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2 Long-Run Growth Theories and Empirics: Anything New?

T. N. Srinivasan

2.1 Introduction

After a hiatus of over two decades, scholarly attention has returned to theoretical and empirical analyses of economic growth and development. Recent contributions, variously described as "endogenous" growth theory and "new" growth theory, have included many of the factors that have long been viewed as contributing to growth and development in an analytically coherent framework. Such features as significant scale economies, pervasive externalities (particularly in the generation and diffusion of technological knowledge), and the accumulation of human capital have been incorporated, not as some exogenous deus ex machina for generating growth, but as processes interacting with, if not also generated by, the behavior of producers, consumers, and the government. Renewed interest in empirically testing some of the implications of theories and estimating the contributions to growth of various factors has also been stimulated by these contributions. Interestingly, the revival of interest in growth theory came soon after developments in the theory of international trade, which also grounded scale economies and the generation of technological knowledge in the rational behavior of agents operating in necessarily imperfectly competitive markets. For this reason, recent models of growth and trade not only have recognizable analytical similarities, but also more importantly, shed light on related issues in theory, empirics, and policy. Let me illustrate with just one among many possible examples.

In the context of the long-run effects of variations in saving and investment

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rates, an important theoretical question is, Does an increase in the rate of investment (leaving aside for the moment the question of whether the rate is exogenous or endogenous) have only a *level* effect, i.e., it changes only the long-run *level of output per worker,* or does it also have a *growth* effect, i.e., it changes the long-run *rate of growth of output per worker?* An analogous theoretical question in the context of international trade is, Does opening up a closed economy to foreign trade have only a level effect (i.e., yield only *static and once and for all* gains from trade) or does it also have a growth effect (i.e., yield *dynamic* gains from trade as well)? In the context of finance, the issue is, Does the relaxation of financial repression generate largely static gains or does the functioning of financial institutions have a key role in the growth process?

A related empirical question is the following: Does the evidence—either from a long time series for individual entities such as regions, countries, or subregions within countries or from a cross section of entities at different points of time—confirm, for example, that variations in factor accumulation have, in effect, only level effects? This is the implication of a neoclassical model in which all entities have access to the same constant-returns-to-scale production function with the marginal product of any factor diminishing to zero as its use is increased indefinitely relative to other factors. That is, loosely speaking, regardless of their differences with respect to accumulation, do all entities grow in the long run at a rate determined by the rate of growth of exogenous factors such as its labor force and technical progress? An interesting empirical-cum-policy issue is whether orientation toward foreign trade is at the heart of the spectacular growth performance of East Asian economies and their Southeast Asian followers, and, by the same token, whether the poor performance of some of their South Asian neighbors is explained by excessive inward orientation? Put another way, does openness to trade generate dynamic gains?

The theoretical, empirical, and policy-oriented literature on long-run growth and trade has grown by leaps and bounds since its revival by Lucas (1988) and Romer (1986). The recent literature on international trade, innovations, and growth, initiated by Grossman and Helpman (1990), is well covered in their later monograph (Grossman and Helpman 1991). I do not propose to survey these literatures. Instead, in section 2.2, by placing some of the recent theoretical models in juxtaposition with the earlier growth models, I argue that it is misleading to characterize the earlier models as necessarily implying that sustained growth in per capita income is impossible in the absence of exogenous technical progress and to suggest that, in contrast, recent models generate such growth by endogenizing the growth process including that of technical change. On the contrary, sustained growth is possible in the former even in the absence of technical progress as long as the marginal product of an accumulable factor of production (such as capital) has a positive lower bound, regardless of how much it is accumulated relative to other factors. While it is true that in recent growth models the process of growth and technical progress is *endogenous* and that, in some, multiple steady states are possible, these features were also present in some of the earlier models. Also, increasing, rather than constant, returns to scale, which are characteristic of some of the recent models, are neither necessary nor sufficient to generate sustained growth. Section 2.2 also briefly describes a growth model due to Raut and Srinivasan (1991) with endogenous fertility and externalities to population density, where nonlinear dynamics generates a plethora of outcomes (depending on the functional forms, parameters, and initial conditions) that include not only the neoclassical steady state with exponential growth of population with constant per capita income and consumption, but also growth paths which do not converge to a steady state and are even chaotic. Per capita output grows exponentially (and superexponentially) in some of the examples.

In section 2.3 I briefly and selectively review the recent empirical literature on growth, focusing attention in particular on the serious inadequacies of cross-country studies from the perspective of the specification of the model to be estimated, the techniques of estimation, and above all the database used for estimation. Section 2.4 concludes the paper with a few remarks on the findings from the recent growth literature and their policy implications, if any.[1]

2.2 Growth Theories: Past and Present

Theorizing about long-run growth revived after a hiatus of over two decades since the last spurt in the 1950s and 1960s. The latter was itself inspired by much earlier and pioneering works of Frank Ramsey (1928) on optimal saving and of von Neumann (1945) on balanced growth at a maximal rate, and also by dynamic extensions of the Keynesian model by Harrod (1939) and later by Domar (1947). In the largely neoclassical growth-theoretic literature of the 1960s and earlier, one could distinguish three strands.

The first strand is *positive* or, better still, *descriptive* theory aimed at explaining the stylized facts of long-run growth in industrialized countries (particularly in the United States), such as the steady secular growth of aggregate output and the relative constancy of the share of savings, investment, labor, and capital income in aggregate output. These stylized facts themselves had been established by the works of empirically oriented economists, such as Abramovitz (1956), Denison (1962), and Kuznets (1966), who were mainly interested in accounting for observed growth. Solow's (1956, 1957) celebrated articles and later work by Jorgenson and Griliches (1966) and others are examples of descriptive growth theory and related empirical analysis. Uzawa (1961, 1963) extended Solow's descriptive one-sector model into a two-sector model. As Stiglitz (1990) remarked, by showing that the long-run steady state growth rate could be unaffected by the rate of savings (and investment) and that, even in the short run, the rate of growth was mostly accounted for by

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[1] I have drawn extensively from Raut and Srinivasan (1993) in writing this paper.

the rate of labor-augmenting technical progress, Solow challenged the then-conventional wisdom.

The second strand is *normative* theory, which drew its inspiration from Ramsey's (1928) classic paper on optimal saving. In contrast to the descriptive models in which the aggregate savings rate was exogenously specified (usually as a constant over time), the normative models derived time-varying savings rates from the optimization of an intertemporal social welfare function. There were mainly two variants of such normative models: one-sector models (e.g., Koopmans 1965; Cass 1965) and two-sector models (Srinivasan 1962, 1964; Uzawa 1964). The contribution of Phelps (1961) is also normative, but it focused only on the steady state level of consumption per worker, rather than on the entire transitional time path to the steady state, and solved for that savings rate which maximized the steady state level of consumption per worker.

The third strand of theory is neither primarily descriptive nor primarily normative, though it is related to both. Harrod's dynamic extension of the Keynesian model (with its constant marginal propensity to save) raised the issue of stability of the growth path by contrasting two growth rates: the *warranted* rate of growth that would be consistent with maintaining the savings-investment equilibrium and the *natural* growth rate as determined by the growth of the labor force and technical change. In this model, unless the economy's behavioral and technical parameters keep it on the knife edge of equality between warranted and natural growth rates, there would be either growing underutilization of capacity if the warranted rate exceeds the natural rate or growing unemployment if the natural rate exceeds the warranted rate. Indeed this knife-edge property resulting from Harrod's assumption that capital and labor are used in fixed proportions led Solow to look for growth paths converging to a steady state by replacing Harrod's technology with a neoclassical technology of positive elasticity of substitution between labor and capital.

Von Neumann's (1945) model is also part of the third strand. In this model production technology is characterized by a finite set of constant-returns-to-scale activities with inputs being committed at the beginning of each discrete production period and outputs emerging at the end. There are no nonproduced factors of production such as labor or exhaustible natural resources. In the "primal" version, von Neumann characterized the vector of activity levels that permitted the maximal rate of *balanced growth* (i.e., growth in which outputs of all commodities grew at the same rate) given that the outputs of each period were to be ploughed back as inputs in the next period. In the "dual" version, a vector of commodity prices and an interest rate were derived which had the properties that the value of output of each activity was no higher than the value of inputs inclusive of interest and that the interest rate was the lowest possible. Under certain assumptions about the technology, von Neumann showed, first, that the maximal growth rate of output of the primal version was equal to the (minimal) interest rate of the dual and, second, that the usual complementary slackness relations obtained between the vector of activity levels, prices, growth, and interest rates.

Although prima facie there is no normative rationale for balanced growth and the maximization of the growth rate, particularly in a setup with no final consumption of any good, it turned out that the von Neumann path of balanced growth at the maximal rate has a "normative" property. As Dorfman, Samuelson, and Solow (1958) conjectured and Radner (1961) later rigorously proved, given an objective that is a function only of the terminal stocks of commodities, the path starting from a given initial vector of stocks that maximizes this objective will be "close" to the von Neumann path "most" of the time, as long as the terminal date is sufficiently distant from the initial date, regardless of the initial stocks and of the form of the objective function. This "turnpike" feature was later seen in other growth models in which final consumption is allowed and production involves the use of nonproduced factors. For example, in the Koopmans-Cass model, in which the objective is to maximize the discounted sum of the stream of utility of per capita consumption over time, a unique steady state exists which is defined by the discount rate, the rate of growth of the labor force, and the technology of production. *All* optimal paths, i.e., paths that maximize the objective function and start from different initial conditions, converge to this steady state regardless of the functional form of the utility function. As such, all optimal paths stay "close" to the steady state path "most" of the time.

Barring a few exceptions to be noted below, in the neoclassical growth models production technology was assumed to exhibit constant returns to scale and in many, though not all models, smooth substitution among inputs with strictly diminishing marginal rates of substitution between any two inputs along an isoquant was also posited. Analytical attention was focused on conditions ensuring the existence and uniqueness of steady state growth paths along which all inputs and outputs grew at the same rate—the steady state being the path to which all transitional paths starting from any given initial conditions and satisfying the requirements of specified descriptive rates of accumulation or of intertemporal welfare optimality converged. The steady state growth rate was the *exogenous* rate of growth of the labor force in efficiency units, so that in the absence of (exogenous) labor-augmenting technical progress, output per worker was constant along the steady state.

Turning to the exceptions, Solow (1956) himself drew attention to the possibility that a steady state need not even exist and that even if one existed it need not be unique. Indeed output per worker could grow indefinitely, even in the absence of labor-augmenting technical progress, if the marginal product of capital were bounded below by a sufficiently high positive number. Helpman (1992) also draws attention to this. Also, there could be multiple steady states, some of which are unstable, if the production technology exhibits nonconvexities. We return to these issues below.

There were also exceptions to the exogeneity of technical progress and of the rate of growth of output along a steady state. In the one-sector, one-factor models of Harrod and Domar and the two-sector models of Fel'dman (1928, as described in Domar 1957) and Mahalanobis (1955), marginal capital-output ratios were assumed to be constant so that by definition the marginal product of capital did not decline. The growth rate was *endogenous* and depended on the rate of savings (investment) in such one-sector models and on the aggregate rate of investment and its allocation between sectors producing capital and consumer goods in the two-sector models. Kaldor and Mirrlees (1962) endogenized technical progress (and hence the rate of growth of output) by relating productivity of workers operating newly produced equipment to the rate of growth of investment per worker. And there was the celebrated model of Arrow (1962) of "learning by doing," in which factor productivity was an increasing function of cumulated output or investment. Uzawa (1965) also endogenized technical progress by postulating that the rate of growth of labor-augmenting technical progress was a concave function of the ratio of labor employed in the education sector to total employment. The education sector was assumed to use labor as the only input. Uzawa's model has influenced recent contributions to growth theory. In addition, in the literature on induced innovation (Ahmad 1966; Boserup 1965; Kennedy 1964) technical change was, by definition, endogenous.

The recent revival of growth theory started with the influential papers of Lucas (1988) and Romer (1986). Lucas motivated his approach by arguing that neoclassical growth theory cannot account for observed differences in growth across countries and over time and for its evidently counterfactual prediction that international trade should induce rapid movements toward equality in capital-labor ratios and factor prices.[2] He argued that, "In the absence of differences in pure technology then, and under the assumption of no factor mobility, the neoclassical model predicts a strong tendency to income equality and equality in growth rates, tendencies we can observe within countries and, perhaps, within the wealthiest countries taken as a group, but which simply cannot be seen in the world at large. When factor mobility is permitted, this prediction is powerfully reinforced" (Lucas 1988, 15–16). He then goes on to suggest that the one factor isolated by the neoclassical model, namely, variation across countries in technology, "has the potential to account for wide differences in income levels and growth rates. . . . When we talk about differences in 'technology' across countries we are not talking about knowledge in general, but about the knowledge of particular people, or particular subcultures of people. If so, then while it is not exactly wrong to describe these differences [as] exogenous . . . neither is it useful to do so. We want a formalism that leads us to think about individual decisions to acquire knowledge, and about the conse-

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[2] In fact, besides introducing the constant elasticity of substitution production function, Arrow et al. (1961) and, in his dissertation, Minhas (1963) were concerned precisely with this issue.

quences of these decisions for productivity." He draws on the theory of "human capital" to provide such a formalism: each individual acquires productivity-enhancing skills by devoting time to such acquisition and away from paying work. The acquisition of skills by a worker not only increases her productivity but, by increasing the average level of skills in the economy as a whole, has a spillover effect on the productivity of all workers by increasing the average level of skills in the economy as a whole.

Romer also looked for an alternative to the neoclassical model of long-run growth to escape from its implications that "initial conditions or current disturbances have no long-run effect on the level of output and consumption. . . . In the absence of technical change, per capita output should converge to a steady-state value with no per capita growth" (Romer 1986, 1002–3). His is "an equilibrium model of endogenous technological change in which long-run growth is driven primarily by the accumulation of knowledge by forward-looking, profit-maximizing agents" (1003). While the production of new knowledge is through a technology that exhibits diminishing returns, "the creation of new knowledge by one firm is assumed to have a positive external effect on the production possibilities of other firms . . . [so that] production of consumption goods as a function of stock of knowledge exhibits increasing returns; more precisely, knowledge may have an increasing marginal product" (1003).

It should be noted that the spillover effect of the average stock of human capital per worker in the Lucas model and of knowledge in the Romer model are externalities unperceived (and hence not internalized) by individual agents. However, for the economy *as a whole* they generate increasing scale economies even though the perceived production function of each agent exhibits constant returns to scale. Thus by introducing nonconvexities through the device of a Marshallian externality Lucas and Romer were able to work with an intertemporal competitive (albeit a socially nonoptimal) equilibrium. Thus both avoid facing the problem[3] that research and development (R&D) efforts that lead to technical progress are "naturally associated with imperfectly competitive markets, as Schumpeter (1942) had forcefully argued" (Stiglitz 1990, 25). Later work by others (e.g., Grossman and Helpman 1991) formulated models in which firms operating in imperfectly competitive markets undertook R&D.

In sorting out the differences between neoclassical and recent growth models it is useful to start with Solow's growth model. Solow assumes an aggregate production function,

$$Y_t = A_t F(K_t, b_t L_t), \tag{1}$$

where Y_t is aggregate output at time t, K_t is the stock of capital, L_t is labor hours at time t, and A_t ($A_0 \equiv 1$) is the disembodied technology factor (i.e., index of total factor productivity), so that output at time t associated with any combina-

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[3] However, in Romer (1990) innovation is driven by profit-maximizing entrepreneurs.

tion of capital stock and labor input in efficiency units is A_t times the output at time zero associated with the same combination. Analogously, b_t (with $b_0 \equiv 1$) is the efficiency level of a unit of labor in period t, so that a unit of labor at time t is equivalent to b_t units of labor at time zero. Thus the technical progress induced by increases in b_t is *labor augmenting*. It is easily seen that technical progress through A_t is Hicks neutral, and that through b_t is Harrod neutral.

Let $\tilde{k}_t \equiv K_t/b_tL_t$, the ratio of capital to labor in efficiency units in period t, let $k_t \equiv K_t/L_t$, the ratio of capital to labor in natural units, and let $y_t \equiv Y_t/b_tL_t$, the level of output or income per unit of labor in efficiency units. Solow made the following crucial assumptions:

ASSUMPTION 1 (Neoclassical). F is homogeneous of degree one in its arguments and concave.

Given assumption 1, the average product of an efficiency unit of labor, i.e., $(1/b_tL_t)F(k_t, b_tL_t)$, equals $F(\tilde{k}_t, 1)$. Let $f(\tilde{k}_t) = F(\tilde{k}_t, 1)$. Clearly, concavity of F implies concavity of f as a function of $\tilde{k}_t$. In fact, f is assumed to be strictly concave with $f(0) = 0$.

ASSUMPTION 2 (Inada).

$$\lim_{\tilde{k}\to 0} f'(\tilde{k}) = \infty \quad \text{and} \quad \lim_{\tilde{k}\to\infty} f'(\tilde{k}) = 0.$$

In a closed economy, assuming that labor is growing exogenously as $L_t = (1 + n)^t L_0$, human capital or skill level is growing exogenously as $b_t = (1 + b)^t$, capital is depreciating at the rate δ per period, and denoting by c_t the level of consumption per efficiency unit of labor, we have

$$\tilde{k}_{t+1} = \frac{A_t f(\tilde{k}_t) + (1 - \delta)\tilde{k}_t - c_t}{(1 + n)(1 + b)}. \tag{2}$$

Solow further assumed that the savings rate is constant, i.e., $c_t = (1 - s)y_t$. Then equation (2) becomes

$$\tilde{k}_{t+1} = \frac{sA_t f(\tilde{k}_t) + (1 - \delta)\tilde{k}_t}{(1 + n)(1 + b)} \equiv g(\tilde{k}_t). \tag{3}$$

Equation (3) is the fundamental difference equation of the Solow model. If there is no disembodied technical progress, so that $A_t = 1$ for all t, then the phase diagram of the dynamic system can be represented as in figure 2.1. It is clear from figure 2.1 that, starting from any arbitrary initial capital-labor ratio $\tilde{k}_0$, the economy will converge (ignoring the inessential problem due to discreteness of time) to the steady state $\tilde{k}^*$, defined by $g(\tilde{k}^*) = \tilde{k}^*$, in which all the per capita variables, including per capita income, will grow at the rate b. Thus if $b = 0$, per capita income, consumption, and savings do not grow along the steady state. Further, policies that permanently affect the savings rate, or fertility rate, will have no long-run growth effects.

It is clear from figure 2.1, however, that out of the steady state (i.e., in the short run) economies will exhibit growth in per capita income even without

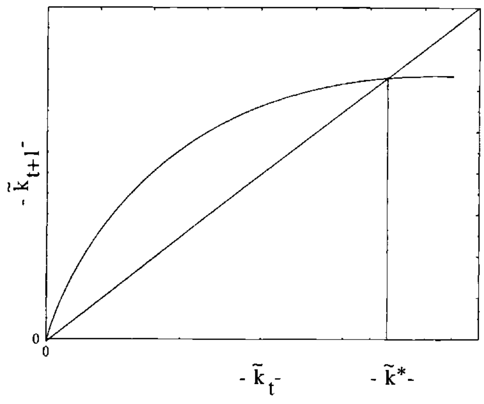

Fig. 2.1 Phase diagram of Solow model $g(\tilde{k}_t)$

technological change. The rate of growth will depend on the initial capital-labor ratio and the time period over which the average growth rate is calculated. It can be shown that the average growth rate *decreases* as the initial capital-labor ratio $\tilde{k}_0$ (and hence initial income per head) *increases*. As the initial capital-labor ratio tends to $\tilde{k}^*$, the average growth rate of per capita income converges to b, the exogenously given rate of labor-augmenting technical progress. This is indeed one of the convergence hypotheses that are tested in the recent empirical literature on growth. Policies that affect s and n clearly affect growth rates out of the steady state. However, the effects of changes in s and n on the growth rate of per capita income are only temporary, and the marginal product of capital will be declining over time. It should be noted, however, that this predicted fall in the marginal product of capital is not observed, for example, in U.S. historical data.

It is also clear that per capita output can grow indefinitely even in traditional growth models if the marginal product of capital is bounded away from zero as the capital-labor ratio grows indefinitely. Thus the standard neoclassical assumption that the marginal product of capital is a strictly decreasing function of the capital-labor ratio is not inconsistent with indefinite growth of per capita output. It has to diminish to zero as the capital-labor ratio increases indefinitely to preclude such growth. This is easily seen from equation (3).

Consider the simplest version of the neoclassical growth model with $b_t = 1$ and $A_t = 1$ for all t, so that $\tilde{k}_t = k_t$. Let $f(0) = 0$ and let the marginal product of capital, i.e., $f'(k)$, be bounded away from $(n + \delta)/s$ (i.e., $f'(k) > (n + \delta)/s$ for all k). Strict concavity of $f(k)$, together with $f(0) = 0$, implies $f(k) > kf'(k) > k(n + \delta)/s$, so that from equation (3) it follows that $k_{t+1} > k_t$. This in turn implies that output per worker, $f(k_t)$, grows at a positive rate at all t. Moreover, given strict concavity of $f(k)$, it follows that $f'(k)$ is monotonically decreasing and, hence, has a limiting value as $k \to \infty$, say, γ_y, that is at least as large as $(n + \delta)/s$. As such it can be verified that the asymptotic growth rate of output and consumption will be at least as large as $[s\gamma_y - (n + \delta)](1 + n) \geq 0$. The savings rate, s, can be made endogenous, thus leading to a theory of endogenous and sustained long-run growth in per capita income. Thus the neoclassical framework can endogenously generate long-run growth in per capita income. However, the assumption that the marginal product has a positive lower bound is not particularly attractive since it implies that labor is not essential for production.[4]

A primary goal of the recently revived growth theory is to build models that can generate sustained long-run growth in per capita income. A related objective is to ensure that the long-run growth rate of income (and, in fact, the entire time path of income) not only depends on the parameters of the production and utility functions, but also on fiscal policies, foreign trade policies, and population policies. In most models of "new" theory, the primary goal is accomplished through increasing scale economies in aggregate production. The resulting nonconvexities lead to multiple equilibria and hysteresis in some models so that history (i.e., initial conditions as well as any past shocks experienced by the economy) and policies have long-term effects.

In assessing the role of increasing scale economies in growth, it is useful to distinguish between generating *sustained growth* in output per head and *endogenizing* the rate of growth. For example, with the production function $Y = K^a L^b$, where $0 < a, b < 1$ and $a + b > 1$, and the labor force growing *exogenously* at the rate n there exists a unique steady state (regardless of the savings rate) in which output grows at the exogenous rate of $n(a + b - 1)/1 - a > 0$. Thus *increasing scale economies together with a marginal product of capital strictly diminishing to zero* (i.e., $0 < a < 1$) leads to *sustained* but *exogenous* growth. On the other hand, *constant returns to scale with a marginal product of capital bounded away from zero* at a sufficiently high positive number leads to *endogenous* and *sustained* growth. Thus increasing scale economies by themselves need not generate endogenous growth. It is also important to distinguish how different types of increasing returns to scale in aggregate production arise in various growth models. I consider here only two types: locally increasing marginal product of capital and scale economies due to spillover effects. For simplicity assume that in equation (1) $L_t \equiv 1$, $A_t = 1$, and $b_t = 1$, for all $t \geq 0$. The first type arises when the marginal product of capital, $f'(k)$, first increases with k and then decreases, or more generally when $f''(k) = 0$ has more than one but a finite number of solutions.

The second type arises in the models of Lucas and Romer. Building on the works of Arrow (1962) and Sheshinski (1967), Romer (1986) considers an economy in which there are n identical firms; each has a production function

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[4] One can easily prove this as follows: Suppose $\inf_{(K,L)>0} \frac{\partial F}{\partial K} \equiv \gamma > 0$. Since F is homogeneous of degree one, $F(1, L/K) = \partial F/\partial K + (L/K)(\partial F/\partial L) \geq \partial F/\partial K > \gamma > 0$. Now suppose $L \rightarrow 0$, then it follows that $F(1, 0) > 0$.

of the form $Y_i = G(K_i, L_i, K)$, where K_i is the stock of knowledge capital or R&D capital employed by firm i, $K = \sum_{i=1}^{n} K_i$ is the industry level aggregate stock of knowledge, and L_i is labor or any other inputs. K is assumed to have a positive spillover effect on the output of each firm, although the choice of K is external to the firm. Romer assumes that, for fixed K, G is homogeneous of degree one in other inputs. Supposing that all identical firms choose identical inputs, we can write $Y_i = G(K_i, L_i, nK_i)$. Define $F(K_i, L_i) \equiv G(K_i, L_i, nK_i)$. It is obvious that F exhibits increasing returns to scale in the inputs K_i and L_i. Again, in addition to these scale economies one needs to assume that the asymptotic marginal product of aggregate capital is positive in order to generate endogenous growth. Empirical support for the spillover effect of R&D capital is found in several empirical investigations (see Bernstein and Nadiri 1989 on Canadian industry data; Jaffe 1986 on the U.S. manufacturing firm–level data; Raut 1991b on Indian manufacturing firm–level data).[5]

Following Uzawa (1965), Lucas (1988) endogenizes Harrod-neutral (i.e., labor-augmenting) technological change through a mechanism of human capital accumulation. Suppose a worker of period t is endowed with b_t of human capital, or skill, and one unit of labor. He has to allocate his labor endowment between accumulating skills and earning wage income. If he devotes the fraction ϕ_t of his time in the current production sector and $1 - \phi_t$ (where $0 \leq \phi_t \leq 1$) in the learning sector (such as school or some vocational training program), he can increase his human capital in the next period by

$$\dot{b}_t = b_t\delta(1 - \phi_t). \tag{4}$$

The budget constraint for the representative agent is given by

$$c_t + \dot{k}_t = F(k_t, \phi_t b_t) - (n + \delta)k_t. \tag{5}$$

From equation (5) it is clear that for given c_t and k_t, the agent faces a trade-off. He can spend more time currently (i.e., choose a larger ϕ_t) in the production sector and thus have a larger *current consumption* or *future physical capital*, or choose a lower ϕ_t and thus have *larger future human capital* (i.e., higher $\dot{b}_t$) and hence a *larger future stream of output.* It is clear that he would divide his savings between human capital and physical capital in a balanced way so that the marginal product of capital does not fall to zero. Under the further assumption that the production function is of the Cobb-Douglas form

$$F(K, L) = A(b_t)K_t^{\alpha}(b_t L_t)^{\beta}, \quad \alpha + \beta = 1, \quad \alpha, \beta > 0, \tag{6}$$

where the spillover effect is given by $A(b_t) = Ab_t^{\mu}$, $0 < \mu$, it can be shown that, along the balanced growth path, the capital-labor ratio and hence per capita income and consumption will be growing at the rate

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[5] However, Benhabib and Jovanovic (1991) do not find any evidence for spillover using the U.S. macrodata.

$$\gamma_y = \left(\frac{1 - \beta + \mu}{1 - \beta}\right)(1 - \phi)\delta, \tag{7}$$

where ϕ_t is a constant equal to ϕ. Since γ_y is a function of ϕ, which is endogenously determined, the growth rate of per capita income is endogenously determined.

It should be noted that even if there is no spillover effect, i.e., $\mu = 0$, γ_y is positive, and this of course is the consequence of the assumption that the marginal return to time devoted to skill accumulation is constant and not diminishing. As Lucas himself points out, this is crucial for generating sustained growth per capita consumption in the long run. Since the opportunity cost of time spent on skill acquisition is foregone income that could have been used for consumption or accumulation of physical capital, this crucial assumption should be viewed as the equivalent of assuming that the marginal product of physical capital is constant as in the Harrod-Domar model.

The Lucas model is essentially a two-sector growth model. Human capital and the process of its accumulation play essentially the same role as the capital goods sector in the two-sector model of Mahalanobis (1955). In this model, marginal product of capital in the capital goods sector is constant—an assumption that is the equivalent of Lucas's crucial assumption about the process of human capital accumulation (Srinivasan 1993a).[6] The rate of growth of income and consumption was endogenously determined in the Mahalanobis model by the share of investment devoted to the accumulation of capacity to produce capital goods. The share $(1 - \phi_t)$ of time devoted to skill acquisition plays an analogous role in the Lucas model.

Linearity of the technology of skill acquisition in the Lucas model is restrictive. It leads to a unique balanced growth solution. However, if a nonlinear (convex) technology is assumed, there could be multiple optimal balanced growth paths that are locally stable, as has been shown by Azariadis and Drazen (1990).

Raut and Srinivasan (1991) present a model that not only endogenizes growth and the process of shifts in production possibilities over time (i.e., technical change) but also generates richer dynamics than the models of recent growth theory. First, by assuming fertility to be endogenous,[7] they preclude the possibility of aggregate growth being driven solely by exogenous labor force growth in the absence of technical change. Second, by assuming that population density has an external effect (not perceived by individual agents) on the

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[6] It is also evident that the absence of long-run growth effects of trade in dynamic versions of Heckscher-Ohlin-Samuelson–type models of international trade is again due to their implicitly or explicitly precluding the marginal product of capital being bounded away from zero.

[7] There are a number of models in the literature in which the interaction of endogenous fertility and productive investment in human capital are analyzed in a growth context. My purpose here is not to survey this literature. I refer the interested reader to one of the very interesting such models by Becker et al. (1990).

production process either through its negative congestion effect or through its positive effect in stimulating innovation and technical change, they make the change in production possibilities endogenously determined by fertility decisions of individual agents. However, unlike the new growth literature, their model, which is an extension of Raut (1985, 1991a), is not necessarily geared to generating steady states. In fact, the nonlinear dynamics of the model generates a plethora of outcomes (depending on the functional forms, parameters, and initial conditions) that include not only the neoclassical steady state with exponential growth of population with constant per capita income and consumption, but also growth paths which do not converge to a steady state and are even chaotic. Per capita output grows exponentially (and superexponentially) in some of the examples.

The model draws on the insights of E. Boserup (1981) and J. Simon (1981) who, among others, have argued that the growth of population could itself induce technical change. In the Boserup model, increasing population pressure on a fixed or very slowly growing supply of arable land induces changes in methods of cultivation, not simply through substitution of labor for land by choice of techniques within a known set but, more importantly, through the invention of new techniques. Simon also attributes a positive role for increases in population density in inducing technical progress. Since having a large population is not sufficient to generate growth (Romer 1990), it is important to examine the mechanism by which population density influences innovation. However, neither of the two authors provides a complete theory of induced innovation. Raut and Srinivasan do not provide one either; they point out that the inducement to innovate will depend largely on the returns and risks to resources devoted to innovative activity and that there is no particular reason to suggest that preexisting relative factor prices or endowments will necessarily tilt these returns toward search for technologies that save particular factors. They simply analyze the implications of assuming that technical change is influenced by population density (strictly speaking, population size) in a world where fertility is endogenous.

More precisely, they assume that technical change in our model economy is Hicks neutral and that its rate is determined by the change in the size of the working population. Thus, instead of the aggregate production function in equation (1), they use the following:

$$Y_t = A(L_t)F(K_t, L_t). \tag{8}$$

However, for both consumers and firms in this economy, $A(L_t)$ is an externality. This externality is introduced in a model of overlapping generations in which a member of each generation lives for three periods, the first of which is spent as a child in the parent's household. The second period is spent as a young person working, having and raising children, and accumulating capital. The third and last period of life is spent as an old person in retirement, living off support received from each of one's offspring and from the sale of accumulated capital. All members of each generation are identical in their preferences defined over their consumption in their working and retired periods. Thus, in this model the only reason that an individual would want to have a child is the support the child will provide during the individual's retired life. Production (of a single commodity which can be consumed or accumulated) is organized in firms which buy capital from the retired and hire the young as workers. Markets for product, labor, and capital are assumed to be competitive.

Formally, a typical individual of the generation which is young in period t has n_t children (reproduction is by parthenogenesis!), consumes c_t^t and c_{t+1}^t in periods t and $t + 1$, and saves s_t in period t. She supplies one unit of labor for wage employment. Her income from wage labor while young in period t is w_t, and that is her only income in that period. A proportion α of this wage income is given to her parents as old age support. While old in period $t + 1$, she sells her accumulated saving to firms and receives from each of her offspring the proportion α of his or her wage income. She enjoys a utility $U(c_t^t, c_{t+1}^t)$ from consumption. Thus her choice problem can be stated as

$$\max_{st,nt>0} U(c_t^t, c_{t+1}^t), \tag{9}$$

$$c_t^t + \theta_t n_t + s_t = (1 - \alpha)w_t, \tag{10}$$

$$c_{t+1}^t = (1 + r_{t+1})s_t + \alpha w_{t+1} n_t, \tag{11}$$

where θ_t is the output cost of rearing a child until young.

Profit maximization of the producer yields

$$w_{t+1} = A(L_{t+1})[f(k_{t+1}) - K_{t+1} f'(k_{t+1})], \tag{12}$$

$$1 + r_{t+1} = A(L_{t+1})f'(k_{t+1}), \tag{13}$$

where $f(k) = F(k, 1)$ (since $F(K, L)$ is assumed to be homogeneous of degree one) and $1 + r_t$ is the price of capital in period t. In equilibrium, the private rates of return from investing in children and physical capital are equal so that arbitrage opportunities are ruled out. This implies that

$$\frac{\alpha w_{t+1}}{\theta_t} = 1 + r_{t+1}. \tag{14}$$

Plugging equations (12) and (13) in equation (14), we get an implicit equation linking k_{t+1}, θ_t, and α. It can be shown that, under standard neoclassical assumptions on the production function, we can solve for k_{t+1} as a function $\Psi(\theta_t/\alpha)$. Since $k_{t+1} = s_t/n_t$ (given the assumption that capital depreciates fully in one generation), the budget constraints (10) and (11) become, respectively,

$c^t_t = (1 - \alpha)w_t - S_t$ and $c^t_{t+1} = (1 + r_{t+1})S_t$, where $S_t = [\theta_t + \Psi(\theta_t/\alpha)]n_t$. S_t can be thought of as total savings.

Denote the solution of the above utility maximization problem by $S_t = H(w_t, 1 + r_{t+1})$. The solutions for n_t and s_t can be expressed as

$$(15) \qquad n_t = \frac{H(w_t, 1 + r_{t+1})}{\theta_t + \Psi(\theta_t/\alpha)}, \quad s_t = \frac{H(w_t, 1 + r_{t+1})}{\Psi(\theta_t/\alpha)[\theta_t + \psi(\theta_t/\alpha)]}.$$

Equation (15) determines the dynamics of the system. First consider the simplest case in which the child-rearing cost $\theta_t = \theta$, for all $t \geq 0$. It is clear that $k_{t+1} = k^*$, defined by $k^* = \psi(\theta/\alpha)$, for all $t \geq 1$ in this case. Assuming further that the utility function is Cobb-Douglas, i.e., $U = a \log c^t_t + (1 - a) \log c^t_{t+1}$, we have $H(w_t, 1 + r_{t+1}) = (1 - a)w_t$. Equation (15) now yields

$$n_t = \frac{L_{t+1}}{L_t} = \frac{(1 - \alpha)(1 - a)}{(\theta + K^*)} w^* A(L_t),$$

or

$$(16) \qquad L_{t+1} = \lambda L_t A(L_t) \equiv G(L_t),$$

where $\lambda = [(1 - \alpha)(1 - a)w^*]/(\theta + k^*)$. From equation (8), one notes that per capita income is given by $y_t = A(L_t)f(k^*)$. Thus, the dynamics of population long-run behavior of per capita income hinge on the function $A(L_t)$. It should be recalled that, although the fertility decisions of individuals determine L_t and hence $A(L_t)$, this is an unperceived externality. A few possibilities are depicted in figures 2.2*A*–2.2*C*.

Suppose $A(L_t)$ is such that $G(L_t)$ is a concave function which is zero at $L_t = 0$ and satisfies the Inada condition. Then, in the long run, the population will be stationary and per capita income will be constant as in the standard neoclassical growth model. This is shown in figure 2.2*A*. Now suppose that $G(L_t)$ is concave but $G'(L_t)$ is bounded away from one. In this case, we have long-run growth in L_t and hence in per capita income. This is shown in figure 2.2*B*.

Suppose now that $A(L_t)$ is a logistic function with a positive asymptote, such as $A(L) = \gamma e^{-(L-\bar{L})2}$, for $L \geq 0$. It can be shown (Raut and Srinivasan 1991) that there are multiple steady states. Figure 2.2*C* shows a case of two steady states L^* and L^{**}. $G(L)$ reaches its maximum at $\bar{L}$. The properties of these steady states depend on the parameter values. If the maximum $\bar{L}$ is to the right of L^{**}, then L^{**} is locally stable and there exists a neighborhood around L^{**} within which the system is monotonic. On the other hand, if $\bar{L}$ is to the left of L^{**}, as in figure 2.2*C*, there can be a nongeneric set of parameter values for which the system will exhibit endogenous fluctuations that can be damped, exploding, or even chaotic. However, since α can affect λ, if α is partly influenced by the government through social security schemes, the government can shift $\bar{L}$ to the right of L^{**} and thus, locally at least, a social security program can stabilize fluctuations.

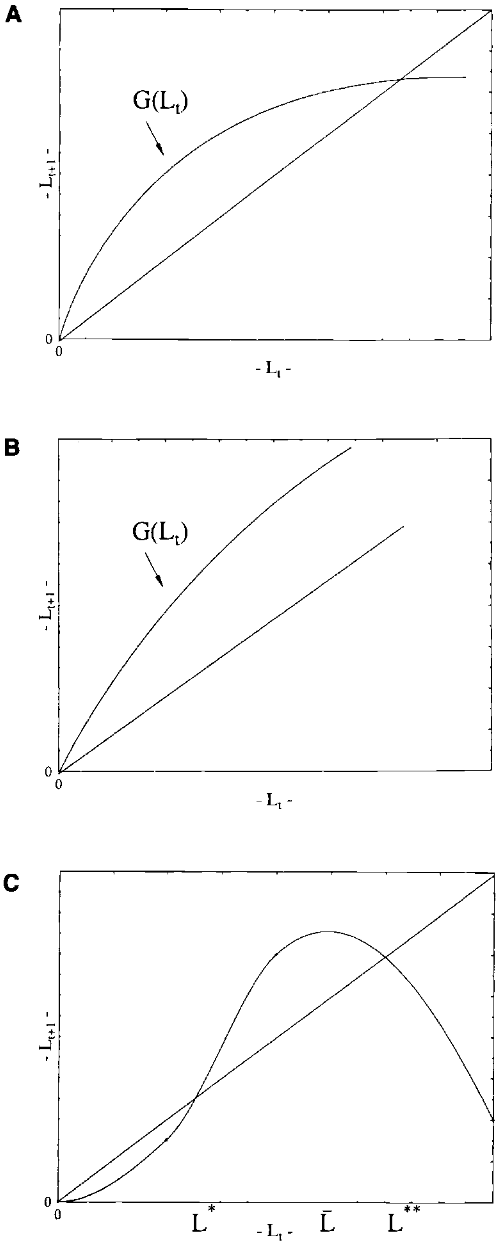

Fig. 2.2 ***A:*** **Stationary population and income.** ***B:*** **Sustained growth in population and income.** ***C:*** **Phase diagram of** $G(L_t)$**.**

More general childbearing costs are considered by Raut and Srinivasan (1991, sec. 4a), involving parent's time and depending on the rate of technological change. Naturally these lead to more complicated dynamical problems. They show that there can be superexponential growth in per capita income in the long run in the case of some specific functional forms for general costs of childbearing.

To sum up this section, the starting point of some, though not all, of the recent contributions to growth theory is a misleading characterization of neoclassical growth theory of the 1960s and earlier as implying that a steady state growth path always exists along which output grows at a rate equal to the exogenously specified rate of growth of the labor force in efficiency units. Thus, in the absence of labor-augmenting technical progress, per capita income does not grow along the steady state path. Policies that affect savings (investment) rates have only transient effects on the growth rate of per capita output, though its steady state *level* is affected. Even a cursory reading of the literature is enough to convince a reader that neoclassical growth theorists were fully aware that a steady state need not exist and that per capita output can grow indefinitely even in the absence of technical progress, provided the marginal product of capital is bounded away from zero by a sufficiently high positive number. Moreover, they showed that, once one departs from the assumption that the marginal product of capital *monotonically* declines to zero as the capital-labor ratio increases indefinitely, multiple steady state growth paths (only some of which are stable) are likely and that the steady state to which a transition path converges will depend on initial conditions. Attempts at endogenizing technical progress were also made by theorists of the era.

It was argued above that the perceived problems of neoclassical growth theory are not inherent features of all the growth models of the era but only of those which assumed the marginal product of capital (or more generally of any reproducible factor) diminishes to *zero* as the input of capital (or that factor) is increased indefinitely relative to other inputs. Instead of directly relaxing this assumption about production technology, the "new" growth theorists in effect make assumptions that are analogous to assuming that the marginal product of capital is bounded away from zero. In some of the models this is achieved by introducing a factor other than physical capital (e.g., human capital, or stock of knowledge) which is not subject to inexorable returns. In doing so, some authors end up with an aggregate production function that exhibits increasing scale economies. Unsurprisingly, in such models multiple equilibria are possible.

The Raut-Srinivasan (1991) model takes a different approach to endogenizing technical progress and growth by assuming fertility and savings to be *endogenous* and the size of the total population to have an external effect (of a Hicks-neutral type) either through the negative influence of congestion or the positive stimulation of faster innovation. This model generates a rich set of growth paths for per capita income and consumption, some of which do not converge to a steady state and are even chaotic.

2.3 Empirics of Growth

The recent revival in theories of long-run growth has also revived its empirical analysis. Of course, such analysis has a long history going back to the pioneering works of Simon Kuznets (1966), Abramowitz (1956), and Denison (1962). Solow himself followed his justly celebrated article (Solow 1956) on the theory of growth with an almost equally celebrated empirical analysis (Solow 1957) of long-run growth in the United States. The early pioneers and Solow were interested in growth accounting, i.e., apportioning the observed long-run growth in real output between the growth of factor inputs on the one hand and the growth of total factor productivity on the other. Some recent studies (Benhabib and Jovanovic 1991; Boskin and Lau 1992a, 1992b; Jorgenson 1990; Kim and Lau 1992a, 1992b, 1992c) are in the growth accounting tradition. Many of the other recent empirical studies (Baumol 1986; Barro 1989; Barro and Sala-i-Martin 1992; DeLong 1988; Dowrick and Nguyen 1989; Jorgenson 1990; Mankiw, Romer, and Weil 1992) attempt to test an aspect of neoclassical growth theory, namely, convergence of the economy to the steady state.

The strong version of the convergence hypothesis asserts that, if all economies had access to the *same aggregate production function* exhibiting constant returns to scale in capital and effective labor inputs, experienced the *same rate of growth of labor force* and labor-augmenting technical progress, and saved and invested the *same share of output,* they would all converge to the *same steady state* at which output and capital would grow at the same rate as effective labor, i.e., the sum of the rates of growth of labor force and labor-augmenting technical progress. The weak version, known as "conditional" convergence, allows for possible differences in steady state levels of output across economies due to differences in savings rates and initial level of labor-augmenting technical progress functions. The publication by Summers and Heston (1988, 1991) of purchasing power parity (PPP) adjusted data for a large number of countries for the period since 1960 enabled tests of a variety of convergence hypotheses.

Jorgenson (1990) commemorated 50 years of research on economic measurement by contributing to the theme of economic growth and its sources. He points out that until recently "the study of sources of economic growth has been based on the notion of an aggregate production function [which makes] it possible to summarize a welter of detailed information within a single overarching framework. . . . At the same time the concept of an aggregate production function is highly problematical, requiring very stringent assumptions on production patterns at the level of individual sectors of the economy" (1990, 19). In contrast to Solow (1957), Jorgenson finds that growth of inputs, rather than growth in total factor productivity, was the driving force behind the expansion of the U.S. economy between 1947 and 1985. In the growth of value added at 3.28 percent per year on the average during this period, growth of capital inputs accounted for 44 percent, labor inputs 34 percent, and productivity accounted for the least, namely, 22 percent. The difference between followers of Solow (1957) and of Jorgenson arises from the fact that Jorgenson carefully distinguishes the separate contributions of capital and labor quality from the contributions of capital stock and hours worked. This distinction is extremely important since both capital and labor inputs are very heterogeneous. Solow (1957) and others following him do not allow for quality differences in their measurement of quantity of inputs. Since Jorgenson's assumptions about the aggregate production function are strictly neoclassical (in particular, returns to scale are assumed to be constant and externalities are virtually absent), the fact that he is able to explain most of the observed growth in the United States by growth of inputs appropriately measured suggests that, if his framework is accepted, the analytical innovations of recent growth theory need not be invoked to explain growth performance!

Unfortunately, it is not simple to decide whether Jorgenson's framework or other frameworks that maintain neoclassical assumptions are indeed the appropriate ones. After reviewing the conventional methodology of the measurement of technical progress and growth accounting and the results of the growth-accounting exercises of various authors, Boskin and Lau point to two major

> pitfalls of maintaining the traditional assumptions of constant returns to scale, neutrality of technical progress and profit maximization with competitive output and input markets in the measurement of technical progress and growth accounting. First, . . . for an economy in which aggregate real output and inputs are all growing over time, it is in general difficult to identify separately the effects of returns to scale and technical progress—either one can be used as a substitute explanation for the other. Thus, to the extent that there are increasing returns to scale, maintaining the hypothesis of constant returns to scale results in an over estimate of technical progress; and to the extent there are decreasing returns to scale, maintaining the hypothesis results in an underestimate. . . . A further implication (of maintaining constant returns to scale when there are increasing returns to scale) is that the contributions of the capital and labor inputs to economic growth will also be underestimated. The reverse is true if there are decreasing returns to scale.
>
> Second, . . . if technical progress is non-neutral, then the rate of technical progress at time *t* will vary depending on the quantities of capital and labor inputs at time *t*. Moreover, technical progress by many periods cannot be expressed simply as a cumulative sum of the technical progress that has occurred over the individual periods, nor can it be expressed simply as an average (Boskin and Lau 1992a, 24).

In a series of papers, Boskin and Lau (1992a, 1992b) and Kim and Lau (1992a, 1992b, 1992c) apply "a new framework for analysis of productivity and technical progress, based on the direct econometric estimation of an aggregate meta–production function, that does not require the traditionally maintained assumption. . . . This new approach enables the separate identification of not only the degree of returns to scale and the rate of technical progress . . . but also their biases, if any" (Boskin and Lau 1992a, 33).

Their application (Boskin and Lau 1992b) to the Group of Five countries (France, West Germany, Japan, the United Kingdom, and the United States) shows that, while the assumption that all countries have the same underlying meta–production function of the transcendental logarithmic form cannot be rejected, traditional growth-accounting assumptions are all rejected. Returns to scale are found to be sharply diminishing, and technical progress may be represented as purely capital augmenting and capital saving rather than labor saving. Their growth-accounting exercise leads them to conclude that technical progress is found to be the most important source of growth, accounting for more than 45 percent, followed by growth of capital input. Kim and Lau (1992c) apply the same approach to nine countries including the Group of Five and the four East Asian newly industrialized countries (NICs)—Hong Kong, Singapore, South Korea, and Taiwan. Interestingly, they find that the hypothesis of a single meta–production function applying to all nine countries cannot be rejected. While they reaffirm the findings of Boskin and Lau that technical progress can be represented as purely capital augmenting, they cannot reject the hypothesis that there has been no technical progress in the NICs, with more than 80 percent of their economic growth being explained by capital accumulation.

It has long been argued (Mahalanobis 1955; Rosenberg 1963) that the cost of equipment (and alternatively investment in equipment) might have an important role to play in the growth process. Indeed, in arguing for the establishment of a domestic heavy machinery industry, Mahalanobis insisted that "for rapid industrialization of an under-developed country it would be desirable to keep the cost of capital goods as low as possible. The further removed the type of capital goods under consideration is from the production of final consumer goods the greater is the need of keeping the price low. Heavy machinery which would manufacture machinery to produce investment goods is the furthest removed from the consumption end" (Mahalanobis 1955, 51).

Interestingly enough, some economic historians have attributed the Western success in industrialization to the development of heavy industries, particularly those producing machine tools and capital goods. In words that echo Mahalanobis's, quoted above, Nathan Rosenberg asserts that "a major handicap of underdeveloped countries, then, is located in their inability to produce investment goods at prices sufficiently low to assure a reasonable rate of return on prospective investments. Reasoning symmetrically, of the most significant propelling forces in the growth of currently high-income countries has been the technological dynamism of their capital goods industries which has maintained the marginal efficiency of capital at a high level" (Rosenberg 1963, 226).

More recently DeLong and Summers (1991) found that variations in investment in equipment explained a significant part of the variations in economic growth in countries. Kim and Lau (1992b) test a version of a related hypothesis, namely, that technical progress is embodied in new investments so that it can affect the output of an economy only through the form of new capital goods. They found, using an aggregate meta–production model incorporating vintage effects, that the hypothesis of no embodied technical progress can be rejected for the Group of Five countries, with the vintage effect; namely, the productivity of new equipment relative to that in the preceding period is higher by 4 to 5 percent. The contribution of embodied technical progress to growth was found to range from 55 percent for Japan to 70 percent for the other four countries.

The studies by Lau and his coauthors, on the one hand, restore a significant role for productivity growth in explaining aggregate growth, but on the other, they find little productivity growth in NICs. This creates a problem for those who attribute the spectacular growth of NICs to the dynamic productivity gains arising from their outward orientation!

The time-series–cum–cross-section analyses of growth by Jorgenson and by Lau and his coauthors have the virtue that the econometric model they estimate is derived from a well-specified theory and, further, that the possibility of testing the specification is also present. Unfortunately, many recent cross-sectional analyses of growth using "data" from literally a hundred or more countries (e.g., Barro and Lee 1994 include 133 countries in growth-rate regressions) are rarely based on a well-specified theoretical model. For example, inclusion of variables such as school attainment of the population or some measure of educational stock is motivated merely by appeals to the role of human capital in growth. However, without an analytical framework that formalizes the process of human capital accumulation (e.g., learning by doing) and how it relates to *aggregate* growth in different economies, it is impossible to infer anything meaningful from the significant statistical significance (or lack thereof) of the estimated parameter associated with the human capital variable.

Indeed, as Lucas (1993) points out in his extremely stimulating paper, "establishing the importance of learning by doing for productivity growth on a specific production process is very different from establishing its importance for an entire economy as a whole, or even an entire sector" (252–53). In attempting to explain episodes of sustained and rapid growth over nearly three decades, as in East Asian economies, Lucas correctly suggests that one needs a theory that incorporates the *possibility* of rapid growth episodes, but that at the same time does not imply their occurrence as a simple consequence of the relative backwardness of the countries experiencing them. In his view, a successful theory should be as consistent with the experience of Korea, with its rapid growth since the mid-1960s, as with that of the Philippines, which experienced no such growth, although both economies started from roughly similar situations. Lucas finds that models of technical learning with spillover such as those of Stokey (1988), Young (1991), and Grossman and Helpman

(1991) constitute such a theory. Whether or not this is the case, the cross-sectional growth analysts, by the very fact of their estimating the same model using data from many countries, *assume* that the theory, if any, that is implicit in the estimated model is applicable to all of them! For example, Mankiw et al. (1992) go as far as to *assume* that the *sum* of the rates of labor-augmenting technical progress and depreciation of capital are the *same* (i.e., 5 percent per year) *across* 98 *countries* ranging from Angola to Zimbabwe and *over time,* between 1960 and 1985!

In a series of papers Levine and Renelt (1991, 1992) and Levine and Zervos (1993a, 1993b) have thoroughly reviewed the methodological, conceptual, and statistical problems of, as well as isolated what they deem "robust" findings from, cross-country studies. The data and measurement problems are far more serious than they realize. For example, in the cross-country study of growth by Barro and Lee (1994) the variables considered include school attainment, life expectancy at birth, and infant mortality in 1965, 1975, and 1985. In Sen's (1993) study of "regress," the change in the rate of mortality of children under five years during 1965–91 is an important indicator. Unfortunately, the authors do not recognize that the data they use for many developing countries are at best projections and certainly not actual observations. According to the United Nations (1991), relatively reliable and recent (i.e., a reference period of 1980 or later) data for estimating life expectancy at birth (respectively, infant mortality) are not available for as many as 87 (respectively, 65) out of 177 less-developed countries, many of which are included in the Barro and Lee (1994) study! The same source points out that reliable data on levels of mortality under age five are not available for 29 countries, and available data related to a period prior to 1980 for as many as 54 out of the same 117 countries. UNESCO (1991) finds that, out of a total of 145 countries (including developed countries), for 19 no data exist on adult literacy since 1970 and for 41 the latest data relate to a year in the decade 1970–79!

Many of the cross-country studies use GDP data based on the PPP exchange rate, put together by Summers and Heston (1988, 1991). Although Summers and Heston are careful to list the problems with their data, including in particular identifying commodities that are close to being identical in different countries so that they can be priced out using a common set of prices, users pay scant attention to their warnings (see the appendix). It is one thing to adjust for international differences in *price* structures as Summers and Heston do. But what they do not adjust for, and what in many cases is more serious, are *biases* in measurement of quantities (Srinivasan 1993b). Indeed Summers and Heston (1991) themselves assign a quality rating of D+ or D to the data of 66 out of their 138 countries, most of which are less-developed countries, 37 of them African countries. Data on investment are particularly unreliable. Biases, as well as measurement errors, might vary in an unknown fashion over time and across countries, and obviously such variations have implications for growth regressions.

Levine and Renelt (1992) and Levine and Zervos (1993b) use the methodology of extreme-bound analysis pioneered by Edward Leamer for distinguishing "robust" from "fragile" relationships between policy and outcome indicators. In this methodology, in a cross-country regression, a set of basic explanatory variables, *I*, is always included and *Z* is a set of up to three explanatory variables chosen from a pool of policy indicators. *M* is the policy indicator of particular interest. If the coefficient of *M* in the regression is consistently significant and of the same sign as the set of *Z* variables is varied over the pool of policy indicators, then the relationship between the dependent variable and policy indicator *M* is deemed "robust," otherwise it is "fragile." The motivation for this is the finding in Levine and Renelt (1992) that small changes in the explanatory variables produce different conclusions about the relationship between individual policies and growth outcomes in cross-country studies. While the motivation is admirable and the procedure certainly interesting, there are conceptual problems with the procedure. In principle, the use of different sets of variables to explain the *same* dependent variable imply different "models" of growth. As such, the sign, as well as the statistical significance, of the coefficient of a given variable *M* is thus model specific. Should the sign or significance change as "models" are changed, does it imply that the relationship between *M* and the dependent variable should be viewed as fragile? I think not: The reason is that the sign itself may be specific to the model, and certainly the test of significance is model specific. For example, the same policy variable *M* may be positively related to growth in one model or theory of growth as represented by the other variables included, and negatively related in another. This problem does not disappear, even if the policy variables included in the pool are of the same "genre" (i.e., trade policy, financial policy, etc.) as *M*.

It is worth recognizing that policy indicators as well as some of the other variables often included in cross-country regressions are *endogenous*. In studies involving cross sections repeated over time, country-specific effects (fixed or random) are sometimes included. Since the other explanatory variables (particularly policy variables) might plausibly correlate with country-specific effects as Deaton (1995) points out, the random effects estimator will be inconsistent. On the other hand, if these effects are treated as *fixed*, removing fixed effects by differencing introduces a correlation between the disturbance term in the differenced regression and its explanatory variables, if the latter include lagged values of the dependent variable. If the number of time periods over which the cross sections are repeated is small relative to the number of countries included in each cross section, the fixed effect estimate will also be inconsistent. Not all analysts address such problems by the use of appropriate econometric techniques, such as the use of instrumental variables. Even those who do rarely report how good the instruments actually used were and how robust the results were to changes in the instruments.

2.4 Conclusions and Policy Implications

The purpose of the cross-country regression analysis is not only to "explain" the growth process and its determinants but also presumably to derive policy lessons. In an earlier set of studies, Chenery (1960) and Chenery and Syrquin (1975, 1989) suggested that their cross-country regression "can be thought of as reduced forms of a more detailed general equilibrium system" (Chenery and Syrquin 1975, 10) and viewed their analysis as leading "to the identification of three main patterns of resource allocation identified . . . as: *large country, balanced allocation; small country, primary specialization; small country, industry specialization*" (1975, 4). In inferring a typology of development patterns from a policy perspective, these authors were eclectic since they were aware that causal interpretation of reduced-form relationships is hazardous. Their inferences were based on comparing countries that are following similar development patterns and the policies chosen by countries under similar conditions.

There can be no doubt that the recent contributions to the theory and empirical analysis of the process of growth have substantially increased our knowledge about the analytics of growth and the potential role of human capital accumulation, investment in research and development, international trade, and externalities and scale economies (arising in part from nonrivalry and nonexcludability in use of knowledge) in the growth process. Whether public policy intervention in the economy is called for from the perspective of influencing the growth process and, if so, what the character of such intervention should be are issues on which recent work has provided some valuable insights; but understandably, no conclusive answers have yet emerged. For example, if the contribution of *endogenous* factor accumulation is *small* and an overwhelming share of observed growth is due to *exogenous* technical progress, as in the Solow (1957) story of U.S. growth, there is little that public policy could do to affect the growth process significantly. In contrast, if most of growth could be attributed to factor accumulation (physical and human), as in Jorgenson (1990), then public policy intervention could influence growth. This is not to say either that the U.S. experience is likely to be repeated in the developing world or that public policy intervention is desirable from a welfare perspective.

To take another example, it is undeniable that the East Asian economies of Hong Kong, Korea, Singapore, and Taiwan have not only grown substantially faster than almost all other developing countries over the three decades since 1960, but also shown rapid and sustained growth that is historically unprecedented. Whether it is a miracle, as a recent study (World Bank 1993) and Lucas (1993) deem it, is arguable. All four countries had two things in common in their policy, namely, their emphasis on human capital and on outward orientation, while they differed in the extent of government intervention in markets, ranging from no intervention in Hong Kong to extensive intervention in Korea.

The nature of their regimes differed as well, although all were authoritarian to a considerable extent. Analogous to the Solow-Jorgenson differences in accounting for U.S. growth, in the case of East Asia some find substantial contribution of total factor productivity growth to total growth, whereas Kim and Lau (1992c) and Young (1993) find factor accumulation (human and physical capital) accounting for most of their growth. To what extent their outward orientation and public policy interventions contributed to their unprecedented growth is a matter of intensive debate as well, with some (e.g., Anderson 1989) emphasizing that interventions in the economy succeeded only where they met the test of competitiveness in world markets and the World Bank (1993) being in the middle!

Cross-country regressions testing some version or the other of the convergence hypothesis relating to *aggregate* growth, whatever other insights they have yielded about the growth process, by their very nature have little to say about the microeconomic forces that together generate the aggregate outcome. Here again the observations of Lucas are pertinent:

> I do not intend these conjectures about the implications of a learning spillover technology for small countries facing given world prices to be a substitute for the actual construction of such a theory. . . . What is the nature of human capital accumulation decision problems faced by workers, capitalists and managers? What are the external consequences of the decisions they take? The purpose cited here considers a variety of possible assumptions on these economic issues, but it must be said that little is known, and without such knowledge there is little we can say about the way policies that affect incentives can be expected to influence economic growth (Lucas 1993, 270).

Appendix

The Summers-Heston Data

There are two extrapolations involved in the Summers-Heston data: the first from *benchmark countries* (which varied from 16 in 1970 to 56 in 1985) to *other countries* for the benchmark year, and the second, from *benchmark years* (1970, 1975, 1980, and 1985) to *other years* in the period 1960–85 (Summers and Heston 1991, app. A-2).

For the first, they use "capital city price surveys conducted around the world by the United Nations International Civil Service Commission, a British firm serving an association of international businesses, and the U.S. State Department" (1991, 341). While recognizing that "the price indexes appropriate for this very special population—high-income non-nationals, living usually in capital cities—does not properly reflect all the prices in the country, of course, nor do the individual price weights reflect the relative importance of the individual goods in the countries for the nationals" (341), they nonetheless found a structural relationship "in the benchmark country's PPP and its postallowance PPP" and exploited it "to estimate for the non-benchmark countries missing PPP's from their post allowance PPP's" (342).

For the second, they go from a benchmark year, say 1985, to other years "by applying the relevant growth rates from the constant-price national accounts series—the values for the year of interest divided by the corresponding 1985 ones—to the 1985 number" (343). As is well known, using one set of prices as opposed to another in appraising growth performance can lead to biases. For example, if the domestic price structure deviates significantly from world prices (assumed to be constant over time for simplicity) because of distortionary nonoptimal tariff policies, the production possibility frontier could unambiguously shift outward and real GDP at domestic prices could show *growth* from one period to the next, while the same outputs evaluated at world prices, show a *decline* (Bhagwati and Hansen 1973). In any case, Summers and Heston correctly caution that "growth rates based on international prices can differ significantly from those based on national prices, but when they do, it is nearly always the case that relative prices within the countries have changed substantially over the period" (1991, 361). I might add that rapid development over an extended period will almost always involve substantial changes in relative prices, particularly of the basket of internationally traded goods relative to nontraded goods.

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Comment

Paul M. Romer

Research on economic growth alternates between periods of boom and bust. These fluctuations disrupt the cumulative nature of scientific inquiry. When a topic like growth goes out of fashion, much of what is known in the area is not transmitted to students. Then when activity picks up, a new generation of researchers wastes time rediscovering results that have previously been established.

This inefficiency can be reduced if there are economists who can span more than one boom in research on growth. The profession is fortunate to have such a scholar in T. N. Srinivasan. He made important contributions to the theory of growth during the 1960s. The work with Lakshmi Raut described here shows that he is doing so once again in the 1990s. This particular paper uses the experience acquired in the first round to comment on recent developments in growth theory. Any economist who was not active in growth theory during the 1950s and 1960s can learn from what he has to say.

Srinivasan makes two general points. As the title suggests, one is about theory and the other is about empirics. The warning about the empirical work is easy to state and hard to dispute: The cross-country data on aggregate measures such as growth rates, literacy rates, and life expectancy suffer from many deficiencies.

Srinivasan would no doubt agree that there is something to be learned from cross-country data. For example, when I was a graduate student, I was taught that there was no correlation in the data between aggregate rates of investment and the rate of growth of income per capita. Now we know that this correlation is quite strong and survives all attempts to hold constant the effects of other variables. Of course, correlation does not resolve questions about causality. Many different theories of growth are consistent with this new addition to our list of stylized facts about growth. But if one is going to use stylized facts, it is surely better to rely on ones that are true instead of ones that are false.

That being said, Srinivasan is correct in arguing that some of the claims

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derived from an analysis of the cross-country data are too strong. There is important measurement error in the underlying data. Empirical analyses would be more useful if they took explicit account of this fact.

I will direct the balance of my comments to the theoretical point in this paper. It can be summarized as follows. All models that exhibit growth at a constant exponential rate contain an equation of the form

$$\frac{dX}{dt} = \_\_X(t). \tag{1}$$

All the disagreement is about the expression that fills in the blank and the name that is attached to the variable X. This equation, or the variable X itself, is often given the colorful label "the engine of growth." When the theory fills in the blank with an expression that remains constant over time, $X(t)$ grows at a constant exponential rate. True to its name as an engine, $X(t)$ pulls the rest of the economy along with it.

In a model with exogenous technological change, $X(t)$ is the level of the technology at date t and a constant—the rate of exogenous technological change—fills in the blank. Linear growth models treat X as a capital good (or a vector of capital goods) and fill in the blank with an expression that depends on the savings or investment rate. Models based on human capital accumulation give a corresponding label to X and fill in the blank with an expression that depends on investment in schooling or on-the-job training. Models of intentional research and development interpret X as a measure of technology and fill in the blank with an expression that depends on research effort.

In this context, the difference between endogenous and exogenous growth models is easy to describe. Exogenous growth models fill in the blank with a constant that is a fundamental parameter of the economy. Endogenous growth models fill it in with an expression that is a function of other basic parameters of the model, including parameters that can be changed by policymakers.

Srinivasan's theoretical point is that there is nothing new about endogenous growth models per se. For decades, there have been models that fill in the blank with an expression that depends on preferences and policy variables. If the construction of an endogenous growth model were the only goal of growth theory, then we could have stopped after John von Neumann presented his linear growth model at a seminar in Princeton in 1932.[1]

Srinivasan reproaches recent growth theorists for claiming that the construction of an endogenous growth rate is an important research achievement. If there are any growth theorists still making this claim, they deserve the rebuke.

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[1] The paper was not published in German until 1938, when Karl Menger invited von Neumann to submit it to a collection of papers. It was not published in English until 1945 (von Neumann 1945). One suspects that von Neumann felt that a problem that, from a mathematical point of view, could be reduced to eq. (1) was too trivial to bother submitting for publication.

Doing so suggests that our methodological preferences should be lexicographic; any endogenous growth model should dominate an exogenous growth model. In fact, the challenge for growth theory is not to produce a model with this particular property—that policy can influence the growth rate. The fundamental goal must be to formulate new models that are right, or at least closer to being right, than existing models.

I can clearly remember the classroom interaction that first pushed me in the direction of work on economic growth. It was not an *exogenous* growth model that I objected to, but an *endogenous* growth model. The professor had just finished presenting the von Neumann model. I interjected that it was obviously a stupid model of growth. Pressed to give a somewhat more articulate description of the model's failings, I set to work on a project that has kept me busy for 15 years.

In retrospect, it is clear that I did not appreciate the subtlety of von Neumann's early contribution to general equilibrium theory. (It is also clear that I was not very tactful.) But all my subsequent work persuades me that my harsh judgment of the model as a model of growth was correct. In the von Neumann model, a vector of goods X can produce a new vector of goods $X' = aX$ for some number $a > 1$. In place of a discussion of new products, new processes, universities, private research labs, patent law, scientific inquiry—all the things that seemed to me then and still seem to me now to be at the heart of economic growth—the model blithely offers up an attractive mathematical assumption that cannot be given any meaningful interpretation.

It is this kind of assumption, one that violates the most obvious facts about the world, that leaves economists open to ridicule. If economists start from assumptions about production that violate physical laws about the conservation of mass—that let goods reproduce like rabbits with an infinite food supply—why should anyone take what we say seriously? It was this kind of analysis by mainstream economists that provoked the equally misleading analysis of the environmental alarmists of the 1970s. They predicted that we were on the verge of economic catastrophe because our food supply (i.e., our natural resources) was running out.

By now it should be beyond dispute that economic growth takes place because people find more valuable ways to make use of the raw materials that have always been available to us in the crust of the earth and in the atmosphere. We have a standard of living that is higher than that of our grandparents, not because we have more stuff—more mass—but because we have learned to do interesting things like make memory chips from existing stuff like silicon. When we rearrange the silicon by growing it in a crystal and mixing it with a few other elements, we make it much more valuable.

Once one starts to think this way, it is clear that a neoclassical model that allows for technological progress is a significant improvement over a linear model like von Neumann's, in which a fixed set of goods breeds ever larger quantities of these same goods. In the long run, the fundamental driving force in our economy is change in what we know, and the neoclassical model highlights a crucial mathematical implication of treating knowledge as an economic good. When we use an expression of the form $Y = AF(K, L)$ or $Y = F(K, BL)$ and admit that F is a constant-returns-to-scale production function, we implicitly acknowledge that aggregate output is not a concave function of *K, L, and A* or *B.*

So if one takes the economics of discovery, innovation, and invention seriously, a neoclassical model with technological change is clearly to be preferred to a model with a fixed set of goods that replicate like rabbits. This is true despite the fact that the neoclassical model makes the rate of growth exogenous and the linear model makes it endogenous. The neoclassical model gets important parts of the economics of growth right in a way that the linear model does not.

But as anyone with any sense will admit, the neoclassical model with exogenous technological change is not the end of the story. The next step is to construct models that can explain where technological change comes from and explore the economic implications of the nonconvexity that the neoclassical model exhibits and then ignores.

It is true that some recent models of growth do little more than revive the von Neumann model and label one of the capital stocks human capital. This is not very helpful. It is these models that Srinivasan justifiably criticizes. But much of the recent work has been concerned with a serious attempt to characterize the economics of processes like learning, discovery, and the diffusion of knowledge.

The goods in the von Neumann model are entirely conventional. Recent models recognize that knowledge or discoveries or ideas are goods that differ from conventional goods in two very important ways. First, it is difficult to establish property rights over these goods—hence the emphasis on spillovers and external effects. Second, in the language of public finance, these goods are also nonrival goods, so they are intrinsically associated with nonconvexities.

We have not yet reached consensus about how to write down a model that blends elements like learning by doing, knowledge spillovers, patents, explicit research and development, and government support for science. But we are once again making a serious effort toward reaching this goal.

So the answer to the question posed in the title of Srinivasan's paper is unambiguously yes. There is something new in long-run growth theory. As he suggests, it does not lie merely in the construction of endogenous growth models. Instead, it comes from efforts to understand ideas and knowledge. Microeconomists have known for some time that the economics of ideas and knowledge differs in important ways from the familiar economics of objects. What growth theory has established is that these differences can be of decisive importance for an analysis of the economy as a whole. We now know that we cannot keep relegating the issues they raise to the footnotes. We cannot content ourselves with bland calls for additional research that we never get around to doing. The economics of ideas can change how we think about fundamental policy issues in growth and development. A great deal is at stake if we get the basic policy answers wrong.

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