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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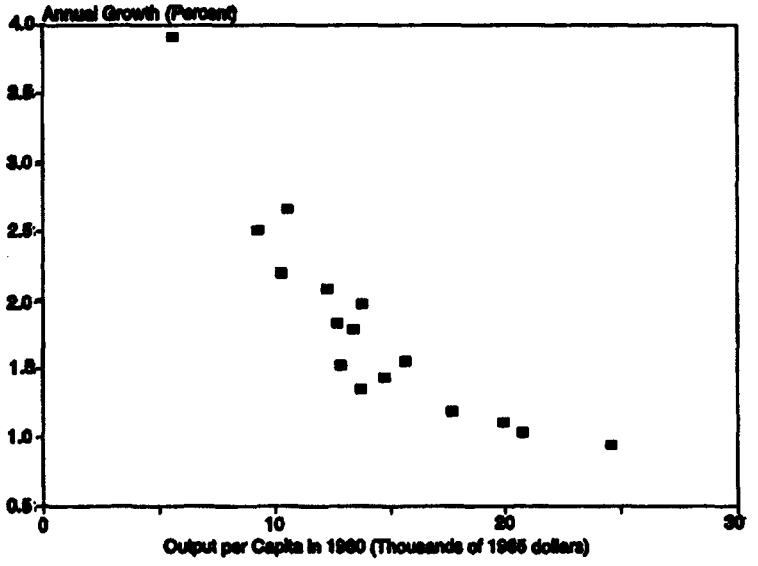
1. See W. Baumol, "Productivity Growth, Convergence and Welfare: What the Long-Run Data Show," *American Economic Review*, vol. 76, no. 5 (December 1986), pp. 1072-1085; A. Maddison, "Growth and Slowdown in Advanced Capitalist Economies: Techniques of Quantitative Assessment," *Journal of Economic Literature*, 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--

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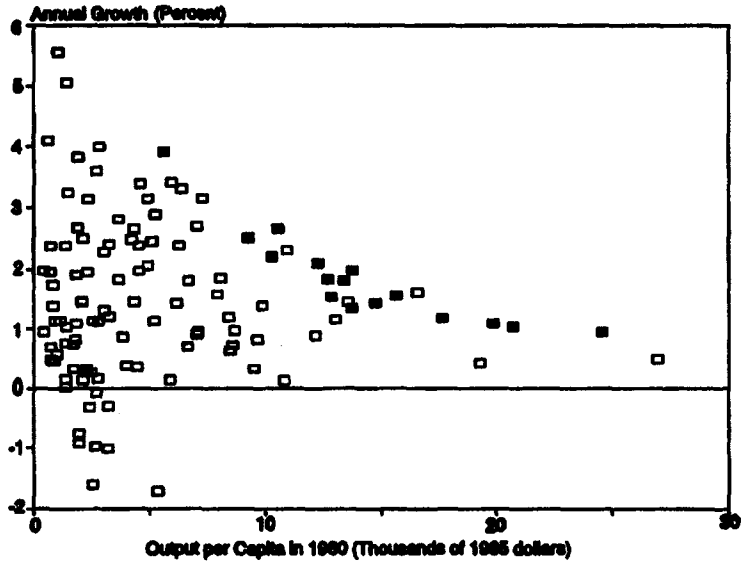
2. See J.B. De Long, "Productivity Growth, Convergence, and Welfare: A Comment," *American Economic Review*, vol. 78, no. 5 (December 1988), pp. 1138-1154.

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

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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

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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

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.