CBO PAPERS

RECENT DEVELOPMENTS IN THE THEORY OF LONG-RUN GROWTH: A CRITICAL EVALUATION

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CONGRESSIONAL BUDGET OFFICE

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PREFACE

Recent developments in the theory of long-run growth suggest that certain federal policies--including deficit reduction--will have much larger effects on economic growth than conventional theory would predict. This Congressional Budget Office (CBO) paper provides a critical survey of the old and new frameworks, with particular emphasis on empirical evaluation of them.

Robert Arnold of CBO's Macroeconomic Analysis Division prepared the paper under the supervision of Robert Dennis and John Peterson. Bruce Arnold, Doug Elmendorf, John Hakken, Doug Hamilton, Kim Kowalewski, Tom Loo, and Ralph Smith made valuable comments on an earlier draft. The paper also benefited from useful suggestions by Martin Neil Baily of the McKinsey Global Institute. Laurie Brown and John Romley helped produce the figures.

Sherry Snyder edited the paper, with the assistance of Chris Spoor, and L. Rae Roy and Dorothy Kornegay prepared it for publication.

Robert D. Reischauer
Director

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SUMMARY

New theories of economic growth developed by Paul Romer and others have led economists to question whether the neoclassical (that is, Solow) model is the most appropriate model of long-run economic growth. The new theories, collectively known as endogenous growth models, try to explain the fundamental forces that drive long-run growth rather than rely on factors determined outside the theory, as the neoclassical theory does. These theories are of interest to policymakers because they imply that government policies, including deficit reduction, can have much larger effects on growth in the long run than Solow's model would predict.

This paper provides a critical survey of the literature on the neoclassical and endogenous growth models, with particular emphasis on the recent explosion of empirical work. It concludes that the evidence does not justify discarding the neoclassical model. With suitable modifications, the neoclassical model can explain some of the anomalies for which it has been criticized, and with these modifications, it fits the historical data better than the new models. In addition, the two frameworks are not really substitutes--the best of the new theories can be interpreted as extensions of the neoclassical model.

THE NEOCLASSICAL MODEL

For over three decades, the neoclassical model has been the primary theoretical framework for virtually every study of long-run economic growth. Developed by Robert Solow, the model features a neoclassical production function that explains the level of output in terms of two factor inputs--labor and capital. Using a few simplifying assumptions about the growth of the inputs, the model predicts the existence of a stable growth path for output. However, in equilibrium, the growth of output is limited to the growth of the labor force, meaning that per capita output (a crude measure of the standard of living) is constant through time. This prediction is at odds with the historical record, which shows sustained increases in per capita output over very long periods. To explain the growth of per capita output, Solow introduced the idea of technological change.

The model's assumptions about decreasing returns ensure that per capita output does not grow without technological progress. Intuitively, this assumption means that successive increases in the amount of, say, capital used in production (holding the number of workers constant) will yield progressively smaller increases in output. If returns to additional investments do not fall, it will always be profitable to invest, capital will continue to accumulate perpetually, and per capita output can rise indefinitely.

Another important prediction of the neoclassical model is known as convergence--a process by which economies with low starting values of per capita output (poor countries) grow faster than those with higher initial values (rich countries). The model predicts that the level of per capita output in all countries will converge to a common level. Convergence occurs in the neoclassical model because of decreasing returns to capital. Investment should be more profitable in poor countries than in rich ones because poor countries have lower levels of capital per worker and, therefore, a higher return to capital. This means that poor countries not only will get a bigger "bang per buck" of investment spending but also will attract a disproportionate share of foreign investment. One problem with the prediction of convergence is that it requires that countries be identical in every respect except their level of per capita output.

Proponents of endogenous growth cite three limitations of the neoclassical model as the motivation for developing their models. First, it relies on technological change to supply growth in per capita output. Instead of explaining the sources of technological change, the model assumes it will occur independent of factors considered by the model. Second, the neoclassical model provides only a rudimentary framework for analyzing the effects of government policy on long-term growth. Although it is not obvious that government actions can raise economic growth, policy changes clearly affect the day-to-day decisions made by consumers, managers, and investors. It would be desirable to have a framework to analyze the effects of such changes on long-term growth. Third, the model has limited tools for analyzing international trade and its link with economic growth. In particular, empirical evidence suggests that countries with an outward orientation seem to grow faster than those that are more protectionist. The neoclassical model, however, cannot address the question of whether openness to trade causes faster growth.

THEORIES OF ENDOGENOUS GROWTH

Economists have recently developed theories that address the shortcomings of the neoclassical model. The defining characteristic of the new models is that they generate growth of per capita output endogenously--that is, without assuming that technological change occurs outside of the model's framework.

Hence, they are known as endogenous growth models. Although the models share the same basic idea, they rely on different mechanisms to drive long-run growth. Some models explain the forces that lead to technological change, and others modify the structure of the model so that investment in physical or human capital sustains growth.

The recent literature on endogenous growth was initiated by Paul Romer, who examined the idea that spillovers could be associated with the accumulation of knowledge. (A spillover is an action taken by one person or firm that affects another person or firm.) Romer showed that spillovers could be strong enough to outweigh the drag caused by decreasing returns to capital and sustain growth in per capita output. Later, Romer refined his model to explain why companies invest in research and development (R&D) when they know that any ideas that result will eventually benefit their competitors. He found that as long as society does not reach some type of technological limit, continuous innovation can allow per capita output to grow forever.

One important advantage of Romer's model is that it does not supplant the neoclassical model. Instead, it fills an important gap in the neoclassical theory by providing a rigorous description of the source of technological progress. Romer points out that if innovation in his model was to stop, then his model would collapse to the neoclassical model.

Following Romer, other economists have developed models that expand the idea of endogenous growth. Although they use different variables and functions, all of the endogenous growth models have the same fundamental characteristic: they reverse the effects of decreasing returns to capital. Several models focus on the importance of accumulating human capital--gaining increased skills through formal education or on-the-job training. Others focus on international trade--in particular, on how the international pattern of comparative advantage influences trade and growth. Still others examine the idea of convergence and whether it is consistent with endogenous growth, or analyze the link between fiscal policy and endogenous growth.

These models of endogenous growth are very abstract, so they do not yield specific policy prescriptions. However, they point to certain types of policies that are more likely than others to influence long-run growth. Those policies include lowering barriers to trade, reducing taxes on capital income, and focusing government spending on services that improve productivity in the private sector. One area that looks particularly promising is human capital and training. Many endogenous growth models point to innovation as the key driver of long-run growth, and to a highly educated labor force as the key input to R&D. Although the models are as yet too crude to support the argument that the government should subsidize training or education, they demonstrate that the government should avoid discouraging investments in human capital.

EMPIRICAL EVALUATION

It is difficult to evaluate two theoretical frameworks that have different explanations about the sources of economic growth when the only sample of data spans a period of sustained growth in per capita output. Heightening the problem of evaluation is the fact that the difference between the two frameworks is more quantitative than qualitative. The assumptions of the neoclassical model ensure that decreasing returns to capital set in rapidly; endogenous growth models assume that decreasing returns do not set in at all. The more slowly decreasing returns set in, the closer the results will be to those in the literature on endogenous growth.

Although definitive conclusions based on the empirical work in this area would be premature, some findings are well supported. Most important, the neoclassical framework is still appropriate for analyzing long-run growth. The latest work suggests that the model may need to be augmented to include human capital or to explain the sources of technological progress but that the basic structure should remain intact.

Most of the recent empirical work evaluating the neoclassical model has centered on the model's prediction of convergence. Much of the early evidence on this question showed that economies did not converge to common levels of per capita output. However, once researchers took account of differences in certain characteristics among countries, they found that economies have converged. What misled earlier researchers was that different countries were converging to different equilibrium levels of per capita output because they had different rates of saving, population growth, and so forth.

The empirical work examining convergence unearthed an anomaly associated with the neoclassical model. Although economies converge as predicted by the model, several papers showed that the rate at which they do so is much slower than the model would predict. One way to reconcile the predictions of the neoclassical model with the empirical evidence is to augment the model to include human capital along with physical capital. Including human capital weakens the effects of decreasing returns in the neoclassical model and slows the predicted rate of convergence to one that is consistent with the data.

Some models of endogenous growth differ from the neoclassical model because they assume that decreasing returns to capital do not exist. A natural test of these models is to measure the extent of decreasing returns, if any. Estimates of the return to capital are elusive, and some of the evidence is contradictory, but the consensus is that decreasing returns to capital do exist.

Models of endogenous growth that rely on the spillover of knowledge (as described by Romer) to drive long-run growth can be evaluated by searching for evidence of such spillovers. And, in fact, there is good evidence to suggest that they do exist. Unfortunately, most empirical analysis relies on firm- or industry-level data and, therefore, does not demonstrate the importance of spillovers for growth of per capita output at the economy wide level. The evidence is, however, extremely suggestive; it is likely that innovation and knowledge spillovers will be key elements of any complete theory of long-run growth.

What conclusions can be drawn from this study? Most important, the neoclassical framework is still the most appropriate model of long-run growth. Its crucial assumptions--in particular, decreasing returns to capital--appear to be justified, and careful empirical studies support many of its predictions. Some recent empirical studies suggest that the model should be augmented to include human capital; doing so raises the model's prediction of the benefits of deficit reduction. The major shortcoming of the model is its assumption of exogenous technological progress.

Recent studies of endogenous growth have provided many new ways to think about long-run growth and a more diverse set of mechanisms for analyzing the effects of government policy. The highly abstract early models have given way to more realistic models that have better empirical support. In fact, it is difficult to make a clear distinction between the neoclassical and endogenous growth frameworks because the differences between the two are steadily shrinking. Many of the latest models are better viewed as extensions of the neoclassical model rather than replacements for it. The models that include an explicit treatment of the economics of innovation provide an important step toward a complete description of the process of technological change.

CHAPTER I

INTRODUCTION

Economic growth is a critical factor in determining living standards over the long term. Although much of the discussion about macroeconomic policy concerns the problem of minimizing short-term fluctuations in output, slight changes in growth rates over the long term will compound to swamp even the largest of cyclical slowdowns. The recession of 1981-1982, for example, witnessed the deepest decline in per capita output since World War II--nearly 5 percent from peak to trough. Although this seems large, it is dwarfed by the effects of the slowdown in growth that occurred during the 1970s. If the average rate of growth experienced from the end of the war to 1973 had been maintained during the 1973-1990 period, per capita output would have been 36 percent higher in 1993 than it turned out to be.

The relatively slow growth of real gross domestic product (GDP) in recent decades, at least compared with growth during the 1950s and 1960s, has spurred interest in federal policies that may promote long-run growth and higher living standards. The current concern about the level of the federal budget deficit stems primarily from its predicted effects on future living standards.

Can the federal government do anything to speed growth and raise living standards over the long term? Clearly, basic government services such as national security, protection of property rights, a justice system, and basic infrastructure are important because they provide the framework for economic activity. But the question remains: Does the government have a role in economic growth beyond providing these basic services?

For the past three decades, the standard tool for analyzing long-run growth has been the neoclassical model of economic growth. The model, however, is unable to analyze the effects of many changes in government policy; it simply lacks the mechanisms required to do so. The neoclassical theory implies that changes in the federal deficit will affect per capita GDP in the long run but that the effects will be relatively modest. According to the model, reducing the deficit will raise the level of national saving, permit more capital investment, and lead to higher living standards in the long run. However, increased national saving and capital investment will provide a one-time boost to the *level* of per capita output but will have no effect on the long-run rate of *growth* of per capita output. The model allows for an increase in the rate of growth of per capita output only if the rate of technological advance increases.

This traditional view has been challenged in recent years by new models of economic growth that, on the surface, appear to fit the empirical evidence better. These models are collectively known as endogenous growth models because they imply perpetual growth in per capita output without relying on technological advances. In general, the new models suggest that policy changes, such as reducing the federal deficit, can have powerful effects on living standards in the long run. These effects are much larger than those the neoclassical model would predict, because they can affect not only the level but also the rate of growth of per capita output.

In addition, many of the new models contain a fuller set of mechanisms for studying the effects of changes in government policy. Some models suggest that taxes should provide incentives to invest in physical capital, whereas others suggest that taxes should favor investment in human capital.[1] Several analysts show that in some situations, government interventions--taxes or subsidies--are not only effective but desirable. The models also open up new avenues for studying how policies on international trade affect economic growth.

The challenge presented by the new models of economic growth has stimulated a round of empirical work evaluating the neoclassical model. Most of the evidence, though still accumulating, generally supports the neoclassical model's assumptions and predictions. However, the empirical evidence indicates that several concepts stressed in the literature on endogenous growth are also important, particularly issues related to human capital.

One promising approach is to incorporate human capital into the neoclassical model, which now includes only physical capital. This addition allows the model to account for many of the empirical anomalies for which it has been criticized. In addition, the literature on endogenous growth may prove useful in understanding the sources of technological progress--a major source of growth that the neoclassical model does not explain. The two frameworks should not be viewed as separate choices; instead, analysts can use elements from each to examine different aspects of the process of long-run economic growth. Further research is required to reconcile the subtle differences between the two.

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1. In this paper, human capital refers to the level of education, skills, or training in a person or in society. A more complete definition would include health or any other resource embodied in people. See G.S. Becker, *Human Capital* (Chicago: University of Chicago Press, 1975).

CHAPTER II

THE NEOCLASSICAL MODEL OF ECONOMIC GROWTH

The neoclassical model of economic growth dates back to the mid-1950s and the work of Robert Solow.[1] That work, which earned Solow a Nobel Prize, established the theoretical framework for nearly all studies of long-run economic growth for the next 30 years. Using a few basic assumptions, Solow demonstrated that in the long run an economy would tend toward an equilibrium marked by continual growth of output. This equilibrium, known as a steady state, is characterized by constant levels of capital per worker and output per worker.

ASSUMPTIONS OF THE NEOCLASSICAL MODEL

Solow's model incorporates several simplifying assumptions.

- The economy's rate of national saving and rate of growth of the labor force are both exogenous (unaffected by other variables explained by the model) and constant.

- The economy is in equilibrium (that is, at full employment).

- Output is produced using two factors--labor and capital--and a neoclassical production function determines how they are combined to produce output.

The neoclassical model also makes three important assumptions about the production function. The first assumption concerns a characteristic of the production function--returns to scale. That term refers to the additional output produced as a result of an increase in all factors of production. The neoclassical model assumes that the production function displays constant returns to scale--that is, a given percentage increase in both capital and labor will yield the same percentage increase in output. For example, doubling the amount of labor and capital used in production would also double the resulting level of output. This assumption is usually justified with an

1. The seminal paper is R.M. Solow, "A Contribution to the Theory of Economic Growth," *Quarterly Journal of Economics*, vol. 70 (February 1956), pp. 65-94. See also T. Swan, "Economic Growth and Capital Accumulation," *The Economic Record*, vol. 32 (1956), pp. 334-361; or D. Cass, "Optimum Growth in an Aggregative Model of Capital Accumulation," *Review of Economic Studies*, vol. 32 (July 1965), pp. 233-240.

argument about replication: a firm that owns a plant that produces $10 million of output each year could in principle produce $20 million by building a second, identical plant next to the first.

Other production functions might be characterized by decreasing or increasing returns to scale. Decreasing returns occur if doubling all inputs to production results in a less-than-doubling of output--for instance, if the second plant in the above example added less than $10 million to output. Increasing returns to scale occur if doubling the inputs yields more than twice as much output.

Second, the model assumes that the production function displays decreasing returns to each input--that is, successive additions of labor or capital (holding the other constant) will yield progressively smaller increments of output. Economists refer to this phenomenon as a declining marginal product of labor or capital. This assumption is particularly important with regard to physical capital. If investment in capital goods is characterized by decreasing returns, then each additional investment project will yield a smaller gain in output than the one before it. In other words, as more and more capital is added to a fixed supply of labor, the additional output that results diminishes steadily.

The third assumption is that markets for goods and inputs have minimal imperfections. This assumption ensures that competition drives down product prices to equal marginal cost, workers' real wages equal the marginal productivity of labor, and the rental rate on capital equipment equals the marginal product of capital. If market imperfections are minimal, researchers can compute the contributions of each input to the growth of output and determine the most important sources of growth, a process known as growth accounting.

IMPLICATIONS OF THE NEOCLASSICAL MODEL

Several implications follow from the assumptions of the neoclassical model. The most important--an economy that grows at a constant rate--is so ingrained and familiar that it might be taken for granted. Other implications are more subtle, but they all can be examined empirically to evaluate the validity of the model. This section discusses the results of the model that are relevant to the theory of endogenous growth and the evaluation of empirical evidence that follows.

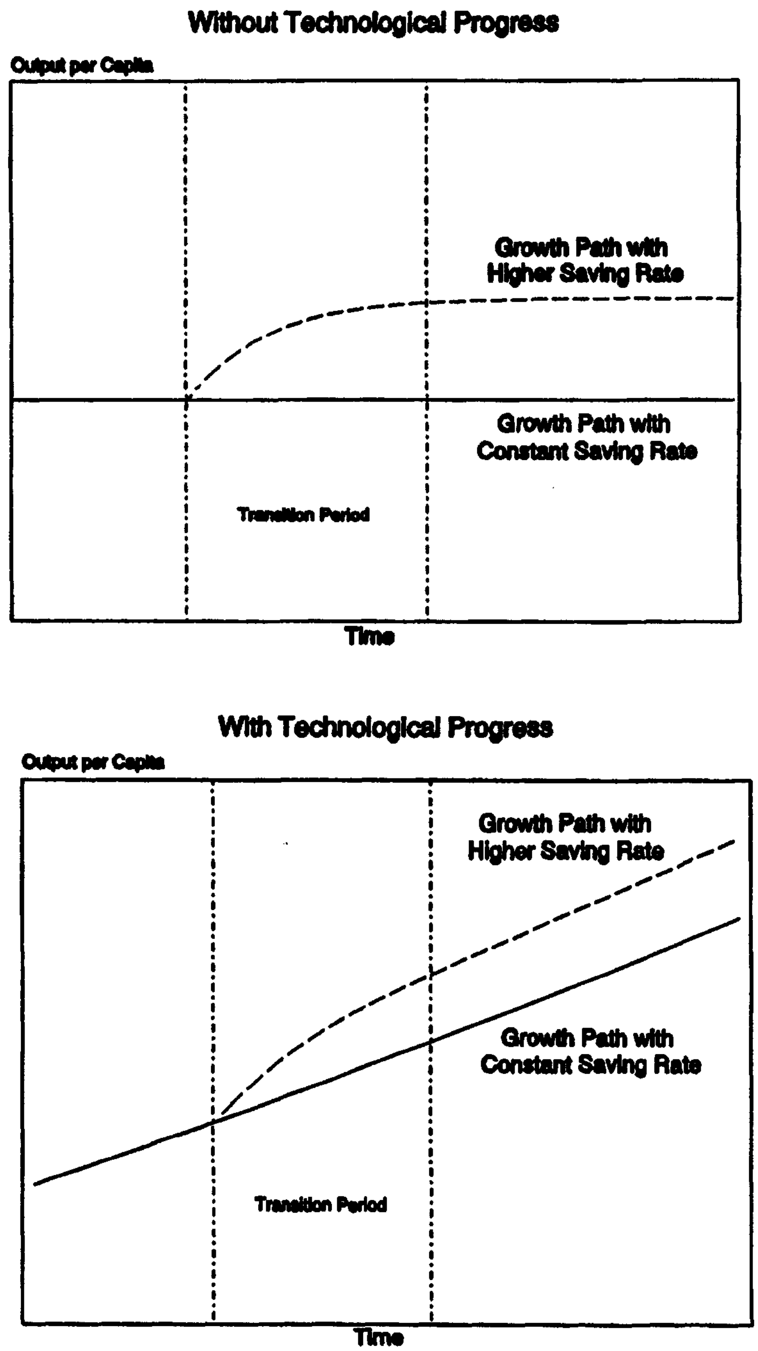
Existence of a Stable Equilibrium with Growth of Per Capita Output

The most important result of the neoclassical model of economic growth is that, in the long run, output grows at a constant rate; that is, the economy reaches a steady state. However, in that simple model, the rate of growth is limited to the rate of growth of the labor force, which means that the model cannot explain long-run growth in output per worker--a crude measure of the standard of living. Further, although a change in an economy's saving rate can affect the level of per capita output, it will have no effect on the economy's steady-state rate of growth (see Figure 1). A permanent increase in the rate of national saving will raise the level of per capita output but will not affect the rate of growth once the economy has reached the new steady state. Of course, during the transition to the new, higher level of per capita output, the economy's growth rate is higher than it would have been otherwise. Estimates of the length of this transition period range from 15 to 40 years.

In order to explain the growth of per capita output over long periods, the neoclassical model introduces the idea of technological progress. In long-run equilibrium, per capita output can grow only if the economy's productive processes are augmented with new technology that produces additional output without additional inputs. If that occurs, then output can expand in the absence of any change in employment or the capital stock. This implication is crucial to the neoclassical model of long-run economic growth; the only source of growth in per capita output is exogenous technological progress (see Figure 1). More important, the model has little to say about the factors that determine the rate of technological change; it instead assumes that the growth of technological change is determined exogenously (in particular, that it has nothing to do with the rate of saving or investment). Therefore, the model provides little assistance to those who want to analyze growth of per capita output.

The model's assumption of diminishing returns to each input ensures that output per worker does not grow in the absence of technological progress. Intuitively, this assumption means that as each new investment project is pursued, the return from that investment (namely, the increase in output and revenues) is lower than that from the previous investment. Investing will be worthwhile for a firm as long as the return from doing so is greater than the cost of capital. At some point, the return from successive investment projects will be driven down to the cost of capital, and further investment (above what is required to replace worn-out capital) will no longer be profitable. The firm

FIGURE 1. EFFECTS OF AN INCREASE IN THE SAVING RATE IN THE NEOCLASSICAL MODEL OF ECONOMIC GROWTH, WITH AND WITHOUT TECHNOLOGICAL PROGRESS



SOURCE: Congressional Budget Office.

will not undertake subsequent investment projects, thus leaving constant the amount of capital per worker and the amount of output produced per worker. If the returns to successive investment projects did not fall, it would always be profitable to invest, capital accumulation would continue perpetually, and per capita output would continue to rise.

Convergence of Economies with Different Starting Levels of Per Capita Output

A second implication of the neoclassical model is known as convergence, or catch-up--a process by which economies with initially low levels of per capita output (poor countries) grow faster than those with initially higher levels (rich countries). The neoclassical model predicts that poor countries will eventually catch up to the rich countries and that the per capita output of both will end up at the same level and rate of growth. This prediction is conditional; it hinges on the assumption that the economies are identical in every respect except for their initial level of per capita output. In particular, the model assumes that the economies have identical production technologies, saving rates, institutional frameworks (for example, legal systems and property rights), and so forth.

Per capita output converges in the neoclassical model because of decreasing returns to capital. The model predicts that an economy with a lower level of capital per worker will have a higher marginal product of capital. Therefore, a poor country should have a higher marginal product of capital than a rich country because it, by definition, has lower levels of output and capital per worker. Thus, if the two countries have identical rates of saving, then the poorer country will grow faster because each additional dollar of investment will produce more goods and services than in the richer country. The model also predicts that investment in a poor country will exceed its pool of savings because the high rate of return on physical capital will attract flows of investment funds from rich countries, speeding the process of convergence.

Relaxing the assumption that all economies have identical production technologies produces another source of convergence. The spread of technology from industrialized countries to developing countries can cause the latter to grow faster. The neoclassical model attributes this growth to technological progress. The theory can accommodate the transfer of technology but does not necessarily predict that it will occur.

Falling Rate of Return on Investment

The neoclassical model also implies that the rate of return on investment (crudely, the profit rate) will fall over time as the level of capital per worker rises toward the steady state. Profits fall because the rate of return to owners of capital varies directly with the marginal productivity of capital. As the amount of capital available to workers in the economy increases, the profit rate decreases as a result of diminishing returns to capital. This assertion is quite simple theoretically but is extremely difficult to verify empirically because the concepts involved--particularly capital itself--are so difficult to measure. In addition, growth resulting from technical progress can mask the effects of a declining profit rate.

LIMITATIONS OF THE NEOCLASSICAL MODEL

Authors who write about endogenous growth have cited several shortcomings of the neoclassical model as the primary motivation for developing their models. The first and most serious limitation of the neoclassical model is that it relies on technological progress to drive growth in per capita output. Instead of explaining the sources of technological change, the model assumes it will occur independent of the factors considered by the model.[2] Yet history is characterized by sustained growth in per capita output over long periods, with no evidence of a persistent decline. The neoclassical model therefore fails to explain what is arguably the most important source of growth--technological change.

Second, the neoclassical model provides only a rudimentary framework for analyzing the effects of government policy on economic growth. The model lacks any explicit channels through which the government can permanently raise the rate of growth of per capita output (except policies that speed up technological progress). The answer to the question of whether policy affects growth is not immediately obvious, but that question cannot be asked, much less answered, within the confines of the neoclassical model. Changes in government policy, however, clearly affect the decisions that workers, managers, and investors make every day. Having a theory of long-run growth

2. Although Solow and others later extended the basic neoclassical model to explain the growth in technical change, none were able to provide a complete theory of the source of technical change. See R.M. Solow, "Investment and Technical Progress," in K.J. Arrow, S. Karlin, and P. Suppes, eds., *Mathematical Methods in the Social Sciences* (Stanford, Calif.: Stanford University Press, 1960). See also H. Uzawa, "Optimum Technical Change in an Aggregative Model of Economic Growth," *International Economic Review*, vol. 6 (January 1965), pp. 18-31; and D.W. Jorgenson and F. Griliches, "The Explanation of Productivity Change," *Review of Economic Studies*, vol. 34 (July 1967), pp. 249-283.

that could be used to analyze the effects of such changes would therefore be desirable.

Although the neoclassical theory is well equipped to analyze the effects of at least one policy change--namely, lowering the federal deficit--it predicts that deficit reduction will have a relatively weak impact on output. The Congressional Budget Office (CBO) estimates that each percentage point of permanent increase in the ratio of national saving to gross domestic product would, in the long run, permanently raise consumption by about 1 percent above what it would have been without the increase in saving.[3] But in order to raise national saving by 1 percent of GDP, the deficit must be reduced by a greater amount, perhaps as much as 3 percent of GDP. The greater reduction is required because lowering the federal deficit seems likely to spur a drop in private saving and foreign borrowing. If so, then the increase in funds available for private investment will be smaller than the amount by which the deficit is reduced.

Third, the model contains only a few tools for analyzing how policies that expand (or contract) the volume of international trade affect growth. Studies of international trade in the neoclassical tradition have demonstrated that the liberalization of trade yields one-shot gains that result from reallocating resources to more productive uses. In addition, empirical evidence indicates that countries with an outward orientation tend to grow faster than those that adopt a more protectionist stance. The missing link is a theoretical demonstration of beneficial effects on the rate of growth (rather than merely on the level of output) stemming from more liberal trade policies.

GROWTH ACCOUNTING

After Solow devised his model of economic growth, other economists developed a method to estimate the contributions of the factor inputs (labor and capital) to the growth of output. Early efforts discovered that an alarmingly large fraction of growth--over 40 percent, by some estimates--went unexplained by the inputs and had to be attributed to technological progress.[4]

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3. See Congressional Budget Office, *The Economic and Budget Outlook: Fiscal Years 1994-1998* (January 1993), Chapter 5.

4. See E.F. Denison, *Why Growth Rates Differ: Postwar Experience in Nine Western Countries* (Washington, D.C.: Brookings Institution, 1967). For more details about growth accounting, see E.F. Denison, *Trends in American Economic Growth, 1929-1982* (Washington, D.C.: Brookings Institution, 1985); A. Maddison, "Growth and Slowdown in Advanced Capitalist Economies: Techniques of Quantitative Assessment," *Journal of Economic Literature*, vol. 25, no. 2 (June 1987), pp. 649-698; or D.W. Jorgenson, F. Gollop, and B. Fraumeni, *Productivity*

This finding raised the question: How good can the neoclassical theory be if it explains only 60 percent of the growth of output? Subsequent refinements to the method of accounting for growth have reduced the proportion of unexplained growth, thereby diminishing the impact of this critique and providing more support for the neoclassical model.

The assumptions of the neoclassical model make it easy to account for the growth of output in terms of the growth of the factor inputs. The assumption of perfect competition, in particular, aids in the accounting process by easing the computation of output elasticities of labor and capital. An output elasticity measures the percentage change in output that would result from a 1 percent change in one of the inputs. Under the model's assumptions, these elasticities can be approximated by the shares of labor compensation and capital income in the value of output. For example, payments to owners of capital in the United States are roughly 30 percent of total income, which means that the elasticity of output with respect to capital is 0.3. Therefore, a 10 percent boost in the capital stock leads to a 3 percent increase in the level of output.

Once the elasticities have been computed, one can account for the separate contributions of labor and capital to the growth of output over a given period by weighting the growth of each input by its output elasticity. Table 1 illustrates such an exercise using data collected by the Bureau of Labor Statistics (BLS) for the nonfarm business sector in the United States. It shows the proportion of the growth of output that can be explained by the growth of the factor inputs, once each has been weighted by its output elasticity. During the 1948-1990 period, for example, 33 percent of the growth in output resulted from an expansion of hours worked (labor) and 34 percent from increased capital services. Growth in multifactor productivity--a measure of the joint productivity of labor and capital--must account for all remaining growth in output because it is computed as a residual. It is, by definition, the portion of growth in output that is unexplained by the growth of labor and capital.

On average, only 68 percent of the growth in output over the postwar period can be explained by the growth of labor and capital. This finding demonstrates a gap in the neoclassical theory; the remaining growth is assumed to occur as a result of technological progress (as measured by multi-

and U.S. Economic Growth (Amsterdam: North Holland, 1987).

TABLE 1. ILLUSTRATION OF ACCOUNTING FOR GROWTH IN THE PRIVATE NONFARM BUSINESS SECTOR (In percent)

	Average Annual Rate of Growth				Contribution to the Growth of Output[b]		
Period	Output	Labor[a]	Capital	MFP	Labor[a]	Capital	MFP
1948-1990	3.6	1.7	4.1	1.1	33	34	32
1948-1960	3.5	1.1	3.5	1.6	22	30	46
1960-1973	4.7	1.8	4.6	2.1	26	29	44
1973-1990	2.7	2.0	3.2	0.1	53	46	2

SOURCES: Congressional Budget Office using data from the Bureau of Labor Statistics.

NOTES: Dates correspond to peaks in the business cycle, as measured by the National Bureau of Economic Research.

MFP = multifactor productivity.

a. Measured as an index of hours worked, adjusted for changes in workers' levels of education and experience.

b. Calculated as the growth of each factor input (weighted by its output elasticity) and of multifactor productivity as a percentage of the growth of output. The calculations assume that labor's output elasticity is 0.7 and capital's output elasticity is 0.3.

factor productivity) and is not attributed to economic forces in the standard theory. One goal of growth accounting is to improve the estimates of labor and capital in order to reduce the role of multifactor productivity. If a more sophisticated accounting raises the contribution of labor and capital, then the contribution of multifactor productivity will fall. This drop is important because it reduces the proportion of growth that is not explained by the theory and may indicate that a larger proportion of growth can be directly affected by government policies, such as reducing the deficit.

To some degree, the estimate formed by BLS has already reduced the contribution of multifactor productivity. The series that BLS uses for the capital and labor inputs are not, as one might expect, simply the stock of capital and the number of hours worked. Rather, they are both indexes designed to capture the different levels of productivity inherent in different types of capital goods and in workers with different levels of education and experience.

BLS's capital input is an index designed to measure the flow of capital services that derives from a given stock of capital. When constructing this index, each type of capital asset (for example, producers' durable equipment, structures, inventories, and land) is weighted according to its level of productivity, which permits a more accurate accounting for growth. If, for example, a dollar of investment spending shifted to a more productive type of capital, this series would grow faster, but a series based on the capital stock would not. A method of accounting for growth that used the series in Table 1 would, correctly, attribute the increased production to the capital input, but one that was based on the capital stock would attribute the added output instead to multifactor productivity, giving a misleading view of the role of technological progress in fostering growth.

In fact, investment spending in the United States has shifted toward assets with higher marginal productivity during the past two decades; the share of investment devoted to equipment has risen while the share going to structures has declined, and a larger share of equipment purchases has been devoted to computers. If the capital input is measured using the capital stock instead of capital services, some of the growth in output caused by this shift will be attributed mistakenly to technological progress.[5]

To compute the labor input, BLS disaggregates hours worked into subcategories that differ according to sex, education, and work experience. It then weights each category by the corresponding rate of hourly earnings to adjust each type of labor by its level of productivity. If employers decide to substitute more productive labor for less productive labor (for example, experienced workers for youths), production can increase without any change in hours worked. A measure of labor based on hours worked will not capture the increase in effective labor, but BLS's will. Dale Jorgenson, who has done a similar disaggregation, estimates that the increase in hours worked accounts for about two-thirds of the growth of the labor input and that one-third stems from improvements in the productivity of labor resulting from substitutions among different types of labor.[6]

5. Dale Jorgenson estimates that using the capital stock instead of capital services would capture only 20 percent of the growth of the capital input. See D.W. Jorgenson, "Productivity and Economic Growth," in E.R. Berndt and J.E. Triplett, eds., *Fifty Years of Economic Measurement: The Jubilee of the Conference on Research in Income and Wealth* (Chicago: University of Chicago Press, 1990).

6. For more details, see Jorgenson, "Productivity and Economic Growth"; D.W. Jorgenson, "Comments and Discussion" [on Baily and Schultze], *Brookings Papers on Economic Activity: Microeconomics* (1990), pp. 407-412; or Jorgenson, Gollop, and Fraumeni, *Productivity and U.S. Economic Growth.*

CHAPTER III

THEORIES OF ENDOGENOUS GROWTH

Economists have developed new theories that address the limitations of the neoclassical theory. The primary contribution of these new theories is that they display steady-state growth in per capita output without relying on exogenous technological change. The models are referred to as endogenous growth models because growth occurs as a result of forces the model explicitly considers. In one sense, these models have made endogenous the technological change that the neoclassical model assumed was exogenous.

Unlike the neoclassical model, many of the models in the literature on endogenous growth provide a framework for analyzing the effects of government policies on economic growth. Based on the models, analysts are able to recommend certain taxing and spending policies and to discourage the use of others. In addition, the models suggest that raising the national saving rate (for example, by lowering the deficit) can raise not only the level but also the rate of growth of per capita output. Finally, the models can be applied to policies that would expand or contract the volume of international trade.

ROMER'S THEORY OF LONG-RUN GROWTH: KNOWLEDGE AS A FACTOR OF PRODUCTION

Paul Romer bases his theory of long-term economic growth on the accumulation of knowledge. He explicitly recognizes knowledge as a factor of production, including it with the usual inputs--labor and capital. That, by itself, is not very controversial; it reverses none of the neoclassical theory's conclusions. Romer's contribution is his finding that any technical knowledge discovered by a firm (and embodied in its products) will eventually benefit other firms, even those that do not engage in research and development (R&D). Therefore, firms benefit not only from the knowledge they generate but also from the total stock of knowledge available in the economy. Economists refer to this type of side effect as a spillover, or externality--an action taken by one firm that has an impact, in this case a beneficial impact, on the productivity of other firms.

The Early Models: Introducing Externalities

Romer's early models are fairly abstract. He assumed, for example, that the growth of the body of technical knowledge was directly related to total investment in the economy.[1] He was then able to use the stock of physical capital as a proxy for the stock of knowledge, effectively transferring the spillover associated with knowledge to capital. He assumed that knowledge and physical capital were related because he observed a very high correlation between investment and output in the data--a much higher correlation than the neoclassical model would predict.

If the external effects associated with knowledge are large enough (and Romer assumed that they are), then the production function for the economy as a whole is no longer subject to decreasing returns to capital, and indeed, it displays increasing returns to scale. (Recall from the discussion of the neoclassical model that decreasing returns to capital means that successive additions to capital--with labor held constant--yield smaller and smaller increases to output. Increasing returns to scale means that doubling all inputs to production will more than double output). A rising rate of investment has the usual direct effect on output and an indirect effect (through the stock of knowledge) on the pace of technological change.

As Romer realized, the key to generating endogenous growth is to abolish a single characteristic of the neoclassical model: decreasing returns to capital. More generally, the characteristic shared by all endogenous growth models is nondecreasing returns to the factor that can be accumulated.[2] Physical and human capital are inputs that can be accumulated; firms can increase the available amounts with suitable investments. In contrast, "raw" labor cannot be accumulated; it can and does grow, but not because people are investing in it.[3] By ruling out decreasing returns, endogenous growth models prevent the return to, say, physical capital from being driven all the

1. See P.M. Romer, "Increasing Returns and Long-Run Growth," *Journal of Political Economy*, vol. 94, no. 5 (1986), pp. 1002-1037; P.M. Romer, "Capital Accumulation in the Theory of Long-Run Growth," in R.J. Barro, ed., *Modern Business Cycle Theory* (Cambridge, Mass.: Harvard University Press, 1989); and P.M. Romer, "Crazy Explanations for the Productivity Slowdown," in Stanley Fischer, ed., *NBER Macroeconomics Annual: 1987* (Cambridge, Mass.: MIT Press, 1987), pp. 163-202. For an earlier example of this type of model, see K.J. Arrow, "The Economic Implications of Learning by Doing," *Review of Economic Studies*, vol. 29 (June 1962), pp. 155-173.

2. Xavier Sala-i-Martin, "Lecture Notes on Economic Growth (I) and (II)," Working Papers No. 3563 and No. 3564 (National Bureau of Economic Research, Cambridge, Mass., 1990).

3. A growing literature examines the link between economic growth and fertility. See, for example, G.S. Becker, K.M. Murphy, and R. Tamura, "Human Capital, Fertility, and Economic Growth," *Journal of Political Economy*, vol. 98, no. 5, pt. 2 (October 1990), pp. S12-S37 and the references cited within.

way down to its cost. As a result, investment always remains profitable, which leads to continuous growth in the amount of capital available to each worker and in output per worker.

Romer also assumed that any one firm was so small relative to the overall economy that its investment decisions would have no effect on the total stock of capital or knowledge. The firm would therefore take no account of the second-round effects of its investment decisions on technological progress but would instead maximize profits through its choice of labor and capital, taking the total stock of knowledge as given. Under these conditions, the production function for an individual firm displays decreasing returns to capital and constant returns to scale, as in the neoclassical model; but the production function for the overall economy displays increasing returns to scale.

The most important contribution in Romer's early work was proving that the economy he described would reach a competitive equilibrium that would sustain perpetual growth in per capita output without relying on exogenous technological change. But the presence of an externality implies that market forces will not encourage the socially optimal amount of knowledge to accumulate in his framework. When companies form their plans for investment, they care only about the expected payoff to their own profitability; they ignore the spillover of benefits associated with their technical advances. Thus, from a social perspective, each firm will engage in "too little" investment. An omniscient social planner could improve societal welfare with the appropriate set of subsidies for investment.

Later Refinements: Innovation as the Source of Productivity Growth

Romer has subsequently refined his ideas about the accumulation of knowledge and its role as a driver of long-run growth. His early work saw the accumulation of physical capital and knowledge as strong complements, with growth in knowledge flowing from investment in capital goods: firms invest in capital goods because they improve productivity directly; any indirect effect on the stock of technical knowledge is a positive side effect of which the firm takes no account. In his more recent work, Romer shifts his emphasis to explain why firms invest directly in technical knowledge by undertaking research and development.[4]

4. See P.M. Romer, "Endogenous Technological Change," *Journal of Political Economy*, vol. 98, no. 5, pt. 2 (October 1990), pp. S71-S102; and P.M. Romer, "Capital, Labor, and Productivity," *Brookings Papers on Economic Activity: Microeconomics* (1990), pp. 337-367.

Romer sought to explain why private, profit-maximizing firms would produce technical knowledge through R&D even though such knowledge displays many characteristics of public goods.[5] Like public goods, such as national defense or interstate highways, technical knowledge can be used by an unlimited number of people at the same time. A public good is also "nonexcludable," meaning that its owner cannot preclude others from using it. Romer argues that knowledge is, at best, only partially excludable. A firm that builds a better mousetrap will not be able to prevent others from taking advantage of its new design forever. Even if patents prevent competitors from using the design itself, other firms will benefit from any new technology embodied in it.

In Romer's setup, profit-maximizing firms will undertake R&D even though they know that any inventions they develop will eventually benefit all firms in their industry. A new design is essentially costless to reproduce for sale or use within the firm. Firms can then sell the design (or the goods produced using it) at a price that exceeds the cost of production, thus recouping their investment in R&D. Basically, the innovation gives the firm a degree of monopoly power that allows it to charge a price greater than the marginal cost. Romer assumes that patents will completely protect these monopoly profits, allowing them to persist indefinitely. In more realistic extensions to his theory, however, other firms would be able to take advantage of the new technical knowledge, eliminating the innovating firm's monopoly profits by producing goods that are similar or more advanced.[6] That erosion of the firm's profits would spur further innovation.

The development and marketing of the Lotus Corporation's 1-2-3 spreadsheet program illustrates how innovation can spawn further innovation. The funds Lotus spent to develop 1-2-3 were fixed costs of production because they did not depend on how many copies of the program Lotus planned to manufacture. Once the program was written, additional copies of it could be produced at trivial cost (floppy disks are cheap). The software proved to be wildly popular, allowing Lotus to charge a price well above the marginal cost of production. Eventually, other companies introduced spreadsheet programs that were nearly identical to 1-2-3. The competing programs cut into Lotus's

5. This section draws from P.M. Romer, "Are Nonconvexities Important for Understanding Growth?" *American Economic Review*, vol. 80, no. 2 (May 1990), pp. 97-103.

6. See P. Aghion and P. Howitt, "A Model of Growth Through Creative Destruction," *Econometrica*, vol. 60 (1992), pp. 323-351; G.M. Grossman and E. Helpman, "Quality Ladders and Product Cycles," *Quarterly Journal of Economics*, vol. 106, no. 2 (May 1991), pp. 557-586; or G.M. Grossman and E. Helpman, *Innovation and Growth in the Global Economy* (Cambridge, Mass.: MIT Press, 1991).

market share and profitability, encouraging Lotus to develop new products that it hopes will repeat the success of 1-2-3.

Increasing returns to scale still play a role in Romer's framework. Because knowledge can be used by many people at the same time, the production function for an individual firm displays increasing returns to scale. Consider a firm that each year produces goods worth \$10 million using one factory, 10 workers, and a certain amount of technical knowledge. This firm could produce goods worth \$20 million by building a second plant, hiring 10 more workers, and using the same amount of knowledge. Since output has doubled with a less-than-doubling of the inputs, output would more than double if all of the inputs were doubled. Thus, production is characterized by increasing returns to scale.

As in his earlier models, Romer assumes that spillovers are a central feature of the economy. They occur both in the R&D sector, where a larger stock of knowledge raises the productivity of researchers engaged in R&D, and in the final output sector, where production benefits from a wider range of capital goods. Romer's later model displays constant returns to the accumulation of knowledge--the return on investment in R&D does not fall as the stock of knowledge increases. The resulting equilibrium features endogenous growth in per capita output, driven by the continuous introduction of new products and advances in technology.

In this framework, a new design enables a firm to produce a new good and increases the overall stock of knowledge, which lowers costs for R&D and final output. The crucial assumption for endogenous growth is that the positive effect of increased knowledge on productivity does not weaken as the stock of knowledge grows. If it did--perhaps as science approached a technological frontier--endogenous growth would taper off, and the model would resemble the neoclassical model. Romer notes that this feature makes endogenous growth more an assumption of the model than a result.

Policy Implications

Three important policy prescriptions flow from Romer's theory. The first is the same as that suggested by the neoclassical model--a reduction in the federal deficit. Lowering the deficit would raise the rate of national saving, lower interest rates, and speed growth in Romer's model. Lower interest rates increase the amount of human capital devoted to R&D by raising the discounted value of any given stream of future revenues associated with a new design. More research translates into a permanent increase in the economy's rate of growth.

The second policy prescription is subsidies for R&D. The accumulation of knowledge drives growth in Romer's theory, but because R&D benefits firms other than the innovator, too few resources are devoted to it. Therefore, it is not only possible but desirable for government to influence economic growth in Romer's theoretical framework--specifically, by subsidizing basic research. Failing that, subsidies for educating and training workers (the most important factor in developing technical knowledge) would be the next best policy.[7]

Third, Romer's work suggests several channels through which economies might benefit from expanded international trade.[8] Trade should spur growth by providing researchers with greater incentives to provide new designs: a firm that invents a new product will have access to a larger market (and greater monopoly profits) if the economy is open to trade. Trade also expands the stock of knowledge available to those engaged in R&D by exposing them to more goods produced using the latest designs. Researchers can raise their productivity by learning from new goods produced abroad. In addition, international trade helps prevent the duplication of research efforts across countries. Freer trade implies that the fixed costs associated with developing a new design need to be incurred only once. Human capital is released from reinventing the wheel.

OTHER MODELS OF ENDOGENOUS GROWTH

Numerous theoretical papers have appeared recently in the literature on endogenous growth. The defining characteristic of these theories is that they generate perpetual growth in per capita output without relying on exogenous forces. They each do this in the same basic fashion as Romer's model: by overturning the assumption of decreasing returns. The literature survey that

7. In Romer's latest models (in contrast to his earlier work), subsidies for the accumulation of physical capital may or may not raise growth. See Romer, "Endogenous Technological Change."

8. The most complete exposition of the effects of trade liberalization in Romer's model can be found in L.A. Rivera-Batiz and P.M. Romer, "Economic Integration and Endogenous Growth," *Quarterly Journal of Economics*, vol. 106, no. 2 (May 1991), pp. 531-556.

follows is not exhaustive, but it covers the range of available results and policy prescriptions.[9]

Human Capital in Models of Endogenous Growth

As the primary input used in research and development, human capital plays an important role in models such as Romer's 1990 model, in which endogenous growth results from endogenous technical change. Human capital also plays a prominent role in other models of endogenous growth. Robert Lucas outlines two such models: one involves spillovers from the investment people make in formal education, and the other features productivity growth driven by on-the-job training (learning by doing).[10] In both models, Lucas interprets human capital as the overall level of skill available in the economy.

In the first model, Lucas assumes that society builds human capital by investing in it: workers postpone immediate consumption (by going to college instead of working) in the hope of improving their prospects for consumption (getting a job with higher wages after graduation). However, merely allowing for investment in human capital is not sufficient to support endogenous growth. Lucas also assumes that there is an externality (or side effect) associated with human capital: the productivity of all workers--even those who receive no formal training--benefits from an increase in the general skill level of the overall economy. Lucas made this observation when he noticed that groups of firms producing roughly the same products tend to cluster in the same geographic location, usually a city. He reasoned that firms do this because they benefit from being close to other firms that do similar work. This phenomenon explains why Manhattan has a garment district, a financial district, an advertising district, and so on. Those districts are intellectual centers where ideas are exchanged, either explicitly or implicitly.

Lucas's formulation is very similar to Romer's early model, in which the externality was associated with the accumulation of physical rather than

9. For other surveys of this literature, see the symposium on new growth theory in *Journal of Economic Perspectives*, vol. 8, no. 1 (Winter 1994), pp. 3-72; D.M. Gould and R.J. Ruffin, "What Determines Economic Growth?" *Economic Review*, Federal Reserve Bank of Dallas (Second Quarter 1993), pp. 25-40; or U.S. International Trade Commission, "The Dynamic Effects of Trade Liberalization: A Survey," USITC Publication 2608 (February 1993).

10. R.E. Lucas, "On the Mechanics of Economic Development," *Journal of Monetary Economics*, vol. 22 (1988), pp. 3-42.

human capital.[11] If the externality is large enough, then endogenous growth occurs in the presence of decreasing returns because the incentive to invest in human capital does not diminish as the stock of human capital grows. Under these circumstances, human capital can continue to accumulate indefinitely. However, people invest less in human capital than is socially optimal because they ignore the beneficial spillover associated with their investment. Therefore, Lucas's model suggests that living standards could be raised with a scheme to encourage workers to improve their education and skills.

Lucas notes that this model is consistent with international evidence on migration. If human capital has external effects, then workers in countries with high levels of human capital will be more productive and earn higher wages than those in countries with low levels. Workers in poorer countries, which will have lower levels of human and physical capital, thus have an incentive to migrate to richer countries. Since countries with larger stocks of human capital can remain permanently richer, there is no force for convergence in Lucas's model, and the incentive to migrate can persist indefinitely.

Lucas's second model starts from the premise that workers accumulate human capital through on-the-job training rather than through investments in formal education.[12] In this model, workers accumulate human capital not by withdrawing from the labor force to go to school but by acquiring new skills as they learn to produce an ever-growing range of goods. As long as new goods are continually introduced (and especially if they become more technologically advanced), the stock of human capital will grow, driving growth of per capita output as well. Lucas's framework is not complete because he does not model the factors that cause new goods to be introduced; instead, he assumes that they do.

The experience of the newly industrialized countries (NICs) of eastern Asia suggests that learning by doing is more relevant for the study of long-run growth than is formal education. Lucas argues that the "growth miracles" these countries have experienced since World War II cannot be attributed to formal learning, because changing the level of average education rapidly for an entire nation is difficult. However, he did notice a correlation between the countries that grew the fastest and those that experienced rapid structural

11. See Romer, "Increasing Returns and Long-Run Growth."

12. For examples of similar models, see Alwyn Young, "Learning by Doing and the Dynamic Effects of International Trade," *Quarterly Journal of Economics*, vol. 106, no. 2 (May 1991), pp. 369-405; or Nancy L. Stokey, "Learning by Doing and the Introduction of New Goods," *Journal of Political Economy*, vol. 96, no. 4 (August 1988), pp. 701-717.

change. Lucas asserts that rapid structural change, supported by aggressive export-oriented policies, enabled the NICs to accumulate human capital rapidly through on-the-job training. A focus on exports is important because it allows the mix of goods produced by firms to change more rapidly than the mix of goods desired by domestic consumers.

The Link Between International Trade and Long-Run Growth

Studies that draw on the neoclassical tradition--Solow's basic model assumed closed economies--have difficulty demonstrating a relationship between an economy's growth rate and its degree of openness to trade. In these models, opening an economy to trade will generate a one-time increase in the level of output that results from the reallocation of resources according to comparative advantage. Yet empirical results from the development literature indicate that countries that are open to trade seem to grow faster than those that do not have liberal trade policies. Some models of endogenous growth point to a possible link between trade and growth.

Gene Grossman and Elhanan Helpman outline a mechanism by which trade liberalization can stimulate growth: opening an economy to trade may increase the incentive to innovate by providing entrepreneurs with a larger market for their inventions.[13] Moreover, developing countries can imitate the innovating country by producing close substitutes, which will eventually eliminate the monopoly profits accruing to the innovator. Such imitation will foster technological progress in the follower country and encourage the leading country to innovate further, spurring more inventions and more monopoly profits.

In addition, Grossman and Helpman show that trade policies, such as tariffs or export subsidies, can have important effects on the allocation of resources within a country.[14] They employ models that share many features with those of Paul Romer; in particular, growth is driven by innovation that results from investments in R&D made by private, profit-maximizing firms. However, they add a second production sector and a foreign country to

13. G.M. Grossman and E. Helpman, "Trade, Innovation, and Growth," *American Economic Review*, vol. 80, no. 2 (May 1990), pp. 86-91.

14. See, for example, G.M. Grossman and E. Helpman, "Growth and Welfare in a Small, Open Economy," in E. Helpman and A. Razin, eds., *International Trade and Trade Policy* (Cambridge, Mass.: MIT Press, 1991); Grossman and Helpman, "Quality Ladders and Product Cycles"; G.M. Grossman and E. Helpman, "Comparative Advantage and Long-Run Growth," *American Economic Review*, vol. 80, no. 4 (September 1990), pp. 796-815; or G.M. Grossman and E. Helpman, "Trade, Knowledge Spillovers, and Growth," Working Paper No. 3485 (National Bureau of Economic Research, Cambridge, Mass., October 1990).

Romer's basic framework. In such models, a country that protects a sector that competes with the R&D sector for resources risks lowering its rate of economic growth. Returns to factors of production rise in the protected sector, drawing resources (for example, human capital) out of the R&D sector, thereby slowing innovation and growth.

Grossman and Helpman also show that the effects of trade policies depend on the worldwide pattern of comparative advantage. For example, in Romer's model a subsidy to R&D will speed a country's rate of growth. When Grossman and Helpman extend the model to include a foreign economy, they find that a subsidy to R&D will speed growth only if it is undertaken by countries that have a comparative advantage in R&D. If a country with a comparative disadvantage in R&D subsidizes it (or if international patterns of trade change drastically as a result of the policy action), the subsidy may slow growth.

The specific results of each of Grossman and Helpman's models are not as important as the fundamental lesson embodied in their papers: the effects of trade policies on economic growth will depend on patterns of comparative advantage and on the allocation of resources both at home and abroad. Their work illustrates the hazards of drawing facile conclusions about the benefits of international trade from endogenous growth models. They show that under certain plausible circumstances, a country's rate of growth may fall when it joins the world trading system. Growth would drop if the country had a comparative advantage in R&D and if liberalizing trade led to a shift in demand toward consumption goods. The resulting increase in demand for inputs to produce those goods could draw resources away from R&D and into production, slowing innovation and growth.

Endogenous Growth in the Presence of Constant Returns to Scale

In a standard production function that includes more than one input, assuming nondecreasing returns to one input (as many endogenous growth models do) implies assuming increasing returns to scale. However, increasing returns to scale are not required to generate endogenous growth. Sergio Rebelo stripped endogenous growth down to its barest essentials by devising a model in which production of goods and services displays constant returns to scale.[15] Rebelo assumes that output is produced with one factor input--the

15. S. Rebelo, "Long-Run Policy Analysis and Long-Run Growth," *Journal of Political Economy*, vol. 99, no. 3 (1991), pp. 500-521. For a related model, see L.E. Jones and R. Manuelli, "A Convex Model of Equilibrium Growth: Theory and Policy Implications," *Journal of Political Economy*, vol. 98, no. 5, pt. 1 (October 1990), pp. 1008-1038.

stock of capital, albeit broadly defined to include both physical and human capital. Under this setup, the return from successive investments in capital always remains constant, regardless of the size of the existing stock. As long as this return is greater than the cost of capital, it will always be profitable for firms to invest, and perpetual growth in per capita output will result.

Rebelo's model has two important implications. First, it is possible to generate endogenous growth with constant returns to scale in production, although doing so requires a highly abstract model. Second, the model demonstrates that government tax policy can influence an economy's rate of growth in the long run. In this model, a tax on capital income reduces the after-tax rate of return on investment in capital, thereby diminishing the incentive to invest and lowering the rate of growth. A tax on consumption, in contrast, does not affect the long-run rate of growth; rather, it merely lowers the level of per capita consumption. An income tax, which affects both consumption and investment at the same rate, will do a little of both: it will lower consumption and reduce the rate of growth in the long run.

Fiscal Policy in a Model of Endogenous Growth

Robert Barro makes explicit the effects of government action on the growth rate by introducing a public sector into a simple Rebelo-type model of endogenous growth. Barro assumes that production of private goods and services depends on private capital (broadly defined to include human capital) and on a flow of services from government spending on services that improve private productivity, such as law enforcement, national defense, infrastructure, and so on.[16] The model features decreasing returns to private capital and constant returns to scale (that is, with respect to both physical and human capital). Under those conditions, the private return on investment will not fall as the economy expands as long as government spending rises in tandem with private investment. Growth will continue as long as the government spends a constant proportion of national income on productive government services. If so, then an investment in private capital will cause aggregate income to rise, leading the government to increase its spending, which in turn raises income further.

Barro shows that his model has an optimal ratio of government spending to output, given reasonable values for the model's parameters. If the

16. See R.J. Barro, "Government Spending in a Simple Model of Endogenous Growth," *Journal of Political Economy*, vol. 98, no. 5, pt. 2 (October 1990), pp. S103-S125. For a broader survey of government policy in models of endogenous growth, see R.J. Barro and X. Sala-i-Martin, "Public Finance in Models of Endogenous Growth," *Review of Economic Studies*, vol. 59 (1992), pp. 645-661.

economy is below the optimal ratio, increases in the share of government spending will speed growth; once the optimal ratio has been reached, however, further increases in government spending will reduce the rate of growth. This theory holds only for spending that improves the productivity of private firms. If the government uses part of tax receipts on its own consumption (that is, goods and services that do not benefit private productivity), then growth will be lower than if the government uses all tax receipts for productive spending. Growth slows because the extra spending raises the tax rate without affecting private productivity. People will have less incentive to save and invest because their after-tax rate of return on investment will be lower. Barro provides some empirical support for the idea that increased spending for government consumption lowers the equilibrium rate of growth.

The equilibrium in Barro's model leaves some room for intervention by the government to raise living standards. When private firms make capital investments, they do not account for the fact that such investments will generate additional income (and tax revenue) that will be used for productive government spending, which benefits all firms. Because they ignore this external benefit, private firms tend to invest too little in physical capital. A government intervention that corrects this externality would produce a higher rate of economic growth.

Convergence in a Model of Endogenous Growth

Robert Tamura demonstrates that endogenous growth and convergence can coexist in a single model.[17] He does that by pursuing the simple notion that an idea is more difficult to discover than it is to learn. Convergence of output in Tamura's framework results from convergence in levels of human capital, which occurs because the payoff from additional learning is higher for individuals with low levels of education. A person at the technological frontier must discover new knowledge, so advances are hard to achieve. People whose education and skills are below average can acquire existing knowledge, which is easier to do.

Production of goods and services in Tamura's model is quite similar to that in Rebelo's, featuring a single input (human capital) and constant returns to scale. Tamura, however, assumes that a spillover is associated with human capital in that the level of human capital throughout society has a positive impact on each person's accumulation of human capital. Specifically, he

17. R. Tamura, "Income Convergence in an Endogenous Growth Model," *Journal of Political Economy*, vol. 99, no. 3 (1991), pp. 522-540.

assumes that people with below-average skills and knowledge have a higher rate of return on their investments in human capital than do individuals with above-average levels. Because they have a larger incentive to invest in human capital, people whose skills and knowledge are below average accumulate it faster than people with higher levels. This force causes convergence. Tamura's results apply to countries as well as individuals if the spillover he describes operates across national boundaries.

CONCLUSION

The literature on endogenous growth includes a wide range of models and yields a variety of policy prescriptions. The theoretical models suggest various channels through which countries can spur growth in the long run: they can increase their rates of national saving, lower tax rates on capital income, subsidize human capital or R&D, increase productive government spending, and lower trade barriers.

The theoretical models described above are very abstract, so their predictions about the effects of policy changes should be taken with caution. The analysts who developed the models make many simplifying assumptions so that they can solve the models and focus on specific sources of growth. However, predicting the effects of policy changes in the real world may not be so straightforward.[18] For example, the models typically assume that governments will finance subsidies with lump-sum taxes, which introduce minimal distortions into the economy's pattern of incentives and allocation of resources. Few examples of lump-sum taxes exist; one well-known example was Britain's poll tax, which was a political disaster. Thus, subsidies must in practice be financed using a more distortionary tax (for example, a progressive income tax), which may partially offset the benefits.

Another problem is that these abstract models tend to yield nonspecific policy prescriptions. For example, it is difficult to turn the general dictum to "subsidize human capital" into a specific policy that would encourage investment in education or training. The policy prescription presumes that the government knows which forms of human capital have spillovers associated with them and which do not.

18. This section draws from C.I. Plosser, "The Search for Growth," in *Policies for Long-Run Economic Growth*, a Symposium Sponsored by the Federal Reserve Bank of Kansas City, Jackson Hole, Wyo., August 27-29, 1992 (Kansas City, Mo.: Federal Reserve Bank of Kansas City, 1992).

In addition, the policies that emerge from the endogenous growth models are qualitatively similar to those that would flow from the neoclassical model. The difference is that the new models predict that such policies will affect the rate of growth permanently, whereas the neoclassical model predicts that the effect on growth tapers off as the economy approaches a new steady state. This quantitative difference is important. For example, the neoclassical model predicts that a government policy that encouraged a permanent 10 percent increase in the national saving rate could be expected to raise per capita output by roughly 5 percent after several decades. In contrast, some endogenous growth models imply a much greater gain--perhaps as high as 10 percent or 15 percent--and one that keeps growing.

CHAPTER IV

EVALUATING THE TWO FRAMEWORKS

How can one distinguish between a theoretical framework in which economic growth is exogenous and one in which it is endogenous given the historical record, which spans a period of sustained growth in per capita income? Two worlds--one characterized by endogenous growth and one by neoclassical growth (with exogenous technical change)--will be almost equivalent empirically. An evaluation must exploit the differences between the two frameworks in their fundamental assumptions and predicted reactions to policy interventions.

Heightening the problem of evaluation is the fact that the primary difference between the two frameworks is more quantitative than qualitative. The assumptions of the neoclassical model ensure that decreasing returns to capital set in fairly quickly; endogenous growth models assume that the return to capital (or some other factor that can be accumulated) does not decline at all. The more slowly decreasing returns set in, the closer the results will be to those in the endogenous growth models.

Although empirical work in this area is in its infancy, most of the evidence suggests that the neoclassical framework is still the appropriate one for analyzing issues related to long-run growth. However, a growing body of evidence suggests that the neoclassical model should be augmented to include human capital in order to explain several anomalies associated with the standard version of the model. Including human capital in the model would raise the share of income devoted to a broad definition of capital, which would slow the onset of decreasing returns and allow for persistent differences in levels of output among countries.

TESTING THE PREDICTION OF CONVERGENCE

The neoclassical and endogenous growth models generally predict different patterns of growth among nations. The neoclassical model predicts that the level of average labor productivity (output per worker) in countries that have the same saving rate, production technology, and institutional arrangements will converge at the same level. In other words, poorer countries that fulfill the model's assumptions will catch up to richer ones. Furthermore, decreasing returns to capital ensure that investment in developing countries is more productive and more profitable than it is in industrialized nations. Poor countries will get a bigger bang per buck of investment because they have less capital per worker and, therefore, a higher marginal product of capital.

In contrast to the neoclassical models, most of the endogenous growth models do not predict such convergence among countries with different starting levels of capital per worker. Instead, those models are consistent with a world in which rich countries can remain permanently richer than their poorer neighbors even if the poor countries have identical saving rates, technology, and so forth. The crucial feature in these models that allows for permanent growth--the absence of declining returns to capital investment--means that investment in both rich and poor countries can be equally profitable and thus proceed at the same rate. If rates of investment and economic growth are similar in all countries, then the gap between the levels of income of rich and poor countries may never be closed. By extension, this argument also implies that the economic effects of war, famine, and recession --all of which lower the level of a country's income--may never be erased.

Convergence of Per Capita Output

At first blush, convergence seems obvious since most of the developed world seems to be approaching a common standard of living. Early studies of convergence supported this idea. During the 1980s, economists such as William Baumol, Angus Maddison, and Moses Abramovitz presented evidence that levels of labor productivity around the world are converging.[1] Baumol, for example, used a fairly simple regression to demonstrate the negative relationship between a country's level of labor productivity in 1870 and its average rate of growth during the 1870-1979 period. A similar relationship is illustrated for the 1960-1985 period in Figure 2, which shows that countries that started with lower levels of real gross domestic product in 1960 tended to grow faster over the next 25 years than did countries with higher initial levels. This result supports the convergence hypothesis--poorer countries grow faster than richer countries.

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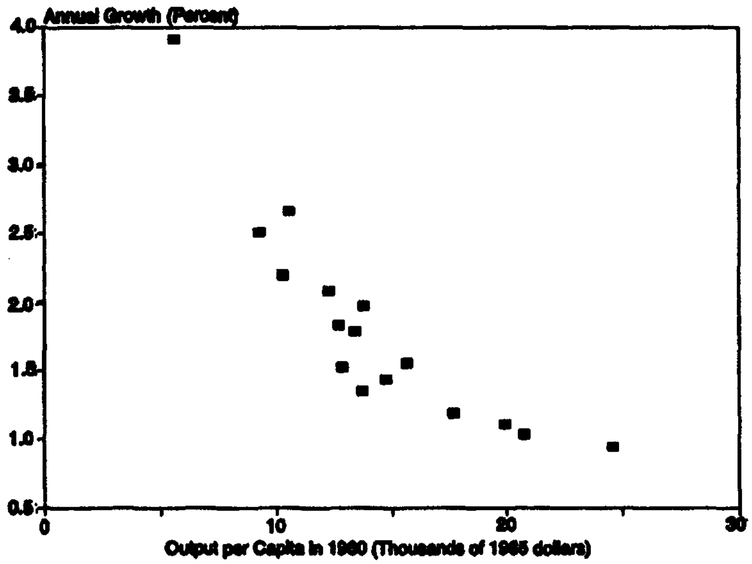
1. See W. Baumol, "Productivity Growth, Convergence and Welfare: What the Long-Run Data Show," *American Economic Review*, vol. 76, no. 5 (December 1986), pp. 1072-1085; A. Maddison, "Growth and Slowdown in Advanced Capitalist Economies: Techniques of Quantitative Assessment," *Journal of Economic Literature*, vol. 25, no. 2 (June 1987); M. Abramovitz, "Catching Up, Forging Ahead, and Falling Behind," *Journal of Economic History*, vol. 46, no. 2 (June 1986), pp. 385-406.

FIGURE 2. CONVERGENCE IN 16 INDUSTRIALIZED COUNTRIES: GROWTH OF OUTPUT PER CAPITA IN THE 1960-1985 PERIOD VERSUS THE LEVEL OF OUTPUT PER CAPITA IN 1960



SOURCE: Congressional Budget Office using data from R. Summers and A. Heston, "The Penn World Table (Mark 5): An Expanded Set of International Comparisons, 1950-1988," *Quarterly Journal of Economics*, vol. 106, no. 2 (May 1992), pp. 327-368.

NOTE: Output is measured in 1985 dollars using a common set of prices and a common currency.

Later studies showed that the early evidence is less compelling. The studies of convergence discussed above used samples that included only developed countries. J. Bradford De Long argues that excluding poor countries from the sample almost guarantees convergence because the study looks only at countries that have, for one reason or another, successfully developed. Indeed, as De Long shows, when tests like Baumol's are repeated with larger samples that also include developing countries, the convergence disappears (see Figure 3).[2] De Long's sample of 117 countries included those that had the capability to converge but were not necessarily rich in 1979. De Long's critique was echoed by Paul Romer, for whom the apparent lack of convergence was a prime motivation for developing his endogenous growth model. Using a sample of 115 countries with market economies, Romer found no evidence that the annual growth rate of per capita income for the 1960-1981 period was high for countries that in 1960 were poorer than the United States.[3]

The tests described thus far have been fairly simple, relying on correlations between the growth of per capita output and its initial level over some sample. The neoclassical model would predict this type of convergence if all of the economies involved had identical characteristics. But economies in the real world are not identical; differences in saving rates and production techniques mean that economies in different countries are approaching different steady states. Further, differences among countries in what Moses Abramovitz calls their "potential for catch-up" will lead to differences in their rate of convergence even if they are heading toward the same steady state.

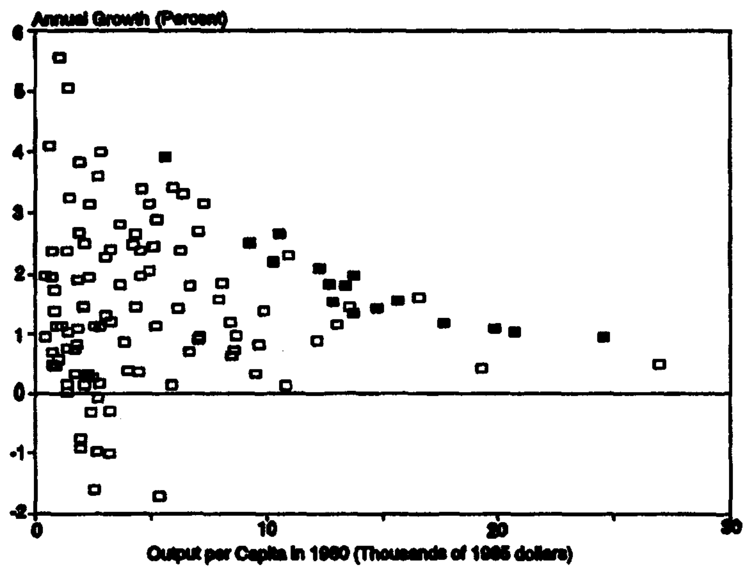
A series of recent analyses have explored whether the failure to find empirical support for the hypothesis of convergence results from differences in steady states among economies. Work by Gregory Mankiw, David Romer, and David Weil provides the clearest exposition of these tests.[4] They argue that the failure of earlier researchers to find convergence in large samples results from differences in steady-state levels of per capita output. Members of the Organization for Economic Cooperation and Development (OECD) have similar rates of saving, population growth, and technological progress--

2. See J.B. De Long, "Productivity Growth, Convergence, and Welfare: A Comment," *American Economic Review*, vol. 78, no. 5 (December 1988), pp. 1138-1154.

3. See P.M. Romer, "Crazy Explanations for the Productivity Slowdown," in Stanley Fischer, ed., *NBER Macroeconomics Annual: 1987* (Cambridge, Mass.: MIT Press, 1987), pp. 163-202.

4. See N.G. Mankiw, D. Romer, and D.N. Weil, "A Contribution to the Empirics of Economic Growth," *Quarterly Journal of Economics* (May 1992), pp. 407-437.

FIGURE 3. CONVERGENCE IN 117 INDUSTRIALIZED AND DEVELOPING COUNTRIES: GROWTH OF OUTPUT PER CAPITA IN THE 1960-1985 PERIOD VERSUS THE LEVEL OF OUTPUT PER CAPITA IN 1960



SOURCE: Congressional Budget Office using data from R. Summers and A. Heston, "The Penn World Table (Mark 5): An Expanded Set of International Comparisons, 1950-1988," *Quarterly Journal of Economics*, vol. 106, no. 2 (May 1992), pp.327-368.

NOTE: Output is measured in 1985 dollars using a common set of prices and a common currency.

the variables that determine the steady state--but expanding the sample to include developing countries makes the sample less homogeneous. If a statistical test can control for differences in the factors that give rise to different steady states, then convergence should reappear. And that is what Mankiw, Romer, and Weil show.

Using a simple convergence regression, they find convergence in a small sample that includes only rich countries but no convergence in a sample that adds developing countries. Basically, they replicate De Long's result. Then they add variables that determine the difference in steady states among countries in the neoclassical model: population growth and the fraction of income invested in physical and human capital. Controlling for these variables produces strong convergence in both samples. They call this phenomenon "conditional convergence" and note that it is entirely consistent with the predictions of the neoclassical model of economic growth. Robert Barro confirms this result by adding a measure of human capital to the standard convergence regression using a sample of 98 countries.[5]

Another way to test for conditional convergence is to examine economies that are more homogeneous and therefore more likely to have similar levels of steady-state output. Two studies by Barro and Xavier Sala-i-Martin attempt to do this by running the standard convergence regression on a sample of 47 U.S. states and a sample of 73 regions in Europe.[6] Their regressions are notable for what they do not include: variables designed to control for differences in steady states. However, they do include variables to control for shocks (for example, the Civil War, or oil and agricultural price shocks) whose effects might vary in different regions of the country. They conclude that the economies in their homogeneous samples have only slight differences in their steady states and display convergence.[7]

The consensus that emerges from these analyses is strong support for the hypothesis of convergence, conditional on the factors that determine a country's steady state. Therefore, the hypothesis should not be stated as "poor

5. See R.J. Barro, "Economic Growth in a Cross Section of Countries," *Quarterly Journal of Economics*, vol. 106 (May 1991), pp. 407-443.

6. See R.J. Barro and X. Sala-i-Martin, "Convergence Across States and Regions," *Brookings Papers on Economic Activity*, no. 1 (1991), pp. 107-179; R.J. Barro and X. Sala-i-Martin, "Convergence," *Journal of Political Economy*, vol. 100, no. 2 (April 1992), pp. 223-251.

7. Douglas Holtz-Eakin confirmed the results about the United States reported by Barro and Sala-i-Martin with more explicit controls for variation in levels of steady state. See D. Holtz-Eakin, "Solow and the States: Capital Accumulation, Productivity and Economic Growth," Working Paper No. 4144 (National Bureau of Economic Research, Cambridge, Mass., August 1992).

countries grow faster than rich countries" but as "countries with wider gaps [between per capita output and its steady-state level] will grow faster." However, the empirical work in these studies brought to light another anomaly associated with the neoclassical model, an anomaly that deals with the rate of convergence.

Rate of Convergence

Studies of conditional convergence have concluded that it occurs at a much slower rate than the neoclassical model would predict. The predicted rate varies according to the values assumed for the variables that determine the steady state (the rates of saving, population growth, and production technology), but the neoclassical model apparently predicts that convergence will occur more rapidly than it has in the past. Is it possible to reconcile the prediction of the model with the empirical evidence?

Using consensus values for the variables that determine the steady state, Barro and Sala-i-Martin show that the simple neoclassical model predicts convergence at a rate of about 12 percent a year.[8] At that rate, an economy below its steady state would move halfway to its steady state in about five and a half years. In their empirical investigation of convergence among the U.S. states, however, Barro and Sala-i-Martin find that the observed rate of convergence is much slower--on the order of 2 percent a year. They find a nearly identical rate--1.8 percent per year--in their study of convergence among 98 countries (once they have controlled for differences in steady states among countries). Mankiw, Romer, and Weil report very similar rates: depending on the estimated equation, they estimate the rate to be between roughly 1 percent and 2 percent a year. (Recall that they control for differences in the steady state and assume a constant saving rate.)

How can one explain the very low rates of convergence observed in these samples? Barro and Sala-i-Martin as well as Mankiw, Romer, and Weil assert that reconciling the model's predictions with historical experience would require highly unreasonable estimates of the variables that determine the steady state. Instead, both sets of analysts suggest that a fundamental assumption of the neoclassical model is the source of the discrepancy--specifically, its estimate of capital's coefficient is too low. The neoclassical model estimates the elasticity of output with respect to capital (capital's coefficient) using the share of capital income in the value of output. That

8. See Barro and Sala-i-Martin, "Convergence." The parameters in the model include the rate of growth of the labor force and of technological change, the depreciation rate, and others that describe consumer preferences.

share has averaged about one-third in the United States during the postwar period. The larger the estimate of capital's coefficient, the weaker the effect of decreasing returns to capital and the slower the implied rate of convergence. These analysts suggest that the empirical results on the rate of convergence are consistent with a higher coefficient for capital, perhaps as large as 0.8.

Augmenting the Neoclassical Model to Include Human Capital

Economists have long recognized that human capital plays a major role in long-run economic growth.[9] Researchers such as Edward Denison, T.W. Schultz, and Jacob Mincer recognized that workers who are better educated and trained are better able to perform their tasks, learn new tasks, and embrace the latest production techniques.[10] Indeed, human capital can be viewed as the fundamental source of technological progress since it is the means by which the stock of knowledge is embodied and transmitted. The relationship between human capital and technological progress is, of course, a theme picked up by the literature on endogenous growth, in which human capital is a key source of economic growth in many models.

Renewed interest in the theory of long-run growth has spurred empirical work that reinforces the conclusions of pioneers such as Denison, Schultz, and Mincer that human capital is an important determinant of growth. Empirical evidence has shown that accumulating human capital through on-the-job training or formal education benefits productivity in the long run. In addition, these studies have suggested a way to reconcile the low rate of convergence found in the data with the faster rate predicted by the neoclassical model.

Empirical evidence of the importance of accumulating human capital has been found in several recent studies. For example, using a cross section of 98 countries, Barro shows that economic growth during the 1960-1985 period is positively related to the 1960 level of human capital. He proxies the stock of human capital using school enrollment rates at the primary and secondary levels for each country. Mankiw, Romer, and Weil have run a similar regression using a slightly different measure of human capital and report

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9. Human capital is also important for explaining differences in relative wages among occupations. See, for example, G.S. Becker, *Human Capital* (Chicago: University of Chicago Press, 1975).

10. See E.F. Denison, *Trends in American Economic Growth, 1929-1982* (Washington, D.C.: Brookings Institution, 1985); T.W. Schultz, *Investment in Human Capital* (New York: Free Press, 1971); and J. Mincer, "Human Capital and Economic Growth," *Economics of Education Review*, vol. 3, no. 3 (1984), pp. 195-205.

essentially the same results.[11] In each study, the relationship between the level of schooling and subsequent growth is positive (better-educated countries grow faster) and statistically significant.

A key contribution made by Mankiw, Romer, and Weil was to recognize that growth in the stock of human capital more closely resembles growth in physical capital than growth in raw labor.[12] The authors augment the neoclassical model to include human capital as an input to production, adding it to raw labor and physical capital. Doing that improves the model's ability to explain the historical record; in particular, it may be the key to explaining why convergence occurs so much more slowly than the standard neoclassical model predicts. Considering a broad notion of capital that includes physical and human capital implies that the estimate of capital's coefficient made by the standard neoclassical model is too low. In that case, some of the compensation paid to labor is, in fact, a return on workers' prior investments in education, which builds human capital. Including human capital in the neoclassical framework raises the coefficient on broad capital, slows the onset of decreasing returns, and reduces the rate of convergence implied by the model.

Mankiw, Romer, and Weil find that the augmented neoclassical model, with its slower predicted rate of convergence, fits the data better and generates the following new implications about the process of economic growth.

- The level and rate of growth of output in the steady state will depend on the rate of investment in both physical and human capital (as they do in the standard neoclassical model).

- The elasticity of steady-state output with respect to the rate of investment is higher in the augmented neoclassical model than in the standard model. That is true even if only the rate of investment in physical capital increases. An increase in that rate will boost output and the level of human capital as long as the rate of investment in human capital remains unchanged. The

11. See Barro, "Economic Growth in a Cross Section of Countries"; and Mankiw, Romer, and Weil, "A Contribution to the Empirics of Economic Growth." See also P.M. Romer, "Human Capital and Growth: Theory and Evidence," in A.H. Meltzer, ed., *Carnegie-Rochester Series on Public Policy*, vol. 32 (Amsterdam: Elsevier Science Publishers, 1990), pp. 251-286. Similar results are reported by M. Knight, N. Loayza, and D. Villanueva, "Testing the Neoclassical Theory of Economic Growth: A Panel Data Approach," *IMF Staff Papers*, vol. 40, no. 3 (International Monetary Fund, Washington, D.C., September 1993), pp. 512-541.

12. See Mankiw, Romer, and Weil, "A Contribution to the Empirics of Economic Growth."

larger stock of human capital will then raise output via a faster pace of technological change.

Robert Barro cites other examples of the implications that follow from including human capital in the neoclassical model.[13] A larger stock of human capital (relative to physical capital) will allow an economy to make a faster transition to its steady state. This effect would help to explain why countries like Germany and Japan made rapid postwar recoveries even though their physical, but not human, capital was destroyed. But it does not bode well for the prospects of countries like Cambodia, which purged its intellectual class during the 1970s. In addition, Barro argues that a larger stock of human capital (relative to physical capital) will help spread the diffusion of technical knowledge. A "follower" nation will be better able to exploit the technology of a "leader" nation if it has a larger stock of human capital.

Finally, adding human capital to the neoclassical model enables the model to accommodate both the mobility of capital and lethargic rates of convergence. Relaxing the assumption that capital is immobile in the standard version of the model results in instantaneous convergence (if there are no imperfections in capital markets), because capital flows quickly from rich countries to poor countries to eliminate differences in real rates of return, raising capital per worker and output. However, under reasonable assumptions, the model that includes human capital is consistent with sluggish convergence even when capital is mobile. If the model assumes, for example, that physical capital can be used as collateral for foreign borrowing but human capital cannot, the augmented model still predicts convergence at a rate of about 2 percent a year.[14] The logic behind this assumption is that physical capital can be repossessed and sold more readily than human capital. For example, a U.S. resident can own a machine or a factory located in another country but cannot own the stream of future earnings associated with a foreigner's investment in human capital.

The regressions run by Mankiw, Romer, and Weil suggest that human capital's coefficient (that is, the elasticity of output with respect to human capital) is about one-third, roughly the same size as the coefficient on physical capital. This estimate implies coefficients of about two-thirds on broad capital and only one-third on raw labor. The authors assert that these values are

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13. See R. J. Barro, "Human Capital and Economic Growth," in *Policies for Long-Run Economic Growth*, a Symposium Sponsored by the Federal Reserve Bank of Kansas City, Jackson Hole, Wyo., August 27-29, 1992 (Kansas City, Mo.: Federal Reserve Bank of Kansas City, 1992).

14. See R.J. Barro, N.G. Mankiw, and X. Sala-i-Martin, "Capital Mobility in Neoclassical Models of Growth," Working Paper No. 4206 (National Bureau of Economic Research, Cambridge, Mass., November 1992).

reasonable based on the difference between the minimum wage and the average level of wages in the manufacturing sector. If the minimum wage reflects the return to raw labor (with little human capital), then the difference between the average wage and the minimum wage will reflect the return to human capital. Since the minimum wage has averaged about one-third to one-half of the average wage, Mankiw, Romer, and Weil estimate that about one-half to two-thirds of labor income (which amounts to nearly one-half of national income) is the return to human capital. This estimate argues for a coefficient on human capital of between one-third and one-half.[15]

An important implication of Mankiw, Romer, and Weil's modification to the neoclassical model is a dramatic increase in the predicted effects of a change in the saving rate. In their setup, a 10 percent increase in the saving rate would raise the steady-state level of per capita output by 10 percent, an effect that is twice as large as the standard model would predict.

Strong evidence indicates that human capital will be an important factor in any convincing theory of long-run economic growth; the question is how. The early evidence suggests that adding human capital to the neoclassical model is a promising approach, clears up many of the model's anomalies, and allows the model to better explain the historical record. Despite the evidence, the question of whether human capital belongs in the neoclassical model is not yet settled. Further research is required to determine whether a new consensus will form around the augmented model. Adding human capital to the neoclassical model would clearly change how economists view the long-run benefits of deficit reduction.

EVIDENCE OF DECREASING RETURNS TO PHYSICAL CAPITAL

The neoclassical model's prediction of convergence rests entirely on the assumption that investment in physical capital exhibits decreasing returns. In contrast, the absence of decreasing returns would provide compelling support for those endogenous growth models that rely on either constant or increasing returns to physical capital. Such evidence, however, would provide an incomplete evaluation of the two types of models because some endogenous growth models allow for decreasing returns to physical capital (and constant

15. Mankiw, Romer, and Weil, "A Contribution to the Empirics of Economic Growth." See also N.G. Mankiw, "Commentary: The Search for Growth," in *Policies for Long-Run Economic Growth*, a Symposium Sponsored by the Federal Reserve Bank of Kansas City, Jackson Hole, Wyo., August 27-29, 1992 (Kansas City, Mo.: Federal Reserve Bank of Kansas City, 1992), pp. 87-92.

returns to a broad notion of capital that includes both physical and human capital).

For a given production function, the existence of decreasing returns to capital depends on the value of the elasticity of output with respect to capital. If this elasticity is less than one, then decreasing returns to capital prevail. The smaller the elasticity, the stronger are the decreasing returns. Recall that the assumptions of the neoclassical model imply that the elasticity of output with respect to capital is about one-third, whereas proponents of the endogenous growth theory argue that the true coefficient would be much closer to one. An estimate of one would imply constant returns to capital.

Econometric estimates of the elasticity of output with respect to capital are generally made using either time-series data or cross-sectional data. In theory, time-series estimates are straightforward; one should be able to estimate the elasticity directly using an ordinary least squares regression that relates output to labor, capital, and technological change for a given country. If the variables enter the equation in logarithmic form, then the regression coefficient on capital will be the elasticity of output with respect to capital.

Such time-series estimates are plagued by statistical problems, however, making their results suspect.[16] In particular, the coefficient on capital is probably biased in these regressions because they violate a crucial assumption of ordinary least squares--the independence of the explanatory variables and the equation's error term. For example, the growth of the capital stock is probably in part a function of output. If so, an unobserved shock to productivity that raises output will indirectly raise the capital stock, inducing a correlation between an explanatory variable (capital) and the error term in the output equation. Under these circumstances, output and capital are simultaneously determined, and ordinary least squares estimates of the elasticity of output with respect to capital will be biased.

The other type of econometric estimate employs cross-sectional data to examine the relationship between output and the accumulation of capital. Cross-sectional regressions use data from many countries (usually averaged over long periods) in order to reduce the econometric problems that afflict the time-series studies. Empirical cross-sectional studies consistently find a strong, positive correlation between capital formation and the rate of

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16. Paul Romer shows that minor changes in specification of these regressions can lead to estimates of the elasticity that range from below zero to above one. See P.M. Romer, "Crazy Explanations for the Productivity Slowdown," p. 185. For another demonstration of the pitfalls of these regressions, see J. Benhabib and B. Jovanovic, "Externalities and Growth Accounting," *American Economic Review*, vol. 81, no. 1 (March 1991), pp. 82-113.

economic growth--that is, countries with high saving rates also have high rates of economic growth. This relationship implies that the elasticity of output with respect to capital is close to one, a result that is difficult to reconcile with the estimate of one-third predicted by the neoclassical model. However, these studies cannot be taken as conclusive evidence in favor of endogenous growth models. A closer look reveals that they do not entirely evade the statistical problems associated with time-series studies and that their results can be reconciled with the neoclassical model. In sum, the assumption of decreasing returns to capital is still justified.

In their review of cross-sectional studies, George Hatsopoulos, Paul Krugman, and Lawrence Summers find a strong relationship between capital formation and growth in labor productivity among the manufacturing sectors of industrialized nations during the 1970-1985 period.[17] They argue that a high rate of capital formation leads to a high rate of growth (not the other way around) because of the similarly strong correlation between productivity growth and the rate of net national saving. They argue that the saving rate influences capital formation but should not be strongly affected by the rate of economic growth.

Hatsopoulos, Krugman, and Summers also provide two reasons to expect that capital's share in total compensation will understate its true contribution to the growth of output. First, since capital goods embody technological change, a country with a high rate of investment will have a more modern and more efficient capital stock. Given two countries that differ only with regard to the age of their capital stock, the country with the younger capital stock will probably be more productive. A high rate of investment will also encourage innovation by providing a larger market and a higher rate of return to entrepreneurs.

Second, the neoclassical model implicitly assumes that the investment's social return is equal to the private return (expressed as the rate of profit). However, if investment in capital has the spillover effects described by Paul Romer, then the social return will exceed the measured private return. Or if labor, through union power or another channel, is able to capture more than

17. See G.N. Hatsopoulos, P.R. Krugman, and L.H. Summers, "U.S. Competitiveness: Beyond the Trade Deficit," *Science*, vol. 241 (July 15, 1988), pp. 299-307. Similar results are reported in Romer, "Crazy Explanations for the Productivity Slowdown"; R. Ram, "Government Size and Economic Growth: A New Framework and Some Evidence from Cross-Section and Time-Series Data," *American Economic Review*, vol. 76, no. 1 (March 1986), pp. 191-203; R.C. Kormendi and P.G. Meguire, "Macroeconomic Determinants of Growth: Cross-Country Evidence," *Journal of Monetary Economics*, vol. 16 (September 1985), pp. 141-163; and W. Easterly, "How Much Do Distortions Affect Growth," *Journal of Monetary Economics*, vol. 32, no. 2 (November 1993), pp. 187-212.

the value of its marginal product as compensation, then the measured rate of profit will underestimate capital's true social return.

J. Bradford De Long and Lawrence Summers have taken the correlation between capital formation and growth one step farther by arguing that one category of investment, machinery, is responsible for the spillover effects on economic growth.[18] They show that countries that invest heavily in equipment also have high rates of productivity growth, and they claim that the correlation is unaffected by changes in specification and sample. Moreover, they argue that causality runs from investment in equipment to growth rather than from growth to equipment, because countries in their sample with high rates of growth also had low equipment prices. If high growth stimulated high investment in equipment, one would expect that high-growth countries would have higher equipment prices than low-growth countries.

Edward Wolff provides further evidence on this issue.[19] By using cross-country data to study convergence, he finds a positive and significant correlation between a country's rate of capital formation and its rate of growth of total factor productivity (commonly interpreted as a measure of technological progress). This finding suggests that capital has two effects on output: a direct effect through an increase in the amount of capital per worker, and an indirect effect through technological progress. These effects are consistent with the hypothesis that capital's share in total compensation understates its true contribution to the growth of output.

Although these cross-sectional studies reach similar conclusions, they do not necessarily imply that accumulation of capital yields additional growth beyond what the neoclassical model would predict. Their results may be consistent with decreasing returns to capital for two reasons. First, the estimates in these studies do not entirely evade the statistical problems that distort the time-series estimates. A growing body of empirical evidence indicates that saving rates are positively correlated with rates of growth across countries.[20] If so, then the correlations reported in the cross-sectional

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18. J.B. De Long and L.H. Summers, "Equipment Investment and Economic Growth," *Quarterly Journal of Economics*, vol. 106, no. 2 (May 1991), pp. 445-502.

19. See E.N. Wolff, "Capital Formation and Productivity Convergence."

20. A positive correlation between saving rates and growth rates might occur if people save in order to reach some target ratio of wealth to income. Under the so-called target-saving hypothesis, faster economic growth raises income, thereby lowering people's wealth-to-income ratio and leading them to save more. For more details, see C.D. Carroll and D.N. Weil, "Saving and Growth: A Reinterpretation," Working

studies may not imply that countries grow faster because they have higher rates of saving and investment (as their researchers suggest). Instead, the correlations may mean that countries have higher saving rates because they grow faster.

Second, the correlation may not reflect a strong relationship between these variables but rather the influence of an unobserved third variable. That would be the case if the conditions that led to the high rates of productivity growth also created conditions for greater investment. For example, a factor such as technological progress might explain the correlations found in the work of De Long and Summers. Rapid technological advance in the production of equipment would not only raise the rate of economic growth but also shift the effective supply curve for equipment outward, lowering the equilibrium price of equipment and raising the amount of equipment purchased. It would also explain why growth in output is more highly correlated with equipment than with structures, a sector not marked by rapid technological progress.

Another difficulty with the cross-sectional studies is that their results are sensitive to changes in sample or specification. De Long and Summers, for example, argue that the correlations they observe indicate the presence of a beneficial spillover associated with investment in equipment. However, although their results hold for an extended sample that includes rich and poor nations, they do not hold for a sample that includes either only OECD nations or only non-OECD nations.[21] If their results are, in fact, caused by spillovers associated with investment in equipment, then their tests should be invariant to the sample used.

Ross Levine and David Renelt also argue that the results of cross-sectional regressions must be interpreted with caution because the results are generally sensitive to changes in specification.[22] The two examine typical cross-sectional regressions and find that many indicators of fiscal, monetary, and trade policy are correlated with growth. However, they also find that most of the relationships can be overturned with small alterations in the set of explanatory variables included in the regression.

Paper No. 4470 (National Bureau of Economic Research, Cambridge, Mass., September 1993).

21. See A.J. Auerbach, K.A. Hassett, and S.D. Oliner, "Reassessing the Social Returns to Equipment Investment," Working Paper Series No. 129 (Economic Activity Section, Division of Research and Statistics, Board of Governors of the Federal Reserve System, December 1992).

22. R. Levine and D. Renelt, "A Sensitivity Analysis of Cross-Country Growth Regressions," *American Economic Review*, vol. 84, no. 2 (September 1992), pp. 942-963.

Although the evidence presented in the cross-country studies argues for a weaker version of decreasing returns to capital, none of the studies suggest that such decreasing returns do not exist (even in the presence of spillover effects). Paul Romer has concluded that:

> The regression evidence shows that increased investment tends to be correlated with a lower marginal product of physical capital. The precision of these estimates is not sufficient to conclude that increased investment has no effect at all on technological change, but at a minimum the estimates show that increased investment does not seem to induce enough technological change to offset completely the diminishing returns associated with increased capital accumulation.[23]

Martin Baily and Charles Schultze buttress this observation by noting that between 1948 and 1968, the amount of capital per worker in the United States fell while the return to capital rose.[24] And the opposite has been true since 1973. This pattern of correlations is exactly what one would expect if capital had diminishing returns. Similar results are reported by Alwyn Young, who examined the postwar economic experience of Hong Kong and Singapore.[25] Young found that although the two economies experienced similar rates of growth during that period, the sources of growth were quite different. Growth in Hong Kong was driven both by the accumulation of labor and capital and by technical progress. In contrast, Singapore's growth was driven almost entirely by the accumulation of labor and capital, especially by investment in physical capital; technical progress played a very small role. Consequently, Singapore experienced sharply decreasing returns to capital. By Young's estimate, the real return to capital in Singapore declined from about 40 percent in the early 1960s to about 10 percent in the late 1980s.

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23. Romer, "Capital, Labor, and Productivity," p. 339.

24. In this comparison, labor is measured in efficiency units, and the marginal product of capital is measured using the profit rate. For details, see M. Baily and C. Schultze, "The Productivity of Capital in a Period of Slower Growth," *Brookings Papers on Economic Activity: Microeconomics* (1990), pp. 369-419.

25. A. Young, "A Tale of Two Cities: Factor Accumulation and Technical Change in Hong Kong and Singapore," in O.J. Blanchard and S. Fischer, eds., *NBER Macroeconomics Annual: 1992* (Cambridge, Mass.: MIT Press), 1992.

DIRECT EVIDENCE OF THE EXISTENCE OF SPILLOVERS OR INCREASING RETURNS TO SCALE

Considering the crucial role that spillovers and increasing returns play in some models of endogenous growth, surprisingly little direct evidence exists to support the idea that they play a significant role in the overall economy. Proponents of endogenous growth models generally set out to explain one or two broad empirical regularities--persistent growth of per capita output or nonconvergence, for example--but have not subjected their models to rigorous empirical scrutiny. Direct evidence of spillovers would help to distinguish which class of models better describes the data. Most of the available evidence, however, is anecdotal or limited to studies conducted on the firm or industry level that do not demonstrate the significance of spillovers in the overall economy.

Paul Romer attempts to demonstrate the importance of spillovers to R&D with three examples reported in the press.[26] In the first, two former employees of Du Pont were convicted of extortion for threatening to reveal the process the company used to make Lycra. In the second, Intel filed suit against a former employee who had used trade secrets at a new company. The third was an investigation into the activities of a firm that allegedly stole mechanical drawings and formulas used to make blades for General Electric turbines.

These three cases are examples of a technological advance that had been designed by one firm and was at risk of spreading (without compensation to the first company) to other firms in the industry; that is, they provide evidence of spillovers. Romer also stresses that the amounts of money at stake were large: the two former Du Pont employees asked the company for \$10 million, Intel asserted that it had spent hundreds of millions of dollars developing its microprocessors, and General Electric claimed its designs were worth \$200 million.

Such anecdotal evidence may demonstrate the existence of spillovers among firms, but it does not demonstrate convincingly their significance for the overall economy. More rigorous empirical treatments also come up short. Adam Jaffee, for example, found that the productivity of a firm's investment in research and development is enhanced by the R&D spending of other firms

26. P.M. Romer, "Are Nonconvexities Important for Understanding Growth?" *American Economic Review*, vol. 80, no. 2 (May 1990). For more examples of spillovers to research and development at the industry and firm level, see N. Rosenberg, *Inside the Black Box: Technology and Economics* (Cambridge: Cambridge University Press, 1982).

in the same industry.[27] He notes, however, that his evidence is largely circumstantial and that factors other than spillovers may play a role. In another study, Ricardo Caballero and Jaffee attempt to measure spillovers using rates at which patents were cited.[28] However, as they point out, the link between the model's theoretical constructs and the data used to estimate them is too weak to support any strong conclusions about the significance of spillovers for the overall economy.

The literature also includes studies of spillovers associated with human capital at the firm or industry level. These studies examine the idea raised by Robert Lucas that an employee will be more productive if he or she works with other employees who have above-average skills or education. In a survey of several of these studies, Larry Katz finds that the evidence suggests such an effect but is not conclusive.[29] However, like evidence regarding spillovers to R&D among firms, the micro-level studies surveyed by Katz do not demonstrate the importance of spillovers for the overall economy because they do not adequately measure the magnitude of the effect.

The best data on the implications of spillovers for the overall economy come from the growth-accounting studies described in Chapter II. Using the neoclassical assumption of constant returns to scale and carefully measuring human and physical capital, growth accountants cannot entirely explain the growth in output over long periods. They attribute the residual to technological progress. Of course, that finding could be the result of violating one of the model's assumptions, mismeasuring the inputs, or technological change, but it at least suggests that spillovers affect the economy. The economywide data, however, may not vary enough to distinguish between increasing returns and technological progress.

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27. A.B. Jaffee, "Technological Opportunity and Spillovers of R&D: Evidence from Firms' Patents, Profits, and Market Value," *American Economic Review*, vol. 76, no. 5 (December 1986), pp. 984-1001.

28. See R.J. Caballero and A.B. Jaffee, "How High Are the Giants' Shoulders: An Empirical Assessment of Knowledge Spillovers and Creative Destruction in a Model of Economic Growth," in O.J. Blanchard and S. Fischer, eds., *NBER Macroeconomics Annual: 1993* (Cambridge, Mass.: MIT Press, 1993).

29. See L.F. Katz, "Commentary: Human Capital and Economic Growth," in *Policies for Long-Run Economic Growth*, a Symposium Sponsored by the Federal Reserve Bank of Kansas City, Jackson Hole, Wyo., August 27-29, 1992 (Kansas City, Mo.: Federal Reserve Bank of Kansas City, 1992).

INTERNATIONAL FLOWS OF LABOR AND CAPITAL

The evidence on the flows of labor and capital between countries is somewhat difficult to explain using the neoclassical model. The standard version of the model, which assumes identical economies and no imperfections in the market, implies instantaneous convergence as capital moves rapidly to equalize returns for all countries. Labor is typically assumed to be immobile. In reality, the world is marked by differences in per capita income that are too large to be explained by differences in ratios of capital to labor. In addition, capital seems to flow in the wrong direction, and workers are subject to persistent pressure to migrate from poor countries to rich countries.

Flows of Capital

The neoclassical model suggests that capital should flow from rich countries to poor countries since poor countries, with their low levels of capital per worker, should have higher rates of profit. Such capital flows would reinforce the neoclassical model's prediction that poorer countries will catch up to richer countries. However, the data seem to indicate that when capital flows, it flows either between rich countries or from poor countries to rich countries.[30]

Martin Baily and Charles Schultze argue that, at least among developed nations, flows of long-term capital are consistent with the predictions of the neoclassical model.[31] They point out that long-term capital flowed from Europe to the United States during the 19th century, presumably in search of opportunities for higher profits. During the 1950s, the flows were reversed; capital per worker was higher in the United States than in the war-ravaged economies of Europe, so capital flowed back to the continent. Baily and Schultze assert that, more recently, declining profit rates in Europe and Japan have spurred flows of capital into the United States.

30. Numerous studies have examined the international mobility of capital. The consensus is that capital is indeed mobile (and more mobile today than it was 20 years ago) and that it flows across international boundaries to even out nominal rates of return. For more details, see M. Feldstein and P. Baccheta, "National Saving and International Investment," in B.D. Bernheim and J.B. Shoven, eds., *National Saving and Economic Performance* (Chicago: University of Chicago Press, 1991), and the references cited within.

31. See M.N. Baily and C.L. Schultze, "The Productivity of Capital in a Period of Slower Growth," *Brookings Papers on Economic Activity: Microeconomics* (1990). Jeffrey Frankel presents evidence that flows of short-term capital eliminate differences in nominal interest rates among developed countries. See J. Frankel, "Quantifying International Capital Mobility in the 1980s," in B.D. Bernheim and J.B. Shoven, eds., *National Saving and Economic Performance* (Chicago: University of Chicago Press, 1991).

The fact that capital is not moving into developing countries (and, indeed, is moving out of those countries) is probably explained by reasons that have nothing to do with ratios of capital to labor or profit rates. Capital may not flow to developing countries because investors have a greater perceived risk that their funds or property might be expropriated or because they lack information about local markets. Other reasons include the lack of infrastructure or other complementary factors of production in developing countries, an adverse political environment (especially with regard to capital controls in the future), or a lack of institutional relationships. Recent experience in Mexico demonstrates the importance of political factors: capital flowed back into the country when the political climate became friendlier to private investment.

Flows of Labor

The evidence on flows of labor between countries is not strong enough to add much to the evaluation of the models of economic growth. Few analysts would argue with the proposition that large and persistent gaps in per capita income among countries result in constant pressure for workers to migrate from poor countries to rich countries. This phenomenon would seem to favor models of endogenous growth, several of which contain specific mechanisms to generate such differences in income. However, the neoclassical model, augmented to include human capital, would predict that any existing gaps in income would persist for decades.

CONCLUSION

What conclusions can be drawn from the foregoing discussion? First and foremost, it is too early to jettison either the neoclassical framework or its basic conclusions about the effects of government policy. The model's crucial assumptions (for example, decreasing returns to capital) appear to be justified, and the model's predictions (for example, convergence) hold when it controls for differences in steady states among countries. In addition, some of the anomalies associated with the model, such as the slow rate of convergence, can be explained by modifying it to include human capital as a factor of production. But even the augmented model requires exogenous technical change in order to generate growth in per capita output. Despite the advances in growth accounting that have reduced the proportion of growth attributable to technical change, the theory still has an important limitation in that a significant portion of economic growth is assumed to occur exogenously.

The studies of endogenous growth have provided many new ways to think about long-run growth and a more diverse set of mechanisms for analyzing the effects of government policy. The early models of Romer and Lucas were highly simplified, but they have given way to more realistic models that have better empirical support. In fact, it is difficult to make a clear distinction between the neoclassical and the endogenous growth frameworks because the differences between the two are shrinking steadily. Many of the latest models are better viewed as extensions of the neoclassical model than as replacements for it. One interpretation of the new models is that they "endogenize" the technical change that is assumed to occur exogenously in the neoclassical model. The explicit treatment of the economics of innovation found in the models of Romer and of Grossman and Helpman is an important step toward accounting for technical change.

What new policies can be recommended based on these studies? None, really. Nearly all of the studies are performed at a high level of aggregation and are therefore too general to provide specific guidelines for policymakers. But the new models indicate broad areas in which to look for policies that may prove to be effective. The most promising area seems to be investment in human capital, including both schooling and on-the-job training. Lower taxes on investment in physical capital, carefully directed investment spending by the government (perhaps in the form of subsidies for R&D), and increased international trade are other recommendations. But one cannot say that investments in any of these areas will result in extraordinary growth; the results are preliminary.

The findings of this survey provide optimism about the benefits of deficit reduction. The best empirical evidence does not support the prediction that reducing the deficit will permanently boost the rate of economic growth (perhaps because of extraordinary returns associated with investment in physical capital). But it does support the augmented neoclassical model, which predicts that the bang per buck of deficit reduction is larger than in the standard version of the model. The results of the new models sound a cautionary note about deficit reduction, however: they suggest that the manner in which the deficit is reduced does matter. If the models have any validity at all, then policymakers should avoid increasing the relative tax burden on capital.