Short-run and Long-run Effects of Capital Taxation on Innovation and Economic Growth

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Abstract

In this study, we examine the effects of capital taxation on innovation and economic growth in an R&D-based growth model. We find that capital taxation has drastically different effects in the short run and in the long run. An increase in the capital income tax rate has both a consumption effect and a tax-shifting effect on the equilibrium growth rates of technology and output. In the short run, the consumption effect dominates the tax-shifting effect causing an initial negative effect of capital taxation on the equilibrium growth rates. However, in the long run, the tax-shifting effect becomes the dominant force yielding an overall positive effect of capital taxation on steady-state economic growth. These contrasting effects of capital taxation at different time horizons may provide a theoretical explanation for the mixed evidence in the empirical literature on capital taxation and economic growth.

Keywords: Capital taxation, economic growth, R&D, transition dynamics

JEL classification: H20, O30, O40

1 Introduction

In this study, we examine the effects of capital taxation on innovation and economic growth in an R&D-based growth model. In the literature of endogenous growth, one of the major issues is whether capital taxation stimulates or impedes growth. Earlier studies employing an AK-type endogenous growth model show that the impact of raising the capital tax rate on long-run economic growth is negative (Judd, 1985; Chamley, 1986; King and Rebelo, 1990; Rebelo, 1991; Jones *et al.*, 1993; Pecorino, 1993, 1994; Devereux and Love, 1994; Milesi-Ferretti and Roubini, 1998), although the quantitative magnitude could be negligibly small (Lucas, 1990; Stokey and Rebelo, 1995).[1] The intuition of this negative growth effect of capital taxation is that a higher capital tax rate discourages the accumulation of physical capital and is therefore detrimental to economic growth. However, on the empirical side, the results are rather inconclusive. Although some empirical studies have found that capital taxation, such as corporate profit tax and capital gains tax, can be harmful to economic growth, other empirical studies have found a neutral or even positive effect of capital taxation on growth.[2]

While capital accumulation is undoubtedly an important engine of economic growth, technological progress driven by innovation and R&D also acts as an important driver for growth; see Aghion and Howitt (2009, p.109) for a discussion on data from OECD countries.[3] Therefore, we use the seminal innovation-driven growth model in Romer (1990), which is a workhorse model in R&D-based growth theory that features both capital accumulation and endogenous technological progress, to explore both the short-run and long-run effects of capital taxation on innovation and economic growth. In our analysis, we consider different tax-shifting schemes. Specifically, we examine the growth effects of capital taxation with tax shifting from lump-sum tax and also labor income tax to capital income tax.

In the case of tax shifting from lump-sum tax to capital income tax, an increase in the capital tax rate leads to a *decrease* in the steady-state equilibrium growth rate via a *consumption* effect of capital taxation. Intuitively, a higher capital tax rate causes households to decrease their saving rate and increase their consumption rate, which in turn leads to an increase in leisure and a decrease in labor supply. Given that labor is a factor input for R&D, a smaller labor supply gives rise to a lower growth rate of technology, which in turn determines the long-run growth rates of output and capital.

[1] Other than focusing on the long-run growth effect, Frankel (1998) studies the dynamics of capital taxation during the transition process.

[2] See Huang and Frentz (2014) for a recent survey that provides a concise summary of the contrasting empirical findings in the literature.

[3] Aghion and Howitt (2009, p.108) report that "TFP growth accounts for about two-thirds of economic growth in OECD countries, while capital deepening accounts for one third."

In the case of tax shifting from labor income tax to capital income tax, an increase in the capital tax rate leads to an *increase* in the steady-state equilibrium growth rate via a *tax-shifting* effect of capital taxation. Intuitively, an increase in the capital income tax rate allows the labor income tax rate to decrease, which in turn leads to a decrease in leisure and an increase in labor supply. The larger labor supply gives rise to higher growth rates of technology, output and even capital despite the lower capital-investment rate caused by the higher capital tax rate. Although the previously mentioned consumption effect of capital taxation is also present, it is dominated by the tax-shifting effect in the long run. However, we find that the relative magnitude of these two effects becomes very different in the short run.

We calibrate the model to aggregate data in the US to provide a quantitative analysis on the dynamic effects of capital taxation on economic growth. We consider the case of tax shifting from labor income tax to capital income tax and find that an increase in the capital tax rate leads to a short-run *decrease* in the equilibrium growth rates of technology and output and a gradual convergence to the higher long-run growth rates of technology and output. The reason for these contrasting short-run and long-run effects is that the consumption effect of capital taxation is relatively strong in the short run. Intuitively, an increase in the capital income tax rate leads to a decrease in the steady-state equilibrium capital-technology ratio. Before the economy reaches this new steady-state capital-technology ratio, households drastically cut down their saving rate below its new steady-state level, which in turn increases their consumption rate substantially. This substantial increase in consumption leads to a substantial increase in leisure and a substantial decrease in labor supply, which in turn reduces temporarily the equilibrium growth rates of technology and output. In the long run, the effect of a lower wage-income tax rate becomes the dominant force and instead raises the supply of labor, which in turn increases the steady-state equilibrium growth rates of technology and output.

Our paper is most closely related to recent studies on taxation and economic growth in the R&D-based growth model. Zeng and Zhang (2002) show that the long-run growth rate is independent of labor income tax and consumption tax but decreasing in capital income tax. In contrast, Lin and Russo (1999) analyze how the taxation of different sources of capital income affects long-run growth and find that a higher capital income tax rate for innovative firms could be growth-enhancing if the tax system permits tax credits for R&D spending. Moreover, by focusing on the stability analysis of equilibria, Haruyama and Itaya (2006) also show that the growth effect of taxing capital income is positive when the economy exhibits indeterminacy. Although these two papers find that capital taxation and economic growth may exhibit a positive relationship, our paper departs from them in highlighting the contrasting dynamic effects of capital taxation on economic growth. More recently, Aghion *et al.* (2013) and Hong (2014) adopt a quality-ladder R&D-based growth model to investigate optimal capital taxation. Their primary focus, however, is on the normative analysis with respect to the Chamley-Judd (Chamley 1986; Judd 1985) result (i.e., the optimal capital tax is zero), while the present paper focuses on the positive analysis regarding the growth effect of capital taxation. Furthermore, their analysis does not deal with the case in which innovation is driven by R&D labor (e.g., scientists and engineers). When R&D uses labor as the factor input, we find that the effects of capital taxation are drastically different at different time horizons. This finding may provide a plausible explanation for the mixed evidence in the empirical literature on capital taxation and economic growth. Finally, we consider a number of extensions to the benchmark model in order to examine the robustness of our results.

The remainder of this study is organized as follows. In Section 2, we describe the basic model structure. In Section 3, we investigate the growth effects of capital taxation. In Section 4, we calibrate the model to provide a quantitative analysis of capital taxation. In Section 5, we explore a number of extensions. Concluding remarks are provided in Section 6.

2 The model

The model that we consider is an extension of the seminal workhorse R&D-based growth model from Romer (1990).[4] In the Romer model, R&D investment creates new varieties of intermediate goods. We extend the model by introducing endogenous labor supply and distortionary income taxes. In what follows, we describe the model structure in turn.

2.1 Household

The economy is inhabited by a representative household. Population is stationary and normalized to unity. The household has one unit of time that can be allocated between leisure

[4] In the case of extending the model into a scale-invariant semi-endogenous growth model as in Jones (1995), the long-run growth effect of capital taxation simply becomes a level effect. In other words, instead of increasing (decreasing) the growth rate of technology, capital taxation increases (decreases) the level of technology in the long run.

and production. The representative household's lifetime utility is given as:[5]

$$U = \int_0^\infty e^{-\rho t} [\ln C_t + \theta(1 - L_t)]\, dt, \tag{1}$$

where the parameter $\rho > 0$ is the household's subjective discount rate and the parameter $\theta > 0$ determines the disutility of labor supply. The utility is increasing in consumption C_t and decreasing in labor supply $L_t \in (0, 1)$.

The representative household maximizes its lifetime utility subject to[6]

$$\dot{K} + \dot{a} = ra + (1 - \tau_K) r_K K + (1 - \tau_L) wL - C - Z. \tag{2}$$

The variable K denotes the stock of physical capital. The variable $a\,(= VA)$ denotes the value of equity shares of monopolistic firms, in which A is the number of monopolistic firms and V is the value of each firm. w is the wage rate. r is the real interest rate, whereas r_K is the capital rental rate.[7] The rates of return on the two assets, physical capital and equity shares, must follow a no-arbitrage condition $r = (1 - \tau_K) r_K$ in equilibrium. The policy instrument Z is a lump-sum tax.[8] The other policy instruments $\{\tau_L, \tau_K\} < 1$ are respectively the labor and capital income tax rates.[9]

By solving the household's optimization problem, we can easily derive the typical Keynes-Ramsey rules:

$$\frac{\dot{C}}{C} = (1 - \tau_K) r_K - \rho, \tag{3}$$

and also the optimality condition for labor supply, which is in the form of a horizontal labor supply curve given the quasi-linear utility function in (1):

$$w = \theta C / (1 - \tau_L). \tag{4}$$

[5] To make our analysis tractable, we specify a quasi-linear utility function. As pointed out by Hansen (1985) and Rogerson (1988), the linearity in work hours may be justified as capturing indivisible labor. To examine the robustness of our results, we will consider a more general utility function $U = \int_0^\infty e^{-\rho t} \left[\ln C_t + \theta \frac{(1-L_t)^{1-\eta}}{1-\eta} \right] dt$ in the quantitative analysis in Section 4 and also an alternative iso-elastic utility function $U = \int_0^\infty e^{-\rho t} \frac{[C_t (1-L_t)^\psi]^{1-\sigma} - 1}{1-\sigma}\, dt$ in Section 5.1.

[6] For notational simplicity, we drop the time subscript.

[7] For simplicity, we assume zero capital depreciation rate.

[8] We allow for the presence of a lump tax simply to explore the implications of different tax-shifting schemes. Our main results focus on the more realistic case of $Z = 0$.

[9] In our analysis, we focus on the case in which $\tau_K > 0$; see for example Zeng and Zhang (2007) and Chu *et al.* (2016), who examine the effects of subsidy policies in the R&D-based growth model.

2.2 Final goods

There is a single final good Y, which is produced by combining labor and a continuum of intermediate goods, according to the following aggregator:

$$Y = L_Y^{1-\alpha} \int_0^A x_i^\alpha di, \tag{5}$$

where L_Y is the labor input in final goods production, x_i for $i \in [0, A]$ is the intermediate good of type i, and A is the number of varieties of intermediate goods. The final good is treated as the *numeraire*, and hence in what follows its price is normalized to unity. We assume that the final goods sector is perfectly competitive. Profit maximization of the final goods firms yields the following conditional demand functions for labor input and intermediate goods:

$$L_Y = (1-\alpha)Y/w, \tag{6}$$

$$x_i = L_Y \left(\alpha/p_i\right)^{\frac{1}{1-\alpha}}, \tag{7}$$

where p_i is the price of x_i relative to final goods.

2.3 Intermediate goods

Each intermediate good is produced by a monopolist who owns a perpetually protected patent for that good. Following Romer (1990), capital is the factor input for producing intermediate goods, and the technology is simply a linear one-to-one function. That is, the production function is expressed as $x_i = k_i$, where k_i is the capital input used by intermediate firm i. Accordingly, the profit of intermediate goods firm i is:

$$\pi_i = p_i x_i - r_K k_i. \tag{8}$$

Profit maximization subject to the conditional demand function for intermediate goods firm i yields the following markup-pricing rule:

$$p_i = \frac{r_K}{\alpha} > r_K. \tag{9}$$

Equation (9) implies that the level of price is the same across intermediate goods firms. Based on equation (7) and the production function $x_i = k_i$, we have a symmetric equilibrium among intermediate firms; i.e., $x_i = x$ and $k_i = k$. Then, we can obtain the following profit function of intermediate goods firms:

$$\pi_i = \pi = \frac{(1-\alpha)\alpha Y}{A}. \tag{10}$$

2.4 R&D

In the R&D sector, the familiar no-arbitrage condition for the value of a variety V is:

$$rV = \pi + \dot{V}. \tag{11}$$

Equation (11) states that, for each variety, the rate of return on an invention must be equal to the sum of the monopolistic profit and capital gain (or loss) . As in Romer (1990), labor is the factor input of R&D. The innovation function of new varieties is given by:

$$\dot{A} = \phi A L_A, \tag{12}$$

where $\phi > 0$ is the R&D productivity parameter and L_A denotes R&D labor. Given free entry into the R&D sector, the zero-profit condition of R&D is

$$\dot{A}V = wL_A \Leftrightarrow \phi AV = w. \tag{13}$$

2.5 Government

The government collects taxes, including capital income tax, labor income tax, and lump-sum tax, to finance its public spending. At any instant of time, the government budget constraint can be expressed as:

$$\tau_K r_K K + \tau_L wL + Z = G. \tag{14}$$

The variable G denotes government spending. To ensure balanced growth, we assume G to be a fixed proportion $\beta \in (0,1)$ of final output such that

$$G = \beta Y. \tag{15}$$

2.6 Aggregation

Since the intermediate firms are symmetric, the total amount of capital is $K = Ak_i = Ak$. Given $x_i = k_i$, $x_i = x$, $k_i = k$, and $K = Ak$, the final output production function in equation (5) can then be expressed as:

$$Y = A^{1-\alpha} K^{\alpha} L_Y^{1-\alpha}. \tag{16}$$

After some calculations using equations (2), (6), (7), (11)-(14), and (16), we can derive the resource constraint in this economy:

$$\dot{K} = Y - C - G. \tag{17}$$

2.7 Decentralized equilibrium and the balanced-growth path

The decentralized equilibrium is a time path of allocations $\{C, K, A, Y, L, L_Y, L_A, x, G\}_{t=0}^{\infty}$, prices $\{w, r, r_K, p_i, V\}_{t=0}^{\infty}$, and policies $\{\tau_K, \tau_L, Z\}$, such that at any instant of time:

a households maximize lifetime utility (1) taking prices and policies as given;

b competitive final goods firms choose $\{x, L_Y\}$ to maximize profit taking prices as given;

c monopolistic intermediate firms $i \in [0, A]$ choose $\{k_i, p_i\}$ to maximize profit taking r_K as given;

d R&D firms choose L_A to maximize profit taking $\{V, w\}$ as given;

e the market for final goods clears, i.e., $\dot{K} = Y - C - G$;

f the labor market clears, i.e., $L = L_A + L_Y$;

g the government budget constraint is balanced, i.e., $\tau_K r_K K + \tau_L w L + Z = G$.

The balanced growth path is characterized by a set of constant growth rates of all economic variables. Let γ denote the growth rate of technology and a "~" over the variable denote its steady-state value. It can be shown that along the balanced growth path, we have

$$\frac{\dot{K}}{K} = \frac{\dot{Y}}{Y} = \frac{\dot{C}}{C} = \frac{\dot{w}}{w} = \frac{\dot{A}}{A} = \tilde{\gamma},\ \dot{L} = \dot{L}_Y = \dot{L}_A = 0.$$

3 Long-run growth effects of capital taxation

In this section we examine the growth effects of the capital tax rate. In general, to maintain a constant proportion of government spending, raising the capital tax is accompanied by a reduction in another tax. As revealed in equation (14), this can be either a reduction in the lump-sum tax (if it is available) or a reduction in the labor income tax (if the lump-sum tax is not available).[10] In the analysis that follows, we deal with each of the two scenarios in turn.

[10] Note that we assume a fixed proportion of government spending G in (15). Therefore, if we want to examine the effect of a change in τ_K without changing τ_L (Section 3.1), we have to assume that Z adjusts

3.1 Tax shifting from lump-sum tax to capital income tax

Equipped with the definition of the decentralized equilibrium in Section 2.7 and defining $\omega = w/A$, $c = C/A$ and $z = Z/A$, we can express the steady-state equilibrium conditions as follows:

$$\tilde{\gamma} = (1-\tau_K)\tilde{r}_K - \rho, \tag{18a}$$

$$\tilde{\omega} = \theta\tilde{c}/(1-\tau_L), \tag{18b}$$

$$\tilde{L}_Y = (1-\alpha)\tilde{x}^{\alpha}\tilde{L}_Y^{1-\alpha}/\tilde{\omega}, \tag{18c}$$

$$\tilde{x} = \tilde{L}_Y(\alpha^2/\tilde{r}_K)^{1/(1-\alpha)}, \tag{18d}$$

$$\tilde{r} = \phi\alpha\tilde{L}_Y, \tag{18e}$$

$$\tilde{r} = (1-\tau_K)\tilde{r}_K, \tag{18f}$$

$$\tilde{\gamma} = \phi\tilde{L}_A, \tag{18g}$$

$$\tilde{L} = \tilde{L}_Y + \tilde{L}_A, \tag{18h}$$

$$\tilde{\gamma} = (1-\beta)\tilde{x}^{\alpha-1}\tilde{L}_Y^{1-\alpha} - \tilde{c}/\tilde{x}, \tag{18i}$$

$$\tau_K\tilde{r}_K\tilde{x} + \tau_L\tilde{\omega}\tilde{L} + \tilde{z} = \beta\tilde{x}^{\alpha}\tilde{L}_Y^{1-\alpha}, \tag{18j}$$

in which ten equations are used to solve ten unknowns $\tilde{\gamma}$, $\tilde{r}_K$, $\tilde{L}_Y$, $\tilde{L}_A$, $\tilde{L}$, $\tilde{\omega}$, $\tilde{c}$, $\tilde{x}$, $\tilde{r}$ and $\tilde{z}$. We briefly discuss how we obtain equations (18). (18a) is derived from the usual Keynes-Ramsey rule (3). (18b) is derived from the optimality condition for labor supply (4). (18c) and (18d) are respectively the demand functions for final-goods labor and intermediate goods, (6) and (7). (18e) is derived from inserting $\dot{V} = 0$ into the no-arbitrage condition in the R&D sector (11), and by using (6), (10) and (13). (18f) is the no-arbitrage condition of asset. (18g) is derived from the innovation function of varieties (12). (18h) is the labor-market clearing condition. (18i) is derived from dividing both sides of the resource constraint (17) by A and using the condition $Ax = K$. (18j) is derived from dividing both sides of the government constraint (14) by A and using the condition $G = \beta Y$.

We first use (18a), (18e), (18f)-(18h) to eliminate $\{\tilde{r}, \tilde{\gamma}, \tilde{r}_K\}$ and express $\{\tilde{L}_Y,\ \tilde{L}_A\}$ as functions of $\tilde{L}$ given by

$$\tilde{L}_Y = \frac{\tilde{L} + \rho/\phi}{1+\alpha},$$

$$\tilde{L}_A = \frac{\alpha\tilde{L} - \rho/\phi}{1+\alpha}.$$

endogenously to balance the budget. Doing so also enables us to make a fair comparison between two tax-shifting regimes: one is from Z to τ_K and the other is from τ_L to τ_K. In the case where tax shifts from τ_L to τ_K (Section 3.2), τ_L adjusts endogenously and thus the role of the lump-sum tax Z becomes irrelevant.

These two equations indicate a positive relationship between $\{\tilde{L}_A, \tilde{L}_Y\}$ and $\tilde{L}$. Moreover, from the previous condition for $\tilde{L}_A$, we can derive the condition $\tilde{\gamma} = (\alpha\phi\tilde{L} - \rho)/(1+\alpha)$, which shows that the steady-state equilibrium growth rate of technology is increasing in $\tilde{L}$. Thus, we have

$$sgn\left(\frac{\partial\tilde{\gamma}}{\partial\tau_K}\right) = sgn\left(\frac{\partial\tilde{L}_A}{\partial\tau_K}\right) = sgn\left(\frac{\partial\tilde{L}}{\partial\tau_K}\right). \tag{19}$$

Accordingly, to investigate the growth effect of the capital tax rate, it is convenient to draw an inference from examining the effect of the capital tax rate on labor $\tilde{L}$.

We now derive an equilibrium expression of labor $\tilde{L}$. By using (8) and (9), we have $\pi = (\frac{1}{\alpha} - 1)\tilde{r}_K K/A$. This expression together with (10) implies that $r_K K = \alpha^2 Y$. Then, dividing both sides of (17) by Y yields

$$\tilde{\gamma}\frac{K}{Y} = 1 - \beta - \frac{C}{Y}.$$

By inserting $C/Y = (1-\tau_L)(1-\alpha)/(\theta\tilde{L}_Y)$, which is derived from (4) and (6), and $r_K K = \alpha^2 Y$ into the above equation and using (18e), (18f) and (18g) along with the conditions for $\tilde{L}_Y$ and $\tilde{L}_A$, we can obtain the following equation with one unknown $\tilde{L}$:

$$\left[1 - \frac{\rho(1+\alpha)}{\alpha\phi(\tilde{L}+\rho/\phi)}\right]\alpha^2(1-\tau_K) = 1 - \beta - \frac{(1-\tau_L)(1-\alpha)(1+\alpha)}{\theta(\tilde{L}+\rho/\phi)}.$$

Simplifying this equation yields

$$\tilde{L} = \frac{1}{1-\Phi(\tau_K)}\left[\frac{1-\tau_L}{\theta} - \frac{\alpha(1-\tau_K)}{(1-\alpha)}\frac{\rho}{\phi}\right] - \frac{\rho}{\phi}, \tag{20}$$

where $\Phi(\tau_K) \equiv (\beta - \alpha^2\tau_K)/(1-\alpha^2)$ is a composite parameter and τ_L is an exogenous policy parameter. Then, from equation (20), we can obtain the following relationship:

$$\frac{\partial\tilde{L}}{\partial\tau_K} = -\frac{\alpha^2}{(1-\alpha^2)[1-\Phi(\tau_K)]^2}\left[\frac{1-\tau_L}{\theta} - \frac{\alpha(1-\tau_K)}{(1-\alpha)}\frac{\rho}{\phi} - [1-\Phi(\tau_K)]\frac{1+\alpha}{\alpha}\frac{\rho}{\phi}\right],$$

which can be further simplified to[11]

$$\frac{\partial\tilde{L}}{\partial\tau_K} = -\frac{\alpha[(1+\alpha)\tilde{L}_A + 2\alpha\rho/\phi]}{(1-\alpha^2)[1-\Phi(\tau_K)]} < 0. \tag{21}$$

[11] The following reasoning ensures that $1-\Phi(\tau_K) = [1-\beta-\alpha^2(1-\tau_K)]/(1-\alpha^2) > 0$. The steady-state consumption-output ratio is $C/Y = 1-\beta-\alpha^2(1-\tau_K) + \alpha^2(1-\tau_K)\rho/(\tilde{\gamma}+\rho)$. Therefore, $\lim_{\rho\to 0} C/Y = 1-\beta-\alpha^2(1-\tau_K)$. In other words, one can restrict $1-\Phi(\tau_K) > 0$ by appealing to the fact that $C/Y > 0$ for all values of ρ.

From (19) and (21), we have established the following proposition:

Proposition 1 *In the case of tax shifting from lump-sum tax to capital income tax, raising the capital income tax rate reduces the steady-state equilibrium growth rate.*

Equation (19) is the key to understanding Proposition 1. It essentially says that the effect of the capital tax rate on long-run growth hinges on its effect on labor $\tilde{L}$. When the capital tax rate is higher, households tend to reduce their investment rate and increase their consumption rate C/Y. The increase in consumption raises leisure and reduces labor supply, by shifting up the horizontal labor supply curve. To see this, we have $w/Y = \frac{\theta}{1-\tau_L} C/Y$ from (4), which shows that an increase in the consumption rate C/Y raises w/Y. Then, from (6), we see that L_Y in $w/Y = (1-\alpha)/L_Y$ is decreasing in w/Y. Similarly, from (13), we see that L_A in $w/Y = \frac{\phi(1-\alpha)\alpha}{\rho+\phi L_A}$ is also decreasing in w/Y. Therefore, a higher capital tax rate reduces the equilibrium levels of labor input, R&D labor and economic growth.

As a useful comparison, we can also examine the long-run growth effect of labor taxation. In so doing, we first obtain $\frac{\partial \tilde{L}}{\partial \tau_L} < 0$ from equation (20). This result, together with $\tilde{\gamma} = (\alpha\phi\tilde{L} - \rho)/(1+\alpha)$, means that increasing the labor taxation (in the case of a tax shift from a lump-sum tax to a labor income tax) reduces long-run growth. The intuition is clear. A capital tax mainly affects the intertemporal choice between consumption and savings (investment), whereas a labor tax directly affects the intratemporal choice between consumption (working) and leisure. When the labor tax rate is higher, households tend to reduce their labor supply and increase their leisure. This in turn reduces the labor supply allocated to the R&D sector and ultimately the long-run growth rate.

3.2 Tax shifting from labor income tax to capital income tax

A lump-sum tax is not a realistic description in most economies. In this subsection, we therefore set aside the possibility of a lump-sum tax and deal with the more realistic case in which a rise in the capital tax rate is coupled with a reduction in another distortionary tax. This kind of tax shifting has been extensively investigated in the literature on factor taxation; see e.g., Judd (1985), Chamley (1986), Niepelt (2004), Aghion *et al.* (2013) and Chen and Lu (2013). Under such a situation we drop $\tilde{z}$ from the model in this subsection. Thus, equation (18j) is rewritten as:

$$\tau_K \tilde{r}_K \tilde{x} + \tilde{\tau}_L \tilde{\omega} \tilde{L} = \beta \tilde{x}^{\alpha} \tilde{L}_Y^{1-\alpha}. \tag{22}$$

It is useful to note that in (22) the labor income tax rate $\tilde{\tau}_L$ becomes an endogenous variable because it needs to adjust in response to a change in the capital tax rate.

The macroeconomy is now described by (18a)-(18i) and (22) from which we solve for ten unknowns $\tilde{\gamma}$, $\tilde{r}_K$, $\tilde{L}_Y$, $\tilde{L}_A$, $\tilde{L}$, $\tilde{\omega}$, $\tilde{c}$, $\tilde{x}$, $\tilde{r}$ and $\tilde{\tau}_L$. By arranging (22) with (6), (16), (18c) and the condition $r_K K = \alpha^2 Y$, we can obtain

$$\tilde{\tau}_L = \frac{(\beta - \alpha^2 \tau_K)}{1-\alpha} \frac{\tilde{L}_Y}{\tilde{L}} = \left(1 + \frac{\rho}{\phi \tilde{L}}\right) \Phi(\tau_K),$$

where the second equality uses $\tilde{L}_Y = (\tilde{L} + \rho/\phi)/(1+\alpha)$. Using the above condition and (20), we can solve the two unknowns $\{\tilde{L}, \tilde{\tau}_L\}$ and obtain the following quadratic equation:

$$\frac{\phi}{\rho}\tilde{L}^2 - \left[\frac{\phi}{\rho\theta} - 1 - \frac{\alpha(1-\tau_K)}{(1-\alpha)[1-\Phi(\tau_K)]}\right]\tilde{L} + \frac{\Phi(\tau_K)}{[1-\Phi(\tau_K)]\theta} = 0.$$

This quadratic equation has two solutions, denoted as $\tilde{L}_1$ and $\tilde{L}_2$, which are given by:

$$\tilde{L}_1 = \frac{B(\tau_K) + \sqrt{B(\tau_K)^2 - 4\Phi(\tau_K)\phi/\{[1-\Phi(\tau_K)]\rho\theta\}}}{2\phi/\rho}, \tag{23a}$$

$$\tilde{L}_2 = \frac{B(\tau_K) - \sqrt{B(\tau_K)^2 - 4\Phi(\tau_K)\phi/\{[1-\Phi(\tau_K)]\rho\theta\}}}{2\phi/\rho}, \tag{23b}$$

where $B(\tau_K) \equiv \frac{\phi}{\rho\theta} - 1 - \frac{\alpha(1-\tau_K)}{(1-\alpha)[1-\Phi(\tau_K)]}$ is a composite parameter.[12]

To ensure that $\tilde{L}$ is positive, we assume that the set of parameters jointly satisfies the condition $B > \sqrt{4\Phi\phi/[(1-\Phi)\rho\theta]}$. Moreover, we restrict our analysis to the case of tax shifting. By definition, tax shifting describes the case where an increase in one tax rate is coupled with a fall in another tax rate. In an online appendix, we show that when $L = \tilde{L}_2$, to hold a constant proportion of the government spending, the labor tax rate actually increases in response to an increase in the capital tax rate.[13] We rule out this irrelevant case and only focus on the solution $L = \tilde{L}_1$. From (23a), we can derive the relationship:

$$\frac{\partial \tilde{L}_1}{\partial \tau_K} = \frac{\rho}{2\phi}\left\{\frac{\partial B}{\partial \tau_K} + \frac{B\partial B/\partial\tau_K + 2\phi\alpha^2/[(1-\alpha^2)(1-\Phi)^2\rho\theta]}{\sqrt{B^2 - 4\Phi\phi/[(1-\Phi)\rho\theta]}}\right\} > 0 \tag{24}$$

where $\partial B/\partial \tau_K = \alpha\left[1 - \Phi + \alpha^2(1-\tau_K)/(1-\alpha^2)\right]/\{(1-\alpha)(1-\Phi)^2\} > 0$. The result in equation (24) leads us to establish the following proposition:

Proposition 2 *In the case of tax shifting from labor income tax to capital income tax, raising the capital income tax rate increases the steady-state equilibrium growth rate.*

[12]For notational simplicity, we suppress the argument of $\Phi(\tau_K)$ and $B(\tau_K)$ in the following equations.
[13]The online appendix is available on the journal's homepage.

It would not be difficult to understand the intuition underlying the positive growth effect given that we have already shown the importance of equilibrium labor input on economic growth from previous discussion. In the present case, there are two conflicting effects on labor supply. The first is the consumption effect that we discussed in Proposition 1; i.e., raising the capital tax rate induces the households to lower the investment rate and increase the consumption rate, which in turn reduces labor supply. The second effect emerges from the channel of shifting taxes from labor income to capital income. A rise in the capital income tax rate leads to a reduction in the labor income tax rate, which tends to boost labor supply. In particular, this latter tax-shifting effect has a more powerful direct impact on the labor market so that it dominates the former one. As a result, the net effect is positive such that a higher capital income tax rate stimulates economic growth in the long run.

4 Short-run versus long-run growth effects of capital taxation: A quantitative analysis

In this section we provide a numerical analysis to contrast the short-run and long-run growth effects of capital taxation. We first generalize the utility function as follows:

$$U = \int_0^\infty e^{-\rho t} \left[\ln C_t + \theta \frac{(1 - L_t)^{1-\eta}}{1-\eta} \right] dt, \tag{25}$$

where $\eta \geq 0$ determines the Frisch elasticity of labor supply. Equation (25) nests equation (1) as a special case when $\eta = 0$. The model features 7 parameters: $\{\rho, \alpha, \beta, \tau_K, \phi, \theta, \eta\}$. We consider the following standard parameter values in the literature. First, we follow Kydland and Prescott (1991) to set the discount rate to $\rho = 0.04$. Second, Elsby *et al.* (2013) estimate that the labor share in the US has fallen to around 0.6, implying that the capital share $\alpha = 0.40$. Third, we set the government spending ratio to $\beta = 0.20$, which is within the commonly accepted range in the macroeconomic literature (e.g., Belo *et al.*, 2013; Chen and Lu, 2013). Fourth, we set $\eta = 1.67$, which implies a Frisch labor-supply elasticity of 1.2; see Chetty *et al.* (2011).[14] Fifth, based on the estimates in McDaniel (2007), the average capital income tax in the US during the period 1950-2003 is about 29%; thus we set $\tau_K = 0.29$.

Using the baseline parameter values given above, we calibrate the total labor supply to be one-third (i.e., $L = 1/3$), giving us the value $\theta = 1.047$. Finally, to generate a steady-state output growth rate of 1.92%, which is the per capita long-run growth rate of the US economy, we derive $\phi = 0.5015$. The parameter values are summarized below.

[14] We consider a wide range of values for the Frisch labor-supply elasticity from 0.5 to infinity and find that our finding of contrasting short-run and long-run effects of capital taxation are robust.

Table 1: Parameter values

ρ	α	β	η	τ_K	θ	ϕ
0.04	0.40	0.20	1.67	0.29	1.047	0.5015

Figure 1 presents the growth effects of varying the capital income tax rate from 0 to 0.6. We can clearly see that, as the capital tax rate increases, the steady-state equilibrium growth rate increases. From this illustrative numerical exercise, we find that if the government raises the capital tax rate from the benchmark value of 29% to a hypothetical value of 50%, the steady-state equilibrium growth rate increases from 1.92% to 2.07%. The intuition can be explained as follows. Although an increase in the capital tax rate exerts a negative effect on economic growth by depressing capital accumulation, it also causes a fall in the labor income tax rate, which boosts labor supply and thus is beneficial to R&D and economic growth. In the long run, the latter effect dominates. Consequently, the steady-state equilibrium growth rate increases in response to a rise in the capital income tax rate.

[**Insert Figure 1 here**]

In the rest of this section, we simulate the transition dynamics of an increase in the capital income tax rate.[15] We consider the case of an increase in the capital income tax rate by one percentage point (i.e., from 29% to 30%).[16] First of all, the higher rate of capital taxation leads to a decrease in the investment rate and an increase in the consumption rate as shown in Figures 2 and 3, where investment $I = \dot{K}$.

[**Insert Figures 2 and 3 here**]

The lower capital-investment rate gives rise to an initial fall in the capital growth rate as shown in Figure 4, which contributes to an initial fall in the output growth rate as we will show later. The rise in the consumption rate increases leisure and decreases labor supply as shown in Figure 5. This decrease in labor supply reduces the amount of factor input available for R&D. As a result, the growth rate of technology also decreases initially as shown in Figure 6.

[**Insert Figures 4, 5 and 6 here**]

Although tax shifting resulting from a higher capital income tax rate gives rise to a lower labor income tax rate, this effect is weak in the short run. However, it becomes a

[15] Details of the dynamic system are provided in an online appendix available on the journal's homepage.

[16] In the case of a larger increase in the capital income tax rate, the qualitative pattern of the transitional paths of variables remains the same. Results are available upon request.

stronger force in the long run as shown in Figure 7. As a result, labor supply eventually rises above the original level, which in turn leads to a higher steady-state equilibrium growth rate of technology. Therefore, the initial drop in the growth rates of output and capital is followed by a subsequent increase. In the long run, the steady-state equilibrium growth rate of output is higher than the initial steady-state equilibrium growth rate as shown in Figure 8. To sum up, the reason for the contrasting short-run and long-run effects of capital taxation on economic growth is that the consumption effect is stronger (weaker) than the tax-shifting effect in the short (long) run.

[Insert Figures 7 and 8 here]

5 Extensions

In this section we consider three extensions. In the first extension, we consider an iso-elastic utility function to explore the importance of the intertemporal elasticity of substitution. In the second extension, we introduce a capital input in the R&D sector. In the third extension, we separate labor inputs into skilled labor and unskilled labor in the production sector. Throughout this section, we only consider the situation where a lump-sum tax is unavailable given that this is the more realistic case.

5.1 Iso-elastic utility function

In dynamic macroeconomic models, the intertemporal elasticity of substitution (IES) in consumption is known to be important in determining the magnitudes of the short-run and long-run effects of fiscal policies. To investigate the role of the IES and whether our results are robust to different values of this parameter, we consider an iso-elastic utility function given by:

$$U = \int_0^\infty e^{-\rho t} \frac{[C_t(1-L_t)^\psi]^{1-\sigma} - 1}{1-\sigma} \, dt, \tag{26}$$

where $\sigma > 0$ is the inverse of the IES, and $\psi > 0$ represents the relative weight of leisure in utility. We simulate the transition dynamics in this model with the primary focus on the effect of the IES. In choosing parameter values, we set the first group of parameters $\{\rho, \alpha, \beta, \tau_K\}$ to be the same as in Section 4 because they are uncontroversial. In particular, we choose $\sigma = 2$ as our benchmark case, which implies an IES in consumption equal to 0.5. This value is consistent with recent empirical estimates; see Guvenen (2006). Then, as previously, we calibrate the total labor supply to be one-third (i.e., $L = 1/3$), and thus we obtain $\psi = 1.3252$. Finally, $\phi = 0.6456$ is chosen to target the steady-state output growth rate of the US economy of 1.92%.

The transition dynamics of the output growth rate with different values of σ are exhibited in Figure 9. We also perform a robustness check on the parameter regarding the leisure preference ψ, as depicted in Figure 10. We can see in Figure 9 that the transition dynamic effects are quantitatively sensitive to σ. The consumption effect is weaker in the case where $\sigma = 4$ (IES=0.25) and is stronger in the case where $\sigma = 0.9$ (IES=1.11). However, in all cases, the contrasting growth effect of capital taxation in the short run and long run is still present. Moreover, the long-run growth effect of raising the capital income tax is positive, whereas the short-run growth effect is negative.[17] As a consequence, we can conclude that our results are qualitatively robust to these two parameters.

[**Insert Figures 9 and 10 here**]

5.2 Allowing for a capital input in the R&D sector

In our baseline model, we assume that innovation uses the labor input alone; i.e., the knowledge-driven specification of R&D in Romer (1990). However, innovation may also require a capital input; e.g., the lab-equipment specification of R&D in Rivera-Batiz and Romer (1991). Hence, in this subsection we extend the baseline model to allow for a capital input in the R&D sector. In this subsection and the next, our numerical analysis will continue to use the iso-elastic utility function for its generality. Moreover, we will only focus on the long-run growth effect of capital taxation in the case of a tax shift from a labor income tax to a capital income tax. Our goal is to examine the robustness of the positive effect of capital taxation on long-run growth.

To introduce R&D capital, the innovation function of new varieties is modified as:

$$\dot{A} = \phi K_A^{\chi} (AL_A)^{1-\chi}. \tag{27}$$

where K_A is the R&D capital and $\chi \in [0, 1)$ denotes the capital share or capital intensity in the R&D sector. We assume that capital inputs are homogeneous in the R&D sector and the intermediate-goods sector. It is obvious that when $\chi = 0$, equation (26) reduces to equation (12). In the case where $\chi > 0$, our baseline model is modified in the following respects. First, since the R&D sector also uses capital, the capital market clearing condition becomes $K = K_A + Ak$. Second, the first-order conditions of the R&D firm are given by:

[17] The long-run growth effect of capital taxation will become negative only if σ is less than around 0.54, which implies a too-high IES that is not supported by empirical evidence.

$$
\begin{aligned}
(1-\chi)\dot{A}V &= wL_A, && \text{(28a)}\\
\chi\dot{A}V &= r_K K_A. && \text{(28b)}
\end{aligned}
$$

Equation (28b) indicates that $\dot{K}_A/K_A = \dot{A}/A$ along the balanced growth path. Compared to the previous macroeconomy, this extended model has introduced an additional equation (28b) and an additional endogenous variable K_A.

We solve the extended model numerically. Baseline parameter values and functional forms are identical as in Section 5.1. Our numerical exercise considers three values of the capital intensity: $\chi = 0$ (the benchmark case), $\chi = 0.05$ (low capital intensity) and $\chi = 0.15$ (high capital intensity). Figure 11 depicts the results. In contrast to our benchmark model, in the case of a low (high) intensity of R&D capital, the long-run growth rate and capital taxation follows an inverted-U (negative) relationship. The main insight here is that our previous result of the positive effect of capital taxation on long-run growth is valid only when the capital intensity is sufficiently low. The intuition is straightforward. In the case where innovation needs capital as an input, raising the capital income tax that depresses capital accumulation brings about an additional adverse effect on innovation and growth. The higher that the capital intensity becomes, the stronger that this adverse effect will be. When the capital intensity is sufficiently high, the adverse effect along with the aforementioned consumption effect will outweigh the beneficial tax-shifting effect, thereby causing the long-run growth rate to fall.

[Insert Figure 11 here]

5.3 Differentiated labor inputs

Our baseline model assumes that labor inputs are homogeneous between innovation and production. Although this setting is standard in the line of the Romer model, some studies, by contrast, assume that innovation is conducted by high-skilled workers (scientists) while production uses low-skilled workers; see Acemoglu (2009). This section deals with this interesting extension.

To this end, we assume that the representative household has one unit of high-skilled labor and one unit of low-skilled labor. The representative household's lifetime utility is thus given by:

$$
U = \int_0^\infty e^{-\rho t}\frac{[C_t(1-H_t)^{\psi_H}(1-L_t)^{\psi_L}]^{1-\sigma}-1}{1-\sigma}\,dt, \tag{29}
$$

where H_t is the supply of high-skilled labor and L_t the supply of low-skilled labor. ψ_H and ψ_L are the weights to leisure for high-skilled and low-skilled workers, respectively. The budget constraint is:

$$\dot{K} + \dot{a} = ra + (1 - \tau_K)r_K K + (1 - \tau_L)(w_H H + w_L L) - C, \tag{30}$$

where w_H and w_L denote, respectively, the wages for high-skilled and low-skilled labor.

The R&D sector uses high skilled-labor; the innovation function of new varieties is $\dot{A} = \phi A H_A$ with H_A denoting the amount of high-skilled labor used for R&D. The final goods production uses both high-skilled and low-skilled labor; the production function of final goods is specified as:

$$Y = H_Y^{1-\alpha-\varepsilon} L_Y^{\varepsilon} \int_0^A x_i^{\alpha} di, \quad 0 \leq \varepsilon \leq 1 - \alpha. \tag{31}$$

H_Y and L_Y denote respectively the high-skilled and low-skilled labor used in the final goods sector. Accordingly, the labor market clearing conditions are $H = H_A + H_Y$ for high-skilled labor and $L = L_Y$ for low-skilled labor. Clearly, as $\varepsilon = 0$, this model reverts to our basic model with only one type of labor.

We simulate this extended model to examine how the long-run growth rate responds to an increase in capital taxation. The baseline values of the uncontroversial parameters $\{\rho, \alpha, \beta, \tau_K, \sigma\}$ are the same as before. Given these standard values, we redo the calibration for the new parameters $\{\psi_H, \psi_L, \varepsilon\}$ and ϕ in the following manner. First, we calibrate the total supply of high-skilled labor to be one-third ($H = 1/3$) to obtain $\psi_H = 0.8128$. Similarly, the supply of low-skilled labor that is equal to one-third ($L = 1/3$) gives us the value $\psi_L = 0.4956$. As for the important parameter ε representing the share of low-skilled labor in final goods production, we calibrate it to match the skill premium of 1.64 ($w_H/w_L = 1.64$), which is based on US data for the period 1970-2011 (Angelopoulos *et al.*, 2015). In that way, we obtain $\varepsilon = 0.249$. Lastly, we set $\phi = 0.4011$ to generate the long-run growth rate of the US economy of 1.92%.

The relationship between the long-run growth rate and capital taxation is depicted in Figure 12, in which we also consider a higher and a lower value of ε as a robustness check. We find that, in accordance with our previous result, raising the capital tax rate stimulates long-run growth in this extended model. The intuition can be briefly explained as follows. On the one hand, when an increase in the capital income tax rate leads to a lower labor income tax rate, L_Y increases which in turn increases the marginal product of high-skilled labor in the final goods sector. Therefore, for a given supply of high-skilled labor, there should be a reallocation of high-skilled labor from R&D to production. This channel is detrimental to long-run growth. On the other hand, the total supply of high-skilled labor also increases because of the lower labor income tax rate, which boosts R&D labor and then long-run growth. Overall, it turns out that the latter effect always outweighs the former effect. As a consequence, a higher capital tax rate unambiguously stimulates long-run growth.

[**Insert Figure 12 here**]

6 Conclusion

In this study, we have explored the short-run and long-run effects of capital taxation on innovation and economic growth in the seminal Romer model. Our results can be summarized as follows. An increase in the capital income tax rate has both a positive tax-shifting effect and a negative consumption effect on innovation and economic growth. In the long run, increasing the capital tax rate has a positive effect on the steady-state equilibrium growth rate because the positive tax-shifting effect strictly dominates the negative consumption effect. However, along the transitional path, increasing the capital tax rate first decreases the equilibrium growth rates of technology and output before these growth rates converge to a higher steady-state equilibrium level. These theoretical implications of capital taxation on economic growth suggest that an empirical analysis of capital taxation and economic growth may benefit from considering the possibility that the effects of capital taxation change sign at different time horizons.

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