# Long-Run Policy Analysis and Long-Run Growth

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# Long-Run Policy Analysis and Long-Run Growth

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The wide cross-country disparity in rates of economic growth is the most puzzling feature of the development process. This paper describes a class of models in which this heterogeneity in growth experiences can be the result of cross-country differences in government policy. These differences can also create incentives for labor migration from slow-growing to fast-growing countries. In the models considered, growth is endogenous despite the absence of increasing returns because there is a "core" of capital goods that can be produced without the direct or indirect contribution of factors that cannot be accumulated, such as land.

## I. Introduction

One of the most surprising features of the process of economic growth is the wide cross-country dispersion in average rates of growth. In the postwar period, countries such as Japan, Brazil, and Gabon saw their level of per capita income expand at a fast pace while other nations experienced no significant change in their standard of living. This paper studies a class of growth models in which cross-country differences in economic policy can generate this type of het-

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erogeneity in growth experiences. In these models certain policy variables, such as the rate of income tax, affect the economy's rate of expansion through a simple mechanism: an increase in the income tax rate decreases the rate of return to the investment activities of the private sector and leads to a permanent decline in the rate of capital accumulation and in the rate of growth.

The class of economies that I propose in this paper shares with Romer's (1986) model the property that growth is endogenous in the sense that it occurs in the absence of exogenous increases in productivity such as those attributed to technical progress in the neoclassical growth model. But, in contrast with Romer's emphasis on increasing returns to scale and accelerating growth, the models discussed here display constant returns to scale technologies and have steady-state growth paths, thus being compatible with the stylized facts of economic growth described in Kaldor (1961).

The simplest model within the class that I consider is a one-sector economy with standard preferences and a production function that is linear in the capital stock. This simple model is usually dismissed as inappropriate to think about growth issues because labor plays apparently no role in the economy and nonreproducible factors such as land are not used in production. The analysis undertaken here of more general models that surpass both of these problems reveals that the simple linear model is a natural benchmark in terms of thinking about the growth process and a good representative of the class of endogenous growth economies that have a convex technology.

Throughout the paper I shall focus on the effects of taxation on the rate of growth. This focus was chosen because tax policies differ significantly across countries but also because the effects of taxation are suggestive of the impact of other government policies, such as those regarding the protection of property rights. The approach will be positive rather than normative: I shall take as given that there are differences in public policy across countries and, at least for now, sidestep the question of whether those different policies can be viewed as optimal.

There is a large literature on tax policy issues in the neoclassical growth model that also concludes that high income tax rates translate into lower rates of growth.[1] But in the neoclassical model, this effect is too weak to explain the observed cross-country differences in growth rates. Economic policy can affect the rate of growth only during the transition path toward the steady state since the steady-state growth rate is given by the rate of *exogenous* technical progress.

[1] Key references in this literature include Krzyzaniak (1967), Sato (1967), Feldstein (1974), Stiglitz (1978), R. Becker (1985), and Judd (1985).

These transitional effects of economic policy cannot have a large impact on the rate of growth, given that the rough constancy of the real interest rate during the last century suggests that transitional dynamics play a modest role in the growth process (King and Rebelo 1989).

This paper is organized as follows. Section II studies a two-sector extension of a linear growth model that incorporates nonreproducible factors in the production process. This model is used to study the effects of taxation and the influence of the rate of savings on the rate of economic growth.

Section III expands this model to distinguish the role of physical capital and human capital along the lines suggested by Lucas (1988). This extended model shows that the feasibility of sustained growth does not require capital to be produced with a linear technology, as might be suggested by Section II and by the models discussed by Uzawa (1965) and Lucas (1988). All that is required to assure the feasibility of perpetual growth is the existence of a "core" of capital goods that is produced with constant returns technologies and without the direct or indirect use of nonreproducible factors.

Treating separately the accumulation of physical and human capital introduces transitional dynamics that are absent in Section II. But the implications obtained for the effects of taxes and of the savings rate along the steady-state path are basically those of Section II, in the case of both exogenous and endogenous leisure choice.

The remainder of Section III is devoted to generalizing the model of Section II along two different directions. First, capital goods produced with nonreproducible factors are introduced in the economy. Second, the consequences of introducing multiple consumption goods are examined. The main policy implications derived in Section II prove to be robust to these generalizations.

Section IV relates the models discussed here to the neoclassical model and to some of the recent growth literature. Section V provides some conclusions and outlines directions for future research.

## II. A Basic Endogenous Growth Model

The point of departure in this paper will be an economy in which there are two types of factors of production: reproducible, which can be accumulated over time (e.g., physical and human capital), and nonreproducible, which are available in the same quantity in every period (e.g., land). The quantity of all reproducible factors will be summarized by the capital good $Z_t$, which can be viewed as a composite of various types of physical and human capital. Similarly, the fixed amount available of nonreproducible factors will be summarized by the composite good $T$.

The economy has two sectors of production. The capital sector uses a fraction $(1 - \phi_t)$ of the available capital stock to produce investment goods $(I_t)$ with a technology that is linear in the capital stock: $I_t = AZ_t(1 - \phi_t)$. Capital depreciates at rate $\delta$ and investment is irreversible $(I_t \geq 0)$: $\dot{Z}_t = I_t - \delta Z_t$.[2] The consumption sector combines the remaining capital stock with nonreproducible factors to produce consumption goods $(C_t)$. Since for steady-state growth to be feasible it must be possible for both consumption and capital to grow at constant (but possibly different) rates, the production function of the consumption industry is assumed to be Cobb-Douglas: $C_t = B(\phi_t Z_t)^{\alpha} T^{1-\alpha}$. This technology permits capital to grow at any rate between $A - \delta$ (the path of pure accumulation) and $-\delta$ (the path along which all production is consumed), and consumption to grow at a rate proportional to that of capital: $g_c = \alpha g_z$.

The economy has a constant population composed of a large number of identical agents who seek to maximize utility, defined as

$$U = \int_0^{\infty} e^{-\rho t} \frac{C_t^{1-\sigma}}{1 - \sigma} dt. \tag{1}$$

These preferences imply that the optimal growth rate of consumption $(g_{ct})$ is solely a function of the real interest rate $(r_t)$: $g_{ct} = (r_t - \rho)/\sigma$. Since in all the economies considered here the real interest rate is constant in the steady state, this ensures that when it is feasible for consumption to grow at a constant rate it is also optimal to do so.

The competitive equilibrium under perfect foresight for all the economies studied in this paper can be computed as a solution to a planning problem by exploring the fact that, in the absence of distortions, the competitive equilibrium is a Pareto optimum. Instead of taking this approach, we shall study directly the competitive equilibrium focusing on the conditions that are relevant to determine the growth rate, since this will be more informative about the economic mechanisms at work in the model.

To describe the competitive equilibrium, it is necessary to have a market structure in mind. In this case, it is easiest to think of the economy as having spot markets for all goods and factors and one-period credit markets. Firms make their production decisions seeking to maximize profits, while households rent the two factors of production ($Z$ and $T$) to firms and choose their consumption so as to maximize lifetime utility (1).

To maximize profits, firms have to be indifferent about employing their marginal unit of capital to produce either consumption goods or capital goods; that is, $p_t A = \alpha B(\phi_t Z_t)^{\alpha - 1}$, where $p_t$ is the relative price of capital in terms of consumption. Since in the steady state the

[2] The dot notation is used for the time derivative, so $\dot{Z}_t = dZ_t/dt$.

fraction of capital devoted to consumption, $\phi_t$, is constant, the relative price of capital declines at the rate $g_p = (\alpha - 1)g_z$. Given that $p_t$ is not constant, the real interest rate for loans denominated in capital goods ($r_{zt}$) is different from that of consumption-denominated loans ($r_{ct}$). Since the (net) marginal productivity of capital in the sector that produces capital goods is constant and equal to $A - \delta_z$, equilibrium in the capital market requires that $r_{zt} = A - \delta_z$. A standard arbitrage argument implies that the interest rate for consumption-denominated loans is related to $r_{zt}$ by $r_{ct} = r_{zt} + g_p$. The steady-state value of $r_{ct}$ is then given by $r_c = A - \delta + (\alpha - 1)g_z$.

Faced with this interest rate, households choose to expand consumption at rate $g_c = (r_c - \rho)/\sigma$. Substituting $r_c$ by its expression and using the fact that $g_c = \alpha g_z$ yield the steady-state value of $g_z$. Net income measured in terms of consumption goods, which is given by $Y_t = C_t + p_t I_t - \delta_z Z_t$, grows at rate

$$g_y = \alpha g_z = \alpha \frac{A - \delta_z - \rho}{1 - \alpha(1 - \sigma)}. \tag{2}$$

There are three properties of the competitive equilibrium that are worth noting. First, this economy has no transitional dynamics; it expands always at rate $g_y$. Second, the parameter $B$ and the amount of land services available in each period ($T$) are absent from the growth rate expression. They determine the level of the consumption path but not the growth rate, suggesting that countries with different endowments of natural resources will have different income levels but not different growth rates. Third, although $C_t$ and $I_t$ grow at different rates, their relative price adjusts in such a manner that the shares of investment and consumption in output ($p_t I_t / Y_t$ and $C_t / Y_t$) are constant.

The influence of preferences and technology on the rate of expansion of this economy is rather intuitive. The rate of growth is higher the greater the net marginal product of capital ($A - \delta_z$) and the elasticity of intertemporal substitution ($1/\sigma$) and the lower the pure rate of time preference ($\rho$).[3]

Equation (2) provides no reason to believe that unceasing growth is more likely than perpetual regression; whether the economy grows

[3] In order for lifetime utility ($U$ in [1]) to be finite, it is necessary that $\rho > \alpha(1 - \sigma)(A - \delta_z)$ to ensure that the growth rate of momentary utility, $(1 - \sigma)g_c$, is lower than the discount rate, $\rho$. If $(1 - \sigma)g_c \geq \rho$, there is a set of feasible paths among which households are indifferent because they all yield infinite utility. The requirement $\rho > \alpha(1 - \sigma)(A - \delta_z)$ is also necessary and sufficient for the transversality condition associated with the households' maximization problem to hold. In all the other models studied in this paper, this type of condition, although not stated explicitly, is implicitly assumed to hold.

or regresses depends on whether $A - \delta_z - \rho$ is positive or negative. However, in the derivation of (2), the irreversible nature of investments in $Z$ was ignored. This irreversibility implies that the lowest feasible growth rate of output is $-\alpha\delta_z$, which corresponds to the path in which investment is zero. When the value of $g_y$ implied by (2) is lower than $-\alpha\delta_z$, the economy reverts to a corner solution in which investment is zero and the growth rate is $-\alpha\delta_z$.

### A. *Long-Run Effects of Taxation*

To illustrate the effects of taxation on this model, two proportional taxes will be introduced: one on consumption at rate $\tau_c$ and the other on investment at rate $\tau_i$. The analysis will be undertaken in a closed economy context, but it is valid in a world of open economies connected by international capital markets if all countries follow the "worldwide tax system."[4]

Government revenue, measured in terms of the consumption good, is given by $T_t = \tau_c C_t + \tau_i p_t I_t$. To isolate the effects of taxation from those of government expenditures, I assume throughout the paper that this revenue is used to finance the provision of goods that do not affect the marginal utility of private consumption or the production possibilities of the private sector.

The only equation used to derive (2) affected by the presence of taxation is the one that determines $r_z$, which is now given by

$$(1 + \tau_i)(1 + r_z) = A + (1 - \delta_z) + \tau_i(1 - \delta_z).$$

The left-hand side of this expression represents the opportunity cost of investing one unit of capital. The right-hand side is the result of using that unit of capital to produce during one period and selling the nondepreciated capital. The term $\tau_i(1 - \delta_z)$ reflects the investment tax refund associated with that sale.

The growth rate of income is in this case

$$g_y = \max\left\{\alpha \frac{[A/(1 + \tau_i)] - \delta_z - \rho}{1 - \alpha(1 - \sigma)}, -\alpha\delta_z\right\}, \tag{3}$$

where the possibility of a corner solution in which the nonnegativity restriction on investment is binding, and hence $g_z = -\delta_z$, is made explicit. Expression (3) shows that the influence of an increase in $\tau_i$ on the growth rate is the same as that of a decrease in $A$: a higher

[4] According to this system, investors pay taxes in their own country on capital income originated abroad but receive credit for any taxes paid abroad on the same income. See Jones and Manuelli (1990) and King and Rebelo (1990) for discussions of the effects of taxation in open economies.

investment tax rate leads to a lower growth rate in economies with strictly positive investment levels. In contrast, permanent changes in $\tau_c$ have effects that are similar to changes in $B$: they do not affect the rate of growth but solely the level of the consumption path. A consumption tax does not distort the only decision made by agents in this economy, the decision of consuming now versus later, and so it is equivalent to a lump-sum tax. Since a proportional tax on (gross) income amounts to taxing consumption and investment at the same rate, an increase in the income tax rate induces a decrease in the rate of growth of this economy.[5]

### B. *Growth and the Savings Rate*

In Solow's (1956) original version of the neoclassical growth model, the savings rate ($s$) was fixed at an exogenous level. In that context, Solow concluded that the savings rate determines only the steady-state levels of the different variables but not their growth rates. In his model, although the speed of convergence toward the steady state depends on $s$, the steady-state growth rate is exogenous and all $s$ does is determine the capital/labor ratio.

The simple model just described can be used to illustrate that this result is an artifact of the exogenous nature of steady-state growth in the neoclassical model. Suppose that the savings rate, defined as the fraction of net output devoted to net investment, is exogenously fixed at the level $s \geq 0$ rather than being chosen to maximize (1). This implies that $\dot{Z}_t = sY_t/p_t$. Following the same steps as before, we can compute the steady-state growth rate as

$$g_y = \alpha \frac{(A - \delta_z)s}{\alpha + (1 - \alpha)s}.$$

This expression implies that higher savings rates lead to higher growth rates, which accords with the positive correlation of these two variables in the data (see Romer 1987). The concept of savings employed here is, however, broader than usual since $Z$ represents a composite of physical and human capital and hence $s$ is the fraction of total resources devoted to both of these accumulation activities. In order to study the effects of changes in the savings rate defined in a stricter sense that encompasses only physical capital accumulation, it is necessary to distinguish between these two types of accumulation. This is one of the objectives of the next section.

[5] This is also the mechanism at work in Boyd and Prescott (1985). In their economy the production technology is linear, so an increase in the income tax rate acts as a displacement to the technology, leading to a decrease in the rate of growth.

### *C. A Linear Endogenous Growth Model*

The basic model can be simplified further by assuming that $\alpha = 1$ and $B = A$. This generates a one-sector economy with a linear production function $Y_t = AZ_t$.[6] This linear model in which everything is reproducible captures the essential features of the class of endogenous growth models with a convex technology. It points to the same growth rate determinants and to the same policy implications as the model just described. It also captures the main qualitative features of the economies studied in the next section in which physical and human capital are treated separately.

## III. Extensions of the Basic Model

This section seeks to investigate whether the properties described in Section II hold more generally by extending that model in several directions: First, the composite capital good $Z$ is disaggregated into physical and human capital, and the resulting economy is studied for the cases of exogenous and endogenous labor supply. Second, capital goods produced with nonreproducible factors are incorporated in the model. Finally, multiple consumption goods are introduced. To simplify the exposition, each of these aspects is considered separately.

### *A. Disaggregating $Z_t$ into Physical and Human Capital*

A natural direction along which the basic model can be expanded is to disaggregate the composite capital $Z_t$ into one type of physical and one type of human capital. To study such a model without burdening the discussion with too much notation, it is convenient to assume that consumption and investment goods are produced in the same sector. Introducing a separate consumption sector as in Section II would not give rise to any substantive changes in the properties discussed below.

As before, the economy is populated by a constant number of identical agents with preferences described by (1). Production takes place according to a Cobb-Douglas production function that combines a fraction $\phi_t$ of the stock of physical capital with $N_tH_t$ efficiency units of labor, which are the result of $N_t$ hours of work undertaken by an individual with $H_t$ units of human capital:[7]

[6] This simple linear economy resembles models discussed in Knight (1935, 1944) and Hagen (1942) in which "everything is capital" in the sense that all factors of production can be accumulated. Models similar to this one have also been employed by McFadden (1967), Benveniste (1976), and Eaton (1981).

[7] See Martins (1987) for an analysis of growth models with different definitions of efficiency units of labor.

$$A_1(\phi_t K_t)^{1-\gamma}(N_t H_t)^{\gamma} = C_t + I_t. \quad (4)$$

Physical capital depreciates at rate $\delta$, and investment is irreversible ($I_t \geq 0$):

$$\dot{K}_t = I_t - \delta K_t. \quad (5)$$

Human capital, which is embodied in each worker, depreciates at rate $\delta$ and can be produced by combining physical capital—$K_t(1 - \phi_t)$ units—with efficiency units of labor.[8] Each worker has one unit of time in each period and consumes an exogenously specified number $L$ of leisure hours. The remaining $1 - L - N_t$ hours are devoted to accumulation of human capital generating $(1 - L - N_t)H_t$ efficiency units of labor:

$$\dot{H}_t = A_2[K_t(1 - \phi_t)]^{1-\beta}[(1 - L - N_t)H_t]^{\beta} - \delta H_t. \quad (6)$$

The technology described by equations (4)–(6) is similar to the one adopted by Lucas (1988, sec. 4), with two main differences: there are no externalities, and physical capital is used in the production of human capital.

In specifying this technology, I made three assumptions that make it possible to solve in closed form for the steady-state growth rate: the two production functions were chosen to be Cobb-Douglas, and $K$ and $H$ were assumed to depreciate at the same rate $\delta$. The appendix to the working paper version of this research (Rebelo 1990) demonstrates that the properties emphasized below continue to hold when the production functions are neoclassical with positive cross-partial derivatives and the two depreciation rates are different.

Equations (4)–(6) imply that in the steady state, $C_t$, $K_t$, $I_t$, and $H_t$ all grow at the same rate. There is a continuum of values for this common growth rate that can be sustained with this technology.[9] This makes clear that in order for endogenous steady-state growth to be feasible, the technology to produce capital does not need to be linear but only constant returns to scale, that is, linearly homogeneous. The

[8] The embodiment assumption plays a key role in the analysis. It implies that two agents with the same level of human capital, $H$, who work for $N$ hours generate $2NH$ units of labor in efficiency units. With disembodied human capital, each worker would be able to use the other's human capital, and the number of efficiency units that would result from their collaboration would be $4NH$. In the economy described in this section, this would introduce increasing returns to scale, and hence a competitive equilibrium would not exist: production and accumulation of skills would take place in an economywide coalition.

[9] The range of sustainable rates of growth is harder to compute than in Sec. II because it is determined both by the equations that describe technology and by those that characterize efficient production plans (see eqq. [7]–[12]). This range is, however, analogous to that of the basic model: the economy can sustain any growth rate between the steady-state interest rate $r$, described in (13), and $-\delta$.

reason why the production function of the capital sector in Section II had to be linear was that linearly homogeneous functions of a single variable are linear.

To describe the perfect-foresight competitive equilibrium, it is convenient to think of households as directly operating the economy's technology.[10] Efficient production decisions are characterized by two conditions. The first one is static in the sense that it regards the optimal allocation of the existing stock of physical capital and the available efficiency units of labor across the two activities. In an efficient allocation, the marginal product of physical and human capital measured in terms of units of physical capital has to be equated in the two sectors; that is,

$$\begin{aligned}(1-\gamma)A_1(\phi_t K_t)^{-\gamma}(N_t H_t)^{\gamma} \\ = q_t(1-\beta)A_2[(1-\phi_t)K_t]^{-\beta}[(1-L-N_t)H_t]^{\beta}\end{aligned} \tag{7}$$

and

$$\begin{aligned}\gamma A_1(\phi_t K_t)^{1-\gamma}(N_t H_t)^{\gamma-1} \\ = q_t\beta A_2[(1-\phi_t)K_t]^{1-\beta}[(1-L-N_t)H_t]^{\beta-1},\end{aligned} \tag{8}$$

where $q_t$ is the relative value of the human capital in terms of physical capital. Eliminating $q_t$ from (7) and (8) yields a familiar requirement of efficiency in production: the marginal rate of transformation must be equated in the two sectors. With Cobb-Douglas production functions, this amounts to the following relation between the capital-labor intensities in the two sectors:

$$\frac{\gamma}{1-\gamma}\left(\frac{\phi_t K_t}{N_t H_t}\right) = \frac{\beta}{1-\beta}\left[\frac{(1-\phi_t)K_t}{(1-L-N_t)H_t}\right]. \tag{9}$$

The second efficiency condition is dynamic in nature and concerns the decision of investing in physical capital versus human capital. Having a new unit of physical capital available is worth its net marginal product in the production sector:

$$r_t = (1-\gamma)A_1(\phi_t K_t)^{-\gamma}(N_t H_t)^{\gamma} - \delta. \tag{10}$$

An alternative to investing in one more unit of capital is to accumulate $1/q_t$ units of human capital, which yields a net return expressed in terms of physical capital goods equal to

$$r_t^* = \beta A_2[(1-\phi_t)K_t]^{1-\beta}[(1-L-N_t)H_t]^{\beta-1}(1-L) - \delta + \frac{\dot{q}_t}{q_t}. \tag{11}$$

[10] See King and Rebelo (1990) for a discussion of a decentralization scheme in which households decide how much to accumulate of physical and human capital whereas firms undertake production by renting both labor and capital from households.

At the optimum, the rates of return from both activities must be the same, so $r_t = r_t^*$. Since equations (7) and (8) imply that $q_t$ is constant in the steady state (given that $K/H$ is also constant), the steady-state version of the condition $r_t = r_t^*$ has a very simple form:

$$(1-\gamma)A_1\left(\frac{\phi_t K_t}{N_t H_t}\right)^{-\gamma} = \beta A_2\left[\frac{(1-\phi_t)K_t}{(1-L-N_t)H_t}\right]^{1-\beta}(1-L). \quad (12)$$

Equations (9) and (12) can be solved for the capital-labor intensities in the two sectors. Once these are determined, the value of $\phi_t K_t/N_t H_t$ can be used in (10) to determine the steady-state real interest rate, which depends on a geometric average of the two level parameters in the production functions:

$$r = \psi A_1^{\nu} A_2^{1-\nu}(1-L)^{1-\nu} - \delta, \quad (13)$$

where $\nu = (1-\beta)/(1-\beta+\gamma)$ and $\psi$ is a strictly positive function of $\gamma$ and $\beta$. The geometric average weight, $\nu$, is lower than ½ when the share of physical capital in the production of human capital $(1-\beta)$ is smaller than the share of labor in the production of physical capital $(\gamma)$.

Given the real interest rate, the optimal growth rate of consumption is $g_c = (r-\rho)/\sigma$. Since along the steady-state path $I_t$, $K_t$, and $H_t$ all grow at the same rate as consumption, the growth rate of net national income, defined as $Y_t = C_t + I_t - \delta K_t$, is given by

$$g_y = \max\left[\frac{\psi A_1^{\nu} A_2^{1-\nu}(1-L)^{1-\nu} - \delta - \rho}{\sigma}, -\delta\right]. \quad (14)$$

This expression, which makes explicit the possibility of a corner solution with zero investment, is analogous to (2) (for the case of $\alpha = 1$).

The properties of the steady-state growth path are very similar to those suggested by Section II: when the economy is not at a corner solution with zero investment, the rate of growth depends on $A_1$ and $A_2$ and the irreversible nature of investment (in both $K$ and $H$) sets a lower bound to the growth rate.[11]

One interesting new property is that the rate of growth is increasing in the total number of hours worked (both in the output sector and in the accumulation of human capital); that is, the model predicts that economies with hard-working agents will grow faster.

In contrast with the model of Section II, this economy has transi-

[11] As is shown in proposition 2 of the appendix to the working paper version of this research, in an extension of this model in which consumption is produced in a separate sector with a Cobb-Douglas technology that combines physical capital, human capital, and nonreproducible resources, the steady-state growth rate is independent of the level of nonreproducible resources and of the level parameter in the consumption production function. These properties also accord with the findings of Sec. II.

tional dynamics. After we solve for the factor intensities in both industries and determine the steady-state growth rate, equations (6) and (9) can be used to determine the steady-state ratio of physical to human capital, $k = K_t/H_t$. If the initial capital stocks are not in the proportion $k$, there will be a period in which physical and human capital expand at different rates.[12]

## Long-Run Effects of Taxation

As in the basic economy of Section II, a consumption tax is equivalent to a lump-sum tax, and an increase in the rate of income tax induces a decline in the rate of growth. This effect of taxation is, however, weaker than in the model of Section II. Income taxation makes the private sector decrease the capital/labor ratio in both sectors of activities, substituting away from the input whose production is taxed (physical capital). As a result, the steady-state value of the after-tax real interest rate is equal to $r = (1 - \tau)^{\nu}\psi A_1^{\nu} A_2^{1-\nu}(1 - L)^{1-\nu} - \delta$, and so the impact of $\tau$, the income tax rate, on the steady-state growth rate is smaller than in Section II, being weaker the closer $\nu$ is to zero. If the shift to more human capital–intensive technologies did not take place, the after-tax steady-state real interest rate would be $r = (1 - \tau)\psi A_1^{\nu} A_2^{1-\nu}(1 - L)^{1-\nu} - \delta$, and the impact of taxation on growth would be similar to that of Section II. This would also be the case if production of both output and human capital were included in the tax base since there would be no scope for adjusting factor intensities.

The model proposed by Lucas (1988, sec. 4) is, when one abstracts from the human capital externality, a limit case of this economy in which physical capital is not used in the production of human capital so that $\beta = 1$. In this limit case, $\nu = 0$ and $\psi = 1$, so both the real interest rate and the rate of growth are independent of $A_1$ and of the rate of income tax. This independence arises from the fact that when $\beta$ is one, the rate of return to investment in human capital ($r_t^*$ in eq. [11]) is constant and equal to $(A_2 - \delta)(1 - L)$. In an efficient production plan the capital-labor intensity in the output sector ($K/NH$) is chosen so that the rate of return to physical capital accumulation, which coincides with the real interest rate ($r_t$ in [10]), is also $(A_2 - \delta)(1 - L)$. For this reason, taxing income in the Lucas economy changes the factor intensity in the output sector and in the economy as a whole but has no impact on the steady-state real interest rate and growth rate.[13]

[12] See King and Rebelo (1986) for a discussion of these dynamics and Barro (1989) for an investigation of their empirical implications.

[13] This would not be true, however, if the production of human capital were included in the definition of the tax base. In that case, taxing income acts like a change in both $A_1$ and $A_2$ affecting the growth rate.

In this economy, income taxes affect the steady-state real wage rate (per efficiency unit of labor), which is given by

$$w = \lambda \frac{[(1 - \tau)A_1]^{1+\mu}}{[A_2(1 - L)]^{\mu}}, \tag{15}$$

where $\lambda$ is a strictly positive function of the shares $\gamma$ and $\beta$, and $\mu = (1 - \gamma)/(1 - \beta + \gamma)$. The elasticity of the wage rate with respect to the tax wedge, $1 - \tau$, is equal to $1 + \mu$. The first component of this elasticity reflects the direct impact of income taxes on the wage rate: workers receive only a fraction $(1 - \tau)$ of the marginal product of labor. The second component, associated with the exponent $\mu$, involves the consequences of the shift to more labor-intensive technology on the marginal product of labor. Both of these effects imply that economies with a high income tax rate have lower after-tax wages than economies with low taxes. This difference in wage rates creates a tendency for workers of slow-growing (high-tax) economies to migrate to high-growth (low-tax) countries regardless of their level of education. These implications for migration are similar but not identical to those emphasized in Lucas (1988). In his model, workers of poor economies tend to migrate to rich ones because the presence of an externality in the production of output implies that, all else equal, richer economies have higher wages.

Growth and the Savings Rate

This model can be used to investigate the relation between the growth rate of output (narrowly defined by excluding human capital accumulation) and the rate of savings, defined as the fraction of net output devoted to net investment in physical capital ($s_t = \dot{K}_t/Y_t$). When the share parameters in the two production functions are identical ($\beta = \gamma$) and there is no depreciation, this relation can be expressed in closed analytical form:

$$g_y = \frac{[A_1 A_2 k^{1-2\gamma}(1 - L)]s}{A_2 k^{1-\gamma}(1 - L) + A_1 s k^{-\gamma}}, \tag{16}$$

where $k$ is the capital/labor ratio in both sectors of activity, which is a function of $A_1$, $A_2$, and $\gamma$. The appendix to the working paper version of this research shows that the positive association between the rate of growth and the rate of savings (narrowly defined) suggested by this particular case is a general implication of the model.

## B. *Endogenous Leisure Choice*

To make leisure endogenous in the model just examined in a manner consistent with steady-state growth, preferences have to be such that each individual chooses a constant rate of expansion of consumption and constant allocations of time between work ($N_t$), leisure ($L_t$), and accumulation of skills ($1 - N_t - L_t$) when faced with a constant real wage (per efficiency unit of labor) and a constant real interest rate. There are two classes of time-separable preferences for which this is the case.

In the first class, momentary utility takes the form $u(C_t, L_tH_t)$, where $u(\cdot)$ has the standard properties (it is concave and twice continuously differentiable) and is homogeneous of degree $b$. This type of momentary utility can be viewed as a formalization of G. Becker's (1965) concept of household production function. Preferences of this form have been employed in the labor literature, namely by Heckman (1976), to rationalize the small response of the number of hours devoted to work in the market to the observed secular increase in real wages.

The consistency of these preferences with steady-state growth is clear from the efficiency condition for leisure, which, from the homogeneity of $u(\cdot)$, can be written as

$$D_2 u\left(\frac{C_t}{H_t}, L_t\right) = w_t D_1 u\left(\frac{C_t}{H_t}, L_t\right).$$

In the steady state, both $C_t/H_t$ and $w_t$ (the real wage rate per efficiency unit) are constant, implying a constant value for $L_t$.

The steady-state real interest rate, which is given by $r = \psi A_1^{\nu} A_2^{1-\nu} - \delta$, is determined by the same type of production efficiency requirements that underlie (13). The term $(1 - L)^{1-\nu}$ is absent in the interest rate expression because of the dependence of utility on leisure in efficiency units ($L_tH_t$), which implies that an extra unit of human capital augments the productivity of the entire time endowment, not just that of the time that is devoted to work, $1 - L_t$. It is easy to show that the optimal growth rate of consumption is related to the real interest rate by $g_{ct} = (r_t - \rho)/(1 - b)$ and that the steady-state growth rate for this economy is given by

$$g_y = \max\left(\frac{\psi A_1^{\nu} A_2^{1-\nu} - \delta - \rho}{1 - b}, -\delta\right).$$

All the properties emphasized in Section II hold for this model. In particular, a consumption tax has no effect on the rate of growth even though labor is endogenous. This results from a combination of two factors: (i) the real interest rate is independent of preferences, and (ii) the growth rate of the marginal utility of consumption is independent of the consumption-leisure mix chosen by the economy because $u(\cdot)$ is homogeneous.

A second class of momentary utility functions consistent with steady-state growth is derived in King, Plosser, and Rebelo (1988) and takes the form

$$u(C_t, L_t) = \begin{cases} \log(C_t) + v_1(L_t) & \text{if } \sigma = 1 \\ \dfrac{C_t^{1-\sigma}}{1-\sigma} v_2(L_t) & \text{if } 0 < \sigma < 1 \text{ or } \sigma > 1. \end{cases}$$

While with the Becker-Heckman preferences the steady-state real interest rate is dictated solely by technology, with this utility function it depends as well on preference parameters. The reason for this is clear from the expression for the rate of return to human capital accumulation:

$$r_t^* = \beta A_2[(1-\phi_t)K_t]^{1-\beta}[(1-N_t-L_t)H_t]^{\beta-1}(1-L_t) - \delta + \frac{\dot{q}_t}{q_t}.$$

In this equation the term $1 - L_t$ reflects the fact that an increase in $H_t$ will augment the productivity of hours worked in both sectors but will not enhance the marginal utility of leisure. Since $L_t$ depends on preferences between consumption and leisure, the real interest rate depends not only on technology but also on parameters of the utility function. This complicates the computation of the steady state to such a point that it is difficult to characterize its properties analytically. Numerical simulations conducted for a wide spectrum of parameter values indicate that taxing income continues to have a negative effect on the rate of growth.

It can be shown analytically that the same cancellation of income and substitution effects that assures that preferences are consistent with steady-state growth implies that taxing consumption induces no change in the economy's growth rate.

### *C. Capital Goods Produced with Nonreproducible Factors*

In all the economies examined until now, nonreproducible factors have been ruled out from the production of capital. Perpetual growth can, however, be consistent with the presence of capital goods produced with nonreproducible factors. This can be illustrated by incorporating a second capital good, denoted by $S_t$, in the model of Section II so that the technology of the economy is

$$C_t = B_1(\phi_{ct}Z_t)^{\alpha_1}(\psi_t S_t)^{\alpha_2}(\mu_t T_t)^{1-\alpha_1-\alpha_2},$$

$$\dot{S}_t = B_2(\phi_{st}Z_t)^{\eta_1}[(1-\psi_t)S_t]^{\eta_2}[(1-\mu_t)T_t]^{1-\eta_1-\eta_2} - \delta_s S_t,$$

$$\dot{Z}_t = AZ_t(1-\phi_{ct}-\phi_{st}) - \delta_z Z_t.$$

The variables $\phi_{ct}$, $\phi_{st}$, $\psi_t$, and $\mu_t$ represent fractions of the various resources allocated to the different activities. The technology used to produce the capital good $S_t$ was assumed to be Cobb-Douglas so that it is feasible to have both $S_t$ and $Z_t$ growing at constant (but possibly different) rates. The growth rate of capital, which can be determined as in Section II, is

$$g_z = \max\left\{\frac{(1-\eta_2)(A-\delta_z-\rho)}{(1-\eta_2)-(1-\sigma)[\alpha_1(1-\eta_2)+\alpha_2\eta_1]}, -\delta_z, -\frac{1-\eta_2}{\eta_1}\delta_s\right\}.$$

Net income measured in terms of the consumption good is given by $Y_t = C_t + p_t\dot{Z}_t + q_t\dot{S}_t$, where $p_t$ and $q_t$ are, respectively, the relative prices of $Z$ and $S$ with respect to consumption. The growth rate of $Y_t$ is proportional to that of $Z_t$:

$$g_y = \left(\alpha_1 + \frac{\alpha_2\eta_1}{1-\eta_2}\right)g_z.$$

As in Section II, this economy has no transitional dynamics; it always grows at the steady-state growth rate.

This economy has two familiar properties. First, its rate of growth is an increasing function of $A$ but does not depend on $B_1$, $B_2$, and $T$. Second, although the production of $C$, $Z$, and $S$ measured in physical units expands at different rates, the relative prices evolve in such a manner that the share of the production value of each of these goods in $Y$ is constant. The policy implications derived in Section II follow from the first of these properties.

This model shows that in order for endogenous growth to be feasible, all that is necessary is that there be a "core" of capital goods that is produced without the direct or indirect contribution of nonreproducible factors. Provided that this core of capital goods exists, endogenous growth is compatible with the presence of consumption and capital goods produced with nonreproducible factors in the absence of increasing returns to scale.

In general, taxing the production of capital goods that are not in the core has no effect on the growth rate. This should not be surprising since the introduction of this type of capital goods amounts to specifying a more complex technology to produce consumption goods, and we have seen that taxing consumption induces no growth effect.

### D. *Multiple Consumption Goods*

The introduction of more than one consumption good leaves the properties of the models we examined virtually unchanged, but it implies that some restrictions across parameters of preferences and technology have to be satisfied in order for steady-state growth to be optimal. To illustrate this, suppose that a second consumption good is introduced in the model of Section II. The two consumption goods, $C_1$ and $C_2$, are produced with the following technologies:

$$C_{1t} = B_1(\phi_{1t}Z_t)^{\alpha_1}(\psi_t T)^{1-\alpha_1}, \quad C_{2t} = B_2(\phi_{2t}Z_t)^{\alpha_2}[(1-\psi_t)T]^{1-\alpha_2},$$

where $\phi_{1t}$, $\phi_{2t}$, and $\psi_t$ represent fractions of the various factors. As in the previous models, these fractions are constant in the steady state. The law of motion for capital is

$$\dot{Z}_t = AZ_t(1 - \phi_{1t} - \phi_{2t}) - \delta_z Z_t.$$

The conditions under which steady-state growth is optimal can be determined by examining some of the equations that characterize the perfect-foresight competitive equilibrium.

If $q_t$ is the relative price of $C_1$ in terms of $C_2$, firms allocate the capital good so as to equate the marginal product of capital in the two consumption sectors:

$$q_t\alpha_1 B_1(\phi_{1t}Z_t)^{\alpha_1-1}(\psi_t T)^{1-\alpha_1} = \alpha_2 B_2(\phi_{2t}Z_t)^{\alpha_2-1}[(1-\psi_t)T]^{1-\alpha_2}.$$

This efficiency condition implies that along a steady-state path, $q_t$ changes at rate $g_q = (\alpha_2 - \alpha_1)g_z$.

Households choose their consumption path so that the marginal rate of substitution between the two goods equals their relative price:

$$u_1(C_{1t}, C_{2t}) = q_t u_2(C_{1t}, C_{2t}).$$

Represent the elasticity of the marginal utility of consumption of good $i$ ($u_i$) with respect to good $j$ by $\sigma_{ij}$. Then this condition can be expressed in terms of growth rates as

$$\sigma_{11}g_{c1} + \sigma_{12}g_{c2} = g_q + \sigma_{21}g_{c1} + \sigma_{22}g_{c2}.$$

Given that the steady-state growth rates of consumption are $g_{c1} = \alpha_1 g_z$ and $g_{c2} = \alpha_2 g_z$, this implies that

$$\alpha_1(1 + \sigma_{11} - \sigma_{21}) = \alpha_2(1 + \sigma_{22} - \sigma_{12}). \tag{17}$$

If this requirement holds, the steady-state growth rate of output expressed in terms of $C_1$ can be computed following the same steps as in Section II:

$$g_y = \max\left(\alpha_1\frac{A - \delta_z - \rho}{1 - \alpha_1 - \sigma_{11}\alpha_1 - \sigma_{12}\alpha_2}, -\alpha_1\delta_z\right).$$

It is easy to verify that this economy has the properties stressed in Section II and hence shares the same policy implications. The steady-state path in this case is not as interesting since there is no reason that restrictions such as (17) should hold. This path still captures, however, some of the properties that are present when (17) or its equivalent does not hold, and hence the fraction of resources allocated to the production of the different consumption goods varies over time.

## IV. Perpetual Growth and Nonreproducible Factors

The class of models described in the previous section can be related to the neoclassical growth model and to some of the recent growth literature by considering a one-sector model in which output is produced according to a Cobb-Douglas technology that combines capital ($K_t$), labor ($N_t$), and nonreproducible factors ($T$).[14] In this economy the law of motion for capital is

$$\dot{K}_t = AK_t^{\alpha_1}N_t^{\alpha_2}T^{\alpha_3} - C_t - \delta K_t, \quad \alpha_1, \alpha_2, \alpha_3 \geq 0, \delta > 0.$$

The equation for the growth rate of capital shows that under the standard assumption of constant returns to scale ($\alpha_1 + \alpha_2 + \alpha_3 = 1$), perpetual growth is unfeasible whenever $N_t$ and $T$ are required to produce output ($\alpha_2 > 0$, $\alpha_3 > 0$):

$$g_{kt} = AK_t^{\alpha_1 - 1}N_t^{\alpha_2}T^{\alpha_3} - \frac{C_t}{K_t} - \delta. \tag{18}$$

Even if all the resources are devoted to capital accumulation, so that $C_t = 0$, the presence of decreasing returns to the only factor of production that can be accumulated, $K_t$, implies that the growth rate of capital has to converge to zero.

### A. *The Neoclassical Model*

In the neoclassical model the assumption of constant returns to scale to production is maintained but nonreproducible factors are ignored ($\alpha_3 = 0$, $\alpha_1 + \alpha_2 = 1$). As discussed in Lucas (1988, sec. 2), this model is generally made consistent with perpetual growth by making the production function time dependent: $Y_t = AK_t^{\alpha_1}(N_tX_t)^{1-\alpha_1}$, where $X_t$ grows at rate $g_x$ and is often taken to represent the effects of technological progress. With this technology it is possible for output, investment, and consumption to grow at rate $g_x$. The steady state of the model is fairly uninteresting since its growth rate is determined by a single aspect of the technology, the growth rate of exogenous techni-

[14] Replacing the Cobb-Douglas technology with a neoclassical production function would imply no substantive changes in the discussion that follows.

cal progress $g_x$. Given that $g_x$ is also the only sustainable growth rate for consumption, the steady-state real interest rate has to be such that households *choose* to expand consumption at this rate. With the preferences described in (1) the steady-state real interest rate is $r = \sigma g_x + \rho$. This shows that in the steady state of the neoclassical model the growth rate is determined entirely by technology and only the real interest rate depends on preferences. In contrast, in the endogenous growth models discussed, the growth rate is always a function of preferences and technology, whereas it is the real interest rate that in some models (e.g., Sec. III*A*) depends only on technology. This symmetry underlies the different steady-state effects of taxation that are obtained in these two classes of models. Policies that lead to a lower steady-state real interest rate lead to growth effects in endogenous growth models but generate only level effects (e.g., changes in the capital/labor ratio) in the neoclassical model.

### *B. Endogenous Growth with Constant Returns*

As we have seen in the previous sections, sustained growth can be made compatible with technologies that display constant returns to scale by assuming that there are constant returns to the factor that can be accumulated ($\alpha_1 = 1$, $\alpha_2 = \alpha_3 = 0$). This seems to imply that both labor and nonreproducible factors are not used in production, but we have seen that $K_t$ can be reinterpreted as being a composite of human and physical capital (which is called $Z_t$ in Sec. II) and that in multisector models nonreproducible factors can be given a productive role.

In a one-sector model, nonreproducible factors can enter the production function only if they are nonessential to production. This idea was explored by Jones and Manuelli (1990), who studied models with technologies of the type $Y_t = AK_t + BK_t^{1-\alpha}T^{\alpha}$.

Both the Jones-Manuelli technologies and those described here involve restrictions on the role that nonreproducible factors can play in production. These restrictions accord with the view, often implicit in historical accounts of the development process, that nonreproducible factors are not a key determinant of long-run growth (see, e.g., Maddison 1982, pp. 46–48).

### *C. Endogenous Growth with Increasing Returns*

Equation (18) makes clear that if nonreproducible factors are essential to production, so that $\alpha_3 > 0$, making sustained growth feasible in the absence of exogenous productivity increases (which implies that $\alpha_1 \geq 1$) means assuming that the technology displays increasing returns to scale ($\alpha_1 + \alpha_3 > 1$). In multicapital models, it is only when we require that nonreproducible factors be indispensable to the production of all capital goods in the economy that we need increasing returns to scale to make perpetual growth feasible. Growth models with technologies that display increasing returns to scale were proposed by Romer (1986), who introduced increasing returns in the form of an externality to maintain the existence of a competitive equilibrium.

## V. Conclusion

This paper describes a class of endogenous growth models that have constant returns to scale technologies. This class of models is attractive because it is consistent with Kaldor's (1961) stylized facts of economic growth and can potentially rationalize the existence of permanent cross-country differences in growth rates as being, at least partly, a result of differences in government policy.

While this paper does not resolve the issue of whether the type of increasing returns and externalities proposed by Romer (1986) is the key to understanding the growth process, it provides two reasons to reevaluate the role that these features play in growth models. First, the models discussed here make clear that increasing returns and externalities are not necessary to generate endogenous growth. As long as there is a "core" of capital goods whose production does not involve nonreproducible factors, endogenous growth is compatible with production technologies that exhibit constant returns to scale. Second, in one of the economies studied (Sec. III*A*), the same type of phenomenon that motivated Lucas (1988) to introduce an externality in his model—the tendency for labor (but not capital) to migrate across countries in search for higher remuneration—arises despite the absence of externalities.

All the models studied in this paper have the implication that the growth rate should be low in countries with high income tax rates and poor property rights enforcement. In a study of 47 countries in the postwar period, Kormendi and Meguire (1986) found that the rate of growth of gross domestic product per capita was, in fact, positively correlated with a proxy for the degree of protection of property rights (Gastil's [1987] civil liberty index). Using the Summers and Heston (1988) data set, Barro (1989) found a negative relation between growth rates and the share of government consumption in gross domestic product. This is also consistent with predictions if one views the government share as a proxy for the rate of income tax.

While these empirical findings are suggestive, much more empirical work is necessary to determine whether actual cross-country differences in policy regimes are large enough to give rise to the cross-sectional variance in growth rates that is observed.

A first step in this process is to study the effects of public policy in economies that are calibrated to reproduce the values of the "great ratios" that appear to be constant in the long run (the labor share, the capital/output ratio, the real interest rate, etc.). This analysis, which is undertaken in King and Rebelo (1990), reveals that small differences in policy regimes can easily mean the difference between growth and stagnation.

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