
| | | (.0012) | | (.0011) |
| Sub-Saharan Africa[k] | — | — | −.0310 | −.0265 |
| | | | (.0055) | (.0047) |
| Latin America[l] | — | — | −.0124 | −.0066 |
| | | | (.0039) | (.0033) |
| $R^2$, individual periods | .05, .38, .22, .31, .08 | .07, .52, .26, 44, .22 | .19, .33, .28, .43, .21 | .24, .45, .33, .52, .25 |

a. Standard errors are shown in parentheses.

b. Real per capita GDP at the start of each five-year interval.

c. 1 plus the average number of years of education attained by the population aged twenty-five and over at the start of each five-year period.

d. The average of the ratio of real government consumption, exclusive of education and defense, to real GDP for each period.

e. An estimate of "natural" openness, based on area and distance measures. This variable is a constant for each country.

f. An average of official tariff rates on capital imports and intermediates, weighted by shares in imports. Only one observation per country was available for the tariff rate.

g. The average of the black-market premium on foreign exchange for each period.

h. The number of revolutions and coups per year, averaged over the full sample, 1960–1985.

i. The ratio of real gross domestic investment to real GDP, averaged over each period.

j. The total fertility rate, averaged over each period.

k. A dummy for countries in Sub-Saharan Africa.

l. A dummy for countries in Latin America.

NOTES: The data are discussed in detail in Barro and Lee 1992.

The dependent variable is the annual growth rate of real per capita GDP over each period (1960–65, 1965–70, 1970–75, 1975–80, 1980–85). These data are from Summers and Heston (1988). There are 365 observations (73 countries and 5 time periods). Coefficients are estimated by the seemingly-unrelated (SUR) technique, which allows a country's error term to be correlated over time. Separate constants are estimated for each time period. Other coefficients are constrained to be the same for all periods.

TABLE 2 Panel Regressions for Ratio of Real Investment to Real GDP and Total Fertility Rate, Five-year Intervals, 1960 to 1985

| Independent variable | Estimated coefficients and Standard errors | | | |
|---|---|---|---|---|
| | *I/Y* | | Fertility rate | |
| Log(initial GDP)[b] | .0256 | .0177 | −.386 | −.280 |
| | (.0067)[a] | (.0070) | (.080) | (.083) |
| Log(school) | .0303 | .0259 | −.331 | −.283 |
| | (.0109) | (.0106) | (.118) | (.116) |
| (*G/Y*) | .049 | .071 | −.55 | −.57 |
| | (.061) | (.061) | (.47) | (.46) |
| Openness log(1 + tariff rate) | .036 | .106 | 27.0 | 20.7 |
| | (.296) | (.277) | (7.2) | (6.4) |
| Log(1 + black-market premium) | −.0095 | −.0127 | .022 | .037 |
| | (.0074) | (.0071) | (.048) | (.046) |
| Frequency of revolutions and coups | −.0033 | .0088 | 1.32 | 1.58 |
| | (.0210) | (.0196) | (.56) | (.50) |
| Sub-Saharan Africa | — | −.0511 | — | 2.15 |
| | | (.0163) | | (.36) |
| Latin America | — | −.0430 | — | .43 |
| | | (.0119) | | (.31) |
| $R^2$, individual periods | .34, .35, | .30, .32, | .47, .53, | .39, .51, |
| | .30, .39, | .27, .43, | .55, .56, | .59, .5, |
| | .36 | .41 | .57 | .70 |

a. Standard errors are shown in parentheses.

b. See notes to Table 1 for definitions of variables.

NOTE: The dependent variable for the first two regressions is the average over each period of the ratio of real gross domestic investment to real GDP (data from Summers and Heston 1988). For the last two regressions, the dependent variable is the average over each period of the U.N. estimate of the total fertility rate (average number of live births per woman over her lifetime).

purchasing power by Summers and Heston [1988].) The estimates apply to a panel data set for 73 countries—those with a full set of data—over five-year periods from 1960 to 1985. There are 365 observations in total, 5 time observations for 73 countries.

The independent variables include the logarithm of real per capita GDP at the start of each period, a number of variables including government policies that can be interpreted as determinants of a country's target position, $y_i^*$, and a measure of educational attainment. See the notes to Table 1 for details.

For given values of the other variables, the estimated coefficient on the logarithm of initial per capita GDP in the first regression of Table 1 is −.017, standard error (s.e.) = .003. Thus, this coefficient differs significantly from zero, and the magnitude indicates a rate of convergence to the long-run target of about 1.7 percent per year.[5]

I included the variable *G/Y*, the ratio to GDP of government consumption purchases—total purchases exclusive of public investment, educational spending, and defense outlays. This government spending variable has a significantly negative effect on the growth rate; the estimated coefficient in the first regression of Table 1 is −.14, s.e. = .03. The items included in this portion of government expenditure would not contribute significantly to productivity and tend to distort private decisions because of the required public finance. Some parts of the expenditures, such as those aimed at the enforcement of regulations, would also have a direct negative effect on productivity. Ongoing research by Easterly and Rebelo (1992) is aimed at pinpointing the effects from detailed aspects of the government's taxes and spending, such as marginal tax rates on capital income and outlays on public investment.

Two variables that reflect distortions of international trade have adverse effects on the growth rate. One variable is a measure of average tariff rates—the estimated coefficient on this variable in the first regression of Table 1 is −.20, s.e. = .10.[6] I attempted to include an index of nontariff barriers generated by the United Nations, but the available data are poor and the variable that I used did not have a significant effect on growth rates. The other trade variable included in the regressions in Table 1 is the black-market premium on foreign exchange. This variable is a general proxy for distortions of foreign trade, but may also more broadly be a proxy for other distortionary policies and for macroeconomic instability. In any event, the estimated coefficient in the first regression of Table 1 is negative and highly significant: −.023, s.e. = .005.

I included the frequency of revolutions and coups as a proxy for political stability. The estimated coefficient in the first regression is significantly negative, −.015, s. e. = .007, but may also reflect a reverse influence from bad economic times to political instability. I looked also at measures of political freedom and civil liberties generated

by Gastil (1987). But these measures did not have a significant effect on growth rates once the other variables listed in Table 1 were held constant. In any event, the overall message from the policy variables included in the regressions is that more interference with markets and political instability are adverse for economic growth.

The educational attainment variable is entered in the regressions as log(1 + total years of schooling for the adult population), where the years of attainment apply to the start of each period. The parameter "1" in the above expression can be viewed as the effective number of years of education obtained without formal schooling.[7] The estimated coefficient on the schooling variable in the first regression, .0232, s.e. = .0041, is positive and highly significant. Thus, for a given value of initial per capita GDP and the other variables, countries grew faster if they began each period with a greater amount of educational attainment. As a quantitative example, if average educational attainment begins at 2 years—the average value prevailing in sub-Saharan Africa in 1980—then an increase by 0.3 years would raise the quantity, 1 + years of attainment, by 10 percent and thereby increase the predicted growth rate by 0.2 percentage points per year. (The effect diminishes gradually over time because $\log(y_{it})$ then follows a higher path than it would have otherwise.)

The second regression shown in Table 1 adds $I/Y$, the ratio of real gross domestic investment to real GDP, and the total fertility rate. (These variables are measured as averages over each period.) In the Solow growth model, the investment ratio (or the saving rate) and the fertility rate (or the growth rate of population) are exogenous variables. These variables do not influence the long-run growth rate, but do affect the long-run level of per capita output, $y_i^*$. An increase in $I/Y$ raises $y_i^*$, whereas a rise in fertility lowers $y_i^*$. Therefore, for a given value of initial per capita GDP, an increase in $I/Y$ would raise the growth rate, whereas an increase in the fertility rate would lower the growth rate (see Mankiw, Romer, and Weil 1992 for further discussion).

From an econometric standpoint, the exogeneity of $I/Y$ and the fertility rate with respect to the growth rate are questionable.[8] In any event, the second regression in Table 1 shows that the estimated coefficient of $I/Y$ is positive and highly significant (.120, s.e. = .021),

whereas that for fertility is negative and significant (–.0037, s.e. = .0012). These results are consistent with the Solow model of economic growth.

For present purposes, the most interesting finding from the second regression is that the inclusion of the investment ratio and the fertility rate roughly halves the estimated coefficient on the schooling variable: the estimated value is now .0109, s.e. = .0041. This result suggests that a good deal of the effect of initial human capital on the growth rate works through its effects on investment and fertility. These channels of effect are examined below.

The third and fourth regressions shown in Table 1 include dummy variables for sub-Saharan Africa and Latin America. Both continent dummies are significantly negative, substantially so for sub-Saharan Africa. The main inference from these results is that the independent variables that I have been able to measure and hold constant are insufficient to explain all of the poor growth performances in these regions. One possibility is that the measure of educational attainment in sub-Saharan Africa, although low, does not fully capture the low levels of human capital in this region.

Table 2 shows regressions in the same form as Table 1 for the investment ratio, $I/Y$, and the total fertility rate. These variables are measured as averages over the periods considered. Note that the schooling variable has a significantly positive effect on $I/Y$ in the first two regressions and a significantly negative effect on the fertility rate in the last two regressions. Thus, these results confirm the idea that part of the influence of initial human capital on the growth rate involves the positive interaction with investment in physical capital and the negative interaction with the fertility rate. The interaction with physical investment would occur, for example, in the model of imbalances between human and physical capital that was worked out by Mulligan and Sala-i-Martin (1992). The interplay with fertility arises in the theory of Becker, Murphy, and Tamura (1990).

The results shown in the second regression of Table 1 showed that the effect of the school-attainment variable on the growth rate remained significantly positive even after holding constant the investment ratio and the fertility rate. A possible interpretation, along the

lines of Nelson and Phelps (1966), is that this effect of human capital reflects the enhanced ability to adopt new technologies.

It should be stressed that the findings on convergence from the cross-country sample in Table 1 do not mean that the typical poor country in Africa, South Asia, or Latin America will tend to catch up to the richer countries in the world. The poor countries have long-run target positions, $y_i^*$, that are as low on average as their current positions, $y_i$, and therefore do not tend to grow especially fast. Convergence toward the rich countries would be predicted only if the underlying determinants of $y_i^*$—such as openness to trade, political stability, and additional determinants that I was unable to measure directly—were improved; the standard growth model provides no basis for predicting these improvements in underlying policies.

## Additional Theoretical Findings about Growth and Convergence

**The saving rate.** Extensions of the Solow growth model by Cass (1965) and Koopmans (1965) built on the earlier work of Ramsey (1928) to determine the saving rate through consumer optimization. As an economy develops, the saving rate need not remain constant (as Solow had assumed), but may instead fall or rise. If the saving rate were high at low levels of per capita income but then declined as an economy developed, then the convergence rate would be higher: poor countries would grow rapidly partly because the rate of return on capital was high and partly because they saved a lot. In contrast, if the saving rate were low initially and then increased with development, then the convergence rate would be reduced: the high rate of return on capital in poor economies would have to fight against the limited supply of savings.

Although the extensions of the neoclassical growth model allow for a formal analysis of the determinants of saving, the end result is that the relation of the saving rate to the level of economic development is ambiguous. The behavior of the rate of return—high when the stock of capital is small and declining as capital is accumulated—suggests that the saving rate would fall as an economy grows. An income effect provides an opposing force: poor countries (that are

converging toward high long-run levels of income) have a large positive gap between long-run ("permanent") and current income and tend accordingly to consume a lot and save little. This force attenuates as the economy develops, and, hence, the saving rate would increase.

The offset of the two forces—the substitution effect from the rate of return and the income effect due to the gap between current and long-run income—leads to an ambiguous pattern for the saving rate. In fact, a more detailed analysis of the consumer-optimization problem suggests that the saving rate could plausibly remain roughly stable as an economy develops. The empirical evidence on the investment ratio shown in Table 2 suggests, however, a weak tendency for the saving rate to rise as economies develop. Thus, there is some indication that the dynamics of the saving rate leads, on net, to a reduction in the rate of convergence.

**Capital mobility.** The theoretical framework considered thus far assumes a closed economy: goods do not move across borders, and the residents or government of one economy cannot borrow from or lend to those in another economy. This assumption is unrealistic for countries, but is especially troubling for the regions of the United States, the western European countries, and Japan.

The introduction of international trade in goods and assets has two types of effects in the context of the standard growth model. First, the long-run target, $y_i^*$, can be affected. The gains from trade and the benefits from specialization suggest that $y_i^*$ would rise when the economy was opened. The exposure to foreign competition can also promote domestic efficiency; for example, Tornell and Velasco (1992) show that the potential for "capital flight" (including the brain drain for human capital) from a country with poorly defined property rights provides competitive pressure that generates an improvement in property rights and, hence, in the incentives to invest domestically. Thus, capital flight can lead indirectly to a higher growth rate.[9]

A second effect is that the potential to borrow and use foreign capital speeds up the adjustment process. Economies with low ratios of capital to labor—in relation to their steady-state values—tend to become international borrowers, whereas those with high ratios tend to become lenders. In the simplest situation of a perfect international

credit market and no adjustment costs for capital accumulation, a small economy with a low starting ratio of capital to labor would adjust instantaneously to its long-run values of capital, production, and wage rates. (The economy's capital income and domestically owned assets tend, however, to converge slowly or not at all to those prevailing elsewhere.) More realistically, a substantial fraction of the capital stock—especially human capital—cannot be financed by foreign borrowing or direct foreign investment. This kind of capital accumulation therefore requires a substantial element of domestic savings. Moreover, the adjustment costs for expanding the stock of human capital are large—that is, the process of expanding human capital cannot be accelerated greatly without encountering a rapid drop-off in the rate of return on investment. These considerations suggest that the speed of convergence for an open economy may not be that much greater than that for a closed economy.

This conclusion is supported by some fragments of empirical evidence. First, the rate of conditional convergence across countries is only slightly less than that for regions of countries, although the mobility of capital would be much greater across the regions. Second, the speed of convergence for measures of production across the U.S. states (based on data for gross state product) is similar to that for measures of income (based on statistics for personal income). If the mobility of capital were a key element, then the rate of convergence should be greater for production (and the stock of productive capital) than for income (and the stock of domestic assets).

**The migration of persons.** Another force that influences convergence is the mobility of labor and persons across economies. Labor, responding to wage-rate differentials, tends to move toward economies that have high ratios of capital to labor (in relation to their steady-state ratios) and to places with high steady-state ratios of capital to labor (because a high steady-state value reflects elements like low tax rates and a high intrinsic level of productivity).[10] The migration of labor toward economies that have high ratios of capital to labor moves the ratios toward their steady-state values and tends thereby to speed up the process of convergence.

Barro and Sala-i-Martin (1991) showed that migration across the

U.S. states from 1900 to 1987 occurred in the anticipated manner: people moved on net toward places with higher per capita personal income after holding constant some measures of amenities and population density. (The results are similar if only the labor compensation part of personal income is used.) Although the estimated effect of per capita income on net migration was positive and highly statistically significant, the magnitude of the effect was not large: a 10 percent increase in a state's per capita income was estimated to raise net in-migration only by enough to raise the state's rate of population growth by about one-quarter percentage point per year. The interpretation is that the costs attached to moving are high even for migration across states within the United States.

The small magnitude of response of migration to income differentials led to the conclusion that internal migration contributed little to the speed of convergence for state averages of personal income. That is, the estimates suggest that the rate of convergence of per capita personal income across the U.S. states—about 2 percent per year—would have been about the same if internal migration had not been possible. Ongoing research on within-country migration for the regions of western European countries generates similar findings. Migration has occurred in the expected direction—toward the richer regions—but this process has not been a major contributor to the estimated speed of convergence of per capita gross domestic product across the regions.

**The diffusion of technology.** The most interesting aspect of recent theories of economic growth, represented by Romer (1990b) and Grossman and Helpman (1991, chapters 3 and 4), concerns theories of technological progress in the leading economies. In these models, a technological advance shows up either as the discovery of a new type of product (a new kind of productive input or a new variety of final good) or as an improvement in the quality or productivity of an existing product. These advances require purposive research effort, although the output from the research sector may involve random elements.

The incentive to commit resources to research requires a reward for success. In the models, the rewards take the form of monopoly rentals on product innovations. That is, a successful innovator's

monopoly position lasts for a while because of first-mover advantages, secrecy, and possibly formal patent protection.[11]

Growth can be sustained in these models if diminishing returns do not apply—that is, if the returns from new discoveries do not decline in relation to the costs of making the discoveries. One reason that diminishing returns may not apply is that the potential supply of new ideas and products is effectively unlimited.

For a single economy, the technological progress generated in recent theoretical models substitutes for the exogenous technological progress that is assumed in the standard growth model. For studying convergence across economies, the interesting application of the new theories is to the process of adaptation or imitation by followers of the innovations that were made by leaders (see Barro and Sala-i-Martin 1992b, chapter 8). The cost of imitation for a follower can be modeled as similar to the cost of discovery for a leader, except that the cost of imitation is likely to be smaller and subject to less uncertainty. These considerations suggest that a follower would grow faster than a leader and thereby tend to catch up to the leader. This conclusion may not hold, however, if the follower country's environment is hostile to investment (in the form here of expenses for technological adaptation) because of poorly defined property rights, high rates of taxation, and so on.

Although innovation in the world economy may not be subject to diminishing returns, the process of imitation by a single country would encounter diminishing returns as it exhausts the pool of innovations from abroad that are readily adaptable to the domestic context. This consideration leads to the usual convergence property: a follower country tends to grow faster the larger the stock of potential imitations, and, hence, the further its per capita income is from that of the leaders. The convergence result is again conditional on aspects of the domestic economy—such as government policies, attitudes about saving, and intrinsic levels of productivity—that affect the returns from technological adaptation.

Direct foreign investment can serve as a substitute for domestic expenditures on technological adaptation and imitation. This foreign activity is likely to have some advantages over local imitation: first, the foreign producer who is familiar with a new technology may have

lower costs for adapting the technology to another location; second, direct foreign investment may get around the credit-market problems associated with loans to less-developed countries (if the collateral represented by the direct investment is better than that embodied in a loan); and third, the incentive to innovate in the first place is appropriately greater if the inventor has foreign rights and is therefore not subject to uncompensated imitation.

Foreign investment of this type has been described as important to the process of economic growth in case studies, such as the one for Singapore by Young (1992). Young also observed that imitation of technology was central to the development of Hong Kong, and many researchers have argued that Japan and other Pacific rim countries have thrived on the adaptation of ideas that were discovered elsewhere. I do not know of studies that systematically assess the effects of technological diffusion and foreign investment on economic growth and convergence for a broad cross section of countries.

## Concluding Observations

A number of forces tend to raise an economy's per capita growth rate when its level of per capita income is further below its long-run target. These forces include diminishing returns to capital, the mobility of capital and labor, and the diffusion of technology from leader to follower economies. This type of conditional convergence does not necessarily imply absolute convergence—that is, a systematic tendency for poor economies to grow faster than rich ones—because the long-run targets can differ. These differences can reflect variations in attitudes toward saving, fertility, and work effort; but the main source of divergence is likely to be government policies that affect the incentives to invest and to operate efficiently.

The existence of absolute convergence—poor economies tending to catch up to rich ones—depends on whether the convergence property applies to government policies and to the other determinants of long-run target positions. Is there some tendency for policies that hinder economic growth to be replaced by favorable policies, or, at least, is there some tendency for all policies to revert to some kind of

mean behavior? The standard growth theory or other economic models considered in this paper provide no basis for predicting this kind of convergence for government policies. This broader question of convergence has to be analyzed by methods of political economy (although, of course, the best political scientists now rely mainly on economic reasoning).

In recent years most of the centrally planned economies have moved away from socialism and toward free markets, whereas the United States has tended to increase its degree of socialism (especially after the departure of President Reagan). Similarly, some of the most poorly managed economies in Latin America—such as Argentina and Mexico in recent years and Chile some time ago—have become heroes. The dispersion in the extent of socialism seems therefore to be narrowing. Perhaps the empirical lesson is that countries have a tendency to converge toward policies that are neither too harmful nor too favorable to economic well-being. I am unsure, however, whether a sound theory of political economy would generate this answer.

# NOTES

1. Data for Oklahoma are unavailable because 1880 preceded the Oklahoma land rush.

2. The relation shown in Figure 3 turns out to be similar if the values are not filtered for the country means. That is, for the seven countries considered here, convergence appears as much across countries as within countries.

3. The data are the values adjusted for differences in purchasing power by Summers and Heston (1988).

4. An imbalance in the other direction—a high ratio of physical to human capital, perhaps as a consequence of an epidemic—also causes the growth rate to depart from its steady-state value. The effect of this kind of imbalance on the growth rate would be relatively weak, however, if the accumulation of human capital were subject to large adjustment costs. Also, in the Uzawa (1964)-Lucas (1988) model, an increase in the ratio of physical to human capital raises the real wage rate (the marginal product of human capital in the production of goods) and tends thereby to deter education—because education is intensive in the relatively expensive input, human capital. Hirshleifer's (1987) discussion of the black death suggests that growth is lower than usual in the aftermath of a sharp decline in human capital.

5. More precisely, because the estimation is carried out at five-year intervals, the coefficient, .0167, has to be adjusted slightly to compute the instantaneous rate of convergence (see Barro and Sala-i-Martin 1992a for the details). The implied convergence coefficient turns out in this case to be 1.8 percent per year.

6. The tariff rate enters as an interaction with an estimate of "natural openness," the country's ratio of imports to GDP that would have occurred in the absence of trade distortions. This openness was estimated to be a negative function of the country's area and its weighted-average distance from major markets. The idea is that distortions due to tariffs have a larger adverse influence on growth for countries that are naturally more open (small countries and countries that are close to major potential trading partners). See Lee 1992 for a discussion.

7. The value 1.0 is close to the nonlinear, maximum-likelihood estimate of this parameter in the form of the first regression shown in Table 1. The value was then restricted to 1.0 and was not reestimated for the various regressions shown. The logarithmic form used in the regressions turned out to fit slightly better than a linear form in attainment.

8. The empirical results are similar, however, if lagged values of $I/Y$ and the

fertility rate are used as instruments. The exogeneity of other variables in the regressions, such as revolutions and coups and the black-market premium, can also be questioned.

9. Another effect of openness on $y_i^*$ arises if the domestic economy's willingness to save differs from that for the world. The opening of an economy to international credit markets would raise $y_i^*$ if the domestic residents were relatively impatient.

10. Openness to migration may also affect an economy's steady-state position. This openness may, for example, allow for a better match between persons and an economy's natural resources and may provide for competitive pressures that influence domestic policies. The latter argument parallels Tornell and Velasco's (1992) discussion about the beneficial effects from capital mobility. There may also be scale effects (positive or negative) if constant returns to scale are not a reasonable approximation.

11. I am focusing on the role of these models as positive theories of economic growth and not on the often contradictory inferences that have been drawn for desirable governmental policies. The policy implications derive from positive or negative gaps between social and private rates of return. Positive gaps can reflect uncompensated spillover benefits in research and production, the consequences of monopoly pricing of the existing goods, and the disincentive effects from taxation. Negative gaps can come from the seeking of existing monopoly rentals by new entrants or from congestion effects (negative spillovers from economic activity).

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