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Do Distortionary Taxes Always Harm Growth?*

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Abstract

This paper examines the long-run effects of capital income taxes, labor income taxes, and expenditure taxes in an R&D-based model of endogenous growth with endogenous labor supply. The main contribution of this paper is to investigate how tax effects on long-run growth are influenced by the emergence of indeterminate equilibria. Indeterminacy in this instance arises due to nonseparable preferences between consumption and leisure, in conjunction with prior distortionary taxes. In contrast to conventional wisdom, we show that higher distortionary taxes improve long-run growth, as well as social welfare, when the steady state is indeterminate.

Keywords: Endogenous growth, R&D, Indeterminacy, Distortionary tax

JEL classifications: E62, H20

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1 Introduction

This paper revisits the role of endogenous labor supply in the analysis of the effects of taxes on long-run growth. Our analysis is based on two important results established in the growth literature. First, in the presence of endogenous labor supply, consumption, and labor income taxes have adverse effects on growth. The taxes make leisure more attractive than consumption, hence non-leisure activity, which in turn adversely affects the incentive for growth-promoting activity (e.g., human capital accumulation). These effects are similar in nature to a capital income tax, which decreases the returns to capital accumulation.

Second, the endogeneity of labor supply can cause fundamental changes in the stability nature of long-run equilibria (see, e.g., Benhabib and Farmer, 1994). That is, indeterminacy becomes possible, in the sense that a continuum of equilibrium trajectories all converge to the same steady state. More specifically, the introduction of endogenous labor supply can change the sign of the Jacobian matrix of a given dynamical system evaluated at the steady state.

The importance of the second result in relation to the first regarding the tax effects on growth can be appreciated by noting Samuelson's Correspondence Principle, which essentially means that comparative statics properties in a steady state are directly linked to the dynamical behavior of the system in the neighborhood of the steady state. The present paper applies Samuelson's Correspondence Principle to demonstrate that the long-run effects of taxes on growth obtained for a determinate steady state will be reversed in the presence of indeterminacy. This result is shown using an R&D-based model in the form of an expanding variety of capital goods. Indeterminacy arises because of nonseparable preferences between consumption and leisure, coupled with positive externalities from innovations and prior tax distortions.

Fiscal policy is examined in a number of growth models. In neoclassical growth models, taxes affect the steady state level of income, but have no effect on growth in the long run.¹ Fiscal policy influences long-run growth only in endogenous growth models, which can be roughly classified into two strands according to the types of engines of growth.

The first strand of models emphasizes the accumulation of physical and human capital as reproducible factors under the assumption of constant-returns-to-scale accumulation technology (e.g., Devereux and Love, 1994; Stokey and Rebelo, 1995; Milesi-Ferretti and Roubini, 1998). These models show that, in general, both labor and capital income taxes reduce the long-

¹For example, see Turnovsky (1982) and Sinn (1987).

run growth rate. Indeed, these two distortionary taxes effectively act as a tax on human capital income, as well as on capital income, thereby discouraging either form of accumulation.

The second strand focuses on technological change resulting from the R&D efforts of profit-maximizing agents (see, e.g., Romer, 1990). Based on Romer (1990), Lin and Russo (1999) find that lower income taxes on non-innovative firms result in higher growth rates and improved welfare, as the policy diverts resources to innovative firms. They also show that a lower tax on innovating firms can be growth- and welfare-reducing if the tax system permits tax credits for R&D expenditure. Zeng and Zhang (2002) reexamine the growth effects of taxation using the non-scale endogenous growth model of Howitt (1999) where horizontal and vertical R&D innovations simultaneously take place. They show that a capital income tax is harmful for growth by discouraging saving and thus investment, whereas the consumption and labor income taxes do not affect the growth rate despite allowing endogenous labor supply. However, these studies lack the stability analysis of equilibria, which is the focus of this paper. We argue that this omission is not innocuous, because the model's stability properties provide vital information on tax effects, as is demonstrated.

Among the existing literature, Pelloni and Waldmann's study (2000) is the most closely related to the present study. Their paper considers the effects of taxes, using the *AK* model based on learning-by-doing effects. They find that distortionary taxes can promote growth and improve welfare when equilibria are indeterminate. The present paper differs from Pelloni and Waldmann's study in three important respects.

First, this paper conducts tax policy analysis, using Rivera-Batiz and Romer's (1991) R&D-based model of endogenous growth augmented with endogenous labor supply.² This allows us to explore the tax policy effects in the model based on the microeconomic foundations of innovating firms in imperfectly competitive markets. It is also interesting to examine the robustness of Pelloni and Waldmann's results under such a plausible setting in line with the R&D-based growth model. Second, we consider three types of taxes: a capital income tax, a labor income tax, and a consumption tax, each of which is accompanied by compensating lump-sum transfers. This approach is not only common in the tax policy literature, but also analytically convenient because it isolates the pure incentive effect of the tax through eliminating the

²Rivera-Batiz and Romer (1991) present two different specifications of R&D technology. The first, entitled "knowledge driven specification", is also examined in Romer (1990). For the purposes of analytical tractability, we employ the second, entitled "lab equipment specification", which is not identical to ours because in their specification human capital is a production factor. We thank an anonymous referee with regard to this point.

direct income effect. It therefore provides more clear-cut results, that enable us to make a sharper comparison of the results of this analysis and earlier work. Third, Pelloni and Waldmann, for analytical convenience, assume that there are no pre-existing taxes, which means that a tax increase is simple the introduction of a new tax. In contrast, we allow prior distortionary taxes. In other words, Pelloni and Waldmann's analysis would be inappropriate for examining the effects of real-world taxes that are far from "small", a point made by Vandendorpe and Friedlaender (1976), among others, in the static tax incidence literature. In addition to those quantitative impacts on long-run growth and welfare, we also show that prior distortionary taxes may modify the nature of the stability properties of the model (i.e., the likelihood of indeterminacy) leading also to qualitative changes in tax effects.

The present paper is structured as follows. Section 2 introduces the model. The stability properties of the long-run equilibria are investigated in Section 3. Section 4 explores the effects of taxes on long-run growth. Section 5 conducts the same analysis, but under different preferences. Section 6 concludes.

2 The Model

2.1 Households and Government

Assume a unit measure of identical infinitely lived households. Each is endowed with one unit of time, which is allocated between labor supply and leisure, and has the following preferences (see, e.g., Milesi-Ferretti and Roubini, 1998; Pelloni and Waldmann, 2000):³

$$\int_0^\infty \frac{c(t)^{1-\sigma}}{1-\sigma} (1-l(t))^{1-\eta} e^{-\rho t} dt, \quad \sigma \neq 1, \quad (1)$$

where c is the individual's consumption, $0 \leq l \leq 1$ is the individual's labor supply, $\sigma > 0$ denotes the inverse of the intertemporal elasticity of substitution in consumption, $\eta > 0$ is the elasticity of labor supply and $\rho > 0$ is the subjective rate of time preference. The following two conditions are required for strict concavity of the instantaneous utility function in (1):

$$\sigma > 1 - \eta > 0 \text{ if } \sigma < 1, \text{ while } \eta > 1 \text{ if } \sigma > 1. \quad (2)$$

³When $\sigma = 1$, the preferences are represented by

$$\int_0^\infty \left[\ln c(t) + (1-l(t))^{1-\eta} \right] e^{-\rho t} dt.$$

The budget constraint faced by the representative household is given by

$$\dot{k}(t) = (1 - \tau_w) w(t) l(t) + (1 - \tau_k) r(t) k(t) + z(t) - (1 + \tau_c) c(t),$$

where k , w , r , and z represent saving in the form of equity, the real wage rate, the interest rate, and transfer payments that are rebated to households in a lump sum fashion, respectively. The variables τ_k , τ_w , and τ_c indicate the tax rates applied to capital, labor income, and consumption, respectively.

The intertemporal utility maximization of the representative household that chooses saving and labor supply involves the first-order conditions:

$$c(t)^{-\sigma} (1 - l(t))^{1-\eta} = \lambda(t) (1 + \tau_c), \quad (3a)$$

$$\frac{c(t)^{1-\sigma}}{1 - \sigma} (1 - \eta) (1 - l(t))^{-\eta} = \lambda(t) (1 - \tau_w) w(t), \quad (3b)$$

$$\dot{\lambda}(t) - \rho \lambda(t) = -\lambda(t) (1 - \tau_k) r(t), \quad (3c)$$

the given initial level of equity holdings, and the transversality condition $\lim_{t \rightarrow \infty} e^{-\rho t} \lambda(t) k(t) = 0$. λ stands for the shadow price of asset accumulation.

First, taking logarithms of both sides and time derivatives of (3a), and substituting (3c) into the resultant expression yields

$$\sigma \frac{\dot{c}(t)}{c(t)} + (1 - \eta) \frac{\dot{l}(t)}{1 - l(t)} = (1 - \tau_k) r(t) - \rho. \quad (4)$$

This shows that the capital income tax has a direct negative effect on consumption growth by reducing the after-tax rate of return on equity, while all taxes indirectly affect consumption growth through variations in labor supply and interest rates.

Next, dividing (3b) by (3a) we obtain

$$\frac{1 - \eta}{1 - \sigma} \frac{c(t)}{1 - l(t)} = \frac{1 - \tau_w}{1 + \tau_c} w(t). \quad (5)$$

This condition requires that the marginal rate of substitution between consumption and leisure should be equated to the real wage rate, adjusted for the consumption and wage taxes at each point in time. A higher labor income tax rate and a higher consumption tax rate induce substitution away from consumption towards leisure through lowering the after-tax wage and through raising the after-tax price of consumption, respectively.

To focus on the problem at hand, we rule out a market for government bonds and government expenditures. We focus on the differential incidence of taxes in which the government has to run a balanced budget at each point

in time, through adjusting the size of transfer payments to households, when it changes tax parameters. The government's flow budget constraint is thus expressed by

$$z(t) = \tau_k r(t) k(t) + \tau_w w(t) l(t) + \tau_c c(t).$$

2.2 Production

Assume three production sectors where final output, intermediate goods, and the blueprints for new goods are produced. It is taken that perfect competition prevails in all sectors, except for the intermediate goods sector where a temporary monopoly exists.

2.2.1 Final Output

Final output, Y , is produced using labor, l , and a continuum of intermediate capital goods, x_i , according to the following production function:

$$Y(t) = l(t)^{1-\alpha} \int_0^{n(t)} x_i(t)^\alpha di, \quad 0 < \alpha < 1, \quad (6)$$

where n represents the number of varieties of differentiated intermediate goods that expands over time due to technological progress. The price of the final product is normalized to one. Profit maximization of the competitive final-goods firm requires the following first-order conditions:

$$w(t) = (1 - \alpha) \frac{Y(t)}{l(t)}, \quad (7)$$

$$p_i(t) = \alpha l(t)^{1-\alpha} x_i(t)^{\alpha-1}, \quad \forall i \in [0, n(t)], \quad (8)$$

where p_i represents the rental price of intermediate good i in terms of the final good.

2.2.2 Intermediate Capital Goods

Each intermediate good is produced by a monopoly firm, which has a perpetually protected patent for the good. A blueprint for a new intermediate good is purchased from a successful R&D firm. The only input into the production of intermediate goods is capital, which the firm rents from households in a perfectly competitive rental market. One unit of the intermediate good is produced with one unit of capital. Given the prevailing rental rate r , the monopoly firm chooses a price to maximize its profit:

$$\pi_i(t) = (p_i(t) - r(t)) x_i(t) \quad (9)$$

subject to the demand function (8). Profit maximization yields the following monopoly price:

$$p_i(t) \equiv p(t) = \frac{r(t)}{\alpha}. \quad (10)$$

The parameter $\alpha < 1$ inversely measures the intermediate monopolist's market power. Substituting (10) into (9), we obtain

$$\pi_i(t) = \frac{1 - \alpha}{\alpha} r(t) x_i(t). \quad (11)$$

2.2.3 R&D

We make a research-lab assumption regarding R&D technology. Specifically, $1/\delta$ number of blueprints of intermediate goods is produced with one unit of final goods, i.e.,

$$\dot{n}(t) = \frac{R(t)}{\delta}, \quad (12)$$

where R represents the amount of final output devoted to R&D activities. There is free entry into R&D so that anyone can pay the R&D cost to secure the net present value of the returns from discovering a new design $v(t)$:

$$v(t) = \delta. \quad (13)$$

A successful R&D firm charges a price for its design that makes potential buyers indifferent about purchasing or not purchasing the design. That is, the price of a blueprint is equivalent to $v(t)$, which is defined by the following simple arbitrage equation:

$$r(t) = \frac{\pi(t)}{v(t)} + \frac{\dot{v}(t)}{v(t)}. \quad (14)$$

Substituting (11) and (13) into (14) and solving for $x_i(t)$ yields

$$x_i(t) = \frac{\alpha\delta}{1 - \alpha} \equiv \bar{x}, \quad (15)$$

which implies that the output levels of all intermediate goods are the same among these firms and fixed through time.

2.3 Equilibrium

We solve for equilibrium with perfect foresight. To simplify notation, the time argument will be dropped. We also abstract from capital depreciation for simplicity, so that the total stock of producer durables is related to the aggregate stock of physical capital:

$$K = \int_0^n \bar{x} di = n\bar{x}. \quad (16)$$

This implies that the accumulation of capital is equivalent to the rate of technological progress (i.e., $\dot{K}/K = \dot{n}/n$).

Substituting (6) into Y in (7) and using (15) yields $w = (1 - \alpha) n (\bar{x}/l)^\alpha$. Further substitution of this expression into w in (5) and solving for c/n yields

$$\frac{c}{n} = \Delta \frac{1 - l}{l^\alpha}, \quad (17)$$

where $\Delta \equiv (1 - \tau_w)(1 - \alpha)(1 - \sigma)\bar{x}^\alpha / (1 + \tau_c)(1 - \eta) > 0$ is constant.

On the other hand, the final goods market clearing condition, $\dot{K} = Y - R - c$, can be rewritten as $\dot{n}\bar{x} = nl^{1-\alpha}\bar{x}^\alpha - \delta\dot{n} - c$, or equivalently

$$g(\bar{x} + \delta) = l^{1-\alpha}\bar{x}^\alpha - \frac{c}{n}, \quad (18)$$

where $g \equiv \dot{n}/n$ represents the rate of technological progress (i.e., the rate of capital accumulation). This condition can be further simplified to

$$g = \frac{1}{\bar{x} + \delta} \left(l^{1-\alpha}\bar{x}^\alpha - \Delta \frac{1 - l}{l^\alpha} \right) \equiv g(l), \quad g'(l) > 0. \quad (19)$$

Equation (19) is referred to as **the technology condition**, following Rivera-Batiz and Romer (1991). Note that (19) must hold at any point in time, regardless of whether or not the economy is in the steady state.

To characterize the dynamic motion of the model, we need to derive another dynamic equation. For this, we first use the equality between (8) and (10) to obtain

$$r = \alpha^2 \left(\frac{l}{\bar{x}} \right)^{1-\alpha} \equiv r(l), \quad r'(l) > 0. \quad (20)$$

This equation is essentially the demand function for producer durables (capital) with the rental price being decreasing in $\bar{x}$. Taking logs and time derivatives of (17) and substituting the resultant expression into (4) yields

$$\sigma \left(\frac{\dot{n}}{n} - \frac{\dot{l}}{1-l} - \alpha \frac{\dot{l}}{l} \right) + (1-\eta) \frac{\dot{l}}{1-l} = (1-\tau_k) r - \rho. \quad (21)$$

By solving for $\dot{l}$, we can rewrite (21) as

$$\dot{l} = \frac{1-l}{D(l)} \left[g(l) - \frac{(1-\tau_k) r(l) - \rho}{\sigma} \right], \quad (22)$$

where $D(l) \equiv \alpha(1-l)l^{-1} + 1 - (1-\eta)\sigma^{-1} > 0$, given the assumption of strict concavity (2). The term $\sigma^{-1}[(1-\tau_k)r(l) - \rho]$ in (22) represents the steady state growth rate of consumption, as it is obtained from setting $\dot{l} = 0$ in (4). The dynamic motion of the model is completely determined by the technology condition (19), which determines the rate of growth of innovation, and the steady state growth rate of consumption.

3 Dynamics of the Model

The main objective of this paper is to demonstrate that the growth effects of taxes depend critically on the stability properties of long-run or balanced growth equilibria (BGE).

Differentiating (22) with respect to l and evaluating at steady state, we arrive at

$$\left. \frac{d\dot{l}}{dl} \right|_{l=\hat{l}} = \frac{1-\hat{l}}{D(\hat{l})} \left[\frac{dg(\hat{l})}{d\hat{l}} - \frac{1-\tau_k}{\sigma} \frac{dr(\hat{l})}{d\hat{l}} \right], \quad (23)$$

where a “hat” over variables denotes their long-run values. The first term in the square brackets on the right-hand side of (23) stands for the slope of the technology condition (19) along the BGE in (l, g) space. The second term represents the slope of the curve $\sigma^{-1}[(1-\tau_k)r(l) - \rho]$. Therefore, the sign of (23) hinges on the relative slopes of these curves.

Figures 2-5 show the graphs of the technology condition (19) and the curve $\sigma^{-1}[(1-\tau_k)r(l) - \rho]$, depending on the relative slopes of these curves. Note also that both curves are monotonically increasing in l at a decreasing rate, which means that multiple steady state or balanced growth equilibria are possible. To focus on the main purpose of this paper, however, we do not explore the case of multiple equilibria. Instead, we assume that the steady state is unique (at least locally).

The intersection points of the two curves in Figures 2-5 give the long-run growth rate $\hat{g}$ along the BGE path. Stability of the BGE can be easily

checked using those figures and (23). If the technology condition is steeper than the curve $\sigma^{-1}[(1 - \tau_k)r(l) - \rho]$, then $d\dot{l}/dl > 0$, meaning that the fixed point $\hat{l}$ is a repeller, i.e., the BGE is locally determinate. In contrast, if the technology condition is less steep than the curve $\sigma^{-1}[(1 - \tau_k)r(l) - \rho]$, then $d\dot{l}/dl < 0$. Then the fixed point $\hat{l}$ is an attractor, i.e., the BGE is locally indeterminate. To summarize (see Appendix A also):

Proposition 1 A balanced growth path of the economy is locally indeterminate if and only if

$$1 + \frac{1 - \sigma}{1 - \eta} \frac{1 - \tau_w}{1 + \tau_c} \left(1 - \alpha + \alpha \hat{l}^{-1}\right) - \frac{1 - \tau_k}{\sigma} \alpha < 0 \quad (24)$$

and locally determinate if and only if inequality (24) is reversed.

Note first that when $\sigma > 1$, $\eta > 1$ by virtue of (2) and thus the left-hand side of (24) cannot be negative. As a result, $\sigma < 1$ is a necessary condition for indeterminacy. To provide intuition for this proposition, suppose that the initial level of l is lower than the BGE level of labor $\hat{l}$, which makes the production of final output smaller. Moreover, the consumption level associated with this lower l should be higher than that at the BGE because of the complementarity of leisure (recall (5)). Because these two impacts together make the resources devoted to R&D smaller, the economy's growth rate $g (= \dot{n}/n)$ will be lower than the growth rate along the BGE, $\hat{g}$. This description corresponds to an economy located southwest of the BGE in Figures 2-5. Starting from a point associated with such an economy along the technology condition (19), whether the economy converges to or diverges from the BGE (i.e., point E) depends on whether inequality (24) holds or not, i.e., the magnitude of the responses of $g(l)$ and $r(l)$ to changes in l , i.e., $dg(l)/dl$ and $dr(l)/dl$ in (23).

If $g(l)$ is very sensitive to changes in l compared to $r(l)$ (i.e., if the technology condition cuts the curve $\sigma^{-1}[(1 - \tau_k)r(l) - \rho]$ from below, depicted in Figure 2), then the steady state growth rate of consumption is greater than that of technological progress, when the initial level of l is lower than its BGE level $\hat{l}$. The consumption-capital ratio c/n begins to rise, although c and n both keep growing at positive rates. A continuing increase in n causes an upward shift of the labor demand curve implied by (7). At the same time, the labor supply curve implied by (5) also shifts upward due to a continuing increase in c . Because these two curves continue to move upward, the long-run effect on employment may not be clear. To pin down this long-run effect diagrammatically, we define the **detrended** labor demand and **detrended** labor supply functions as follows:

$$\frac{w}{n} = (1 - \alpha) \left(\frac{\bar{x}}{l} \right)^\alpha \quad \text{and} \quad \frac{w}{n} = \frac{c}{n} \frac{1 + \tau_c}{1 - \tau_w} \frac{1 - \eta}{(1 - \sigma)(1 - l)}. \quad (25)$$

The **detrended** labor supply curve (i.e., the second equation in (25)) unambiguously shifts upward in response to the increased ratio c/n , while the **detrended** labor demand curve (i.e., the first equation in (25)) remains intact. As a result, the equilibrium level of employment falls, as illustrated in Figure 1. As this fall in l induces the economy to move away from the BGE (i.e. point E), the economy is unstable and thus the “flow variable” l should jump to the BGE level. That is, the BGE is determinate.

In contrast, if $g(l)$ is less sensitive to changes in l (i.e., if the technology condition cuts the curve $\sigma^{-1}[(1 - \tau_k)r(l) - \rho]$ from above, depicted in Figure 3), then the ratio c/n begins to fall when the initial level of l is lower than its BGE level. This decline causes the **detrended** supply curve to shift downward, while leaving the **detrended** labor demand intact, thereby boosting employment. As a result, l and thus $g (= \dot{n}/n)$ gradually return to the BGE along the technology condition (19), and the BGE is stable, i.e., indeterminate.

In what follows, we use an example to show under what parameter values equilibrium exhibits indeterminacy. Following the existing literature, we initially assume that $\alpha = 0.5$, $\rho = 0.03$, $\tau_k = \tau_w = 0.3$ and $\tau_c = 0.15$. Although there is large uncertainty about the size of the parameter δ , by postulating the annual rate of interest, r in (20) equal to 0.03 we can choose $\delta = 20, 30$ or 40 so that l belongs to the interval $(0, 1)$. Because the estimates for the elasticities of labor supply, η , and intertemporal substitution, $1/\sigma$, also vary widely, taking into account the requirement for concave utility functions (i.e., $1 > \sigma > 1 - \eta > 0$), we have tried a variety of combinations of these two values σ and η . However, we cannot find any combination of values that is compatible with indeterminacy.

In view of (24), we have to choose larger values for τ_w and τ_c , and smaller values for τ_k to generate indeterminacy. For example, when we set $\tau_w = 0.7$, $\tau_c = 0.2$ and $\tau_k = 0.1$ in conjunction with $\delta = 30$, $\sigma = 0.11$ and $\eta = 0.9$, we find that indeterminacy occurs. Indeterminacy also emerges for even larger values of τ_w and τ_c and/or smaller values of τ_k , whereas when $\delta = 40$ indeterminacy never occurs for most of the values of τ_w and τ_c (retaining $\tau_k = 0.1$) within the plausible range of $\hat{l}$, i.e., $(0, 1)$. These observations are consistent with Raurich (2003), in which a larger tax on labor income (which requires a smaller tax on capital income due to the government’s budget balance) is needed for the emergence of indeterminacy.⁴

⁴Note also that in Raurich’s model (2003) the introduction of both the public good

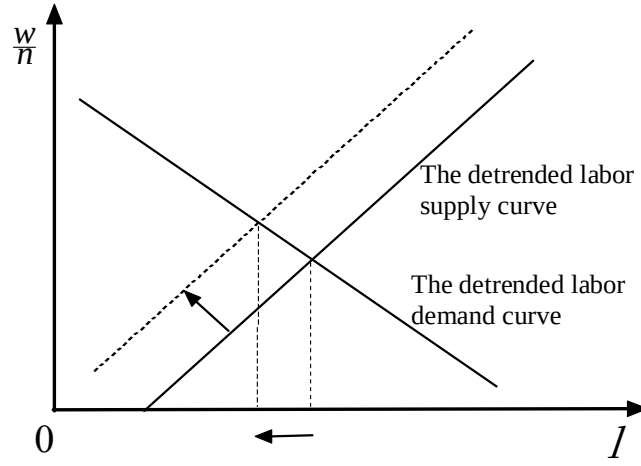


Figure 1: Equilibrium in the labor market when the consumption-capital ratio c/n is increased

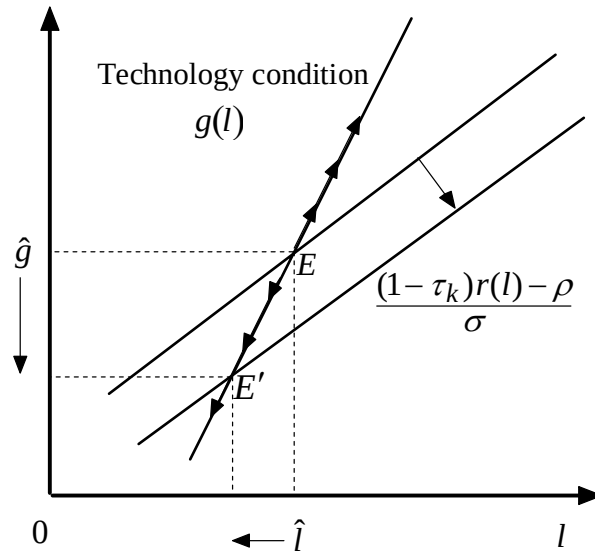


Figure 2: The effects of the capital income tax in a determinate BGE

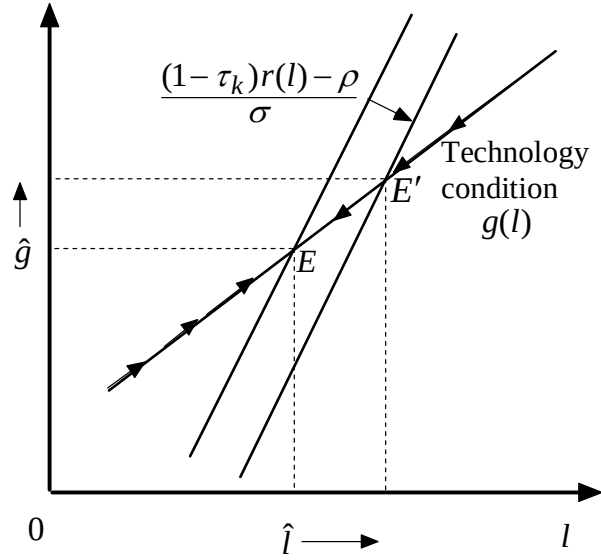


Figure 3: The effects of the capital income tax in an indeterminate BGE

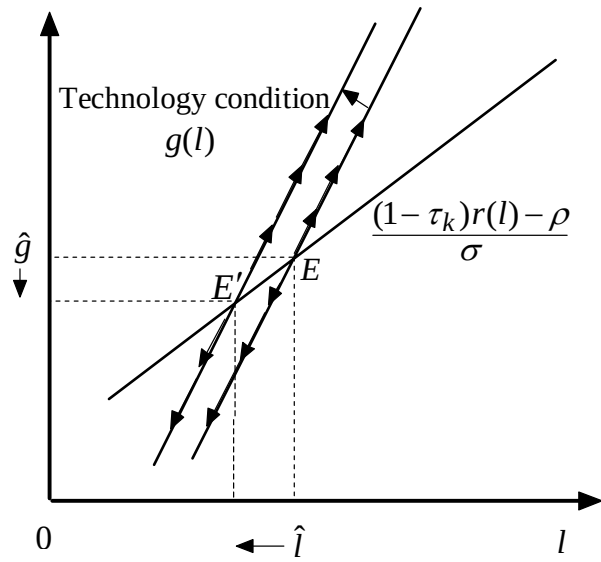


Figure 4: The effects of the labor income tax (or the consumption tax) in a determinate BGE

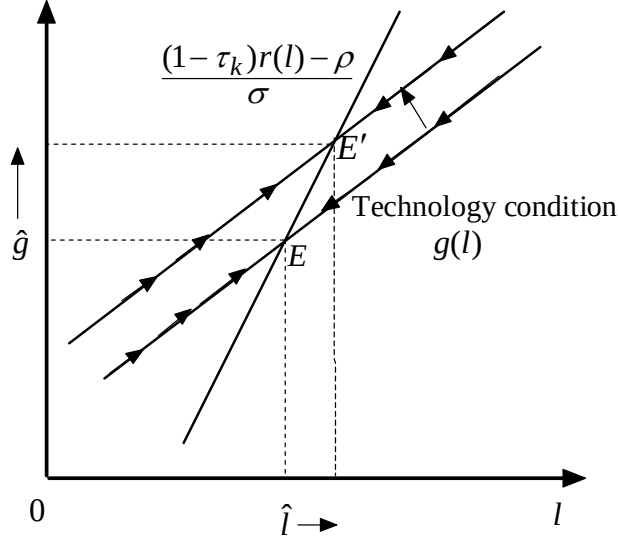


Figure 5: The effects of the labor income tax (or the consumption tax) in an indeterminate BGE

4 Growth Effects of Taxation

This section examines the growth effects of taxes along the BGE path. First we consider a capital income tax. Suppose that the economy is initially in the BGE (i.e., point E in Figure 2-5) and that an unanticipated and permanent increase in the capital income tax occurs. Note that this tax increase shifts only the curve $\sigma^{-1}[(1 - \tau_k)r(l) - \rho]$ downward. Nevertheless, the ultimate effect of this shift on employment depends on the stability nature of the BGE, i.e., the relative slopes of the technology condition and the curve $\sigma^{-1}[(1 - \tau_k)r(l) - \rho]$.

The case of a determinate BGE (i.e., the technology condition is steeper than the curve $\sigma^{-1}[(1 - \tau_k)r(l) - \rho]$, depicted in Figure 2) is examined first. A higher rate of capital income tax will weaken the intertemporal substitution effect as a result of the decreased after-tax rate of return. Because the BGE moves southwestward due to the downward shift of the curve $\sigma^{-1}[(1 - \tau_k)r(l) - \rho]$, the new BGE (i.e., point E' in Figure 2) is characterized by lower employment and a lower balanced growth rate. If employment were to stay at the old BGE (i.e., point E in Figure 2), the growth rate

into the nonseparable utility function and the public input into the production function makes indeterminacy more likely compared to the present model with endogenous labor supply.

of innovation ($= \dot{n}/n$) exceeds that of consumption, thus leading to a fall in the consumption-capital ratio c/n . As explained in the previous section, this causes the **detrended** labor supply curve to shift downward, while the **detrended** labor demand curve remains unchanged, thereby boosting employment. As this rise in l prevents the economy from approaching the new BGE, both g and l should instantaneously jump to the new BGE.

In the case of an indeterminate BGE (i.e., the technology condition is less than that of the curve $\sigma^{-1}[(1 - \tau_k)r(l) - \rho]$, depicted in Figure 3) the tax effect is reversed. As one can see, the new BGE (i.e., point E' in Figure 3) entails higher l and higher g . It is easy to show that l gradually rises to its new BGE level through adjustment in the labor market; hence the new BGE is stable (i.e., indeterminate). Intuition for this result is just the opposite of that given for the determinate case.

Next, consider the consumption and labor income taxes. Note that those taxes affect the technology condition only. When either of the taxes is increased, consumption becomes more expensive relative to leisure (or leisure becomes cheaper relative to consumption), inducing substitution away from consumption to leisure. This induced fall in consumption diverts more resources to R&D, thus raising $\dot{n}/n$. This explains why only the technology condition shifts upward.

To examine the growth effects of consumption and labor income taxes, first consider the case of a determinate BGE. The new BGE (i.e., point E' in Figure 4) featuring smaller l and smaller g is obtained as a result of the upward shift of the technology condition. At the old BGE (i.e., point E in Figure 4) the steady state growth rate of consumption is less than that of innovation, thus leading to smaller c/n . Hence, employment begins to rise, which in turn further drives the economy away from the new BGE. As a result, the economy (i.e., the equilibrium level of employment) must jump to the new BGE.

In the case of an indeterminate BGE, Figure 5 shows that the taxes boost growth and employment in the new BGE (i.e., point E' in Figure 5). Because the ratio c/n declines, employment is increased. This movement in l allows the economy to gradually approach the new BGE. These results are summarized in the next proposition:

Proposition 2 In the long run, (i) $\partial \hat{g}/\partial \tau_j < 0$ and $\partial \hat{l}/\partial \tau_j < 0$, $j = k, w, c$ for a determinate BGE, and (ii) $\partial \hat{g}/\partial \tau_j > 0$ and $\partial \hat{l}/\partial \tau_j > 0$, $j = k, w, c$ for an indeterminate BGE.

At first sight, statement (ii) in Proposition 2 appears to be “paradoxical”, probably because it contradicts the conventional view that tax substitution

from nondistortionary taxes to distortionary taxes, such as lump-sum taxes, has an adverse effect on growth. Such an intuition, according to Proposition 2, is not robust. Advocates of a lower capital income tax have often based their suggestions on theoretical arguments. Nevertheless, empirical support for lower capital income taxes as a means of promoting economic growth is much less clear-cut than one would expect (see, e.g., Easterly and Rebelo, 1993; Engen and Skinner, 1996). Indeed, to explain this lack of empirical support, Uhlig and Yanagawa (1996) and Kam (2002) show that, in an overlapping generations framework, capital income taxes can favor economic growth when the tax revenue is used for income redistribution from old to young people, who are the only savers. Hence, growth-enhancing tax effects arise for reasons not related to the issue of whether equilibria are determinate or indeterminate. In contrast, the present paper offers an alternative theory that points toward growth-enhancing effects of taxation on the basis of the stability nature of long-run equilibrium in an R&D-based endogenous growth model.

Furthermore, it may be instructive to give an alternative interpretation of our comparative statics results. Towards this end, consider the BGE version of (22) with $g = g(l)$ in (19):

$$\rho + \sigma g(\hat{l}) = (1 - \tau_k) r(\hat{l}). \quad (26)$$

This expression allows us to interpret the steady state condition (26) as “the modified golden rule’s condition”, which is familiar in the infinite-horizon representative agent model of exogenous growth with capital income taxes (e.g., Sinn, 1987; Turnovsky, 1982). The left-hand side of (26) can be viewed as the opportunity cost of holding one unit of productivity-adjusted capital (or equity),⁵ and the right-hand side is the after-tax return from holding one unit of productivity-adjusted capital. When the after-tax return on equity is less than the opportunity cost as a result of increased τ_k , there are two ways of adjusting l to restore the equality of (26); namely, either increasing l to raise the return on capital or decreasing l to reduce the opportunity cost. Which mechanism is at work depends on the relative magnitudes of the responses of $g(l)$ and $r(l)$ to variations in l . If the opportunity cost is more responsive than the return, then l should fall so as to restore the equality of (26), and vice versa. Therefore, the sign of $\left. \frac{d\dot{l}}{dl} \right|_{l=\hat{l}}$ in (23), which reflects the relative responsiveness of $g(l)$ and $r(l)$, plays dual roles in

⁵The left-hand side of (26) may also be interpreted as “the effective discount rate” in the sense that it contains the effect from diminishing marginal utility of consumption due to continuing growth of c at rate $\hat{g}$, in addition to the pure rate of time preference.

determining the comparative statics properties and in dictating the stability properties of the BGE.

Proposition 2 is similar to the results of Pelloni and Waldmann (2000) in which they demonstrate that capital income taxes have a growth-enhancing effect when the steady state is indeterminate. We further show that other distortionary taxes, such as consumption and labor income taxes, can have a similar growth-enhancing effect. It is also important to note that the pre-existing distortionary taxes would alter the likelihood of indeterminacy and thus the long-run effects of the taxes, which has not been identified by Pelloni and Waldmann's model. In fact, the smaller the existing capital income tax, the steeper the curve $\sigma^{-1}[(1 - \tau_k)r(l) - \rho]$ (but the technology condition remains intact), and thus the more likely it is that the "paradoxical" result emerges. On the other hand, the greater the existing consumption or labor income taxes, the less steep the technology condition (but the slope of the curve $\sigma^{-1}[(1 - \tau_k)r(l) - \rho]$ remains unchanged), and thus the less responsive $g(l)$ to changes in labor supply. This also makes the "paradoxical" result more likely.

5 Welfare Effects of Taxation

In this section we examine the welfare effects along the BGE in response to changes in the taxes. The level of welfare along the BGE path, denoted by W_{BG} , is calculated by substituting (17) into c in (1):

$$W_{BG} \equiv \int_0^\infty \frac{\hat{c}^{1-\sigma}}{1-\sigma} (1 - \hat{l})^{1-\eta} e^{-\rho t} dt = \frac{(n_0)^{\sigma-1} (1 - \hat{l})^{1-\eta} (\hat{c}_0)^{1-\sigma}}{1-\sigma} \frac{1}{\rho - g(1-\sigma)}, \quad (27)$$

where

$$\hat{c}_0 \equiv n_0 \frac{1-\sigma}{1-\eta} \frac{1-\tau_w}{1+\tau_c} (1-\alpha) \bar{x}^\alpha \frac{1-\hat{l}}{\hat{l}^\alpha} \quad (28)$$

is the BGE level of consumption associated with the initial number of variety n_0 . Note that as the transversality condition implies that $\rho - g(1 - \sigma) > 0$, $W_{BG} > 0$. Appendix B shows how $dW_{BG}/d\tau_j$ (for $j = k, c, w$) are related to $d\hat{l}/d\tau_j$, respectively. Therefore, we have

Proposition 3 An increase in any of the respective taxes increases (decreases) welfare along the BGE path if and only if the BGE is locally indeterminate (determinate).

Propositions 3 appears to go against the conventional viewpoint that tax substitution from nondistortionary taxes (such as lump-sum taxes) to distortionary taxes usually has an adverse effect on welfare. In contrast, such substitution may improve welfare in the present endogenous growth model, because the growth effect on consumption plays a dominant role in determining the ultimate effect on welfare in endogenous growth models. More precisely, when the tax increase enhances the growth rate of consumption, unbounded consumption growth, which keeps augmenting welfare, tends to outweigh the negative effect of the increased labor supply on welfare. This also means that when the equilibrium exhibits indeterminacy, the optimal rates of those distortionary taxes in terms of maximizing welfare should be positive and greater far from zero (recall also that larger labor and consumption taxes make indeterminism more likely to occur). This stands in a sharp contrast with Chamely (1985) where in the absence of spillover effects the long-run distortionary taxes, which maximizes social welfare, should be eventually eliminated.

Propositions 2 and 3 are a straightforward generalization of Propositions 2 and 3 of Pelloni and Waldmann (2000) in the following senses. First, our paradoxical results are obtained in a setting with more plausible microeconomic foundations, in which the profit-maximizing behavior of innovating firms in imperfectly competitive markets generates endogenous growth. Despite this difference, we confirm the robustness of their results. Second, although their results have been derived in an economy where there are no pre-existing distortionary taxes, Propositions 2 and 3 reveal that Pelloni and Waldmann's results continue to hold, even in an economy with pre-existing distortionary taxes. In fact, they analyze the first-order welfare effect, and thus they ignore the excess burden associated with prior distortionary taxes. Accordingly, their welfare analysis tends to underestimate welfare losses (or gains). Nevertheless, Proposition 3 indicates that the welfare effects of capital income taxation derived by Pelloni and Waldmann remain valid.

6 Alternative Preferences

In this section we conduct the same analysis under another popular utility function which is slightly different from (1):⁶

$$\int_0^\infty \frac{[c(1-l)^\eta]^{1-\sigma} - 1}{1-\sigma} e^{-\rho t} dt, \quad \sigma \neq 1. \quad (29)$$

We assume $\sigma > \eta / (1 + \eta)$, which is required for strict concavity.

The first-order conditions are given by (3c),

$$c^{-\sigma} (1-l)^{\eta(1-\sigma)} = \lambda (1 + \tau_c), \quad (30a)$$

$$\eta c^{1-\sigma} (1-l)^{\eta(1-\sigma)-1} = \lambda (1 - \tau_w) w, \quad (30b)$$

which leads to the following marginal rate of substitution between consumption and leisure:

$$\eta \frac{c}{1-l} = \frac{1 - \tau_w}{1 + \tau_c} w. \quad (31)$$

Using (30a) and (3c), we can obtain the following Keynes-Ramsey rule analogous to (4):

$$\sigma \frac{\dot{c}}{c} + (1 - \sigma) \eta \frac{\dot{l}}{1-l} = (1 - \tau_k) r(l) - \rho.$$

Following the same procedure as before, the dynamics of employment is given by

$$\dot{l} = \frac{1-l}{Q(l)} \left[g(l) - \frac{(1 - \tau_k) r(l) - \rho}{\sigma} \right],$$

where $Q(l) \equiv \alpha(1-l)l^{-1} + 1 - \eta(1-\sigma)\sigma^{-1} > 0$ due to the concavity assumption. To summarize:

Proposition 4 A balanced growth path of the economy is locally indeterminate if and only if

$$1 + \frac{1 - \tau_w}{(1 + \tau_c) \eta} \left(1 - \alpha + \alpha \hat{l}^{-1} \right) - \frac{1 - \tau_k}{\sigma} \alpha < 0 \quad (32)$$

and locally determinate if and only if inequality (32) is reversed. Moreover, Propositions 2 and 3 continue to hold.

⁶When $\sigma = 1$, the preferences are represented by

$$\int_0^\infty [\ln c + \eta \ln(1-l)] e^{-\rho t} dt.$$

It follows from (32) that the larger the consumption and/or labor income taxes, the more likely the BGE is to display indeterminacy, as in the previous model. Despite these similarities, the condition for indeterminacy in the present model, (32), differs from that of the previous model, (24), because of the absence of the term $1 - \sigma$ in (32). It turns out that this absence makes indeterminacy of equilibria less likely compared to the previous model. Indeed, it is easy to show⁷

Proposition 5 When all taxes are initially set to zero, the BGE is locally determinate, and thus an increase in any of the respective taxes decreases the growth rate and welfare along the BGE path.⁸

7 Conclusion

This paper investigates the relationship between the stability properties of the BGE and the growth effects of taxes in an R&D-based model with endogenous labor supply. Our analysis shows that stability analysis is important in determining the responses of the economy to tax reforms. When the BGE is unstable or determinate, all taxes unambiguously discourage long-run growth. On the other hand, fiscal policy stimulates growth in a stable or indeterminate BGE. These results reveal that Samuelson's Correspondence Principle holds true in the sense that the stability properties of the model and its comparative statics are tied on a one-to-one basis.

Admittedly, the results in this paper depend on model specification. We have analyzed the models with different preferences, while retaining the same production function. Hence, it is natural to examine tax effects under other forms of production functions, such as a CES production function to examine the robustness of our results. The flexibility of this production function may also be useful for establishing that more realistic parameter values are

⁷The proof is straightforward. Setting all taxes to zero, we can demonstrate that the following inequalities hold:

$$1 + \frac{1 - \alpha + \alpha \hat{l}^{-1}}{\eta} - \frac{\alpha}{\sigma} > 1 + \frac{1 - \alpha + \alpha \hat{l}^{-1}}{\eta} - \frac{\alpha(1 + \eta)}{\eta} = \frac{\eta + 1 - \alpha + \alpha \hat{l}^{-1} - \alpha(1 + \eta)}{\eta} > 0.$$

The first inequality in the above expression follows from the concavity condition $\sigma > \eta/(1 + \eta)$, while it is easy to demonstrate that the numerator on the far right-hand side is positive.

⁸Although Hintermaier (2003) demonstrates that under the nonseparable concave utility function such as (29) in an AK model augmented with endogenous labor supply indeterminacy never arises, Proposition 5 is consistent with his result.

consistent with indeterminacy. Second, we have assumed that neither human capital nor (raw) labor is used in R&D, unlike the model employed Romer (1990) and Rivera-Batiz and Romer (1991). This extension inevitably introduces an additional state variable into the model, thus complicating the stability analysis. Despite its analytical difficulty, this extension surely deserves further study.

Appendix A: Condition for Indeterminacy

To derive an explicit condition for indeterminacy, we first need to know the explicit forms of $dg(l)/dl$ and $dr(l)/dl$ along the BGE path. Differentiating (19) and (20) yields

$$\begin{aligned} \left. \frac{dg(\hat{l})}{dl} \right|_{l=\hat{l}} &= (\bar{x} + \delta)^{-1} \left[(1 - \alpha) \hat{l}^{-\alpha} \bar{x}^\alpha - \Delta \frac{-\hat{l}^\alpha - (1 - \hat{l}) \alpha \hat{l}^{\alpha-1}}{\hat{l}^{2\alpha}} \right], \\ &= (\bar{x} + \delta)^{-1} \hat{l}^{-\alpha} \frac{(1 - \alpha) \bar{x}^\alpha}{(1 + \tau_c)(1 - \eta)} \left[(1 + \tau_c)(1 - \eta) + (1 - \sigma)(1 - \tau_w)(1 - \alpha + \alpha \hat{l}^{-1}) \right], \end{aligned} \quad (\text{A1})$$

and

$$\left. \frac{dr(l)}{dl} \right|_{l=\hat{l}} = \alpha^2 (1 - \alpha) \left(\frac{\hat{l}}{\bar{x}} \right)^{-\alpha} \frac{1}{\bar{x}}. \quad (\text{A2})$$

Combining (A1) with (A2) gives

$$\begin{aligned} \frac{dg(\hat{l})}{dl} - \frac{1 - \tau_k}{\sigma} \frac{dr(\hat{l})}{dl} &= (\bar{x} + \delta)^{-1} \hat{l}^{-\alpha} \frac{\bar{x}^\alpha (1 - \alpha)}{(1 + \tau_c)(1 - \eta)} \\ &\quad \left[(1 + \tau_c)(1 - \eta) + (1 - \sigma)(1 - \tau_w)(1 - \alpha + \alpha \hat{l}^{-1}) \right] - \frac{1 - \tau_k}{\sigma} \alpha^2 (1 - \alpha) \left(\frac{\hat{l}}{\bar{x}} \right)^{-\alpha} \frac{1}{\bar{x}}. \end{aligned} \quad (\text{A3})$$

Ignoring $(\hat{l}/\bar{x})^{-\alpha}$ and $1 - \alpha$ on the right-hand side of (A3) leads to

$$\begin{aligned} &\frac{(\bar{x} + \delta)^{-1}}{(1 + \tau_c)(1 - \eta)} \left[(1 + \tau_c)(1 - \eta) + (1 - \sigma)(1 - \tau_w)(1 - \alpha + \alpha \hat{l}^{-1}) \right] - \frac{1 - \tau_k}{\sigma} \alpha^2 \frac{1}{\bar{x}} \\ &= \frac{1 - \alpha}{\delta} \left[1 + \frac{1 - \sigma}{1 - \eta} \frac{1 - \tau_w}{1 + \tau_c} (1 - \alpha + \alpha \hat{l}^{-1}) - \frac{1 - \tau_k}{\sigma} \alpha \right], \end{aligned} \quad (\text{A4})$$

where the equality in (A4) follows from using $(\bar{x} + \delta)^{-1} = (1 - \alpha)/\delta$. Inspection of the second equation in (A4) reveals that the signs of (A4) and thus (A3) hinge on the sign of the left-hand side of (24).

Appendix B: Proof of Proposition 2

Setting $\dot{l} = 0$ in (22), we have the following BGE condition:

$$g(\hat{l}) - \frac{(1 - \tau_k)r(\hat{l}) - \rho}{\sigma} = 0. \quad (\text{B1})$$

After substituting (19) and (20) into $g(\hat{l})$ and $r(\hat{l})$ in (B1), respectively, we totally differentiate the resultant expression of (B1) with respect to τ_k :

$$\frac{d\hat{l}}{d\tau_k} = \frac{-(1 - \alpha)^{-1} \alpha \hat{l} \sigma^{-1}}{1 + \frac{1 - \sigma}{1 - \eta} \frac{1 - \tau_w}{1 + \tau_c} \left(1 - \alpha + \alpha \hat{l}^{-1}\right) - \frac{(1 - \tau_k) \alpha}{\sigma}}.$$

In a similar way, we can obtain

$$\frac{d\hat{l}}{d\tau_w} = \frac{-\frac{1 - \hat{l}}{1 + \tau_c} \frac{1 - \sigma}{1 - \eta}}{1 + \frac{1 - \sigma}{1 - \eta} \frac{1 - \tau_w}{1 + \tau_c} \left(1 - \alpha + \alpha \hat{l}^{-1}\right) - \frac{(1 - \tau_k) \alpha}{\sigma}},$$

and

$$\frac{d\hat{l}}{d\tau_c} = \frac{-\frac{1 - \hat{l}}{1 - \tau_w} \frac{1 - \sigma}{1 - \eta}}{1 + \frac{1 - \sigma}{1 - \eta} \frac{1 - \tau_w}{1 + \tau_c} \left(1 - \alpha + \alpha \hat{l}^{-1}\right) - \frac{(1 - \tau_k) \alpha}{\sigma}}.$$

Differentiating (19) with respect to the respective tax rates and noting that $\Delta \equiv (1 - \tau_w)(1 - \alpha)(1 - \sigma)\bar{x}^\alpha / (1 + \tau_c)(1 - \eta)$, we have

$$\begin{aligned} \frac{dg(\hat{l})}{d\tau_k} &= \frac{(1 - \alpha)(\bar{x}/\hat{l})^\alpha}{\bar{x} + \delta} \left[1 + \frac{1 - \sigma}{1 - \eta} \frac{1 - \tau_w}{1 + \tau_c} \left(1 - \alpha + \alpha \hat{l}^{-1}\right) \right] \frac{d\hat{l}}{d\tau_k} \quad \text{Q 0} \\ \text{iff } \frac{d\hat{l}}{d\tau_k} &\quad \text{Q 0}, \\ \frac{dg(\hat{l})}{d\tau_j} &= \frac{(1 - \alpha)(\bar{x}/\hat{l})^\alpha}{\bar{x} + \delta} \frac{(1 - \tau_k) \alpha}{\sigma} \frac{d\hat{l}}{d\tau_j} \quad \text{Q 0 iff } \frac{d\hat{l}}{d\tau_j} \quad \text{Q 0, } j = w, c. \end{aligned}$$

Appendix C: Proof of Proposition 3

Differentiating the right-hand side of (27) with respect to τ_k results in

$$\frac{dW_{BG}}{d\tau_k} = \frac{(n_0)^{1-\sigma}}{(1-\sigma)[\rho - g(\hat{l})(1-\sigma)]^2} \left[\frac{d\Gamma(\hat{l})}{d\tau_k} \left\{ \rho - g(\hat{l})(1-\sigma) \right\} + \Gamma(\hat{l}) \frac{dg(\hat{l})}{d\tau_k} (1-\sigma) \right], \quad (C1)$$

where $\Gamma(\hat{l}) \equiv (1-\hat{l})^{1-\eta}(\hat{c}_0)^{1-\sigma}$. It is seen from (C1) that the sign of $dW_{BG}/d\tau_k$ is determined according to the sign of

$$\frac{d\Gamma(\hat{l})}{d\tau_k} \left\{ \rho - g(\hat{l})(1-\sigma) \right\} + \Gamma(\hat{l}) \frac{dg(\hat{l})}{d\tau_k} (1-\sigma). \quad (C2)$$

To sign (C2) we first differentiate $\Gamma(\hat{l})$ with respect to τ_k :

$$\frac{d\Gamma(\hat{l})}{d\tau_k} = -\frac{\Gamma(\hat{l})}{1-\hat{l}} \left[(1-\eta) + (1-\sigma) \left(1 - \alpha + \alpha\hat{l}^{-1} \right) \right] \frac{d\hat{l}}{d\tau_k}, \quad (C3)$$

where the second equality in (C3) follows from substitution of

$$\frac{d\hat{c}_0}{d\tau_k} = -\Delta \frac{1 - \alpha + \alpha\hat{l}^{-1}}{\hat{l}^\alpha} \frac{d\hat{l}}{d\tau_k},$$

which is obtained from differentiating (28) with respect to τ_k .

Substituting (C3), (B2), and the BGE condition, $\rho = (1-\tau_k)r(\hat{l}) - \sigma g(\hat{l})$, into (C2), (C2) can be rewritten as

$$\begin{aligned} & -\frac{\Gamma(\hat{l})}{1-\hat{l}} \frac{d\hat{l}}{d\tau_k} \left[(1-\eta) + (1-\sigma)(1-\alpha + \alpha\hat{l}^{-1}) \right] \left[(1-\tau_k)r(\hat{l}) - g(\hat{l}) \right] \\ & + \Gamma(\hat{l}) \frac{(1-\alpha)(\bar{x}/\hat{l})^\alpha}{\bar{x} + \delta} \left[1 + \frac{1-\sigma}{1-\eta} \frac{1-\tau_w}{1+\tau_c} \left(1 - \alpha + \alpha\hat{l}^{-1} \right) \right] (1-\sigma) \frac{d\hat{l}}{d\tau_k}. \end{aligned} \quad (C4)$$

Further, substituting (19) and (20) into $g(\hat{l})$ and $r(\hat{l})$ in (C4), respectively, and ignoring the terms $\Gamma(\hat{l})$, $d\hat{l}/d\tau_k$ and $(\hat{l}/\bar{x})^{-\alpha}$ leads to

$$\begin{aligned} & \frac{1}{1-\hat{l}} \left[(1-\eta) + (1-\sigma)(1-\alpha + \alpha\hat{l}^{-1}) \right] \left[(1-\tau_k)\alpha^2 \frac{\hat{l}}{\bar{x}} - \frac{1}{\bar{x} + \delta} \left\{ \hat{l} - \bar{x}^{-\alpha} \Delta \left(1 - \hat{l} \right) \right\} \right] \\ & + \frac{1-\alpha}{\bar{x} + \delta} \left[1 + \frac{1-\sigma}{1-\eta} \frac{1-\tau_w}{1+\tau_c} \left(1 - \alpha + \alpha\hat{l}^{-1} \right) \right] (1-\sigma). \end{aligned} \quad (C5)$$

It is tedious but straightforward to show that (C5) simplifies to

$$\begin{aligned} & \frac{(1-\alpha)}{\delta} \left[(1-\eta) + (1-\sigma)(1-\alpha + \alpha \hat{l}^{-1}) \right] \frac{\hat{l}}{1-\hat{l}} \{1 - (1-\tau_k)\alpha\} + \\ & \left(1 - \frac{1-\tau_w}{1+\tau_c} \right) (1-\alpha)(1-\sigma). \end{aligned} \quad (C6)$$

As it turns out that all terms appearing in (C6) are positive, the sign of $dW_{BG}/d\tau_k$ depends positively on the sign of $d\hat{l}/d\tau_k$.

Similarly, for $j = w, c$ we have

$$\begin{aligned} \frac{dW_{BG}}{d\tau_j} = & \frac{(n_0)^{1-\sigma} \Gamma(\hat{l})(\bar{x}/\hat{l})^\alpha}{(1-\sigma)[\rho - g(\hat{l})(1-\sigma)]^2} \frac{1-\alpha}{\delta} \left[(1-\eta) \left\{ -1 + \frac{1-\tau_w}{1+\tau_c} \left(1 - \frac{(1-\tau_k)\alpha}{\sigma} \right) \right\} \right. \\ & \left. \frac{\hat{l}}{1-\hat{l}} \{ (1-\tau_k)\alpha - 1 \} + \frac{1-\sigma}{1-\eta} \frac{1-\tau_w}{1+\tau_c} (1-\alpha) \right] + \frac{(1-\alpha)(1-\tau_k)\alpha(1-\sigma)}{\sigma} \left] \frac{d\hat{l}}{d\tau_j}. \end{aligned} \quad (C7)$$

Using (C7), we can show that⁹

$$\text{sign} \left(\frac{dW_{BG}}{d\tau_j} \right) = \text{sign} \left(\frac{d\hat{l}}{d\tau_j} \right), \quad j = w, c.$$

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⁹Detailed derivations are available from the corresponding author upon request.

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