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# Growth Effects of Income and Consumption Taxes

The effects of income and consumption taxation are examined in the context of models in which the growth process is driven by the accumulation of human and physical capital. The different channels through which these taxes affect economic growth are discussed. It is shown that the effects of taxation on growth depend crucially on whether the sector producing human capital is a market sector, on the technology for human capital accumulation, and on the specification of the leisure activity. In general, the taxation of factor incomes (human and physical capital) is growth reducing, while the effects of a consumption tax depend on the specification of leisure. The paper also derives implications for the growth-maximizing choice of tax instruments.

THE MERITS OF A SHIFT from current tax systems based on personal income taxation to one based on an expenditure tax are at the center of policy debates on tax reform in the United States and elsewhere. According to its proponents, an expenditure tax would eliminate the bias against savings inherent in a system based on income taxes, known as "double taxation of savings." Eliminating this bias would encourage capital accumulation, thus raising future living standards. In this context, the relevant concept of capital includes both its physical and human components; therefore, a comparison of income and consumption taxes has to take into account their effects on the accumulation of both forms of capital. In this paper we explore the growth and welfare implications of income and consumption taxes in models where growth is endogenously determined by private agents' accumulation of physical and human capital.

While the debate on the relative merits of consumption versus income taxation has a long intellectual history, which we briefly survey in section 1, this paper is more closely related to a number of recent theoretical contributions in the endogenous growth literature that have explored the effects of income and consumption taxes on economic growth. A seminal paper by Eaton (1981) showed that taxes can reduce growth in an endogenous growth setting. King and Rebelo (1990), Rebelo (1991),

This is a revised version of National Bureau of Economic Research working paper no. 5317. The authors are grateful to Michael Devereux, Kenneth Judd, Noriaki Kinoshita, Enrique Mendoza, Sergio Rebelo, Howell Zee, and two referees for helpful discussions and suggestions. The opinions expressed reflect those of the authors and not of the International Monetary Fund.

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*Journal of Money, Credit, and Banking,* Vol. 30, No. 4 (November 1998)

Pecorino (1993), Devereux and Love (1994), and Stokey and Rebelo (1995) present analytical and calibration results showing that income taxes are in general growth reducing, while the growth effects of consumption taxes depend on model specification.[1]

This paper generalizes the results of previous contributions and presents some new results in the context of a unified analytical framework. By explicitly discussing the channels through which labor income, capital income, and consumption taxes affect resource allocation and growth, it shows how the effects of taxation depend crucially on (i) the specification of leisure, (ii) the structure of the human capital accumulation sector, and (iii) its tax treatment. With regard to the first point, the paper considers different formulations of the leisure activity, such as raw time, quality time, and home production. With regard to the second, it examines the case in which the production of human capital requires only human capital and hours and the case in which it requires physical capital inputs as well. With regard to the third, it explores the implications of considering the production of human capital (education) as a nonmarket or a market activity, and the effects of a subsidy to human capital accumulation in the latter case. Finally, it discusses growth-maximizing tax policy when the government has to run a balanced budget.

The structure of the paper is as follows. Section 1 presents a survey of the debate on the relative merits of consumption versus capital and labor income taxation. Section 2 presents the model, and section 3 solves for the competitive equilibrium. The positive analysis of the effects of different taxes on the growth rate of the economy is presented in section 4; section 5 studies the growth-maximizing tax structure. Section 6 discusses quantitative and empirical aspects, and section 7 concludes.

## 1. SURVEY OF THE LITERATURE

An early argument for the superiority of consumption taxes over income taxes was formulated by Hobbes in 1651. John Stuart Mill and, in more recent times, Kaldor (1955) have presented arguments in favor of consumption taxes relative to income taxes.[2] Mill's concern was with the double taxation of savings implicit in an income tax, a double taxation that a consumption tax avoids. However, what should matter is not how often one is taxed but rather how heavily one is taxed. An income tax leads to a heavier taxation of deferred (future) consumption relative to current consumption, while a consumption tax that is uniform over time imposes the same burden on current and future consumption. Therefore, the choice between consumption and income taxation can be expressed as a question over the optimal rates of taxation of present and future consumption. In a traditional public finance approach, this question has

1. Bull (1993), Jones, Manuelli, and Rossi (1993, 1997), and Milesi-Ferretti and Roubini (1996) discuss optimal taxation issues, and show that the optimal tax plan consists in accumulating government assets in the short run and setting all taxes equal to zero in the long run. The implications for the optimal taxation of factor incomes in all these endogenous growth models differ from the traditional Chamley-Judd result about the optimality of long-run zero taxation of capital income and positive taxation of labor income in neoclassical exogenous growth models (Judd 1985; Chamley 1986).

2. See Kay (1989) for a good historical survey of this debate.

been analyzed in terms of the relative substitutability of consumption and leisure at different points in time. Since leisure is an untaxed factor, standard optimal taxation principles imply that one should tax more heavily goods that are more complementary with leisure [see Corlett and Hague (1953) and the survey in Auerbach (1985)].

In an intertemporal context, authors such as Atkinson and Sandmo (1980), King (1980), and Stern (1992) argued that on theoretical grounds uniform consumption taxation is not unambiguously superior to income taxation. Feldstein (1978) and Boskin (1978) focussed instead on the quantitative effects of the taxation of capital income on the long-run capital-labor ratio and income per capita. Specifically, Feldstein (1978) argued that capital income was taxed excessively and that large efficiency gains could be obtained by eliminating the capital income tax and replacing it with a labor income or consumption tax. Summers (1981) extended the work of Feldstein and Boskin by considering an optimal growth model with endogenous savings decisions. He argued that if the intertemporal elasticity of substitution is high and the time horizon of the agent is very long, the savings rate will be very sensitive to its real return and a change in capital income taxes would have a very strong effect on the accumulation of capital and the long-run capital-labor ratio in the economy.[3] Normative analysis by Judd (1985) and Chamley (1986) showed that when the tax instruments available are a capital income tax and a labor income tax, the optimal long-run tax on capital income is zero while it is positive for labor income; the same result is obtained when a labor income tax is replaced by a consumption tax.

More recently, the study of the interaction between tax policy and economic growth has been stimulated by the development of endogenous growth theory. Several authors have used these models to study both positive and normative aspects of tax policy. Lucas (1990), King and Rebelo (1990), Kim (1992), Jones, Manuelli, and Rossi (1993), Pecorino (1993), Devereux and Love (1994), and Stokey and Rebelo (1995) among others use simulations in order to quantify growth and welfare effects of tax reforms, such as, for example, a shift from income to consumption taxes or a lowering of capital income taxes. Although the quantitative growth and welfare effects identified by these studies differ considerably, they all point out that consumption taxation induces fewer distortions than capital and labor income taxation. Optimal taxation analysis by Bull (1993) and Jones, Manuelli, and Rossi (1997) shows that the optimal long-run values of all distortionary taxes (including the consumption tax) are zero when there is no restriction on the government's intertemporal borrowing and lending decisions and leisure is modeled as "raw time." The optimality of zero long-run taxation of human and physical capital is, intuitively, a consequence of the well-known public finance principle that intermediate goods should not be taxed (Diamond and

3. Numerical simulations presented by Summers suggested that replacing income taxes with consumption taxes would lead to a 18 percent increase in steady-state income, driven by a large increase in the long-run capital-labor ratio. These steady-state gains have to be weighed against the costs of lower consumption along the transition. Such transitional costs are explicitly taken into account in simulations from OLG general equilibrium models by Auerbach, Kotlikoff, and Skinner (1983), Fullerton, Shoven, and Whalley (1983), and Auerbach and Kotlikoff (1987). The benefits of switching from an income tax to a consumption tax (or a labor income tax) are confirmed, but the average welfare gains are lower (of the order of two percentage points of income).

Mirrlees 1971). In endogenous growth models, consumption and income taxes have different growth and welfare effects, the growth effects of consumption taxes being in general less strong.

In next three sections, we focus on the channels through which taxes affect resource allocation and growth, and on their sensitivity to the specification of the model. In section 6 we also review quantitative findings and empirical evidence.

## 2. THE MODEL

We consider a three-sector economy. The first sector produces final goods (and physical capital); the second produces human capital and the third produces a nonmarket good—a leisure activity that can take the form of "home production," "quality time," or "raw time."

### *2.1 Technology*

Physical output is produced with a constant returns to scale (CRS) technology that uses human capital $H$ and physical capital $K$ as inputs. The technology is assumed to take the Cobb-Douglas form:

$$Y_t = A(v_t K_t)^{\alpha}(u_t H_t)^{1-\alpha} \tag{1}$$

where $v(u)$ is the fraction of physical (human) capital devoted to the production of goods. The capital stock is assumed to depreciate at the rate $\delta$.

Human capital is produced by households with a CRS technology that uses both human and physical capital as inputs, as in Rebelo (1991). "Education" is therefore a nonmarket activity. In section 3.2 we discuss the case in which the production of human capital is a market activity, whose inputs are taxed. Human capital is assumed to depreciate at a rate $\delta$, equal for simplicity to the depreciation rate of physical capital, and to have a Cobb-Douglas production function:[4]

$$\dot{H}_t = B(x_t K_t)^{\beta}(z_t H_t)^{1-\beta} - \delta H_t \tag{2}$$

where $x(z)$ is the fraction of physical (human) capital devoted to the accumulation of human capital. An alternative specification of the education technology, intermediate between nonmarket and market specifications, would feature market goods instead of physical capital as an input in the education sector, as in Heckman (1976) and Jones, Manuelli, and Rossi (1997). We shall discuss its implications in sections 3.2 and 4.

4. Stokey and Rebelo (1995) show that the growth effects of taxation are not very sensitive to the elasticity of substitution between capital and labor, which is restricted to equal unity in the Cobb-Douglas case. Results generalize to the case in which the technologies are CRS with positive cross-derivatives. The assumption about depreciation allows the derivation of a simple closed-form solution for the growth rate, without affecting the qualitative nature of the results.

### 2.2 *The Government*

The government finances public expenditure using factor income taxation and bonds. In order to ensure that public expenditure does not become negligible with respect to the size of the economy, we assume that in the long run it grows as the same rate as output. Without loss of generality, we assume that government bonds are tax exempt. The instantaneous budget constraint faced by the government is given by

$$\dot{B}_t = r_t B_t + G_t - T_t \tag{3}$$

where $B_t$ are government bonds, $r_t$ is their rate of interest, and $T_t$ is total tax revenue. The usual no-Ponzi-game condition applies. In every period, the resource constraint of the economy is given by

$$\dot{K}_t = Y_t - \delta K_t - C_t - G_t \tag{4}$$

where $C$ is private consumption and $G$ is government expenditure.

### 2.3 *Private Agents*

The economy is inhabited by identical atomistic agents. They operate the human capital accumulation technology described in equation (2) and they rent human and physical capital to firms. Consumption, investment, and allocation of human and physical capital are chosen so as to maximize the utility function:

$$U = \int_0^\infty e^{-\rho t} u(C_t, L_t) dt \tag{5}$$

where $\rho$ is the rate of time preference, and $L$ is a "leisure activity," which is specified later. We assume that the instantaneous utility function exhibits a Constant Intertemporal Elasticity of Substitution (CIES):

$$u(C_t, L_t) = \frac{(C_t L_t^\eta)^{1-\theta}}{1-\theta} - 1 \tag{6}$$

where $\theta$ is the inverse of the IES. This reduces to $u(C, L) = \log C + \eta \log L$ when $\theta = 1$. This functional form has been shown to be consistent with the existence of a balanced growth path by King, Plosser, and Rebelo (1988). Consumers maximize utility subject to the constraint on human capital accumulation given by (2) and to their budget constraint. Given that they can invest in physical capital and in bonds, their net rates of return must be the same ($r = R^K(1 - \tau^K) - \delta$). If we define nonhuman wealth $W$ as $K + B$, the budget constraint can be expressed as follows:

$$\begin{aligned}\dot{W}_t = {} & [R_t^K(1 - \tau_t^K) - \delta]W_t - (1 - v_t)R_t^K(1 - \tau_t^K)K_t \\ & + R_t^H(1 - \tau_t^H)u_t H_t - C_t(1 + \tau_t^C)\end{aligned} \tag{7}$$

where $R^K$, $R^H$, $\tau^K$, and $\tau^H$ are the rates of return and the tax rates on capital and labor income, respectively, and $\tau^C$ is a consumption tax. The term in $W$ represents the market return on nonhuman wealth: this must be adjusted by subtracting the return on the fraction of capital employed in the education sector (the term in $K$) which is not remunerated because that sector is nonmarket. For the same reason, wage income net of taxes is earned only on effective labor allocated to production ($uH$). Total tax revenues $T$ are equal to $\tau^K R^K vK + \tau^H R^H uH + \tau^C C$.

If human capital accumulation was a market activity, the budget constraint would be

$$\begin{aligned} \dot{W}_t = {} & [R_t^K(1 - \tau_t^K) - \delta]W_t - (1 - v_t - x_t)R_t^K(1 - \tau_t^K)K_t \\ & + R_t^H(1 - \tau_t^H)(u_t + z_t)H_t - C_t(1 + \tau_t^C) - p_t^H(1 - s_t^H)E_t \end{aligned} \tag{8}$$

where $E$ is new human capital (equal to $B(xK)^{\beta}(zH)^{1-\beta}$), $p^H$ is its relative price, and $s^H$ a subsidy to human capital accumulation. A fraction $(x + v)$ of physical capital now earns a market rate of return, and agents earn wage income on effective labor in the education sector ($zH$) as well. Households need to purchase new human capital $E$ which therefore enters with a negative sign in the budget constraint. In this case total tax revenues $T$ would equal to $\tau^K(v + x)R^K K + \tau^H R^H(u + z)H + \tau^C C - s^H p^H E$.

We shall consider three alternative specifications of the leisure activity: "raw time," "home production," and "quality time." In the first, leisure is the fraction of time that is not spent working and "studying":

$$L_t = 1 - u_t - z_t. \tag{9}$$

In the second, leisure is produced with a CRS technology that uses human and physical capital as inputs:

$$L_t = [(1 - v_t - x_t)K_t]^{\phi}[(1 - u_t - z_t)H_t]^{1-\phi}. \tag{9a}$$

This specification of home production is similar to the one used in Benhabib, Rogerson, and Wright (1991) and Greenwood and Hercowitz (1991). In the third, leisure requires the use of human capital, in addition to time:

$$L_t = (1 - u_t - z_t)H_t^{\omega} \quad \omega \leq 1. \tag{9b}$$

This specification of leisure (with $\omega = 1$) goes back to Becker (1965) and Heckman (1976). Note that when $\phi = 0$ and $\omega = 1$ the quality time and home production specifications coincide, while when $\omega = 0$ the quality time specification becomes raw time.

### 2.4 *Firms*

Firms rent capital from households at the rate of interest $R^K$ and hire labor at the wage rate $R^H$. They use these factors to produce goods with the technology described by equation (1). They hire labor and capital up to the point at which their marginal product equates their marginal cost:

$$R_t^K = \alpha A\left(\frac{v_t K_t}{u_t H_t}\right)^{\alpha-1}. \tag{10}$$

$$R_t^H = (1-\alpha)A\left(\frac{v_t K_t}{u_t H_t}\right)^{\alpha}. \tag{11}$$

If human capital was a market activity, a similar set of conditions would apply for the wage and rental rates in that sector.

## 3. THE COMPETITIVE EQUILIBRIUM

The representative consumer takes the paths of $R^H$, $R^K$, $\tau^K$, $\tau^H$, and $\tau^C$ as given and chooses the paths of $C$, $W$, $K$, $H$, $u$, $v$, $x$, $z$ to maximize (5) subject to (2) and (7).

### *3.1 Leisure as "Raw Time"*

When leisure consists of raw time only, the entire physical capital stock is used in the production and education sectors, and therefore $x = 1 - v$. The first-order conditions (FOCs) with respect to $C$, $W$, $K$, $H$, $u$, $v$, and $z$ respectively are presented in an Appendix available from the authors. This economy will exhibit a balanced growth path, along which consumption, physical capital, and human capital grow at the same rate $\gamma$, while factor allocations ($u$, $v$, and $z$) remain constant.[5] The equilibrium conditions along the balanced growth path are

$$\gamma = \frac{1}{\theta}(r-\rho); \tag{12}$$

$$r = (1-\tau^K)\alpha A\left(\frac{vK}{uH}\right)^{\alpha-1} - \delta; \tag{13}$$

$$r = (1-\beta)B\left(\frac{(1-v)K}{zH}\right)^{\beta}(u+z) - \delta; \tag{14}$$

$$\frac{v}{u} = \frac{\alpha}{1-\alpha}\,\frac{1-\beta}{\beta}\,\frac{1-\tau^K}{1-\tau^H}\,\frac{1-v}{z}; \tag{15}$$

$$\gamma = Bz\left[\frac{(1-v)K}{zH}\right]^{\beta} - \delta; \tag{16}$$

5. Mulligan and Sala-i-Martin (1993) and Barro and Sala-i-Martin (1995) give the necessary conditions for the existence of a balanced growth path.

$$\frac{C}{Y} = \frac{1-\tau^H}{1+\tau^C} \, \frac{1-u-z}{u} \, \frac{1-\alpha}{\eta}; \tag{17}$$

$$\frac{C}{Y} + (\gamma + \delta)\frac{K}{Y} = 1 - \frac{G}{Y}. \tag{18}$$

Equation (12) links the growth rate with the net rate of return on capital and with the elasticity of intertemporal substitution. Equation (13) defines $r$ at each point in time, and equation (14) establishes the long-run equality in rates of return between the sector producing goods and the one producing human capital. Equation (15), valid at each point in time, is derived from the equality in the relative net rates of return on physical and human capital in the two sectors. Equation (16) establishes that in the long run human capital grows at the same rate as consumption and physical capital. Equation (17) is the equality between the marginal rate of substitution (MRS) between consumption and leisure and the real rate of return on human capital, and holds at each point in time. Finally, equation (18) is the resource constraint for the economy, where all variables are expressed as a fraction of $Y$. The system of equations (12)–(18) can be solved for the values of $\gamma$, $r$, $K/H$, $C/Y$, $u$, $v$, and $z$ as a function of technology parameters and of the exogenous fiscal variables $\tau^C$, $\tau^H$, $\tau^K$, and $G/Y$. From equations (12)–(15), we obtain the following semireduced expression for the growth rate:

$$\gamma = \frac{1}{\theta}\left\{\left[D(1-\tau^K)^{\alpha\beta}(1-\tau^H)^{\beta(1-\alpha)}(u+z)^{1-\alpha}\right]^{\frac{1}{1-\alpha+\beta}} - \rho - \delta\right\} \tag{19}$$

where $D = (\alpha A)\beta[B(1-\beta)]^{1-\alpha}[(1-\alpha)\beta/\alpha(1-\beta)]^{\beta(1-\alpha)}$ is a function of the technology parameters $\alpha$, $\beta$, $A$, and $B$. For the remainder of this paper we shall assume that the "raw time" version of the model has a unique equilibrium [see Ladrón de Guevara, Ortigueira, and Santos (1997) for a discussion of the potential for multiple equilibria in this type of model].

### *3.2 Human Capital as a Market Good*[6]

Assume that new human capital is produced in a market sector by firms, rather than individuals, and that factor income tax rates are independent of whether the factor is employed in the human capital or final goods sector. Clearly, the gross and net rates of return on human and physical capital have to be the same in both sectors. We also allow for a government subsidy to the purchase of new human capital by individuals, that reduces its price by a factor $1 - s^H$ [see Judd (1995) and Milesi-Ferretti and Roubini (1996) for a discussion]. With respect to the case considered in the previous subsection, the equilibrium rate of return on human capital [equation (14)] will now be calculated net of the labor tax rate and of the subsidy:

6. This is the case considered by Pecorino (1993) and Stokey and Rebelo (1995), who also assume that physical capital and consumption goods are produced in different sectors. This latter assumption, however, has no bearing on the effects of tax rates on economic growth.

$$r = (1-\beta)B\frac{1-\tau^H}{1-s^H}\left(\frac{(1-v)K}{zH}\right)^{\beta}(u+z)-\delta. \tag{14a}$$

Since both sectors are now fully taxed, the relation between the optimal capital/labor ratios in production and education (equation 15) is now independent of tax rates:

$$\frac{v}{u} = \frac{\alpha}{1-\alpha}\,\frac{1-\beta}{\beta}\,\frac{1-v}{z}. \tag{15a}$$

The semireduced form for the growth rate can be expressed as follows:

$$\gamma = \frac{1}{\theta}\left(\left[D(1-\tau^K)^{\beta}\left(\frac{1-\tau^H}{1-s^H}\right)^{1-\alpha}(u+z)^{1-\alpha}\right]^{\frac{1}{1-\alpha+\beta}}-\delta-\rho\right). \tag{20}$$

If physical capital employed in education were to be untaxed (for example, because educational institutions have nonprofit status), the exponent of the capital income tax in equation (21) would be $\alpha\beta$, the same as in (19).

Heckman (1976), building on Ben Porath (1967), specified the production of human capital as a nonmarket activity that used effective labor and (subsidized) market goods instead of physical capital. Under this assumption, the model would be intermediate between the pure nonmarket and market cases, and growth would be

$$\gamma = \frac{1}{\theta}\left(\left[D'(1-\tau^K)^{\beta^*}\left(\frac{1-\tau^H}{1-s^H}\right)^{\beta^*(1-\alpha)}(u-z)^{1-\alpha}\right]^{\frac{1}{1-\alpha+\beta^*}}-\delta-\rho\right). \tag{21}$$

where $\beta^* = \alpha\beta$ is the adjusted capital intensity of the education sector and $D'$ is a function of technology parameters. The effect of capital income taxation on growth is the same as in (20), since income from capital is fully taxed, while the labor tax (divided by the subsidy wedge $1 - s^H$), has the same effect as in (19).

### *3.3 The Model with "Home Production"*

Evaluating the FOCs for the home production model when $H$ is nonmarket along the balanced growth path we obtain equilibrium conditions similar to those derived above, with $x$ replacing $1 - v$. There are, however, a few differences. In particular, conditions (12), (14) and (17) now take the form:

$$\gamma = \frac{1}{\theta-\eta(1-\theta)}(r-\rho); \tag{12b}$$

$$r = (1-\beta)B\left(\frac{xK}{zH}\right)^{\beta} - \delta; \tag{14b}$$

$$\frac{C}{Y} = \frac{1-\tau^H}{1+\tau^C}\,\frac{1-u-z}{u}\,\frac{1-\alpha}{\eta(1-\phi)}. \tag{17b}$$

An additional equilibrium condition reflects the optimal allocation of physical capital between production of consumption goods and of leisure:

$$\frac{v}{u} = \frac{\alpha}{1-\alpha}\,\frac{1-\phi}{\phi}\,\frac{1-\tau^K}{1-\tau^H}\,\frac{1-v-x}{1-u-z} \tag{22}$$

Solving for $\gamma$ the system formed by (12b), (13), (14b), and (15) (with $x$ replacing $1 - v$) we obtain the following reduced-form expression for the growth rate:

$$\gamma = \frac{1}{\theta-\eta(1-\theta)}([D(1-\tau^K)^{\alpha\beta}(1-\tau^H)^{(1-\alpha)\beta}]^{\frac{1}{1-\alpha+\beta}} - \delta - \rho. \tag{23}$$

When human capital is a market sector, we get

$$\gamma = \frac{1}{\theta-\eta(1-\theta)}\left(\left[D(1-\tau^K)^{\beta}\left(\frac{1-\tau^H}{1-s^H}\right)^{1-\alpha}\right]^{\frac{1}{1-\alpha+\beta}} - \delta - \rho\right). \tag{24}$$

### 3.4 *The "Quality Time" Model*

When leisure is quality time, the equilibrium conditions (12) and (14) are modified as follows:

$$\gamma = \frac{1}{\theta-\eta\omega(1-\theta)}(r-\rho), \tag{12c}$$

$$r = (1-\beta)B\left(\frac{xK}{zH}\right)^{\beta}[\omega + (1-\omega)(u+z)] - \delta, \tag{14c}$$

and the semireduced form for the growth rate is

$$\gamma = \frac{1}{\theta-\eta\omega(1-\theta)}\{[D(1-\tau^K)^{\alpha\beta}(1-\tau^H)^{\beta(1-\alpha)}(\omega+(1-\omega)(u+z))^{1-\alpha}]^{\frac{1}{1-\alpha+\beta}} - \rho - \delta. \tag{25}$$

Inspection of (19), (23), and (25) reveals that the "quality time" case is intermediate between the raw time and the home production case. As $\omega$ tends to 1, we get the "home production" case (with $\phi = 0$); as $\omega$ tends to 0, we get the raw time case.

## 4. TAXATION AND LONG-RUN GROWTH

We turn now to a discussion of the channels through which taxes affect long-run growth in the class of models we are considering, and we then state some formal propositions. We take as benchmark the "leisure as raw time" model when human capital is a nonmarket sector, and highlight the differences with alternative model specifications. When we examine the long-run effects of changing a tax rate, an important point should be highlighted. Changing a tax rate will imply a change in government revenue as a fraction of GDP. Since we focus on the balanced growth path, and government spending is taken to be a constant fraction of GDP, we are implicitly changing the long-run level of government debt or assets (as a fraction of GDP). Because of Ricardian equivalence between debt and lump-sum transfers, this is tantamount to assuming that the additional tax revenue gets rebated to consumers in a lump-sum fashion. An alternative approach, not pursued here, would be to consider revenue-neutral changes in tax policy.

### *4.1 The "Raw Time" Model*

Inspection of the system of equations (12)–(18) and the semireduced expression for the growth rate (19) reveals that in general all three tax rates will have an effect on the long-run growth rate of the economy. The channels through which each tax affects long-run growth can be summarized as follows:

*Tax on Physical Capital*

(K.i) It reduces the net-of-tax real interest rate $r$, for a given capital/labor ratio in production $vK/uH$ [see equation (13)]. This has a *negative* effect on growth.

(K.ii) It reduces the capital/labor ratio in production ($vK/uH$) for a given allocation of time between work and leisure, thus increasing the gross-of-tax return on capital [equations (13)–(15)]. This has a *positive* effect on growth, no greater than the negative effect K.i [see equation (19)].

(K.iii) It affects the work (labor/education)-leisure decision ($u + z$), which in turn affects the capital/labor ratio in production [equations (13)–(15)]. The effect on growth depends on parameter values, but is negative if the elasticity of intertemporal substitution $1/\theta$ is sufficiently high.[7]

Irrespective of the value of $\theta$, K.i + K.ii + K.iii $< 0$: that is, the overall effect of a capital income tax on growth is *negative*, as pointed out by Devereux and Love (1994) (see Appendix 1 for a formal proof).

7. See the Appendix for a sketch of the formal proof, which is constructed along the lines of Devereux and Love (1994). The intuitive argument goes as follows. For given labor supply, a higher capital income tax reduces the growth rate, creating a negative wealth effect which induces higher labor supply. On the other hand, higher taxation induces agents to substitute leisure for work. If the intertemporal elasticity of substitution $1/\theta$ is high, the substitution effect dominates and labor supply declines.

*Tax on Human Capital*

(H.i) It raises the capital/labor ratio in production ($vK/uH$) for a given allocation of time between work and leisure, thus reducing the gross-of-tax return on capital [equations (14)–(16)]. This has a *negative* effect on growth.

(H.ii) It affects the labor/education-leisure decision ($u + z$), which in turn affects the capital/labor ratio in production [equations (14)–(16)]. The effect on growth depends on parameter values, but is negative if the elasticity of intertemporal substitution $1/\theta$ is sufficiently high or $\beta$ sufficiently low (see footnote 7).

Irrespective of the value of $\theta$, H.i + H.ii $< 0$: the overall effect of a labor income tax on growth is *negative* (see Appendix 1).

*Tax on Consumption*

(C.i) It affects the labor/education-leisure decision ($u + z$), which in turn affects the capital/labor ratio in production [equations (12), (14)–(16), and (18)]. The effect on growth is *negative* (see Appendix 1).

The indirect effect of taxes on growth through their impact on the labor supply (K.iii, H.ii and C.i) can be explained as follows.[8] In this specification of the model, the fact that $1 - u - z$ units of "raw time" are spent in leisure implies that the corresponding fraction of human capital is "unemployed." Clearly, the more human capital is unemployed each period, the lower are the incentives to accumulation. Therefore the effects of taxes on growth depend on their effects on labor supply.

If physical capital does not enter in the production of $H(\beta = 0)$, as in Lucas (1990), we find that H.i $= 0$ and K.i + K.ii $= 0$ (a labor tax and a capital income tax affect growth only through their impact on the work/leisure decision). A corollary of this finding is that H.ii = C.i (the effect on growth of a labor tax is perfectly analogous to the effect of a consumption tax).

## *4.2 Human Capital as a "Market" Sector*

In this case (section 3.2) we also consider the effects of an education subsidy.

*Subsidy to Human Capital Accumulation*

(S.i) A subsidy to human capital accumulation raises the rate of return to human capital accumulation, thereby increasing the rate of growth [equation (20)].

As can be seen from (20), the subsidy $s^H$ works in the direction of offsetting the negative effect of the labor tax on the rate of return in the human capital sector. With regard to the other forms of taxation, all channels identified earlier will be operative. In addi-

8. We thank a referee for this suggestion.

tion, the fact that factor incomes in the education sector are taxed implies that the labor tax has a stronger direct effect on growth with respect to the case in which education is a nonmarket activity, that is still operative even when $\beta = 0$. This happens because the labor tax directly reduces the rate of return in the sector producing human capital [compare equations (14a) and (14)].

### *4.3 Alternative Specifications of Leisure*

The specification of the leisure activity has important implications for the long-run effects of taxes on economic growth. Consider first the case in which leisure does not provide utility ($\eta = 0$), so that $u + z = 1$. Now equation (19) gives a closed-form expression for the growth rate. Clearly the indirect effects of taxes on growth acting through the impact of taxation on the labor/leisure decision are shut down (K.iii = H.ii = C.i = 0). In particular, this implies that a consumption tax has no growth effects. If in addition human capital is produced with human capital only ($\beta = 0$), factor income taxes have no growth effects (K.i + K.ii = 0, H.i = 0).

When leisure is home production (CRS in $H$ and/or $K$—section 3.3), the term $u + z$ does not appear in the equation for the rate of return on human capital [equation (14b)], and the system can be solved recursively (Milesi-Ferretti and Roubini 1996). Again, the indirect effects of taxes on growth are not operative (K.iii = H.iii = C.i = 0) because all human capital is employed, implying that a consumption tax has no growth effects. If in addition $\beta = 0$ and education is a nonmarket activity, all taxes will have no growth effects (K.i + K.ii = 0 and H.i = 0). If education is a market activity, a labor tax will still reduce growth (and an educational subsidy still increase growth) even when $\beta = 0$. Finally, when leisure is quality time, results are intermediate between the raw time and home production cases; since the leisure technology has decreasing returns to scale in accumulable factors (human capital) an "adjusted" measure of labor supply $\omega + (1 - \omega)(u + z)$ affects the growth rate.

### *4.4 Taxes and Long-Run Growth: Main Results*

In summary, factor income taxes are growth reducing in most endogenous growth models; whether a consumption tax is also growth reducing depends on the specification of the leisure activity. The effect of labor and capital income taxes on growth in models where there is no leisure or where leisure is CRS in reproducible factors depend on two factors: the technology for human capital accumulation and the tax treatment of the education sector. We now state the main results more formally. The first two propositions restate results derived in Milesi-Ferretti and Roubini (1996) regarding the effects of factor income taxation on growth.

PROPOSITION 1: *If leisure is modeled as "raw time" the balanced growth rate of the economy always depends negatively on the tax rates on capital and labor income, regardless of whether H is a market good and of its technology.*

PROOF: Equations (19) and (20) show the direct effects of taxes on growth, for given time spent working or studying. Capital and labor taxes have additional indirect *ef-*

fects on growth through their impact on u + z. Appendix 1 outlines a proof that the overall growth effect is negative. ||

The intuition for the result can be more easily obtained by considering the case where $\beta = 0$, in which case the growth rate can be expressed as $Bz - \delta$.[9] Consider the effects of an increase in the labor tax: while the relative cost of and return to working versus accumulating human capital are unchanged, the return to the leisure activity is increased with respect to the return to work since the time spent in leisure is untaxed. The ensuing increase in time spent in leisure reduces the utilization rate of human capital ($u + z$) and therefore reduces the return to a unit of human capital. As a result, time spent accumulating human capital and the growth rate are both decreased. A similar argument can be made for the effects of changes in capital income taxes on growth, as well as to show that the growth rate depends on the two tax rates when $\beta$ is positive.

PROPOSITION 2: *In the home production model and when there is no leisure, the effects of factor income taxation on long-run growth depend on the human capital accumulation technology and on whether the human capital sector is tax exempt. When physical capital enters directly in the production of human capital ($\beta > 0$), both factor income taxes reduce long-run growth. When $\beta = 0$, the balanced growth rate of the economy is independent of the tax rate on capital income; it is independent of the tax rate on labor income only if the H sector is untaxed.*

PROOF: See equations (23) and (24). ||

The intuition for this result goes as follows. If human capital is produced with human capital only in an untaxed sector, an increase in the labor tax rate reduces the return to human capital and the opportunity cost of education (and, if the model includes home production, the return to the leisure activity) by the same amount. Therefore, the fraction of time spent studying—which in this case determines the growth rate—is unchanged. If instead the education sector is subject to taxation, an increase in the labor tax reduces only the returns to education and therefore its accumulation.

The intuition for the result when $\beta$ is positive is easier to present for the case of no leisure (but is the same in the equivalent cases of leisure as "quality time" or "home production"). We showed above that when $\beta = 0$, the return to and the cost of human capital accumulation (that is, the net of tax wage) are affected in the same proportion by a change in labor taxes, leaving the time allocation decision unchanged. In other terms, since the cost of human capital accumulation is effectively tax deductible, labor income taxation does not affect the incentive to accumulate human capital. However, if physical capital is also used in the production of new human capital ($\beta > 0$), the return to human capital is reduced more than its cost. In particular, the cost of physical capital inputs used in the production of human capital is not reduced by the labor income tax since these inputs are not tax deductible. When the education sector is nonmarket but uses market goods [see equation (21)], the labor income tax will not affect the incentive to accumulate human capital only if the purchase of these goods is fully tax deductible, a point originally made by Boskin (1975) and Heckman (1976).[10]

9. See Rebelo (1991) for an explanation along the same lines.

Finally, note that the real interest rate in the "home production" model (and in the quality time model when $\omega = 1$) is the same as in a model with no leisure ($\eta = 0$). This equivalence results from the fact that leisure is modeled as a nonmarket activity produced with constant returns to scale to reproducible factors, and can therefore be reinterpreted as a nonmarket consumption good.

PROPOSITION 3: *When leisure is either "raw time" or "quality time" with decreasing returns in human capital, a consumption tax reduces long-run growth.*

PROOF: Equations (19) and (25) show that the growth rate depends on the fraction of leisure time. Inspection of the systems of equations (12)–(18) and (12c), (13), (14c), and (15)–(18) reveal that both u and z are a function of $\tau^C$, and therefore $\gamma$ is a function of $\tau^C$. Appendix 1 proves that leisure time is increasing in $\tau^C$, and therefore growth is reduced. ||

The apparent contradiction between Proposition 3 and the claim by Rebelo (1991) and Stokey and Rebelo (1995) that changes in consumption taxes have no growth effects can be explained as follows. Rebelo considers a case in which the additional tax revenues from an increase in the consumption tax are *not* rebated in a lump-sum fashion to consumers. In this case, the income and substitution effects of the consumption tax on labor supply cancel out, so that the leisure choice is unaffected and changes in consumption taxes have no growth effects. This experiment is equivalent to a change in consumption taxes *together with an increase in government spending.* In our model, spending is constant as a fraction of GDP and therefore the extra revenue generated by the consumption tax is rebated in a lump sum to consumers (or reflected in higher private-sector assets), thus offsetting the income effect. The substitution effect causes a reduction in labor supply and, therefore, a reduction in the growth rate.

PROPOSITION 4: *A consumption tax has no effect on the long-run growth rate of the economy in the "home production" model and its subcases.*

PROOF: See equations (23)–(24). ||

The intuition for this proposition is simple. In models where leisure is an activity produced with CRS in reproducible factors, the choice between labor and leisure does not affect long-run growth, because human capital is always fully employed in productive activities. A consumption tax affects the relative consumption of "market goods" and "home-produced goods" (leisure) but generates no incentive to reduce physical and/or human capital accumulation since both types of goods are produced with CRS in accumulable factors.

There is a difference between the home production (or quality time) model and a model with no leisure. In the former, the consumption tax reduces the ratio of consumption to leisure and has an effect on the overall capital/labor ratio of the economy. In the latter, a consumption tax is equivalent to a lump-sum tax, since it does not affect any resource allocation decision. The difference between these models is quite logi-

10. See Trostel (1993) for a detailed presentation of this argument. Recent studies by Dupor, Lochner, Taber and Wittekind (1996) and Steuerle (1996) discuss the effects of the tax treatment of human capital, of subsidies to its accumulation, and the tax deductibility of education expenses.

cal—the "home production" model is a model with two consumption goods, one of which is untaxed, and therefore a consumption tax involves a reallocation of resources across sectors.

PROPOSITION 5: *When education is a market sector, a subsidy to human capital accumulation offsets the direct growth effects of a labor income tax on growth. If the subsidy rate is equal to the labor tax rate, the growth and resource allocation effects of a labor tax become analogous to those of a consumption tax.*

PROOF: See equation (20) for the growth effects of the subsidy. If the subsidy rate $s^H$ is equal to the labor tax $\tau^H$, the only growth and resource allocation effects of the labor tax will come through their effects on the relation between the MRS between consumption and leisure and the real wage [equation (17)] which are analogous to the effects of a consumption tax [see the system of equations (12), (13), (14a), (15a), (16)–(18)]. ||

The intuition for this result goes as follows. In the "raw time" model a labor tax has two effects: a direct effect of discouraging accumulation of human capital (by decreasing the returns to be earned on education) and an indirect effect on the number of hours spent in working/education activities. The first effect is exactly offset by a subsidy to human capital accumulation; the subsidy, however, does not modify the second effect which, analogously to a consumption tax, increases the number of hours spent in the untaxed activity (leisure).

A corollary of this Proposition and of Proposition 4 is that in models in which leisure is "home production" a subsidy to human capital accumulation completely offsets any growth effect of a labor tax. A labor tax will, however, still affect the allocation of resources (inter alia, the ratio between consumption and "leisure"). Finally, note that if investment in physical capital were to be tax deductible, the direct effects of the capital income tax on economic growth would disappear, analogously to the case of the labor tax in the presence of a subsidy to human capital accumulation. The capital income tax would retain its indirect effects through its impact on the choice of leisure hours.

## 5. NORMATIVE IMPLICATIONS AND GROWTH-MAXIMIZING TAX POLICY

The previous section has highlighted the channels through which different taxes affect economic growth and resource allocation. A number of contributions have studied the tax policy that a benevolent social planner would choose in order to maximize the representative agent's welfare. This is known as a "Ramsey planner's problem" (Ramsey 1927), and can be solved in different ways (see Lucas 1990 and Judd 1995).

A formal treatment of this problem when the government is freely allowed to borrow and lend is presented in the working paper version of this paper. For most model specifications the optimal tax policy consists in setting all taxes equal to zero in the long run, with public spending financed out of the return on government assets that are accumulated through budget surpluses along the transition path. These results, analogous to those obtained by Jones, Manuelli, and Rossi (1997), derive from the fact that in an endogenous growth framework any tax that distorts intertemporal decisions has large and permanent costs (in terms of present discounted value of lost consumption and utility) and should therefore be set equal to zero. This suggests that the solution to the optimal taxation problem is characterized mainly by the *time profile* of taxation, featuring high taxation in the short run and no taxation in the long run, a point stressed by Jones et al. (1997) (see also Judd 1995). Simulations by Jones, Manuelli, and Rossi (1993) show that reliance on the consumption tax during the transition is high.

The solution to the optimal taxation problem has the unrealistic feature that the government should accumulate budget surpluses in order to finance future government spending through the returns on its assets. This suggests that in order to derive more realistic implications from this analysis the optimal taxation problem should be formulated differently—for example, by imposing restrictions on the government's ability to borrow and lend intertemporally. We briefly consider here the limiting case in which the government has to balance the budget period by period, and we focus on the growth-maximizing structure of taxation in the long run, rather than on welfare-maximizing tax policy. To our knowledge, Pecorino (1993) provides the only formal analysis of this issue. For reasons of tractability, we limit our analysis to the case in which labor supply is inelastic. This implies that a consumption tax has no growth effects, so that the analysis is restricted to the study of the optimal combination of human and physical capital taxation.[11]

We conducted this exercise for the case in which human capital is a nonmarket sector and for the case in which it is a market sector. While Pecorino (1993) has to rely on simulations to characterize the growth-maximizing tax policy except for the special case in which capital intensities are the same across all sectors, we are able to find closed-form solutions.

PROPOSITION 6: *Assume that labor supply is inelastic. When human capital is a nonmarket sector, the growth-maximizing structure of income taxation requires physical capital and labor to be taxed equally. When human capital is a market sector, the growth-maximizing structure of income taxation requires physical capital to be taxed more heavily than labor when* $\alpha > \beta$ *and vice versa.*

PROOF: See Appendix 2. ||

When human capital is a nonmarket sector, the growth-maximizing tax policy in the long run consists of equalizing taxation of labor and physical capital. When human capital is a market sector, the equality of tax rates breaks down: if the sector producing consumption goods (and physical capital) is more capital intensive, the growth-maximizing combination of tax rates will feature higher taxation of physical capital and vice versa. This result derives from the principle that in order to increase the growth rate, the sector producing consumption goods should be taxed more heavily

11. For the more general case in which a consumption tax has growth effects, we speculate that the growth-maximizing tax structure would still feature heavy reliance on the consumption tax, given that it has growth effects only through the labor/leisure decisions while factor income taxes also affect directly accumulation decisions.

than the sector producing capital goods, as also stressed in Pecorino (1993). When the sector producing human capital is not taxed, however, relative capital intensities cease to matter: the equalization of tax rates is due to the fact that the elasticity of long-run growth with respect to tax changes is proportional to their contribution to revenue [see equations (A6) and (A7)].

## 6. TAXES AND GROWTH: QUANTITATIVE ASPECTS

As pointed out in section 1, several authors have studied the macroeconomic and welfare consequences of tax reforms by calibrating models so as to reflect features of real world economies (typically, the United States). Lucas (1990), King and Rebelo (1990), Kim (1992), Jones, Manuelli, and Rossi (1993) and Pecorino (1993) consider the same policy experiment of a shift from capital income taxation to a consumption tax and/or labor tax in the context of endogenous growth models, obtaining substantially different growth and welfare effects. Stokey and Rebelo (1995) show that these different estimates depend on the models' structure and calibration, and argue that, although growth effects of tax reforms are likely to be modest, the welfare effects can be substantial because of the large reallocation of factors across sectors. Similar findings are reported by Devereux and Love (1994), who show that explicit consideration of transitional dynamics is important for the evaluation of the welfare consequences of tax reforms. They also provide an analytical characterization of these dynamics following a number of revenue-neutral tax changes, and show that increases in the capital income tax are more "costly" than increases in the labor income tax because they involve a large reduction in the capital/labor ratio as factors are shifted to the production of human capital.

In addition to the theoretical studies we have discussed so far, there have been a number of empirical studies that have examined the cross-country evidence on the effects of taxes on economic growth, such as Koester and Kormendi (1989), Engen and Skinner (1992), and Easterly and Rebelo (1993a, b). Because of the difficulty in constructing comparable, consistent measures of tax rates for a sufficiently large number of countries, these empirical studies rely on aggregate measures of the tax burden, such as the ratio of tax revenue to GDP, as a proxy for average effective tax rates, or on sums of statutory income tax rates or income tax returns weighted using income distribution data, as a proxy for aggregate marginal tax rates. Although results differ from study to study, a common feature is that it is difficult to identify statistically significant effects of taxes on economic growth once other determinants of long-run growth are controlled for.

The tax measures used in these studies are rough approximations of the tax variables defined in the models, and do not distinguish between different types of taxes. However, more detailed cross-country studies of the tax structure, such as King and Fullerton (1984) on the taxation of income from capital, have focussed on a small sample of countries. Mendoza, Milesi-Ferretti, and Asea (1997) use tax measures constructed following the methodology developed by Mendoza, Razin, and Tesar

(1994) to study the effects of labor, capital, and consumption taxes on private investment and growth in a panel of nineteen OECD countries. Their findings, especially for factor income taxes, are qualitatively and quantitatively consistent with those predicted by theory and model calibration exercises. Private investment is found to be significantly negatively correlated with labor and capital income taxes, and positively correlated with consumption taxes. Income taxes enter with a negative coefficient in growth regressions, although their effects are for the most part statistically and economically insignificant. These studies confirm the importance of focussing on the composition of tax instruments when examining the macroeconomic implications of taxation.

## 7. CONCLUDING REMARKS

In this paper we examined the macroeconomic effects of consumption and factor income taxation on resource allocation, economic growth, and welfare. In particular, we have underlined the role played by the technology for human capital accumulation, the tax treatment of the "education" sector, and the nature of the leisure activity in determining the effects of labor, capital, and consumption taxes.

It was shown that a consumption tax involves only one fundamental distortion—it affects the choice between time spent in "productive" activities (labor and education) and in leisure time in favor of the latter, and therefore reduces the growth rate of the economy. This choice is affected in a similar fashion by income taxes, but these also involve other distortions that reduce capital accumulation and growth. Unrestricted optimal taxation exercises yield in general zero taxation of both factor incomes and consumption in the long run, with accumulation of government assets along the transition path. We have therefore focussed on the growth-maximizing choice of factor income taxes and found that it critically depends on the relative capital intensity of the goods and the education sector, as well as on whether the education sector is a taxed market sector. Further insights can be gained by introducing heterogeneity among economic agents, in order to address distributional considerations, and by explicitly considering transitional dynamics.

## APPENDIX 1: PROOF OF PROPOSITIONS (1) AND (3)

The proof follows Devereux and Love (1994). Using equations (12), (14), and (16), it is possible to express the share of time spent working as follows:

$$z = \xi(u + z) \tag{A1}$$

where

$$\xi = (1 - \beta)\frac{\gamma - \delta}{\theta\gamma + \delta + \rho}. \tag{A2}$$

We can then use (A1) together with equations (13), (15), (17), and (18) to determine a relation between the time spent working or studying $u + z$ and the rate of growth through the variable $\xi$:

$$u + z = \frac{1}{1 + \frac{1+\tau^C}{1-\tau^H}\frac{\eta(1-\xi)}{1-\alpha}\left[1 - g - \frac{\xi}{(1-\xi)(1-\beta)^2}[\alpha(1-\beta)(1-\xi)(1-\tau^K) + (1-\alpha)\beta\xi(1-\tau^H)]\right]} \tag{A3}$$

where the term in brackets beginning with $1 - g$ is the share of consumption in output. This relation, together with the semireduced form for the growth rate (19), determine $\gamma$ and $u + z$. Equation (A3) is monotonically increasing in $\xi$: therefore, the relation between $u + z$ and $\gamma$ it describes depends crucially on the sign of $\xi'(\gamma)$.

In order to determine the effects of taxes on economic growth, it is useful to plot the schedules (19) and (A3) in ($\gamma$, $u + z$) space. The first schedule is upward sloping and monotonically increasing. The second schedule could be upward or downward sloping, depending on the sign of $\xi'(\gamma)$. In the former case, the schedule is always below one, and therefore has to intersect the first schedule from above as long as the equilibrium is unique. An increase in the consumption tax shifts the second schedule downward, irrespective of its slope, while leaving the first unaffected. This unambiguously reduces growth and $u + z$, thus proving Proposition 3. An increase in the tax on labor or physical capital shifts the first schedule upward and the second downward. Both shifts reduce the growth rate, thus proving Proposition 1. The effects on labor supply are ambiguous. When the second schedule is upward sloping, labor supply falls, while it may rise or fall when the second schedule is downward sloping.

When leisure is a market good, equations (A2) and (A3) become

$$u + z = \frac{1}{1 + \frac{1+\tau^C}{1-\tau^H}\frac{\eta(1-\xi)}{1-\alpha}\left[1 - g - \frac{\xi(1-\tau^K)}{(1-\xi)(1-\tau^H)(1-\beta)^2}[\alpha(1-\beta)(1-\xi) + (1-\alpha)\beta\xi]\right]}; \tag{A4}$$

$$\xi = (1-\beta)(1-\tau^H)\frac{\gamma + \delta}{\theta\gamma + \delta + \rho}. \tag{A5}$$

The qualitative effects of taxes on growth are the same as those discussed for the case above.

## APPENDIX 2: GROWTH-MAXIMIZING TAX POLICY

### *2A. Human Capital as a Nonmarket Sector*

The problem of the government is to set $\tau^K$ and $\tau^H$ so as to maximize

$$\text{Max}\frac{1}{\theta}\left[D[(1-\tau^K)^{\alpha\beta}(1-\tau^H)^{\beta(1-\alpha)}]^{\frac{1}{1-\alpha+\beta}}-\delta-\rho\right] \tag{A6}$$

$$\text{s.t.}\quad \tau^K R^K vK+\tau^H R^H uH=G$$

where the growth rate is the same as in (19) with $u + z = 1$. Dividing both sides of the budget constraint by $Y$ and using (10) and (11), we can express it as follows:

$$\alpha\tau^K + (1-\alpha)\tau^H = g \tag{A7}$$

where $g = G/Y$. It is straightforward to show that this implies $\tau^K = \tau^H = g$, thus proving the first part of Proposition 6.

*2b. Human Capital as a Market Sector*

The problem facing the government in this case is the following:

$$\text{Max}\frac{1}{\theta}\left[D[(1-\tau^K)^{\beta}(1-\tau^H)^{1-\alpha}]^{\frac{1}{1-\alpha+\beta}}-\delta-\rho\right] \tag{A8}$$

$$\text{s.t.}\quad \tau^K R^K K+\tau^H R^H H=G$$

where the growth rate is the same as in (20) with $s^H = 0$ and $u + z = 1$. The budget constraint is

$$\tau^K R^K K + \tau^H R^H H = G\,. \tag{A9}$$

In this case, the "tax base" is given by $Y^* = Y + p^H E$, where $E$ is the output of the education sector and $p^H$ its relative price. In order to calculate the growth-maximizing tax policy, we assume that government spending is a constant fraction of $Y^*$. Using consumers' optimality conditions, the budget constraint can be expressed as follows:

$$\frac{\beta(1-\alpha)+u(\alpha-\beta)}{1-\alpha+u(\alpha-\beta)}\tau^K+\frac{(1-\alpha)(1-\beta)}{1-\alpha+u(\alpha-\beta)}\tau^H=g \tag{A10}$$

where $u$ can be determined by (A1) and (A4), taking into account that $z = 1 - u$. The solution of the problem is

$$\tau^K = g + (\alpha-\beta)\Psi_1$$
$$\tau^H = g - (\alpha-\beta)\Psi_2 \tag{A11}$$

where $\Psi_1$ and $\Psi_2$ are positive polynomials. This proves the second part of Proposition 6. Note that the equality between labor and capital income tax rates when $\alpha = \beta$ would not hold if expenditure were calculated as a fixed fraction of $Y$, rather than $Y^*$. The reason is that the labor tax tends to reduce the relative size of the human capital sector, and therefore to increase the relative size of public expenditure. This implies the desirability of a higher tax rate on physical capital income.

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