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ENDOGENOUS GROWTH AND THE CHOICE OF TAX BASE*

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ABSTRACT

This paper explores the implications of different types of growth supporting mechanisms for the welfare costs of taxation in the context of a perfect-foresight two-sector model with linear endogenous growth. A calibrated version of this model is used to obtain numerical estimates of the welfare impact of equal-yield unanticipated tax changes through transitional analysis. The results of our simulations indicate that the size of the welfare effects of tax reform depends crucially on the mechanism underlying the production of knowledge, on the degree of complementarity between knowledge creation and physical investment, and on factor intensities. As in a neoclassical setting, a move from income taxation to wage taxation can be welfare improving. When growth is fuelled by investment in knowledge by optimizing agents, however, the presence of endogenous growth mechanisms considerably strengthens the case in favour of a consumption tax in comparison with a wage tax. Finally, we find that if knowledge production is tax-sheltered or subsidized, the welfare effects of tax reforms are substantially reduced and close in size to those obtained in a model with exogenous technological change.

KEYWORDS: Optimal Taxation, Growth.

JEL CLASSIFICATION: H21.

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1 Introduction

The analysis of the dynamic efficiency effects of taxation has traditionally been cast in the context of the neoclassical growth model, and has primarily focussed on the distortions induced by taxes on savings behaviour and on the accumulation of physical capital (Summers (1981); Auerbach, Kotlikoff and Skinner (1983)). In a neoclassical growth model the long-run growth rate of the economy is exogenously determined, and equal to the rate growth of labour endowments. This rigidity in the intertemporal allocation of labour limits the size of the dynamic responses to tax changes. Consequently, estimates of the welfare costs of taxation in the literature are quite small, typically in the order of 1-2% of GNP, although marginal welfare costs can be much larger (Ballard, Shoven, and Whalley (1985); Judd (1987)).

In contrast with this public finance tradition, recent literature has emphasized endogenous generation of knowledge as an important source of economic growth.[1] With endogenously generated knowledge, the intertemporal allocation of labour is no longer fixed, and the long-run growth rate of the economy can thus vary. This literature has shown that a number of government policies, including tax policies, can have substantial effects on long-run growth. With regard to taxation, King and Rebelo (1990) have shown that, when growth is endogenous, small variations in tax rates can produce large changes in long-run growth rates. Their study also examined the welfare costs associated with a balanced-budget increase in income tax rates and

[1]For a survey and discussion of old and new theories of economic growth, see Romer (1988).

found that the presence of endogenous growth can dramatically raise the efficiency costs of income taxation in comparison with traditional analyses.

Their study, however, focusses on a model with private investment in human capital by optimizing agents, which is only one of a number of different models that have been proposed to explain endogenous generation of knowledge. These competing views of the engine underlying growth can have different implications for tax policy. With reference to endogenous growth models where production is linear in a broad concept of capital, Barro and Sala-I-Martin (1992) have shown that the key factor in determining the efficiency effects of taxes is their impact on the wedge between social and private returns to investment. Such impact, in turn, depends crucially on the type of growth engine postulated.

To explore the implications of some of these different mechanisms for efficient tax design, this paper develops a two-sector, perfect-foresight model with linear endogenous growth, which is able to accommodate three basic types of growth engine, namely exogenous technological change, learning-by-doing and investment in knowledge by optimizing agents. The model is then used to analyze the impact of equal-yield, unanticipated tax changes from a comprehensive income tax to alternative tax structures, by numerically simulating the transition path of the economy to a balanced-growth path after the tax change takes place. Several forms of tax replacement are analyzed: a removal of capital income taxes, a removal of labour income taxes, a move to a consumption tax, and a move to a wage tax. For the case where technological growth is the result of optimizing investment in knowledge, we also examine the possibility that knowledge production may be tax-sheltered in comparison with physical investment, or directly subsidized. Our simulations yield estimates of the growth and welfare impacts of tax changes under different assumptions as to the mechanisms underlying growth. The sectoral disaggregation of the model also enables us to explore the implications of asset price capitalization effects and factor substitution effects arising from these tax changes.

The results of our simulations indicate that, when growth is endogenous, the inhibiting effects of income taxation on growth can be substantial. The welfare costs of distortionary taxes can also be substantial. Not surprisingly, their size is correlated, albeit imperfectly, with their impact on long-run growth, which provides some support for adopting growth performance as a guiding criterion of efficient tax design. The welfare impacts of tax changes vary considerably, depending on the mechanism underlying the production of knowledge, on the degree of complementarity between physical investment and knowledge production, and on factor intensities.

When technological change is the result of learning-by-doing, knowledge spillovers are completely external to economic agents' decisions. The presence of distortionary taxes compounds the distortions arising from these external effects, and the welfare impacts of tax changes can thus be quite pronounced. With learning-by-doing, as in a neoclassical model, a move to a wage tax has the same effects as a move to a consumption tax. In contrast, when knowledge production is the result of optimizing choices by private agents, consumption taxation is superior to wage taxation, since the latter distorts human capital investment decisions. In this case, our simulations show that the presence of endogenous growth mechanisms strengthens considerably the case in favour of a consumption tax, although, as in a neoclassical model, a move from comprehensive income taxation to wage taxation can also be welfare improving. Finally, we find that if knowledge production is tax-sheltered or subsidized, the welfare effects of tax reform are considerably reduced and close in size to those obtained in a neoclassical growth model.

The rest of this paper is organized as follows. Section 2 presents our model, and Section 3 discusses the implications of endogenous growth for tax policies. Section 4 describes our experiments and results. Section 5 concludes with a summary of our findings.

2 A model of endogenous growth with taxes

This section presents the basic structure of a two-sector model of endogenous growth with taxes, which is able to accommodate the two main types of endogenous growth mechanisms, namely learning-by-doing and human capital investment by optimizing agents.

We begin our discussion by focussing on a growth model with learning-by-doing, where technological growth is the result of economy-wide dynamic spillovers that are completely external to agents' decisions as in the models of Uzawa (1965), and Lucas (1988). We assume that agents are infinitely lived, which implies that the timing of revenue collection is neutral.[2] This enables us to focus on the inherent efficiency prop-

[2]This specification can also be interpreted as a compact representation of an overlapping generations structure with bequests (Barro (1988)). Such specification, however, abstracts from the possibility that knowledge may be cohort-specific and therefore imperfectly bequeathable (Nerlove,

erties of different taxes, while abstracting from issues of intergenerational incidence and debt financing.

There are two primary inputs to production: knowledge-augmented labour, L, and physical capital, K. The two productive sectors produce goods from these primary inputs by means of constant returns-to-scale technologies. Given a feasible allocation, $L_t^1, L_t^2, K_t^1, K_t^2$, of the available resources in period t, the associated output pair Q_t^1, Q_t^2, will be

$$Q_t^1 = f^1(L_t^1, K_t^1), \tag{1}$$

$$Q_t^2 = f^2(L_t^2, K_t^2), \tag{2}$$

where f^1 and f^2 are quasiconcave, homogeneous production functions.

Production activities generate economy-wide knowledge spillovers as fixed proportions of their output levels. We will denote with ϵ^1 and ϵ^2 the quantities of knowledge generated by production activities per unit of output, and, without loss of generality, we will assume that sector 1 is "knowledge intensive" relative to sector 2, i.e., it generates comparatively more knowledge than sector 2 per dollar of output.[3]

We model knowledge as a non-rivalrous, non-congestible public good. Furthermore

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Razin, Sadka, and von Weizsäcker (1993)).

[3]To see why this is a fitting definition of knowledge intensity, consider a marginal reallocation of resources from sector 2 to sector 1. This will result in an increase in the aggregate creation of knowledge if the marginal rate of transformation between the outputs of sectors 2 and 1 (which equals the ratio of their respective marginal costs, mc^2/mc^1) is greater than the ratio ϵ^2/ϵ^1, i.e., if $\epsilon^1/mc^1 > \epsilon^2/mc^2$.

its impact on productivity is assumed to be uniform across sectors. In each period, the net addition to the stock of knowledge per worker (net of depreciation), h_t, results from a combination of endogenous knowledge spillovers and exogenous productivity change, the latter being proportional to the stock of knowledge by a factor ϕ, i.e.,

$$h_t = \frac{\epsilon^1 Q_t^1 + \epsilon^2 Q_t^2}{N_t} + \phi H_t, \tag{3}$$

where N_t represents unaugmented labour, which is assumed to grow at rate γ. In this formulation, the case where $\phi \geq 0$ and $\epsilon^1 = \epsilon^2 = 0$ corresponds to the neoclassical assumption of exogenous productivity growth. The stock of knowledge per worker, H_t, evolves according to the following process:

$$H_{t+1} = H_t + h_t. \tag{4}$$

Thus, the aggregate quantity of knowledge-augmented labour available for in each period is simply equal to

$$L_t = H_t N_t. \tag{5}$$

The stock of physical capital, K_t, depreciates at rate δ. Its law of motion is

$$K_{t+1} = K_t(1-\delta) + I_t. \tag{6}$$

Each unit of physical investment, I_t, is produced by means of a constant returns technology which employs produced goods as its inputs, i.e.,

$$I_t = g(I_t^1, I_t^2). \tag{7}$$

The representative agent's preferences are defined over quantities of produced goods consumed, C_t^1 and C_t^2, and are intertemporally separable, with a constant rate of time preference through time. For simplicity, leisure is assumed to be fixed. In this economy the government levies proportional taxes on labour income, τ_L, on interest income, τ_K, and on consumption, τ_C. Gross-of-tax factor prices are then equal to

$$\hat{w}_t = \frac{1}{1-\tau_L} w_t, \tag{8}$$

$$\hat{r}_t = \frac{1}{1-\tau_K} r_t, \tag{9}$$

where and w_t and r_t respectively represent the net-of-tax wage rate and the net-of-tax rental price of capital, net of depreciation allowances. All tax revenues are returned to consumers. Let us focus on a decentralized equilibrium and normalize contemporary prices so that the price of one unit of investment, p_t^I, is equal to unity. Then, we can write the consumer's budget constraint at time 0 as

$$\sum_{t=1}^{\infty} \frac{(1+\tau_C)(p_t^1 C_t^1 + p_t^2 C_t^2)}{\prod_{j\le t}(1+r_j)} \le \sum_{t=1}^{\infty} \frac{w_t L_t}{\prod_{j\le t}(1+r_j)} + R + A, \tag{10}$$

where R is the present value of tax revenue transfers, and A is non-human wealth:

$$A = K_1 \sum_{t=1}^{\infty} \frac{r_t}{\prod_{j\le t}(1+r_j)}. \tag{11}$$

For given prices, tax rates and total tax revenue transfers, constrained utility maximization yields consumer demands C_t^1, C_t^2, and investment levels I_t, in all periods. Cost minimization by investors yields unit demands for produced goods, ι_t^1, ι_t^2. Cost minimization by firms yields unit input demands $l_t^1, l_t^2, k_t^1, k_t^2$. A sequence of prices w_t, r_t, p_t^1, p_t^2, together with a sequence of output levels Q_t^1, Q_t^2, and with a given present value tax revenues transfer, R, will support a decentralized intertemporal equilibrium if all markets clear in all periods, i.e.,

$$Q_t^1 = C_t^1 + \iota_t^1 I_t, \tag{12}$$

$$Q_t^2 = C_t^2 + \iota_t^2 I_t, \tag{13}$$

$$l_t^1 Q_t^1 + l_t^2 Q_t^2 = L_t, \tag{14}$$

$$k_t^1 Q_t^1 + k_t^2 Q_t^2 = K_t; \tag{15}$$

if all productive sectors break even in all periods, i.e.,

$$p_t^1 = \hat{w}_t l_t^1 + \left(\hat{r}_t + \delta p_t^I\right) k_t^1, \tag{16}$$

$$p_t^2 = \hat{w}_t l_t^2 + \left(\hat{r}_t + \delta p_t^I\right) k_t^2, \tag{17}$$

$$p_t^I = p_t^1 \iota_t^1 + p_t^2 \iota_t^2; \tag{18}$$

and if the tax revenue transfer, R, equals actual tax revenues, i.e.,

$$R = \sum_{t=1}^{\infty} \frac{\tau_C(p_t^1 C_t^1 + p_t^2 C_t^2) + \tau_L \hat{w}_t L_t + \tau_K \hat{r}_t K_t}{\prod_{j\leq t}(1+r_j)}. \tag{19}$$

Since production exhibits constant returns to scale in physical and non-physical capital, balanced growth is possible in this model. As in a neoclassical model, the long-run net-of-tax rate of return is equal to the sum of the rate of time preference and the long-run rate of productivity growth. On the other hand, the long-run rate of growth is endogenous in this model, since the rates of accumulation of human and physical capital can both vary. Growth will be higher, *ceteris paribus*, the higher the level of output of sector 1 (the knowledge intensive sector) relative to the level of output of sector 2.

Here, the engine of growth is represented by economy-wide dynamic knowledge spillovers (learning-by-doing), which are simply a by-product of production activities, and are completely external to the optimizing processes of economic agents. Because of these external effects, decentralized allocations are typically inefficient, and result in suboptimal long-run growth rates. It follows that public policy may play a central role in bringing the economy closer to its optimal growth path.

Several recent models of exogenous growth, such as the one proposed by Romer (1986), have moved away from the notion that technological growth is the accidental effect of production spillovers, and have postulated instead that technological change arises from intentional investment decisions by optimizing agents in response to market incentives. In our model, we can represent such optimizing behaviour by assuming that agents fully internalize the knowledge spillovers generated by production activities.

To force internalization, we must introduce knowledge spillovers in the production decisions of firms by including the value of knowledge creation in the value of the output produced by each sector. This internalization can be represented by means of specific output subsidies, v_t^1, v_t^2, paid by consumers to firms and equal to the value of knowledge generated per unit of output, i.e.,

$$v_t^1 = \epsilon^1 \theta V_t, \tag{20}$$

$$v_t^2 = \epsilon^2 \theta V_t, \tag{21}$$

where

$$V_t = \frac{1}{N_t} \sum_{j=t+1}^{\infty} \frac{N_j w_j}{\prod_{m=t+1}^{j} (1+r_m)}, \tag{22}$$

and where θ represents the degree of internalization of knowledge spillovers, which will be equal to unity with full internalization. Then, the zero profit conditions for producers become

$$p_t^1 + v_t^1 = \hat{w}_t l_t^1 + \left(\hat{r}_t + \delta p_t^I\right) k_t^1, \tag{23}$$

$$p_t^2 + v_t^2 = \hat{w}_t l_t^2 + \left(\hat{r}_t + \delta p_t^I\right) k_t^2, \tag{24}$$

and disposable income for the representative consumer will be reduced by the total value of the subsidy.[4]

With optimizing investment in knowledge, and in the absence of taxes and other market imperfections, decentralized allocations are Pareto optimal. Although there exist policies that will raise steady-state growth, such policies are efficiency-worsening. Thus, on efficiency grounds, there is no specific corrective role for public policy to play.

3 Taxation, growth, and welfare

We now turn to a discussion of the effects of different taxes within the analytical framework of our model. We will compare and contrast the implications for tax design of three basic views of the process of technological change: exogenous growth, learning-by-doing, and optimizing investment in knowledge.

In a neoclassical growth model, income taxation distorts savings decisions by introducing a wedge between the social and private (i.e., net-of-tax) rates of return to physical investment. With infinitely-lived agents and exogenous productivity growth,

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[4]Notice that a one-sector endogenous growth model with optimizing investment in human capital is just a special case of the two-sector model with full internalization presented here, where we assume that sector 2 is completely specialized in producing goods (i.e., $\epsilon^2 = 0$), and sector 1 is completely specialized in the production of knowledge (i.e., the demand for Q^1 is zero).

the latter is constant in the long run. Thus, income taxation raises the long-run gross-of-tax rate by the full amount of the tax and leads to a suboptimal size of the capital stock. The consequent intertemporal misallocation of resources, specifically of capital services, results in deadweight losses. In a two-sector model, the welfare cost of income taxation will also depend on relative factor intensities. The welfare cost of taxes will be higher the more capital-intensive is the production of investment goods relative to the production of consumer goods (Hamilton, Davies, and Whalley (1989)). When growth is exogenous, however, the intertemporal reallocation of capital services induced by taxation is limited by the fact that the allocation of labour services, the other input to production, is intertemporally rigid.

In an endogenous growth model, however, the intertemporal allocation of labour services is more flexible. Although labour services cannot be directly transferred from one period to the other, production of knowledge can increase the availability of labour services in future periods. Consequently, the intertemporal allocative effects of taxes can be much larger. At the same time, the fact that the long-run rate of productivity growth is variable implies that, in a closed economy, the long-run rate of return to physical investment will no longer be constant.[5] Thus, interest income taxation can lower the long-run net-of-tax rate of return to physical capital, and produce a stronger negative impact on the stock of physical capital.

If endogenous growth is fuelled by a learning-by-doing process, where the gener-

[5]In a small open economy where financial capital is internationally mobile, and in the absence of foreign tax credits, the net-of-tax rate of return will be constant even when growth is endogenous.

ation of knowledge is completely external to optimizing decisions (i.e., $\theta = 0$ in (20) and (21)), decentralized allocations will be inefficient even in the absence of distortionary taxes.[6] A tax on interest income will further inhibit growth and compound the preexisting distortions associated with the presence of these external effects. In the absence of internalization of knowledge spillovers, wage taxation is equivalent to a consumption tax, which, in the absence of labour-leisure choices, is equivalent to a lump-sum tax. On the other hand, since decentralized allocations are inefficient, a consumption tax is generally not optimal, and a subsidy to physical investment may be welfare improving, acting as an imperfect substitute for targeted subsidization of knowledge production.

With learning-by-doing, the impact of income taxation on growth will also depend on the relative size of the knowledge spillovers generated by the production of investment goods relative to the production of consumer goods. If knowledge is mainly associated with the production of investment goods, the fall in investment arising from the tax will magnify the growth impact of taxation, whereas if the production of consumption goods is principally responsible for productivity growth, the impact on growth will be accordingly reduced.

In contrast with a learning-by-doing model, in a model with investment in knowledge by optimizing agents, decentralized allocations will be efficient. Nevertheless,

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[6] In particular, when the economy is open, a free trade equilibrium is not socially optimal (Young (1991)). In our analysis, we restrict our attention to the closed economy case and abstract from the linkages which may exist between tax policies and trade policies.

the presence of endogenous growth may have important implications for tax design. When knowledge spillovers are internalized by private agents, a wage tax is no longer equivalent to a consumption tax. Taxation of labour income directly depresses the rate of return to investment in knowledge by lowering the after-tax wage rate (in (20) and (21)). Thus, wage taxation will tend to lower the stock of knowledge in the economy. In turn, since knowledge is complementary to capital in production, it will also indirectly tend to lower the return to physical capital. Similarly, taxation of interest income will have a direct effect on physical investment and an indirect one on human capital investment.

An issue that has been analyzed with regard to individual human capital investment decisions over the life-cycle is the preferential treatment of human capital under an income tax, stemming from the fact that the time inputs in human capital investment are untaxed. This differential treatment of human and non-human investment produces an inter-asset substitution effect away from physical capital (Heckman (1976)). To represent this form of tax-sheltering of human investment in our model we may assume that the two productive sectors experience proportional abatements of factor taxes, α^1, α^2, that are equal to their respective value shares of knowledge production in total revenues, i.e.,

$$\alpha_t^1 = \frac{v_t^1}{p_t^1 + v_t^1}, \tag{25}$$

$$\alpha_t^2 = \frac{v_t^2}{p_t^2 + v_t^2}. \tag{26}$$

Gross-of-tax factor prices for the two sectors are then

$$\hat{w}_t^1 = \frac{1}{1-(1-\alpha_t^1)\tau_L} w_t, \tag{27}$$

$$\hat{r}_t^1 = \frac{1}{1-(1-\alpha_t^1)\tau_K}\, r_t, \tag{28}$$

$$\hat{w}_t^2 = \frac{1}{1-(1-\alpha_t^2)\tau_L}\, w_t, \tag{29}$$

$$\hat{r}_t^2 = \frac{1}{1-(1-\alpha_t^2)\tau_K}\, r_t. \tag{30}$$

In this case, although interest income taxation generates an inter-asset distortion as well as an intertemporal distortion, tax-sheltering of knowledge production mitigates the inhibiting effects of wage taxation on growth.

Finally, we may also consider the case where internalization of knowledge spillovers is the result of government intervention. Suppose that, in this case, the government takes into account the gross-of-tax wage rate in the determination of production subsidies.[7] Then, (22) becomes

$$V_t = \frac{1}{N_t} \sum_{j=t+1}^{\infty} \frac{N_j w_j/(1-\tau_L)}{\prod_{m=t+1}^{j}(1+r_m)}. \tag{31}$$

Alternatively, we may think of this case as of a situation where knowledge spillovers are internalized by private agents but where, at the same time, the government subsidizes knowledge production at a rate (per unit of knowledge) equal to

$$S_t = \frac{1}{N_t} \sum_{j=t+1}^{\infty} \frac{N_j w_j \tau_L/(1-\tau_L)}{\prod_{m=t+1}^{j}(1+r_m)}. \tag{32}$$

This scheme effectively neutralizes the distortionary impact of wage taxes, which will thus be equivalent to a consumption tax. Taxation of interest income will, however, still have an inhibiting effect on growth.

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[7]In the presence of other distortions, this simple rule does not necessarily guarantee an optimal level of provision of knowledge.

Other types of growth mechanisms have been proposed in the literature, which may yet have different implications for tax design. Some of these mechanisms are somewhat related to the mechanisms discussed above. For example, in models where knowledge spillovers are internalized by monopolistically competitive firms (as in Romer (1990)), decentralized allocations are socially inefficient and are associated with suboptimal long-run growth rates. This case represents an intermediate situation between a pure learning-by-doing model and a model with private investment in knowledge. On the other hand, other growth mechanisms may have very different implications for tax design. Barro and Sala-I-Martin (1992), for instance, show that when knowledge is a public good subject to congestion, the long-run growth rate of the economy will be above the socially optimal rate. In this case, income taxes act as user fees and may raise welfare.

The conclusion from the above discussion is that endogenous growth can have important implications for tax design, which hinge on the type of growth mechanism assumed. Furthermore, the quantitative importance of these mechanisms will depend on a number of structural characteristics of the economy, such as the relative weight of investment goods and consumption goods in the generation of knowledge spillovers, and relative factor intensities. In what follows, we explore the quantitative importance of some of these links by means of a numerical implementation of the model outlined in the previous section.

4 Simulating tax changes

This section presents numerical simulations of the impact of unanticipated tax reforms, using a calibrated version of the model presented in Section 2. We simulate the effects of equal-yield changes from a base case comprehensive income tax to other forms of taxation: a replacement of interest income taxes with a consumption tax, a replacement of labour income taxes with a consumption tax, a move to a consumption tax, and a move to a wage tax. These simulations yield a complete characterization of the transition path from the initial steady-state to the new balanced growth path, and enable us to obtain numerical estimates of the growth and welfare impacts of the analyzed tax changes.

We assume a rate of population growth of 1.5% and calibrate our model to an initial balanced growth path with a 3.5% growth rate, and a 5% real net-of-tax rate of return. This combination implies a rate of productivity growth approximately equal to 1.97%, and a rate of time preference approximately equal to 2.97%. The rate of depreciation of physical capital is 10%.

Functional forms as specified as follows. Production functions are Cobb-Douglas:

$$f^1(L_t^1, K_t^1) = (L_t^1)^{\lambda^1}(K_t^1)^{1-\lambda^1}, \tag{33}$$

$$f^2(L_t^2, K_t^2) = (L_t^2)^{\lambda^2}(K_t^2)^{1-\lambda^2}. \tag{34}$$

The production function for investment goods is also Cobb-Douglas:

$$g(I_t^1, I_t^2) = (I_t^1)^{\mu}(I_t^2)^{1-\mu}. \tag{35}$$

Preferences are described by an intertemporally separable utility function, featuring unitary elasticities of intertemporal and intratemporal substitution:

$$U(C) = \sum_{t=1}^{\infty} \left(\frac{1+\gamma}{1+\beta}\right)^t \log\left[\left(C_t^1\right)^\zeta \left(C_t^2\right)^{1-\zeta}\right], \tag{36}$$

where β is the rate of time preference. In our calibration procedure, we exogenously select a value for the factor intensity ratio, ρ, which we define as follows:

$$\rho = \frac{\lambda^1/(1-\lambda^1)}{\lambda^2/(1-\lambda^2)}, \tag{37}$$

and then choose input value shares so as to obtain a capital-labour ratio of 1/3 in the initial steady state.

In all of our simulations, we assume that only one sector in the economy generates knowledge and consider four different scenarios with different assumptions as to the composition of consumption and investment activities and their relationship with productivity growth. In the first three scenarios, we select ρ to be equal to 3 (implying that sector 1 is labour-intensive). In our first scenario, we assume that only sector 1, the labour-intensive sector, generates spillovers ($\epsilon^1 > 0$, $\epsilon^2 = 0$), and we choose values for μ and ζ respectively equal to 0.8 and 0.2, which implies that one dollar of investment mobilizes four times as much sector 1 production (and thus knowledge production) as one dollar of consumption does. This scenario is close in spirit to Arrow's (1962) original notion of learning-by-doing, where knowledge is a by-product of the accumulation of physical capital. In the second scenario, we choose to maintain the assumption that the sector that generates knowledge spillovers is labour-intensive, but assume μ and ζ to be both equal to 0.2. This corresponds to a situation where knowledge production is relatively specialized and is labour-intensive, and where investment and consumption have identical factor intensities. In the third scenario we select $\epsilon^1 = 0$, $\epsilon^2 > 0$, $\mu = 0.8$ and $\zeta = 0.2$, implying that investment is labour-intensive, but consumption is relatively more knowledge intensive than investment. The fourth scenario is analogous to the first one, except that factor shares are identical across sectors (i.e., ρ=1). In all cases, the values for the spillover coefficients are chosen so as to support an initial steady-state growth rate of 3.5%.

For each of these scenarios, we examine five different cases, summarized in Table 1, each corresponding to a different set of assumptions about the mechanism supporting growth. Case 1, represents the neoclassical case, where the rate of productivity growth is exogenous, i.e., $\phi > 0$ and $\epsilon^1 = \epsilon^2 = 0$. In all other cases, there is no exogenous technological change ($\phi = 0$). Case 2 corresponds to a pure learning-by-doing process where the rate of internalization of knowledge spillovers, θ, is equal to zero, whereas in Case 3 there is full internalization of spillovers by private agents ($\theta = 1$). To characterize the next two cases, it is convenient to rewrite (25) and (26) as

$$\alpha_t^1 = \eta \frac{v_t^1}{p_t^1 + v_t^1}, \tag{38}$$

$$\alpha_t^2 = \eta \frac{v_t^2}{p_t^2 + v_t^2}. \tag{39}$$

In this specification, when $\eta = 0$ knowledge production is not tax-sheltered, whereas in Case 4, when $\eta = 1$, there is full tax sheltering of human investment. We also rewrite (32) as

$$S_t = \vartheta \frac{1}{N_t} \sum_{j=t+1}^{\infty} \frac{N_j w_j \tau_L/(1-\tau_L)}{\prod_{m=t+1}^{j} (1+r_m)}. \tag{40}$$

Thus, Case 5, where $\vartheta = 1$, represents a situation where knowledge production is subsidized by the government so that the double taxation of knowledge investment is fully eliminated.

Table 1: Main Features of Assumed Cases

		Cases				
		1	2	3	4	5
Exogenous technological growth	(ϕ)	0.0197	0	0	0	0
Rate of internalization of knowledge spillovers	(θ)	0	0	1	1	1
Tax-sheltering of knowledge production	(η)	0	0	0	1	0
Subsidization of knowledge production	(ϑ)	0	0	0	0	1

In the initial steady state the government levies a proportional income tax at a rate of 30%. In order to obtain equal-yield comparisons, we impose the following revenue requirement on the government: the present value of tax revenues must be sufficient to guarantee a constant real transfer to consumers in present value terms. This real transfer is computed by using an ideal price index based on consumers' preferences.[8] Thus, following a tax change, we must allow a subset of tax rates to adjust endogenously so as to meet the revenue requirement. For our simulations we use a resolution of five years, and allow a time span of 250 years for the economy to get close to a new balanced growth path.[9]

Figure 1 shows the transition to a new balanced growth path following a move to consumption taxation in Case 3 (private internalization) for our first scenario.

[8]Since preferences ar homothetic, we can express this price index in terms of a unit expenditure function dual to the assumed utility function.

[9]We compute equilibrium factor prices with a numerical accuracy of four decimal digits.

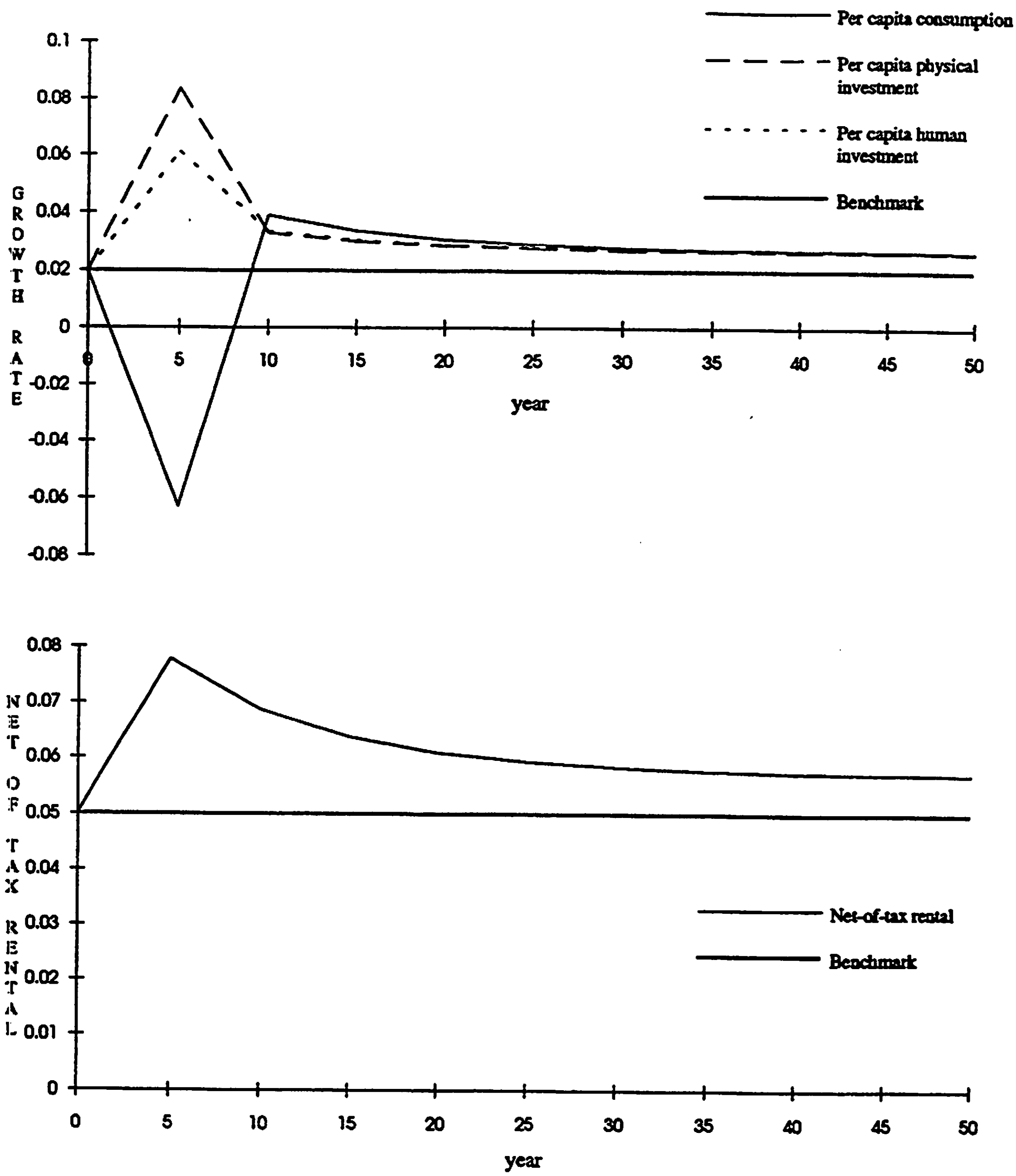

Figure 1: Move to Consumption Taxation – Transition Path
First Scenario, Case 3 (Private Internalization)

Immediately after the tax change, the increase in the net-of-tax rate of return to physical capital causes per capita consumption to fall, allowing a rapid adjustment in the stocks of physical capital and knowledge. After this initial shock, per capita consumption keeps growing at rates higher than the initial steady-state growth rate, and the net-of-tax rate of return converges to a long-run equilibrium value that lies above the benchmark value of 5%. The transition paths for our other experiments exhibit similar patterns.

The results of our experiments are summarized in Tables 2 to 5, which report, for each case, the terminal rate of growth and the proportional welfare change. The latter is equal to the equivalent variation of the tax change as a proportion of initial wealth (human and non-human) evaluated at pre-tax change prices.[10]

In all scenarios, the welfare gains of moving from a comprehensive income tax to a consumption or wage tax are around 1% with exogenous technological growth, but rise dramatically when growth is endogenous. In the first scenario (Table 2), when growth is based on a learning-by-doing mechanism (Case 2), moving to a consumption or wage tax raises welfare by almost 14%. Notice that in this case, as in the neoclassical case, a move to a consumption or wage tax and a replacement of interest income taxes by consumption taxes are all equivalent, and a removal of wage taxes has no effect. With private internalization of knowledge spillovers (Case 3), a removal of wage taxes raises

[10]For this purpose, we specify a linearly homogeneous utility function, ordinally equivalent to the utility function (36), so that we can obtain the proportional equivalent variation simply as the proportional change in utility.

Table 2: Welfare and Growth Effects of Tax Changes (%)
First Scenario ($\epsilon^1 > 0$, $\epsilon^2 = 0$, $\mu = 0.8$, $\zeta = 0.2$)
Sector 1 Labour-Intensive ($\rho = 3$)

	Cases				
	1	2	3	4	5
Replacement of capital income taxes with consumption taxes					
Welfare change	0.8	13.9	7.1	2.7	2.0
Terminal growth rate	3.5	3.7	3.7	3.6	3.7
Replacement of labour income taxes with consumption taxes					
Welfare change	0.0	0.0	11.2	3.3	0.0
Terminal growth rate	3.5	3.5	3.9	3.7	3.5
Move to a consumption tax					
Welfare change	0.8	13.9	13.7	4.2	2.0
Terminal growth rate	3.5	3.7	4.2	3.8	3.7
Move to a wage tax					
Welfare change	0.8	13.9	5.5	1.8	2.0
Terminal growth rate	3.5	3.7	3.7	3.6	3.7

Table 3: Welfare and Growth Effects of Tax Changes (%)
Second Scenario ($\epsilon^1 > 0$, $\epsilon^2 = 0$, $\mu = \zeta = 0.2$)
Sector 1 Labour-Intensive ($\rho = 3$)

	Cases				
	1	2	3	4	5
Replacement of capital income taxes with consumption taxes					
Welfare change	1.0	6.4	5.4	3.1	2.6
Terminal growth rate	3.5	3.6	3.7	3.6	3.7
Replacement of labour income taxes with consumption taxes					
Welfare change	0.0	0.0	10.9	2.5	0.0
Terminal growth rate	3.5	3.5	4.0	3.7	3.5
Move to a consumption tax					
Welfare change	1.0	6.4	14.1	4.5	2.6
Terminal growth rate	3.5	3.6	4.2	3.8	3.7
Move to a wage tax					
Welfare change	1.0	6.4	2.2	2.1	2.6
Terminal growth rate	3.5	3.6	3.6	3.6	3.7

Table 4: Welfare and Growth Effects of Tax Changes (%)
Third Scenario ($\epsilon^1 = 0$, $\epsilon^2 > 0$, $\mu = 0.8$, $\zeta = 0.2$)
Sector 1 Labour-Intensive ($\rho = 3$)

	Cases				
	1	2	3	4	5
Replacement of capital income taxes with consumption taxes					
Welfare change	0.8	5.1	3.6	2.5	1.9
Terminal growth rate	3.5	3.6	3.6	3.6	3.6
Replacement of labour income taxes with consumption taxes					
Welfare change	0.0	0.0	3.2	2.8	0.0
Terminal growth rate	3.5	3.5	3.6	3.6	3.5
Move to a consumption tax					
Welfare change	0.8	5.1	5.4	3.7	1.9
Terminal growth rate	3.5	3.6	3.8	3.7	3.6
Move to a wage tax					
Welfare change	0.8	5.1	3.0	2.0	1.9
Terminal growth rate	3.5	3.6	3.6	3.6	3.6

Table 5: Welfare and Growth Effects of Tax Changes (%)
Fourth Scenario ($\epsilon^1 > 0$, $\epsilon^2 = 0$, $\mu = 0.8$, $\zeta = 0.2$)
Equal Factor Intensities ($\rho = 1$)

	Cases				
	1	2	3	4	5
Replacement of capital income taxes with consumption taxes					
Welfare change	1.0	21.8	10.1	3.6	2.5
Terminal growth rate	3.5	3.8	3.8	3.7	3.8
Replacement of labour income taxes with consumption taxes					
Welfare change	0.0	0.0	15.7	5.0	0.0
Terminal growth rate	3.5	3.5	4.1	3.8	3.5
Move to a consumption tax					
Welfare change	1.0	21.8	18.2	6.0	2.5
Terminal growth rate	3.5	3.8	4.3	4.0	3.8
Move to a wage tax					
Welfare change	1.0	21.8	8.9	2.5	2.5
Terminal growth rate	3.5	3.8	3.8	3.6	3.8

welfare by 11.2%, whereas a removal of capital income taxes raises welfare by only 7.1%. This gap is smaller in the presence of tax-sheltering of knowledge investment (Case 4), which lowers the taxation of labour inputs in knowledge production (the labour-intensive sector).

A move to wage taxation is welfare improving in all cases and in all scenarios. This result can be partly attributed to the fact that initial human wealth is larger than non-human wealth, and thus an unanticipated move from capital to wage taxation raises the implicit lump-sum content of the total tax revenues. This finding may also indicate that, given our model formulation and assumed parameter values, physical investment is relatively more elastic with respect to its after-tax rate of return than investment in knowledge is.

In the first scenario, a move to a consumption tax produces a substantial increase in the long-run rate of growth, but its welfare impact is slightly smaller than in the learning-by-doing case. When investment in knowledge is tax-sheltered (Case 4), the welfare impact of tax changes is substantially reduced, although their impact on growth is still sizeable. Finally, when knowledge production is subsidized (Case 5), wage taxation is non-distortionary, and the welfare effects of tax changes are much closer in size to those obtained when technological change is exogenous.

In the second scenario (Table 3), the welfare impact of a move to a consumption tax is higher with private internalization (Case 3) than in the learning-by-doing case (Case 2). This finding reflects the fact that, in this scenario, the knowledge spillover of capital goods production is rather limited. Notice that in Case 3, moving to a consumption tax produces much larger welfare gains (14.1%) than a move to wage taxation (2.2%).

In the third scenario (Table 4), when the production of consumer goods is knowledge-intensive, there is less output complementarity between physical investment and knowledge production than in the two previous scenarios. Consequently, all welfare effects are smaller. With private internalization of knowledge spillovers (Case 3), asset capitalization effects also occur in human capital production. While in the first two scenarios knowledge is produced in the labour-intensive sector, here it is produced in the capital-intensive sector, which results in reduced welfare gains from lowering the wage tax rate.

In the fourth scenario (Table 4), when consumer goods and investment goods exhibit identical factor intensities, the welfare impact of tax changes tends to be magnified by asset price capitalization effects affecting physical investment, resulting in very substantial welfare gains (21.8% in Case 2).

Overall, the results of our experiments indicate that the effects of taxes on long-run growth performance convey only imperfect information about their welfare impacts. In all scenarios, for example, the long-run growth impact of tax changes are largest in Case 3 (private internalization), but in two out of four scenarios welfare gains are highest in Case 2 (no internalization).

In selecting our scenarios we have chosen to focus on different configurations of share parameters, although other parameters, such as the rate of depreciation of physical capital and substitution elasticities, may also play an important role in our model. In particular, the intertemporal elasticity of substitution, which is assumed to be equal to unity in our experiments, is a key parameter in determining the size of the welfare costs associated with intertemporal distortions.[11] Adopting a lower and perhaps more realistic value, all welfare results would be considerably reduced. Also, taking into account adjustment costs in the formation of physical and human capital stocks could alter the comparative responsiveness of physical and non-physical investment to changes in tax rates.

5 Conclusion

The impact of tax policies on growth performance has long been a central concern in the policy debate on tax reform, particularly in developing countries, but it has not traditionally occupied a central role in the literature on efficient tax design. The recent increase in research activity on endogenous growth models has in part vindicated this neglect, showing that tax policies can have important effects on long-run growth and welfare.

In this paper we have analyzed the implications of various growth mechanisms for the dynamic efficiency costs of alternative tax structures. Our findings suggest that the welfare impact of unanticipated tax changes is generally correlated, albeit imperfectly, with their impact on long-run growth performance, but the comparative performance of different tax schemes depends crucially on the growth supporting mechanism assumed. Furthermore, the size of the welfare effects of tax changes can vary considerably, depending on the degree of complementarity between knowledge

[11] The larger the value of this elasticity the larger the welfare effects of intertemporal distortions.

production and physical investment and on factor intensities. As in a neoclassical setting, a move from income taxation to wage taxation can be welfare improving, but when growth is fuelled by investment in knowledge by optimizing agents the presence of endogenous growth mechanisms strengthens the arguments for favouring a consumption tax over a wage tax on efficiency grounds. On the other hand, if knowledge production is tax-sheltered or subsidized, the advantages of consumption taxation in comparison with wage taxation are considerably reduced.

The general conclusion of our analysis is that with endogenous technological change, the intertemporal allocative effects of taxation can be quantitatively much larger and qualitatively much richer than in the traditional growth models discussed in the public finance literature. Perhaps the most striking feature of our results is that, when growth is endogenous, estimates of the welfare effects of taxes seem to be extremely sensitive to the type of growth supporting mechanism assumed as well as to the productive structure of the economy. This suggests that a correct identification of the mechanisms underlying growth is crucial for the optimal design of tax policies.

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