Optimal flat-rate taxes on capital—a re-examination of Lucas' supply side model

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We examine the transitional dynamics of Lucas' supply side model of the US economy in order to specify the effects of capital taxation on economic growth and welfare. We restrict the analysis to policy plans characterized by constant capital taxes and require the government to maintain a balnced budget. Under these restrictions, the optimal tax rate on capital is shown to be positive and sensitive to the government expenditure rule. Welfare can be further increased by the introduction of a tax on asset holdings.

1. Introduction

Should capital be taxed? The literature on second-best taxation does not provide a clearcut answer to this question. On the one hand, capital taxes are known to be efficient in the short run because capital stocks are in fixed supply. Capital taxation has no distorting effects and a government should raise as much revenue as possible from taxes on assets. On the other hand, it is a well-known result that, in growth models with infinite-lived individuals, second-best tax policies do not foresee capital taxation in the long run.[1] Chamley (1986) and Judd (1985) have analyzed the problem of a social planner whose objective is to maximize the welfare of an infinite-lived representative individual by choice of a time path for tax policies. They find that whenever the optimal policy leads the economy to a balanced growth path, capital taxes must converge to zero. A policy plan that maximizes the welfare of an infinite-lived consumer therefore implies high initial taxation of capital stocks or capital income and, subsequently, a reduction of all capital taxes to zero (Chamley, 1986, Theorem 1 and 2).

It is difficult to interpret this theoretical result as speaking either in favor of or against capital taxation as the Chamley–Judd asymptotic result also holds for other taxes as well in a large class of endogenous growth models. Jones *et al.* (1993, 1997), Bull (1993), and Milesi-Ferretti and Roubini (1995) analyze optimal taxation of capital income, labor income, and consumption. They fnd that the latter two tax

[1] Zero capital taxation need not be optimal in models with finite-lived individuals (see e.g. Atkinson and Sandmo, 1980; Summers, 1981; and Auerbach *et al.*, 1983). For a review of this literature, the reader is referred to Milesi-Ferretti and Roubini (1995) and Stern (1992).

rates must converge to zero in models of human capital accumulation as well. Accordingly, the optimal long-run tax rate on both labor income and consumption is zero, too.

The framework of the present paper diverges from the one used by Chamley (1986) in two important ways. First, we study a model of human capital accumulation. And second, we only consider a simple form of capital tax policies consisting of once-and-for-all changes in the capital tax rate. Due to its simplicity, these policies seem to be among the most realistic in practice. Under these assmptions, optimal capital income taxation is shown to be strictly positive.

Our analysis is based upon the endogenous growth model of the US economy in Lucas (1990). In his study, Lucas finds significant welfare gains in the long run from the abolition of capital income taxes. The gains amount to those induced by an increase of consumption in the neighborhood of 5%. Lucas further predicts that the consideration of transition effects reduces welfare gains to approximately 1%. We explicitly solve for the transition dynamics of Lucas' endogenous growth model to get a precise estimate of these welfare gains. A previous analysis of the transition dynamics in Lucas' model can be found in Laitner (1995). Our approach differs from Laitner's in two ways: first, Laitner applies local approximation techniques to solve the non-linear dynamics. As a consequence, he can only analyze small policy changes. In this study, we refrain from Taylor approximation around the steady state and solve the transitional dynamics with non-linear numerical techniques. As a consequence, we are able to determine the optimal tax policy. Second, we analyze the sensitivity of Lucas' and Laitner's results with regard to the assumption of fiscal spendings.[2] We show that the optimal capital tax rate is sensitive to the government expenditure rule.

While research on tax policy has so far mainly focused on he effects of taxation of income flows, little is known about the role of wealth taxation.[3] In the present paper, we examine the role of both capital income taxation and taxation of capital stocks. We will quantify the short run impact of a policy which taxes capital stocks in comparison to the one of a policy which relies on income taxation only.

In addition, our analysis examines the following secondary questions:

(i) What are the long run effects of capital taxation on growth? How do results vary with respect to crucial parameters such as the elasticity of labor supply and the intertemporal elasticity of substitution?
(ii) How is dynastic welfare affected by different constant-tax plans and what is the impact of taxation on welfare of different generations?

[2] Laitner further introduces government debt in the model of Lucas (1990). We, instead, demand the government budget to balance at any point in time.

[3] An exemption is Atkinson (1971).

Our results can be summarized as follows:

(i) As our main result, we find that the optimal tax rate on capital is positive. Depending on the fiscal expenditure rule, however, the optimal tax rate varies significantly and may take either the value of 9% or 32% for the two cases considered in this paper. Including the use of wealth taxes as an additional policy instrument further increases welfare.

(ii) Capital taxes both on stocks and income flows increase growth in our raw-time leisure model. The reason is simple: a higher capital income tax rate permits a reduction of the labor income tax. As a consequence, the opportunity costs of leisure increase and individuals spend both more time working and more time on education. Human capital accumulation accelerates and the growth rate increases as well (see also Grüner and Heer, 1994). Growth rate effects are more pronounced if the government keeps expenditures constant relative to output rather than relative to human capital as in Lucas (1990).

(iii) Capital taxes have a different impact on welfare in different generations. For example, a once-and-for-all decrease of the capital tax from 36% to 20% decreases the welfare for about the first two years, while it increases discounted utility for the following 25 years. From then on, growth effects make future generations worse off.

The paper is organized as follows. Section 2 introduces the model. In Section 3, we study the growth effects of different tax bases. Section 4 analyzes the transitional dynamics. In Section 5, welfare effects of capital taxation are derived taking restrictions on government behavior into account. Section 6 concludes.

2. The model

2.1 Households

Our analysis is based upon the closed-economy endogenous growth model in Lucas (1990). The population consists of infinitely many identical individuals, each maximizing lifetime utility

$$\int_0^{\infty} e^{-(\rho-\lambda)t} U[c(t), x(t)]dt \tag{1}$$

$c(t), x(t)$, and ρ denote *per capita* consumption, leisure, and the time preference rate, respectively. Population $N(t)$ grows at a constant rate $\lambda = \dot{N}(t)/N(t)$. Instantaneous utility is CES in consumption and leisure with the intertemporal elasticity of substitution $1/\sigma$. Dropping the time argument in the following we may write

$$U(c, x) = \frac{1}{1-\sigma}[c\psi(x)]^{1-\sigma} \tag{2}$$

Following Lucas, we specify the function $\psi(x)$ as

$$\psi(x) = x^{\alpha}, \quad 0 < \alpha \tag{3}$$

The individual can allocate his time B to work u, learning v, or leisure x

$$B = x + u + v \tag{4}$$

The human capital of the representative individual, h, is determined by the time v he allocates to learning according to

$$\dot{h} = hG(v) \tag{5}$$

where $G(v) = Dv^{\gamma}$. Physical capital k accumulates according to

$$\dot{k} = (1-\theta)uhw + (1-\tau)rk + b - c - \lambda k - \phi k \tag{6}$$

Individuals receive income from both labor and capital. Pre-tax labor income is given by the product of the wage rate w, the time people work, u, and the human capital h. As in Lucas (1990), taxes are imposed on income from labor and capital at the rates of θ and τ, respectively. In addition, we introduce a tax on the capital stock with marginal tax rate ϕ. Furthermore, the individual receives transfers b from the government. Physical capital k does not depreciate.

Individuals take the wage w and the interest rate r as given and maximize utility (1) subject to the three constraints (4), (5) and (6). The first-order conditions of the household can be found in Lucas (1990).

2.2 Production

Production *per capita* y is a function of the stock of human capital h, the time individuals supply as labor, u, and the capital stock per capita, k. Output is produced with a CES technology

$$y = F(k, uh) = a_0(a_1 k^{\sigma_p} + a_2 uh^{\sigma_p})^{1/\sigma_p} \tag{7}$$

where σ_p denotes the elasticity of substitution in production. The production per effective labor is defined by $f(z) := F(z, 1)$ where $z := k/uh$.

In a market equilibrium, factors are rewarded with their marginal products

$$w = f(z) - zf'(z) \tag{8}$$

$$r = f'(z) \tag{9}$$

2.3 The government

The government receives revenues from taxing labor income, capital income, and the capital stock. The government budget is balanced so that government consumption g and transfers b equal tax revenues at any point in time t

$$g + b = \theta uhw + \tau rk + \phi k \tag{10}$$

Since the capital stock is the only asset held by households, the capital tax ϕ can be interpreted as a wealth tax and we will henceforth use the two terms interchangeably.[4] In this paper, we will consider a change of either τ or ϕ,

[4] As there is only one kind of asset in our economy, we cannot distinguish between the different effects of a capital income tax and a wealth tax on the household's portfolio choice. Such effects should certainly play an important role if additional types of assets are introduced into our model.

where θ adjusts in order to keep the government budget (10) balanced at any point in time.

2.4 The calibration of the model

Most of the parameter values are taken from Lucas' original analysis of the 1985 US economy. The values of the parameters can be found in Table 1; for a complete derivation of the parameters, the reader should refer to the article of Lucas (1990).

As emphasized by Rebelo and Stokey (1995), the intertemporal elasticity of substitution $1/\sigma$ plays a crucial role in determining the effects of fiscal policies on the growth rate. Lucas assumes a constant value of $\sigma = 2$. However, empirical estimates of the intertemporal elasticity of substitution $1/\sigma$ vary considerably. Therefore, we also calculate the impact of different values of σ on the balanced growth rate (see Section 3). Real business cycle models like Kydland and Prescott (1982) and Hansen (1985) apply a value of σ at the height of 1.5 and 1.0, respectively, while Jones *et al.* (1993) use values in the range of 1.0 and 2.5. Rebelo and Stokey (1995) find the elasticity of labor supply to be a critical parameter as well. We use a value of both $\alpha = 0.5$ and $\alpha = 5$ for our numerical calculations as suggested by Lucas (1990). Jones *et al.* (1993) even apply a value as high as 7.09 for the upper limit of α.

Lucas examines the effects of a reduction of capital income taxes to zero. In his analysis, both fiscal variables b/h and g/h are constant on the new balanced growth path. Lucas chooses the values of 40% and 36% for the flat-rate taxes on labor and capital income, respectively. We choose the same tax rates and set the 1985 tax rate

Table 1 Benchmark calibration of parmeter values

Intertemporal elasticity of substitution	$1/\sigma$	0.5, 1
	α	0.5, 5
Population growth rate	λ	0.014
Time preference rate	ρ	0.034
Time budget	B	2.131
	D	0.0353
	γ	0.8
Substitution elasticity, production function	σ_p	−2/3
	a_0	0.7701
Capital income share	$a1$	0.361
Labor income share	$a2$	0.639
1985 output	y	1
Government transfers	b/y	0.18
Government consumption	g/y	0.21
Capital income tax rate	τ	0.36
Labor income tax rate	θ	0.40

on wealth equal to zero.[5] Using (8) and (9), the government budget (10) can be rewritten as

$$\theta u[f(z) - zf'(z)] + \tau uzf'(z) + \phi uz = \frac{g}{h} + \frac{b}{h} \tag{11}$$

Like most of the work on optimal taxation in growth models, Lucas (1990) takes the path for government spending and transfers as given. This is a shortcut which becomes necessary in the representative agent framework where there actually is no need for redistributive taxation. Moreover, he requires that $b/h = 0.18$ and $g/h = 0.21$ along the balanced path. This assumption, however, is not innocuous. It implies that any policy which increases the capital intensity z and, hence, $f(z)$ has to finance a smaller government sector. This requirement gives an advantage to low capital income taxes τ as they increase the capital intensity z.[6] For this reason, we analyze the dynamics of Lucas' model for two different government expenditure rules. In our benchmark specification, we demand that the relative size of the government sector $(b + g)/y$ must be at its 1985 values at any point in time. In this case, the government budget is assumed to be

$$\theta\left[1 - \frac{zf'(z)}{f(z)}\right] + \tau\frac{zf'(z)}{f(z)} + \phi\frac{z}{f(z)} = \frac{g}{y} + \frac{b}{y} \tag{12}$$

In our second specification, we use Lucas' original assumption (11) of constant expenditures relative to human capital.

3. Balanced growth

How does capital taxation affect long-run growth? In this section, we analyze the impact of taxation on growth and compute the sensitivity of the growth rate with respect to critical parameter values. On a balanced growth path, consumption, output, physical capital, and human capital grow at the same rate ν and the time allocation is constant. The balanced growth equilibrium is characterized by eqs (12), (4), and

$$u[f(z) - (\lambda + \nu)z] = \frac{c}{h} + \frac{g}{y}uf(z) \tag{13}$$

$$\nu \equiv \frac{\dot{h}}{h} = Dv^{\gamma} \tag{14}$$

$$\rho + \sigma\nu + \phi = (1 - \tau)f'(z) \tag{15}$$

$$\frac{\alpha}{x}\frac{c}{h} = (1 - \theta)[f(z) - zf'(z)] \tag{16}$$

$$\rho - \lambda + (\sigma - 1)\nu = uD\gamma v^{\gamma - 1} \tag{17}$$

[5] A look into the IMF government revenue statistics shows that this is a rather innocent simplification which permits us to keep Lucas' data as a benchmark case.

[6] For a constant ratio $(b + g)/h$, the government share $(g + b)/y$ would fall from 39% to 36% following an abolition of the capital income tax.

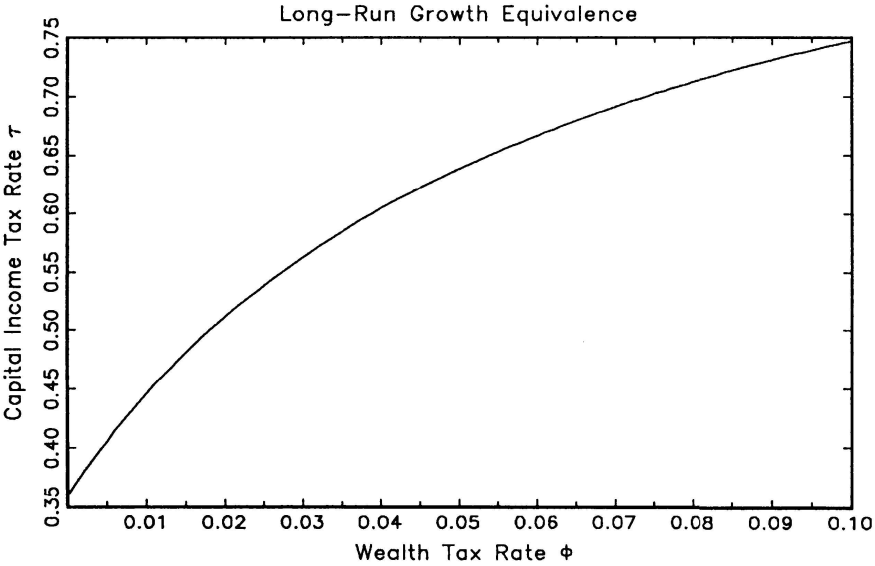

Fig. 1. Wealth tax and capital income tax

From (12) and (15), it is straightforward to show that capital income taxes τ and taxes on the capital stock ϕ are equivalent in the long run (see Fig. 1). Every balanced growth path where only capital income is taxed can also be replicated by one characterized by pure wealth taxation. Both taxes, however, will have different effects along the transition path as will be discussed in Section 4.

We solved the system (12)–(17) numerically for the values of $z, u, v, x, c/h$, and ν given the parameters from Table 1. Table 2 reports the sensitivity of the growth rate with respect to the capital income tax rate τ for the two government budget rules (11) and (12), respectively. We analyzed the effect of different choices of the elasticity of labor supply and the intertemporal elasticity of substitution, respectively. For a capital income tax rate of $\tau = 50\%$, the US growth rate would rise by approximately 1.5% in the long run, from 1.5% to 1.523% under government expenditure rule (12). Accordingly, the effects of an increase in the tax rate τ are modest for Lucas' benchmark calibration of α and σ. As found by Rebelo and Stokey (1995), the impact of capital taxes on growth is larger if either the intertemporal elasticity of substitution or the elasticity of labor supply are higher. A value of $\sigma = 1$ leads to a growth rate of 1.545% for $\tau = 0.5$. For $\alpha = 5$, the growth rate ν even increases to 1.559%. In order to keep the government share constant at 39% for $\tau = 0.5$, labor income taxes can be decreased by about 7% to 35% as well.

Furthermore, notice that, by imposing government expenditure rule (12), the quantitative effects of a change in the capital income tax rate τ on the growth rate ν are magnified compared to those in the original Lucas' model. For example, for the benchmark calibration with $\sigma = 2$ and $\alpha = 0.5$, the growth rate falls to $\nu = 1.445\%$

Table 2 Asymptotic growth rate ν for different capital income tax rates τ

	$\alpha = 0.5$, $\sigma = 2$	$\alpha = 5$, $\sigma = 2$	$\alpha = 0.5$, $\sigma = 1$	$\alpha = 5$, $\sigma = 1$
Government budget (11)				
τ				
0%	1.473	1.408	1.450	1.275
10%	1.482	1.439	1.467	1.351
20%	1.490	1.468	1.483	1.420
30%	1.498	1.491	1.496	1.479
40%	1.503	1.509	1.505	1.521
50%	1.504	1.515	1.508	1.536
Government budget (12)				
τ				
0%	1.445	1.370	1.393	1.179
10%	1.460	1.405	1.423	1.262
20%	1.476	1.441	1.453	1.350
30%	1.491	1.479	1.483	1.445
40%	1.507	1.518	1.514	1.546
50%	1.523	1.559	1.545	1.656

Notes: The growth rates ν are given in %.

following the abolition of capital income taxes in our model. In the Lucas' model with expenditure rule (11), the growth rate only falls to $\nu = 1.473\%$.

4. Transitional dynamics

The transitional dynamics of our model can be analyzed with the help of a differential equation system in the three endogenous variables, v, c/h, and z. The system is given by

$$\frac{\dot{z}}{z} = \frac{1}{\zeta_4} \cdot \left(\zeta_5 - Dv^{0.8} + \frac{x}{u} \frac{(1-\tau)f'(z) - (\rho + \phi) - \sigma D v^{0.8}}{\sigma - \alpha(1-\sigma)} + \frac{v}{u}\zeta_2 \right) \tag{18}$$

$$\frac{\dot{v}}{v} = \zeta_2 + \zeta_3 \frac{\dot{z}}{z} \tag{19}$$

$$\frac{\dot{(c/h)}}{(c/h)} = \frac{(1-\tau)f'(z) - (\rho+\phi) + \alpha(1-\sigma)\left(\frac{\theta}{1-\theta}(\zeta_1 - \zeta_0) - \zeta_0\right)\frac{\dot{z}}{z} - \sigma D v^{0.8}}{\sigma - \alpha(1-\sigma)} \tag{20}$$

where

$$f(z) = a_0(a_1 z^{\sigma_p} + (1 - a_1))^{(1/\sigma_p)} \tag{21}$$

$$w = f(z) - f'(z)z \tag{22}$$

The remaining endogenous variables can be computed with the first-order condition of the household with respect to leisure and eqs (12) and (4)

$$x = d\frac{c}{h}\frac{1}{(1-\theta)w} \tag{23}$$

$$\theta = \frac{\left(\frac{g}{y}+\frac{b}{y}\right)f(z)}{w} - \frac{\tau f'(z)z}{w} - \frac{\phi z}{w} \tag{24}$$

$$u = B - v - x \tag{25}$$

The values of $\rho, \sigma, \alpha, g/y, b/y, \lambda, D, B, a_0, a_1, a_2$, and σ_p can be read from Table 1. If not mentioned otherwise, we carried out our analysis for the benchmark calibration. The coefficients $\zeta_0, \zeta_1, \zeta_2, \zeta_3, \zeta_4$, and ζ_5 are functions of v, c/h, and z only.[7]

$$\zeta_0 = -\frac{f''(z)\cdot z^2}{f(z) - f'(z)\cdot z} \tag{26}$$

$$\zeta_1 = \frac{(g/y + b/y)f'(z)\cdot z - \tau f''(z)\cdot z^2 - \tau f'(z)z - \phi z}{(g/y + b/y)f(z) - \tau f'(z)\cdot z - \phi z} \tag{27}$$

$$\zeta_2 = -5(\phi + \lambda - (1-\tau)f'(z) + Dv^{0.8} + 0.8Dv^{-0.2}(B - v - x)) \tag{28}$$

$$\zeta_3 = -5\left(\zeta_0 - \frac{\theta}{1-\theta}(\zeta_1 - \zeta_0)\right) \tag{29}$$

$$\zeta_4 = 1 - \frac{x}{u}\left(1 + \frac{\alpha(1-\sigma)}{\sigma - \alpha(1-\sigma)}\right)\left(\frac{\theta}{1-\theta}(\zeta_1 - \zeta_0) - \zeta_0\right) - \frac{v\zeta_3}{u} \tag{30}$$

$$\zeta_5 = (1-\theta)\frac{w}{z} + (1-\tau)f'(z) + \frac{b}{y}\frac{f(z)}{z} - \frac{c}{h}\frac{1}{zu} - (\lambda + \phi) \tag{31}$$

The general equilibrium path obeys (18)–(20) given initial values for k_0 and h_0. As the restriction at the initial time is one-dimensional, the equilibrium path is unique if one eigenvalue of the Jacobi matrix of the differential equation system (18)–(20), evaluated at the steady state, is negative and the other two eigenvalues are positive. In this case, c, v, u, x, and θ jump on the stable manifold, while k/h moves sluggish. For all tax policies considered in this paper, we find the general equilibrium to be saddlepoint stable.[8]

The transitional dynamics are calculated with the help of a non-linear numerical algorithm. In particular, we solved the two-point boundary value problem with the fourth-order Runge–Kutta method applying the technique of reverse shooting.[9]

[7] We refrain from presenting the somewhat tedious algebra that leads to (26)–(31). It is available from the authors upon request.

[8] In Section 5, we will also compare our results with those resulting from the original Lucas' model with constant government expenditures relative to human capital. In accordance with Laitner (1995), we find the general equilibrium path to be unique. Laitner (1995) further discusses stability of the individual-agent economy. As our specification of the individual-agent economy follows the one of Lucas (1990) and Laitner (1995) for both government expenditure rules (12) and (11) considered, we do not repeat his analysis in our paper, but rather refer the interested reader to the paper of Laitner.

[9] A description of his numerical technique is provided by Judd (1998).

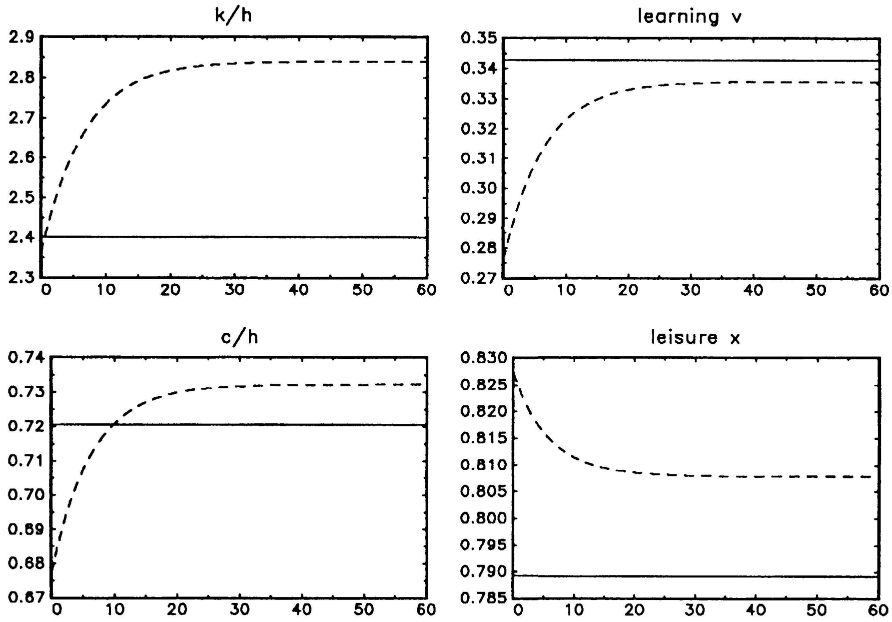

Fig. 2. Transitional dynamics of stationary variables $k/h, v, c/h, x$ for $\tau = 0.20$ (broken line) compared to old steady-state values with $\tau = 0.36$ (solid line)

The computer program (we used GAUSS version 3.01) are available from the authors upon request.

The effects of a permanent decrease of the tax rate τ from 36% to 20% are illutrated by Figs 2 and 3 for the first 60 years following the change of τ. In Fig. 2, the dynamic behavior of the stationary variables k/h, v, c/h, and x is depicted by the broken line. In the new steady state, the values of $k/h, x$, and c/h are higher while the value of v is smaller than those in the old steady state (solid line). All stationary variables, including the wage rate w, the interest rate r, the labor income tax rate θ, and working time u (not illustrated), converge monotonically to their new steady state values.

Following a decrease in the capital income tax rate τ, incentives to invest in physical capital rather than human capital increase and k/h rises gradually over time from $k/h = 2.40$ to its new steady state value $k/h = 2.84$. As a consequence, (i) the wage rate w also increases during transition as the marginal product of (effective) labor is a positive function of k/h, and (ii) the labor income tax rate θ gradually declines to its new steady state value as revenues from capital income taxation relative to output increase over time. Both effects result in increasing opportunity costs of leisure over time and hence leisure x overshoots its new steady state value and monotonically declines from above towards its long-run equilibrium value during transition. A similar over-shooting (or rather under-shooting) phenomenon is also present in the dynamics of the learning time v (see Fig 2).

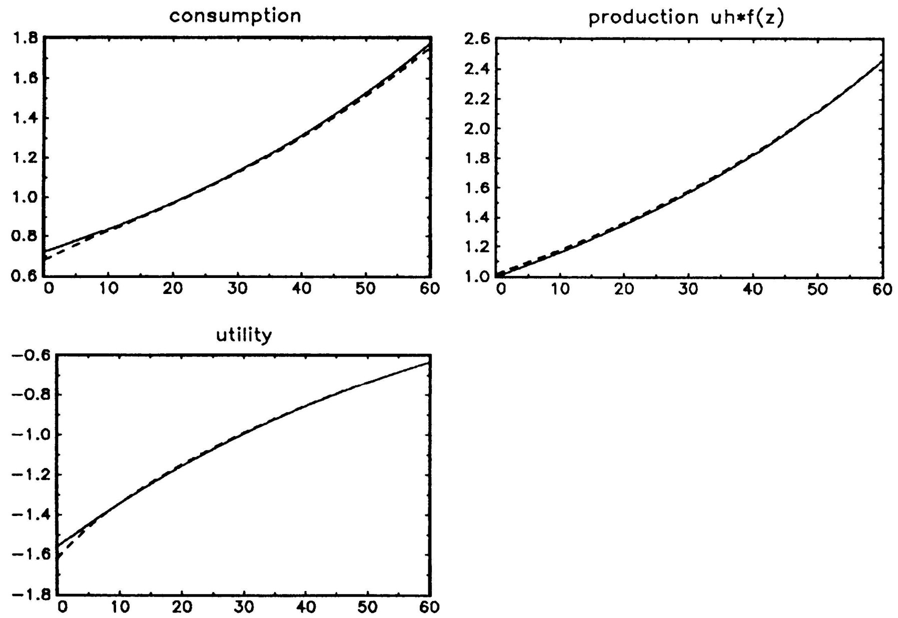

Fig. 3. Transitional dynamics of growing variables $c, y, u(c, x)$ for $\tau = 0.20$ (broken line) and $\tau = 0.36$ solid line)

The behavior of the growing variables c, y, and $u(c, x)$ is illustrated in Fig. 3. In order to build up more physical capital, households save and decrease consumption c on the one hand. On the other hand, leisure x increases. The net effect of a permanent tax cut of τ from 36% to 20% on instantaneous utility $u(c, x)$ is negative in the short run (for the first ten years) and positive in the medium run. The effect of the decline in the growth rate predominantes only in the long run, after approximately 58 years. Similarly, production y exceeds the one in the benchmark case in the short and medium run as household savings increase. In the long run, production y grows at a smaller rate.

In the long run, the allocation by means of taxation of capital income can be replicated by a corresponding choice of wealth taxation. The short-run dynamics, however, differ. The reason is the different dynamics of the two tax bases, the interest income rk and the capital stock k. Consider two different policies: (i) a decrease of the capital income tax rate τ; and (ii) a decrease of the wealth tax ϕ with both policies implying the same asymptotic steady state. Following a decrease in τ or ϕ, k/h gradually increases to its new steady state value (see Fig. 2). Similarly, the interest rate falls during transition. As the interest rate is above its long-run equilibrium value along the transition path, the loss in tax revenues following a decrease in capital income taxation, τrk, under policy (i) is more pronounced than the loss in tax revenues following a decrease in wealth taxation, ϕk, under policy (ii). As a consequence, labor income taxes under policy (i) are higher during transition than under policy (ii) and the transition paths of leisure, consumption, production, and

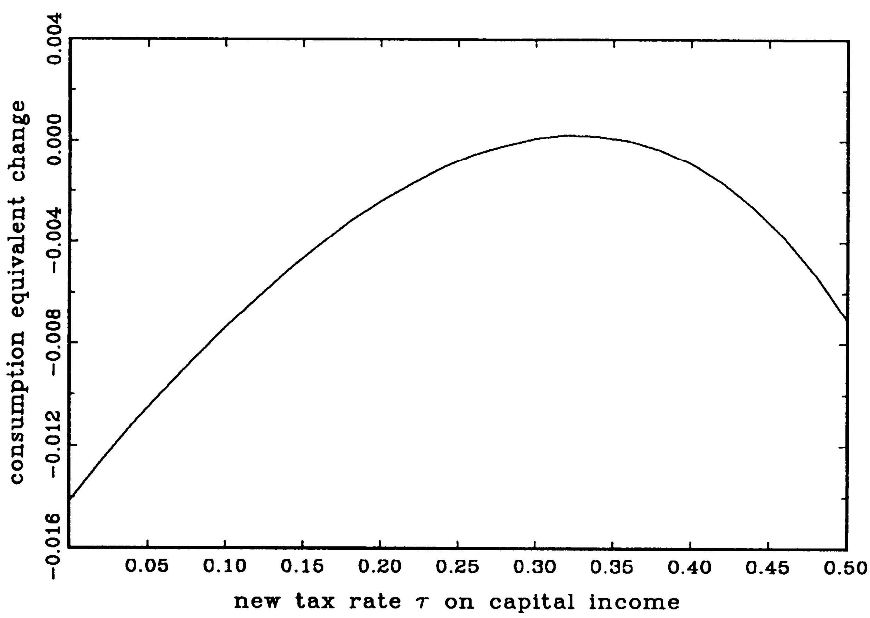

Fig. 4. Welfare following an immediate permanent change of τ under government expenditure rule (12)

utility differ (not illustrated). Hence, wealth taxation is not equivalent to capital income taxation with regard to the intertemporal allocation and can be applied as an additional instrument of fiscal policy in order to increase welfare.

5. Welfare analysis

5.1 Ramsey welfare

The transition dynamics presented in Section 4 can be used to numerically calculate the welfare changes arising from a tax reform.[10] In a first step, we study how a policy change affects Ramsey welfare, i.e. the overall utility of the representative individual as given by eq. (1). Previous studies by Lucas (1990) and Laitner (1995) conclude that a gradual reduction of capital income taxes increases welfare significantly for the 1985 US economy. Lucas (1990) estimates the welfare gain from abandoning all capital taxes to amount to an equivalent increase in consumption of about 1% along the balanced growth path. The results for our modified version of the Lucas' model are in sharp contrast to the ones of Lucas (1990). The optimal tax rate τ on capital income is no longer zero and is found to be at a surprisingly high level of approximately 32% (see Fig. 4). Given the restriction of constant capital tax rates, welfare decreases by 0.24% following a reduction of capital taxes from 36% to 20% (see Table 3). As is obvious from Fig. 3, such a policy results in a decrease of

[10] If not mentioned otherwise, we use government budget (12).

Table 3 Welfare effects following an immediate permant change in tax policy for the benchmark case under government expenditure rule (12)

New tax rate on wealth and capital income	$\phi = 0$ $\tau = 0.36$	$\phi = 0.01$ $\tau = 0.36$	$\phi = 0$ $\tau = 0.20$	$\phi = 0$ $\tau = 0.32$
Utility from (1)	−44.634	−44.764	−44.742	−44.624
Consumption equivalent increase	0%	−0.29%	−0.24%	0.02%

instantaneous utility both in the short and in the long run. Higher incentives to build up physical capital create welfare gains only in the medium run.

Our result of a non-zero optimal capital income tax rate is not surprising. As already pointed out by Jones *et al.* (1997) for the Chamley–Judd set-up with human capital accumulation, (i) the optimal long-run tax rate on labor is zero as well, and (ii) changes in the constraints on tax policies can result in a positive long-run capital income tax rate. As both tax rates θ and τ distort the accumulation of a stock (human and physical capital, respectively) in our economy and θ distorts the marginal substitution between leisure and consumption, the optimal fiscal policy consists of minimizing the sum of these distortions given the feasibility constraint (balanced government budget), implying possibly nonzero rates for the two taxes.

We also calculated the transition dynamics and the Ramsey welfare for the original Lucas model, i.e. replacing eq. (12) by eq. (11). Our results are in accordance with Lucas (1990) and Laitner (1995). In particular, we compute a consumption equivalent increase of 1.27% following a once-and-for-all abandoning of capital income taxation, which compares favorably with Lucas' projecture of 1%. In addition, we find the optimal capital tax rate to be above zero in this model as well amounting to 9% (see Fig. 5). Hence, the result that zero capital taxation is not optimal is robust with regard to the two specifications of the government expenditure rule.

Obviously, welfare effects of fiscal policy depend crucially on the government expenditure rule. The intuition for this result is straightforward. The two government expenditure rules (12) and (11) imply different absolute government expenditure paths (only for the benchmark calibration with $\tau = 0.36$ do these two paths coincide). In particular, (11) implies lower absolute government expenditures during the initial period of transition than (12) for any immediate, permanent change of $\tau < 36\%$. The time path of government expenditures is illustrated in Fig. 6 for an immediate, permanent change of τ to 20%. If government expenditures g are kept constant with respect to human capital (dotted line) according to rule (11), they drop below those of the benchmark case (solid line) at all times. If g is kept constant with respect to output (broken line) according to rule (12), they exceed those of the benchmark case for the first sixty years. As a consequence, the optimal tax rate on capital income is lower under rule (11) than under (12).

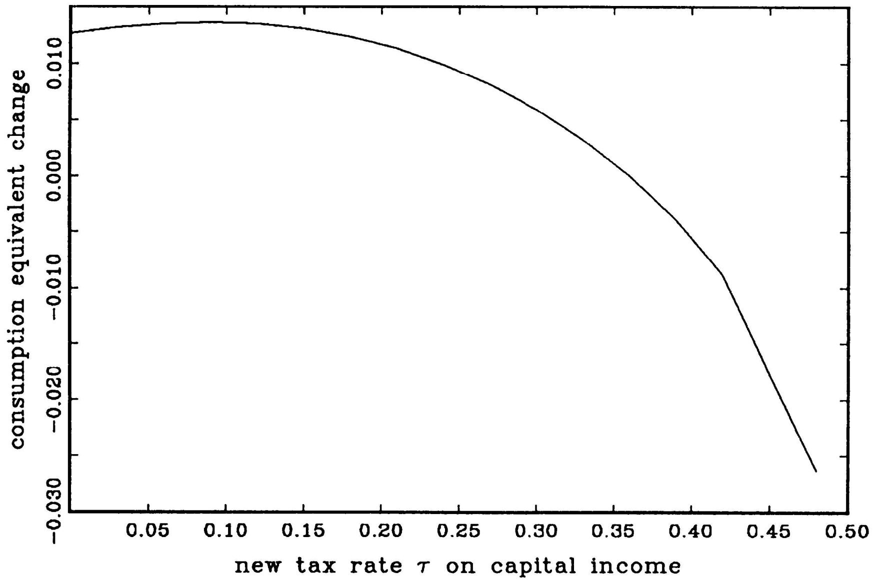

Fig. 5. Welfare following an immediate permanent change of τ under government expenditure rule (11)

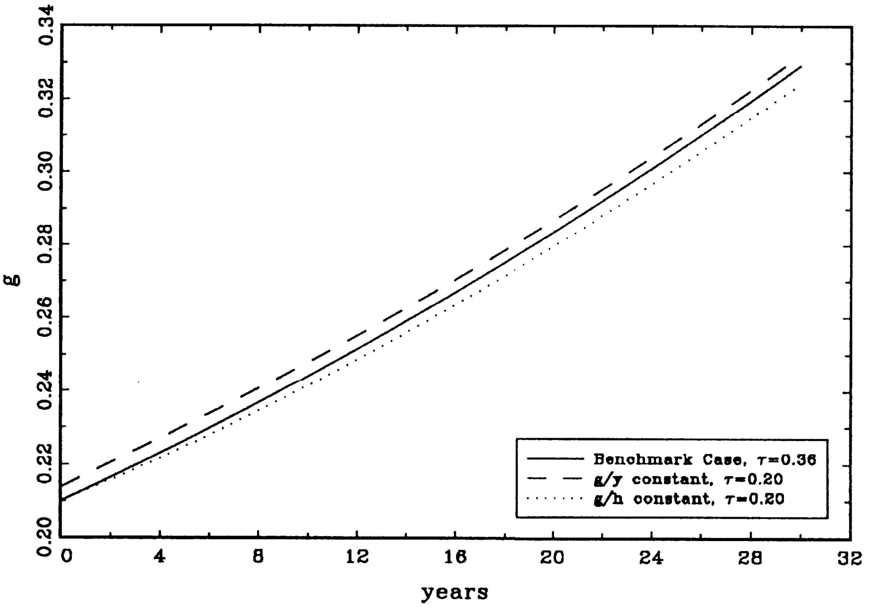

Fig. 6. Absolute government expenditures g following an immediate permanent change of τ

As already pointed out in the previous section, the effects of a tax on capital income and on capital stocks differ during the transition period. We find that, keeping the capital income tax rate constant at its initial value $\tau = 0.36$, a wealth tax rate ϕ of -0.35% maximizes welfare implying a consumption equivalent

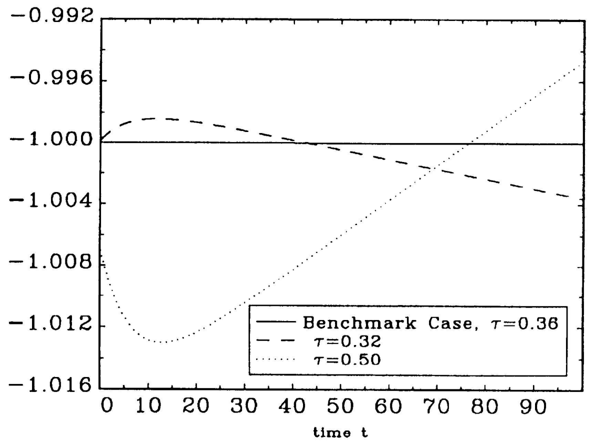

Fig. 7. Welfare ψ of generation T

increase of 0.34% in all periods. Hence, for our calibrated economy, welfare can further be increased by subsidizing asset holdings. The government benefits from having an additional degree of freedom with regard to its fiscal policy, even though the quantitative effect is small as we are already close to the second-best optimum.

5.2 Generational welfare

Welfare in Section 5.1 is measured by the integral of (1). Individuals take the utility of the subsequent generations into account, discounted with the time preference rate ρ. How are different generations affected by once-and-for-all changes of the capital tax policy? We try to give a tentative answer to this question by interpreting Lucas' infinite-lived individuals as dynasties composed of altruistic finite-lived individuals. The integral

$$W_T = \int_T^\infty e^{-(\rho-\lambda)t} U[c(t), x(t)] dt \tag{32}$$

can then be interpreted as the utility of an individual born at time T and is a function of the two tax rates ϕ and τ: $W_T = W_T(\phi, \tau)$. Our numerical analysis of the transition path permits us to specify in detail how this welfare indicator is affected by a policy switch in different periods T. As a measure of welfare we define

$$\psi(T, \phi, \tau) = -\frac{W_T(\phi, \tau)}{W_T(0, 0.36)} \tag{33}$$

as the ratio of welfare under the new and the old policy plan. $\psi(T, 0, 0.32)$ and $\psi(T, 0, 0.50)$, respectively, are illustrated in Fig. 7. A value in excess of -1 indicates that the welfare of generation T increases as a consequence of the change in the tax policy (remember that $W_T < 0$). For the optimal policy $\tau = 32\%$ (broken line), individuals born in the initial 43 periods are made better off. For the following years, generational welfare as measured by (32) decreases below the one for $\tau = 0.36$ as the growth rate effect dominates. Following an increase in the tax rate τ to 50% (dotted line), the welfare of the generations born in the first 76 years is reduced.

6. Conclusion

Recent research on optimal taxation has arrived at the conclusion that capital is a bad thing to tax (*cf*. Lucas, 1990; Laitner, 1995). This conclusion is based on an asymptotic result derived from the analysis of a representative-agent growth model (Chamley, 1986; Judd, 1985). In this paper, we argue that one should be careful to directly infer tax policy recommendations from these results. In our analysis, we require tax reforms to be effectuated instantaneously. The capital income tax rate is changed once and for all at time 0. The introduction of such a restriction is demonstrated to lead to very different results concerning the desirability of capital taxation in models of human capital accumulation. The abandonment of capital taxation reduces welfare. In addition, we show that the introduction of a tax on capital stocks as an additional policy instrument improves welfare. More theoretical research is needed to find out what type of restriction on government policies should be reasonably imposed in an optimal taxation analysis.

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References

Atkinson, A.B. (1971). 'Capital Taxes, the Redistribution of Wealth and Individual Savings', *Review of Economic Studies*, **38**, 209–27.

Atkinson, A.B. and Sandmo, A. (1980). 'Welfare Implications of the Taxation of Savings', *Economic Journal*, **90**, 529–49.

Auerbach, A.J., Kotlikoff, L.J. and Skinner, J. (1983). 'The Efficiency Gains from Dynamic Tax Reform', *International Economic Review*, **24**, 81–100.

Bull, N. (1993). 'When All the Optimal Dynamic Taxes Are Zero', Federal Reserve Board Working Paper No. 137, Washington, DC.

Chamley, C.P. (1986). 'Optimal taxation of capital income in general equilibrium with infinite lives', *Econometrica*, **54**, 607–22.

Grüner, H.P. and Heer, B. (1994). 'Taxation of Income and Wealth in a Model of Endogenous Growth', *Public Finance*, **49**, 158–72.

Hansen, G.D. (1985). 'Indivisible Labor and the Business Cycle', *Journal of Monetary Economics*, **16**, 309–27.

Jones, L.E., Manuelli, R.E. and Rossi, P.E. (1993). 'Optimal Taxation in Models of Endogenous Growth', *Journal of Political Economy*, **101**, 485–517.

Jones, L.E., Manuelli, R.E. and Rossi, P.E. (1997). 'On the Optimal Taxation of Capital Income', *Journal of Economic Theory*, **73**, 93–117.

Judd, K.L. (1985). 'Redistributive Taxation in a Simple Perfect Foresight Model', *Journal of Public Economics*, **28**, 59–83.

Judd, K.L. (1998). *Numerical Methods in Economics*, MIT Press, Cambridge, MA.

Kydland, F. and Prescott, E.C. (1982). 'Time to build aggregate fluctuations', *Econometrica*, **50**, 1345–70.

Laitner, J. (1995). 'Quantitative Evaluations of Efficient Tax Policies for Lucas' Supply Side Models', *Oxford Economic Papers*, **47**, 471–92.

Lucas, R.E. (1990). 'Supply-Side Economics: An Analytical Review', *Oxford Economic Papers*, **42**, 3–42.

Milesi-Ferretti, G.M. and Roubini, N. (1995). 'Growth Effects of Income and Consumption Taxes: Positive and Normative Analysis', Working Paper Series No. 5317, NBER, Cambridge, MA.

Rebelo, S. and Stokey, N. (1995). 'Growth Effects of Flat-Rate Taxes', *Journal of Political Economy*, **103**, 519–50.

Stern, N. (1992). 'From the Static to the Dynamic: Some Problems in the Theory of Taxation', *Journal of Public Economics*, **47**, 273–97.

Summers, L.H. (1981). 'Capital Taxation and Accumulation in a Life Cycle Growth Model', *American Economic Review*, **71**, 533–44.