NBER WORKING PAPER SERIES

SOLOW AND THE STATES: CAPITAL ACCUMULATION, PRODUCTIVITY AND ECONOMIC GROWTH

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Working Paper No. 4144

NATIONAL BUREAU OF ECONOMIC RESEARCH
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Cambridge, MA 02138
August 1992

The author is Associate Professor of Economics and Senior Research Associate, Metropolitan Studies Program, Syracuse University. I thank Sheila Fazzio and Kathleen Staudt for their help in preparing the manuscript and Stephen Rhody for research assistance. I am indebted to participants in seminars at Syracuse University, the Federal Reserve Bank of Philadelphia, and the University of Iowa for their valuable comments on earlier drafts. This research is part of the National Bureau of Economic Research Program in Public Economics and was supported by National Science Foundation grant number SES-8908458.

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ABSTRACT

National, state, and local policy makers have increasingly focused their attention on policies toward economic growth, especially efforts to raise the rate of investment. Recent studies of economic growth have raised a debate over the role played by the investment rate in the long-run performance of the economy. Evidence from the states suggests that the effects of capital accumulation are consistent with the predictions of the neoclassical growth model. At the same time, the estimates indicate a substantial role for human capital accumulation in raising productivity, in contrast to the neoclassical focus on physical capital investment.

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I. INTRODUCTION

National, state, and local policymakers have increasingly focused their attention on policies to raise the rate of economic growth. A large proportion of these efforts are directed toward increasing the rate of saving and capital accumulation; indeed this goal provides a unifying theme to the Federal budget history of the 1980s. In most policy analyses, the theoretical underpinnings of the relationship between capital accumulation and growth are provided by the neoclassical model of growth developed in the 1950s by Robert Solow [1956]. In the Solow model, the long-run level of output per worker is directly tied to the rate of investment in an economy.

A number of recent studies, however, have cast doubt on whether observed economic conditions may be reconciled with the predictions of the model. Most prominently, the neoclassical model suggests that economies converge toward a common steady state for output per worker. Critics argue that existing large disparities in income per capita are inconsistent with the model. In contrast, models of "endogenous growth" embody the capacity for continuous growth, even in the absence of exogenous increases in technical efficiency. As a result, these models predict no tendency for economic conditions to equalize among nations, instead yielding permanent differences in output per worker.[1,2]

This paper re-visits the empirical performance of the Solow model using data drawn from the U.S. states. It is prompted by three observations. The first is the concern by policymakers over the most efficacious means by which to stimulate improved economic performance at the national or sub-national level. Is it true that raising the rate of investment will translate into only a temporary increase in the rate of output growth, but a permanent increase in the level of productivity? Or, for example, can improved tax policy toward investment permanently raise the rate of income growth?

The second is a recent study by Mankiw, Romer and Weil [1990] using the Solow model to explain international differences in output per worker in a cross-section of countries. Their results suggest that any move to write off the Solow model is a bit premature, although the model must be modified to emphasize the role of human capital.

Finally, in a study of the aggregate production characteristics of the U.S. states, Holtz-Eakin [1991a] shows evidence of both constant returns to scale in state-level production functions and diminishing returns to each factor of production. Constant returns to any single factor or overall increasing returns play a critical role in models that generate endogenous growth. Thus, in the absence of these features the Solow model should be capable of explaining state-by-state patterns in growth and productivity.

Focusing on the states has natural advantages. Results from the states are of direct importance to the design of policies by state and local governments. There are research design considerations as well. Empirical tests of growth models typically assume that all economies have access to identical production technologies. The free flow of technology across state borders is consistent with this assumption, unlike, for example, studies using international data. Moreover, there are not large variations in the legal setting, political institutions, or tastes across states. Finally, states offer the opportunity to analyze reasonably large samples of data collected on a consistent basis. States are, of course, open economies with relatively free mobility of factors, necessitating some modification of the basic, closed-economy growth model.

Barro and Sala i Martin [1990, 1991] also examine the growth characteristics of the states, focusing on the convergence of output per worker that is predicted by the basic growth model. They are unable, however, to control explicitly for cross-state variation in the steady state toward which each state economy converges. As shown below, this steady state is characterized in part by the parameters of the state production function. In the absence of direct estimates of these parameters, Barro and Sala i Martin must infer the production characteristics indirectly from an estimated speed of adjustment coefficient. In contrast, the empirical work below specifies explicitly the steady-state in terms of a small number of observable variables, thereby permitting direct estimation of the parameters of the production technology. Further, the techniques employed impose consistency between the estimated characteristics of production and the estimated speed of convergence.

The remainder is organized in three parts. The next section reviews the major predictions of the neoclassical growth model. Data sources, estimation issues and empirical findings are presented in Section 3, while the final section discusses the implications of the econometric findings. To preview the results, I find that the data provide strong support for the Solow model. As in Mankiw, Romer and Weil [1990], however, the aggregate production function must be modified to include explicit recognition of human capital.

2. THE SOLOW GROWTH MODEL: THEORY AND EMPIRICAL IMPLICATIONS

The striking feature of the Solow growth model is its prediction that all economies with the same investment and labor force growth rates will arrive at an identical steady state level of output per worker. The next subsection makes precise the nature of this prediction. Subsection 2.2 covers the notion of convergence, discussing the circumstances under which states will approach the same level of output per worker (unconditional convergence) and situations in which economies that start with lower initial levels of output per worker will grow faster, *ceteris paribus*, than similar economies with higher initial levels of output (conditional convergence). The final subsection examines the implications of heterogeneous capital in the form of public-sector capital or human capital.

2.1 Steady States

The growth model begins with a constant-returns-to-scale production function. With an eye toward the empirical analysis to follow, assume that this takes the Cobb-Douglas form:

$$Y_t = K_t^{\alpha}(\Phi_t L_t)^{1-\alpha} \tag{2.1}$$

where Y_t is output, K_t is capital inputs, Φ_t is a technical efficiency index, and L_t is labor inputs. $\Phi_t L_t$ represents effective labor inputs. Equation (2.1) may be written in intensive form:

$$y_{et} = k_{et}^{\alpha} \qquad (2.2)$$

where the subscript "e" denotes quantities per effective labor unit. Assume that Φ_t and L_t grow at constant rates λ and η, respectively:

$$\Phi_t = \Phi_0 e^{\lambda t} \qquad (2.3)$$

$$L_t = L_0 e^{\eta t} \qquad (2.4)$$

Growth in y_e is proportional to growth in k_e, which is the difference between the growth rate of K and the growth rate of effective labor $(\eta+\lambda)$:

$$\frac{\dot{k}_{et}}{k_{et}} = \left(\frac{\dot{K}_t}{K_t}\right) - (n+\lambda) \qquad (2.5)$$

The growth rate of the capital stock is determined by the difference between fraction of output that represents investment (θ) and losses due to depreciation (δ):[3]

$$\frac{\dot{K}}{K_t} = \frac{\theta y_{et}}{k_{et}} - \delta \qquad (2.6)$$

Collecting the results in equations (2.5) and (2.6) gives:

$$\frac{\dot{k}_{et}}{k_{et}} = \frac{\theta y_{et}}{k_{et}} - (n + \lambda + \delta) \qquad (2.7)$$

Predictions concerning the steady-state levels of output and productivity come from setting the growth rate of capital per effective worker in equation (2.7) equal to zero. The steady state value for effective capital is:

$$k_e^* = \left(\frac{\theta}{\eta+\lambda+\delta}\right)^{\frac{1}{1-\alpha}} \qquad (2.8)$$

Substituting k_e^* into the production function gives the steady state value of effective-labor productivity:

$$y_e^* = \left(\frac{\theta}{\eta+\lambda+\delta}\right)^{\frac{\alpha}{1-\alpha}} \tag{2.9}$$

In practice, one does not observe effective labor units. The model may, however, be translated into predictions concerning the steady state level of output per worker. Letting y denote output per worker, using equations (2.3) and (2.9), and taking logarithms yields:

$$\ln y_t = \frac{\alpha}{1-\alpha}[\ln\theta - \ln(\eta+\lambda+\delta)] + \ln\Phi_0 + \lambda t \tag{2.10}$$

Equation (2.10) suggests a straightforward test of the model. In a cross-section of observations on the U.S. states, the (log) difference between the investment rate and the sum ($\lambda+\eta+\delta$) should predict (log) output per worker. Figure 1 displays the 1986 distribution of output per worker (scaled by the mean) for the forty-eight states used in the regression analysis below. As a glance at the figure indicates, there is considerable variation in productivity across the states; even excluding the outliers at each end suggests a range of roughly 30 percent.

The state-by-state variation in productivity stems from two sources: differences in long-run tendencies for each state and shocks idiosyncratic to 1986. The basic statement of the Solow model is that the former should be explicable in terms of a narrow set of variables. Output per worker should be positively correlated with the investment rate in each state and negatively correlated with ($\lambda+\eta+\delta$), the latter term reflecting "capital requirements" needed to satisfy growth in effective labor and capital consumption. Moreover, the coefficients should be of equal magnitude. Empirical implementation of this test is pursued in Section 3.[4]

2.2 Adjustment to Steady States

A second, and perhaps more important, implication of the model concerns the nature of the transition to the steady state. As noted by Lucas [1988] and Romer [1989], the steady state of a neoclassical growth model will be indistinguishable from the balanced growth path of an endogenous growth model. During the transition to the steady state, however, the neoclassical growth model embodies the convergence hypothesis, two forms of which exist in the literature.

The first, unconditional convergence, argues that all economies will converge toward an identical steady-state level of output. Thus, one should see the absolute dispersion of productivity levels falling over time. Figure 2 displays suggestive evidence in favor of unconditional convergence, using the data for this study. As shown, the dispersion (measured by the coefficient of variation in each year) of output per worker falls fairly steadily over the period 1973 to 1986.

Unconditional convergence, while appealing, is too simple a notion. The Solow model predicts only that "identical" economies -- those with equal investment rates, labor force growth rates, etc. -- will be characterized by identical steady states. As a result, *conditional* upon having identical steady states, output per worker will converge regardless of initial conditions. Accordingly, conditional convergence predicts that when observing the transition to (the same) steady state, one must observe faster growth in those economies that start off at a lower level. Figure 3 contains suggestive evidence on this front; plotting the average annual growth rate for 1973-1986 versus the initial productivity level. The negative correlation predicted by conditional convergence is plainly evident in the raw data.

The difficulty, of course, is that Figure 3 does not control for variations in the steady state. It is possible to employ the basic model to develop a regression test for conditional convergence. Using discrete time, and approximating in the vicinity of the steady state yields:

$$\ln y_{et} - \ln y_{e0} = (1-(1-\gamma)^t)(\ln y_e^* - \ln y_{e0}) \tag{2.11}$$

where y_{e0} is the initial level. The convergence speed parameter, γ, is given by:

$$\gamma = (1-\alpha)(\eta+\lambda+\delta) \tag{2.12}$$

Transforming equation (2.11) into observables yields:

$$\ln y_t - \ln y_0 = (1-(1-\gamma)^t)\left(\frac{\alpha}{1-\alpha}[\ln\theta - \ln(\eta+\lambda+\delta)] + \ln\Phi_0 - \ln y_0\right) + \lambda t \tag{2.13}$$

As equation (2.13) indicates, during the transition to the steady state, the growth rate of y_t is inversely related to the initial level of output (y_0). In contrast, models of endogenous growth do not predict convergence.[5]

Instead, similar economies tend toward identical balanced growth paths, regardless of the starting point. As a result, there is no relationship between initial conditions and subsequent growth rates. An econometric version of equation (2.13) will be useful in discriminating among alternative theories of the underlying nature of economic growth.

In equation (2.13), the adjustment speed depends upon the underlying parameters for technology, tastes, and population growth. For example, assume that α is 0.33, and that $(\lambda+\eta+\delta) = 0.075$. As a result, $\gamma = 0.05$ and the economy will require 13.5 years to adjust one half of the way toward the steady state. Higher values of α lower the speed of adjustment; with $\alpha = 0.67$ the economy will require 27 years to adjust one half of the way toward the steady state.[6]

Factor mobility in open economies will likely both raise the speed of adjustment and increase the tendency to unconditional convergence. Labor will flow from low-productivity to high-productivity regions, slowing the process of capital-deepening. At the same time, capital will flow to areas with a relatively high marginal product; i.e. those less-developed with relatively lower capital per worker. In the process, the speed with which economies will converge to the steady state is likely to increase. At the same time, there is pressure to equalize the steady-state level of output per worker across locations.

2.3 Public-Sector and Human Capital

The importance of public-sector, especially infrastructure, capital and human capital has been the focus of much recent attention. Barro [1990], for example, identifies public-sector capital as a potential source of increasing returns to scale in a model of endogenous growth. It is not obvious, however, that government capital merits such special treatment. First, the dividing line between the private and public sector is hardly distinct. The private sector can, and does, provide roads, utilities, water supplies and many of the infrastructure investments typically identified with government capital. Merely shifting ownership of capital across sectors will not alter its economic characteristics. Moreover, the most recent evidence from the growing literature on the role of infrastructure in augmenting private-sector productivity suggests little in the way of pervasive, economy-wide effects (see Hulten and Schwab [1991] or Holtz-Eakin [1991a]). These observations suggest no need for a distinct treatment of government capital, although it should be included in gross capital formation.

A second special form of capital, human capital, raises more complicated issues. Human capital is the focus of the Lucas [1988] study of the mechanism for endogenous growth, suggesting that any "contest" between neoclassical and endogenous growth should include human capital. In addition, Mankiw, Romer and Weil [1990] find that augmenting the Solow growth model for the presence of human capital markedly improves its predictive performance in a cross-national study of economic growth.

The flow of investment in human capital is, however, difficult to measure, making it impractical to work directly with the rate of investment in human capital. Following Mankiw, Romer and Weil [1990], one may expand the basic model to accommodate the presence of human capital without the need for information on the flow rate of investment. Letting H_t denote the stock of human capital, the production function may be written:

$$Y_t = K_t^{\alpha} H_t^{\beta} (\Phi_t L_t)^{1-\alpha-\beta} \tag{2.14}$$

With this modification, the steady-state becomes:

$$y_e^* = \left(\frac{\theta}{\eta+\lambda+\delta}\right)^{\frac{\alpha}{1-\alpha}} (h_e^*)^{\frac{\beta}{1-\alpha}} \tag{2.15}$$

where h_e^* is the steady state *level* of human capital per effective labor unit. Once again transforming into a form in terms of observable variables yields:

$$\ln y_t = \frac{\alpha}{1-\alpha}[\ln\theta - \ln(\eta+\lambda+\delta)] + \frac{\beta}{1-\alpha}\ln h^* + \frac{1-\alpha-\beta}{1-\alpha}\ln\Phi_0 + \frac{1-\alpha-\beta}{1-\alpha}\lambda t \tag{2.16}$$

Equation (2.16) may serve as the basis for a regression equation analogous to that discussed earlier, with the equation expanded to include the stock of human capital.

In similar fashion, one can modify the analysis of transitions to the steady state to yield:[7]

$$\ln y_t - \ln y_0 = \left(1-(1-\gamma)^t\right)\left(\frac{\alpha}{1-\alpha}\left[\ln\theta - \ln(\eta+\lambda+\delta)\right] + \frac{\beta}{1-\alpha}\ln h^* + \ln\Phi_0 - \ln y_0\right) \qquad (2.17)$$

where the adjustment speed, γ, is given by:

$$\gamma = (1-\alpha-\beta)(\eta+\lambda+\delta) \qquad (2.18)$$

3. EMPIRICAL ANALYSIS

3.1 Econometric Specification and Data

Equation (2.16) embodies the discussion of steady state behavior in Section 2, indicating the relationship between steady-state output per worker and the investment rate, the labor force growth rate, the rate of technical progress, the rate of depreciation, and the stock of human capital. Thus, the initial econometric objective is to estimate the parameters of equation (2.16): α, β, λ, and Φ_0.

One approach to the estimation would be to estimate the model using a single cross-section of data. (See, for example, Mankiw, Romer, and Weil [1990].) In the current context, one could use (log) output per worker in any given year as the dependent variable. Averages for all preceding years would serve as empirical proxies for the right-hand-side variables. Thus, one would estimate the (non-linear) relationship between, say, 1986 productivity and the average rates of investment and labor force growth rate between 1973 and 1986.

Indeed, one could construct such a regression for each year in the sample. Utilizing the panel structure of the data provides one way to exploit the information in all years of the data. Thus, below I estimate equation (2.16) using all the years available. In these estimates, y_{it} is productivity for state i in year t, θ_{it} is the *average* investment rate in state i between the start of the sample (1973) and year t, and η_{it} is *average* labor force growth for state i between

1973 and year t.[8] As noted below, the data available do not permit estimation to use time-series variation in h_i.

One possible objection is that annual observations of output per worker do not correspond to steady-state behavior. The second major message of the previous section, however, concerns the behavior out of the steady state; i.e. convergence. Equations (2.17) and (2.18) show the relationship between output per worker and investment rates labor force growth rates, productivity growth, and the initial level of productivity. As in the case of the estimates of the steady state, I pool data for all the available years in the estimation.[9]

Estimation is done via non-linear least squares. The estimated standard errors are corrected for heteroskedasticity using the method of White [1980].

3.2 Data

Output for each state is taken from the estimates of Gross State Product (GSP) produced by the Bureau of Economic Analysis (BEA). The labor force for each state was obtained from the BEA.[10] Productivity is defined as the ratio of output to the labor force.

Real investment was based on the estimates of private-sector capital in Munnell [1990].[11] The information on GSP and investment were used to compute the investment rate (θ) in each state. To estimate the investment rate inclusive of government capital, information on real capital investment for state and local governments was taken from Holtz-Eakin [1991b].[12] Each variable was computed on an annual basis for the period 1973 to 1986 and, where appropriate, the average value for each state employed in the analysis.

Human capital per worker is proxied by the fraction of individuals, aged 25 or older, having completed four or more years of college.[13] Data for each state is taken from the 1980 *Census of the Population*. As a result, there is no variation over time in the measure of human capital.

The final information required is an estimate of the geometric rate of depreciation (δ). In what follows, I assume that this parameter is identical across states and impose the value $\delta = 0.05$.[14] Sample statistics are shown in Table 1.

3.3 Results

The estimation results are presented in Table 2. Consider the estimates of equation (2.16) for the steady state contained column (1) of Table 2. As the theory indicates, output per worker rises with the difference between the investment share and capital requirements. The estimated elasticity of output with respect to capital is roughly 0.20, slightly below rule-of-thumb estimates of capital's share in output.[15] The elasticity with respect to human capital is of comparable magnitude, 0.21, and is also precisely estimated.[16] Thus, the data suggest that physical and human capital enter the production function in a symmetric fashion.[17] Finally, the estimate of λ suggests a slow, but statistically significant, rate of labor-augmenting technical progress over this period.

At an initial pass, then, the model does well. As shown at the bottom of column (1), however, the adjusted R^2 indicates that a rather small fraction of the variation is explained by the variables central to the model. This could simply reflect a large influence of year-specific shocks.[18] Another possibility is that the low explanatory power may stem from deviations from steady-state levels. To investigate the transition process, estimates of equation (2.17) appear in column (2) of Table 2.

Explicitly controlling for initial conditions raises the estimate of both α and β. The estimated elasticity with respect to physical capital is 0.24, while that for human capital is 0.32.[19] Both are precisely estimated. As in the case of the steady state estimates, the results indicate only a small role for technical progress during the sample period. In addition, the fraction of the variation explained by the equation is now quite large as the adjusted R^2 is 0.91.

One possible objection to the procedure thus far is that it ignores the potentially large cross-state variation in productivity that stems from differing endowments of land, minerals, etc. On the one hand this seems desirable: the purpose of this paper is to take the Solow model seriously and focus on a very narrow set of explanatory variables. Still, to the extent that this exclusion is inappropriate, the estimated parameters may be quite misleading. The estimates presented in column (3) are intended to gauge the sensitivity of the results to these factors. Specifically, the column (3) augments the equation presented in column (2) with cross-sectional information on land area (in logs), urban land area (in logs), and endowments of minerals, coal, oil and natural gas.[20] (Sample statistics for these data are also shown in Table 1.)

Glancing at the estimates, one finds that these measures of endowment have a statistically significant impact on output per worker in each state. Output per worker falls in the larger states, but rises with urbanization. Further, greater endowments of minerals, coal, oil, and gas each raise output per worker. Including these variables has little effect on the estimated elasticity with respect to physical capital and the overall fit of the equation. The estimated elasticity for human capital (0.19) is substantially below that in column (2). It is interesting to note that Mankiw, Romer, and Weil [1990] estimate an elasticity with respect to human capital of roughly 0.30 -- similar to the estimate in column (2). Their equation, however, also does not control for other variation in endowments. It is tempting to speculate that inclusion of such factors would reduce their estimate as well.

Taken at face value, the characteristics of the estimated production function are quite reasonable. Is the same true for the convergence behavior that these estimates imply? The key parameter governing the speed of adjustment to the steady state is γ (see equation (2.18)). Using the estimated parameters (in column (3)) and data for 1986, the mean value is $\gamma = 0.042$, indicating that the typical state economy adjusts toward the steady state by roughly 4 percent in a given year. Put differently, the estimates and 1986 data imply that on average it requires 16.5 years for states adjust one-half of the distance toward the steady state.

Comparable estimates from international data in Mankiw, Romer, and Weil [1990] imply the same adjustment requires 38 years. The estimates in Barro and Sala i Martin [1990], also based on U.S. state data, indicate that the time required for this adjustment is 31 years. These comparisons suggest two lessons. First, adjustment is somewhat faster in the environment of free factor mobility provided by the U.S.. Second, econometric estimates that include information on <u>both</u> the steady state and the adjustment process suggest very different qualitative results.

4. IMPLICATIONS AND CONCLUDING REMARKS

The empirical analysis provides support for the Solow model of economic growth. The average investment rate, the labor force growth rate, the rate of technological progress, depreciation, and human capital accumulation are good predictors of output per worker. Moreover, the estimated parameters of the production function easily satisfy the restrictions implied by the theory. Finally, the strong evidence in favor of both unconditional and conditional convergence argues against simple models of endogenous growth.

All is not perfect, however. The key role played by human capital alters the basic nature of the model. An increase in physical capital, for example, has both direct effect on output and, by increasing human capital formation, a further indirect effect. Because the accumulation of human capital is beyond the scope of this paper -- all inferences are conditional upon the level of human capital in each state -- providing a better understanding of the links between physical capital investment and human capital investment appears to be a promising area for further research.

What are the implications for economic policies? First, the results suggest strongly that raising the investment rate will not yield permanent increases in the rate of economic growth. Instead, following a temporary period of faster growth, output per effective worker will stabilize at a new, higher level. (Bartik [1991] reviews tax and other development policies that may influence the investment rate in states and localities.)

For the nation as a whole, the parameters indicate that greater rates of accumulation of either physical or human capital will raise productivity. For states, however, the effects are not symmetric. Policies to foster physical capital accumulation will translate to a higher marginal products of labor, and thus improved real wages for the states' workers. In contrast, the greater mobility of labor, at least in the short-term, raises the possibility that each state may not reap the benefits of its policies to enhance human capital investment.

Table 1

Sample Statistics

	Mean	Standard Deviation
Investment Rate (Φ) (Percent)	3.81	4.93
Labor Force Growth Rate (η) (Percent)	2.27	3.40
Percent College (h^*) (Percent)	15.9	2.83
Productivity (y) (1982 Dollars)	3.54	0.156
Area (square miles)	61,499	46,452
Urban Area (square miles)	964	868
Mineral (1986 metal mining + non-metallic minerals	177	179
Coal (Demonstrated reserves, 1984)	9,758	22,876
Oil (Proven reserves, 1988)	358	1208
Gas (Proven reserves, 1988)	2813	7105

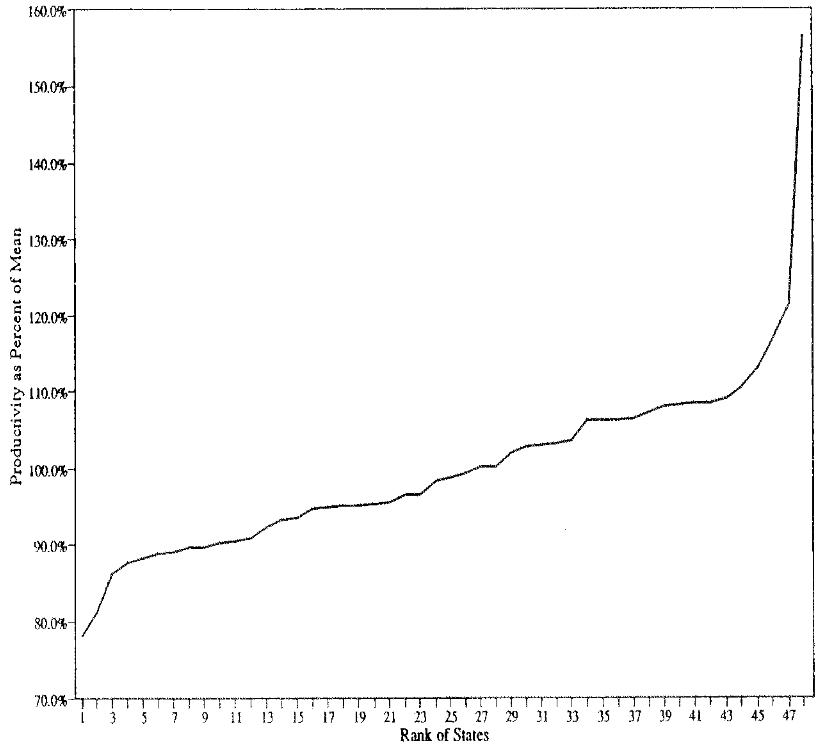
Table 2*

Parameter Estimates

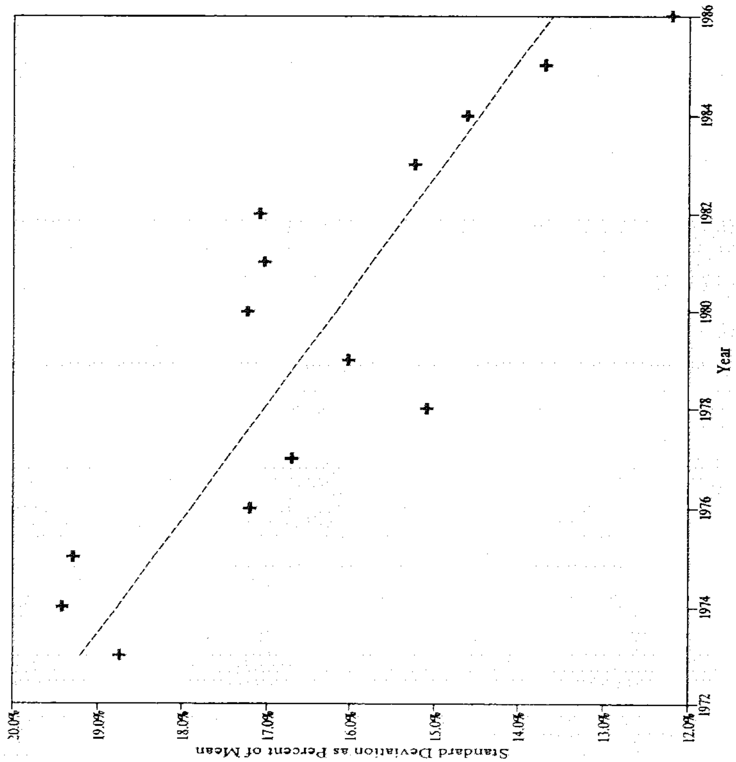
	Steady State	Convergence	
	Basic	Basic	Augmented
α	0.1979 (0.01840)	0.2354 (0.02363)	0.2414 (0.02585)
β	0.2109 (0.02243)	0.3165 (0.03169)	0.1909 (0.02341)
λ	0.005775 (0.001464)	0.001966 (0.001723)	-0.6200×10^{-4} (0.001953)
Φ_0	2.588 (0.1000)	2.106 (0.1457)	2.728 (0.1209)
Area+	--	--	-0.007429 (0.001402)
Urban Area+	--	--	0.003446 (0.002136)
Mineral	--	--	0.6334×10^{-4} (0.1128×10^{-4})
Coal	--	--	0.2102×10^{-6} (0.09433×10^{-6})
Oil	--	--	0.3236×10^{-5} (0.2247×10^{-5})
Gas	--	--	0.7426×10^{-6} (0.3968×10^{-6})
$\bar{R}^2$	0.15	0.91	0.929

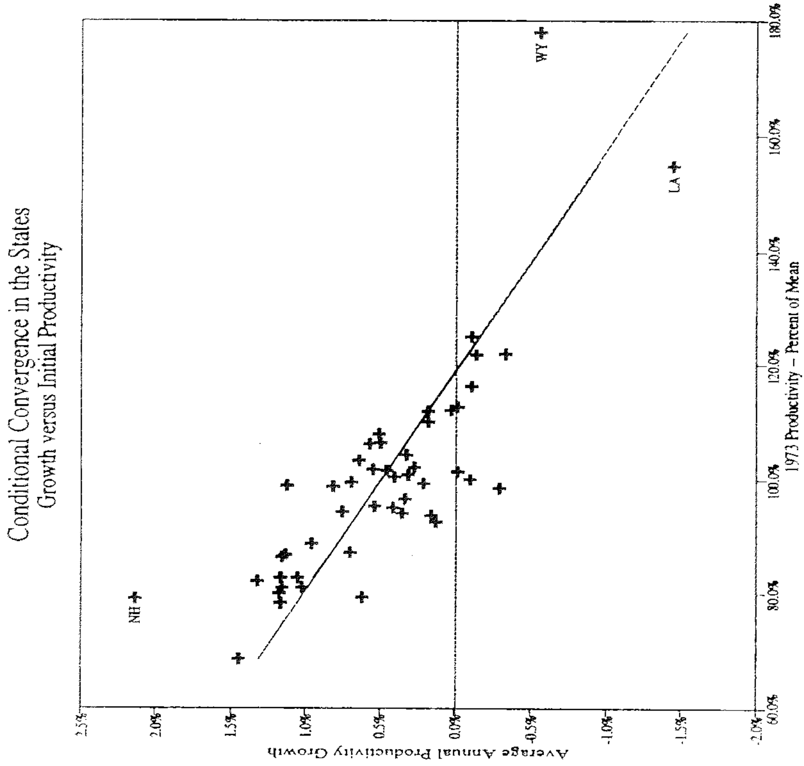
* Standard errors are shown in parentheses. All variables are defined in the text.
\+ Entered as a logarithm.

Distribution of Productivity
1986



Unconditional Convergence in the States
Coefficient of Variation - Productivity




Conditional Convergence in the States
Growth versus Initial Productivity
Average Annual Productivity Growth
1973 Productivity – Percent of Mean
2.5%
2.0%
1.5%
1.0%
0.5%
0.0%
-0.5%
-1.0%
-1.5%
-2.0%
60.0%
80.0%
100.0%
120.0%
140.0%
160.0%
180.0%
NH
WY
LA

Endnotes

1. See, for example, Romer [1986,1989], who focuses on capital accumulation as the key component of endogenous growth; Lucas [1988], who singles out human capital accumulation as the focus of the growth process; or Barro [1990], who concentrates on the role of government capital outlays.

2. The line of demarcation between exogenous and endogenous growth models has grown more murky as recently developed endogenous growth models predict convergence. See, for example, Tamura [1991].

3. In the standard presentation of the model, the key parameter is the saving rate. This follows from the fact that in a closed economy the saving rate and investment rate will coincide. In open economies such as the states, these may differ and the investment rate is the proper focus of attention.

4. This test is the heart of the international analysis by Mankiw, Romer, and Weil [1990].

5. For example, the linear production technology $y = Ak$ yields a simple model of endogenous growth. In the context of the current discussion, this corresponds to $\alpha = 1$. A quick check of equation (2.12) shows that $\gamma = 0$ in these circumstances; i.e. there is no tendency toward convergence. Note also that if $\alpha = 1$, the *growth rate* of the economy depends upon θ. In contrast, if $\alpha \neq 1$, the steady-state *level* of output depends on θ.

6. Barro and Sala i Martin [1990] use estimates of the adjustment speed to infer the nature of the underlying technology, concluding that the production function is characterized by constant returns to scale for broad (physical plus human) capital. The techniques used in this paper permit direct estimation of α.

7. This assumes that all forms of capital depreciate at the same rate.

8. Estimating equation (2.16) using single-year cross-sections for each year in the data produces the same qualitative results as those reported below; the coefficients are of the expected sign and are statistically significant. These results are available from the author upon request.

9. As above, one could estimate the convergence equation using cross-section data for each year. Doing so produces results, available from the author, similar to those from the pooled data.

10. One might be tempted to use total population rather than the labor force. To the extent that population growth is characterized by increases in non-workers (e.g. retirement states such as Florida and Arizona) this is inappropriate. Experiments using per capita measures produced empirical estimates characterized by "wrong" signs and large standard errors.

11. I thank Alicia Munnell for providing these data.

12. The resulting investment measure is not perfect. It excludes inventory investment and residential investment in the private sector, and federal capital outlays in the public sector.

13. Using either the percent having completed high school or the median years of schooling produces essentially identical results.

14. The results are not sensitive to this assumption. Varying the assumed value from 0.025 to 0.075 produced very similar results.

15. Allowing the coefficients on the investment rate and the capital requirements variable to differ does not affect the substantive results. One can never reject the null hypothesis that the coefficients are of equal magnitude.

16. Inclusion of human capital raises the explanatory power of the equation, but does not markedly affect the estimate of α. Excluding human capital yields an estimated α of 0.14, while the adjusted R^2 is 0.08.

17. Mankiw, Romer and Weil arrive at a similar conclusion, but argue that the elasticity is roughly one-third.

18. States in different regions may react differently to macroeconomics stocks. Inclusion of a set of regional dummy variables does not, however, affect the results in any substantial way.

19. Again, excluding human capital does not have an undue influence on the estimated α. The result is an estimate of 0.25. The adjusted R^2 of the restricted equation is 0.88.

20. I thank David Richardson and Pamela Smith for providing these data. Total land area and urban land area are measured in square miles. Minerals is metal mining production plus nonmetallic mineral production in 1986. Coal, oil, and gas are measured as reserves in 1988.

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