Discussion Paper No. 913

DYNAMIC EFFECTS OF ANTICIPATED AND TEMPORARY TAX CHANGES IN A R&D-BASED GROWTH MODEL

Kizuku Takao

August 2014

The Institute of Social and Economic Research
Osaka University
6-1 Mihogaoka, Ibaraki, Osaka 567-0047, Japan

Dynamic effects of anticipated and temporary tax changes in a R&D-based growth model*

Kizuku Takao†
Osaka University

This version: August, 2014

Abstract

Tax changes are often announced before their implementation and are not permanent, but rather only temporary. Accordingly, R&D firms will optimally adjust their investment decisions to fit tax schedule changes. This study analyzes how changes in various tax rates relevant to corporate activities affect growth and welfare, considering their methods of implementation. For this purpose, we consider adjustment costs involved in the investment process and allow firms to make a forward looking investment decision in a R&D-based endogenous growth model. Calibrating the model with U.S. data, we find that a dividend tax cut reduces the level of welfare irrespective of implementation method. On the other hand, a capital gains tax cut and a rise in the R&D tax credit rate enhance the level of welfare irrespective of implementation. However, the announcement of these tax changes prior to implementation reduces their effectiveness.

Keywords: Fiscal policy, R&D, Economic growth

JEL classification: E62, O32, O41

*I would like to express my sincere gratitude to Koichi Futagami, Been-Lon Chen, and Ching-Chong Lai for the beneficial discussions and suggestions. I would also like to thank Juin-Jen Chang, Takeo Hori, Tatsuro Iwaisako, Yukihiro Nishimura, Katsunori Yamada, Hirokazu Ishise, and the participants at the 6th Conference of Macroeconomics for Young Professionals in Osaka, the 2012 Spring Annual Meeting of the Japanese Economic Association in University of Hokkaido, and IEAS seminar in Academia Sinica, 2014 Australian Meeting of the Econometric Society in Hobart, and PET 14 in University of Washington. This paper was written while visiting the Institute of Economics, Academia Sinica. The financial support from Strategic Young Researcher Overseas Visits Program for Accelerating Brain Circulation (Japan Society for the Promotion of Science) is gratefully acknowledged. All remaining errors are mine.

†Institute of Social Economic Research, Osaka University, 6-1 Mihogaoka, Ibaraki, Osaka 567-0047, Japan. E-mail address: takao@iser.osaka-u.ac.jp

1 Introduction

Technological progress achieved through R&D activities is a major source of economic growth. Firms decide upon the scope of their investment in R&D, considering the costs and benefits of these R&D activities, whose values are dependent upon the applicable statutory tax rate. As Hall and Van Reenen (2000) point out, fiscal incentives for R&D investments differ across countries and change over time. The purpose of this study is to provide the clear policy implications arising from tax changes relevant to R&D activities in the context of a R&D-based endogenous growth model.

The novel feature of our study is its focus on growth and welfare not only of unanticipated tax changes, which have permanent implementation periods, but also of anticipated and temporary tax changes. Accordingly, we consider an environment where technological progress is driven by in-house R&D by long-lived value-maximizing firms, and these firms make forward-looking investment decisions regarding in-house R&D activities. In the real world, tax changes are usually announced before their implementation and are not permanent but rather only temporary. In such a situation, firms and households have an opportunity to adjust their intertemporal behavior to fit the tax schedule. For better understanding of taxation policy efficacy, it is important to consider what differences arise depending on how tax changes are implemented.

The present analysis is based on a recent endogenous growth model developed by Peretto (2007, 2011). Specifically, the model considers an economy where long-lived value-maximizing firms continuously improve upon the quality of their specific product through in-house R&D, while simultaneously new firms also enter the market. The model economy contains two types of investment opportunities, i.e., in-house R&D (quality improving) and the creation of a new firm (product proliferation). The model has the advantage of eliminating the well-known undesirable scale effect [Jones (1995)], while keeping the policy effect property, which is supported by a growing body of recent empirical literature.[1]

[1]The first generation R&D-based endogenous growth model [e.g. Romer(1990) and Grossman and Helpman (1991)] predicts that the equilibrium growth rate is increasing in the labor endowment. However, Jones (1995a) refutes this assertion using time-series data covering the post-war period. Then, the following two prominent model types are developed. The former type is referred to as the semi-endogenous growth type [e.g. Jones (1995b) and Segerstrom (1998)]. They resolve the undesirable scale effect property by

Increases in the scale of the aggregate economy are perfectly fragmented by endogenous product proliferation. Aggregate growth is driven by quality growth arising from firm's in-house R&D activities. The intensity of in-house R&D is dependent on the demand for intermediate goods at the individual firm level, not the aggregate level.[2]

However, in the model of Peretto (2007, 2011), a firm's investment decision regarding in-house R&D turns out to be a static problem. This occurs because the model assumes that the production function of in-house R&D is linear. This implies that the current intensity of in-house R&D reflects only on current market conditions and tax rates, not future variables. As a result, if anticipated and temporary tax changes are incorporated into the model's setting, the dynamic response of firm's investment decisions could not be considered, and thus the actual impact of such tax shocks could not be captured.

To overcome this problem, we incorporate a framework of the adjustment costs of investment as used in the literature of investment theory.[3] More specifically, we assume that firms require the convex adjustment costs associated with in-house R&D investments. This specification is indeed more realistic. Some empirical literature points out the existence of high adjustment costs for R&D investments [e.g., Bernstein and Nadiri (1989), Himmelberg and Petersen (1994), and Brown and Petersen (2011)]. In the presence of adjustment costs, firms' investment decisions regarding in-house R&D are a forward-looking problem. The dynamic system of an economy is also characterized by the (tax-adjusted) shadow value of in-house R&D, which determines the intensity of in-house R&D.[4] The shadow value

assuming the diminishing returns in R&D production technologies. This specification yields the result that the steady state growth rate is only pinned down to population growth rate. By contrast, the latter type is referred as the fully-endogenous type [e.g. Peretto (1998), Howitt (1999) and Futagami and Ohkusa (2003)]. They assume that both vertical innovation and horizontal innovation occur. This specification yields the conclusion that the steady-state growth rate is also dependent on the other parameters and policy variables. A recent growing body of empirical literature [e.g. Laincz and Peretto (2006), Ha and Howitt (2007), and Ang and Madsen (2011)] report that the latter type performs well, rather than the former type.

[2] This prediction is consistent with many empirical studies [e.g. Cohen and Klepper (1996), Adams and Jaffe (1996), and Pagano and Schivardi (2003)].

[3] See, for example, Hayashi (1982), Abel (1982), and Abel and Blanchard (1983)

[4] In Peretto (2007), the dynamic system of the economy is characterized by only one state variable (the number of firms per capita). In Peretto (2011), it is characterized by one state variable (the number of firms per capita) and one jump variable (consumption ratio). On the other hand, the dynamic system of the model used in our analysis is characterized by not only the number of firms per capita and consumption ratio but also one additional jump variable (shadow value of innovation).

summarizes all informations relevant to in-house R&D investment decisions. The flexibility provided by the shadow value is very useful in analyzing how investment decisions regarding in-house R&D dynamically react to both anticipated and temporary tax changes.

Using this modified model, we study the policy implications of (1) a dividend tax cut, (2) a corporate tax cut, (3) a capital gains tax cut, and (4) a rise in the R&D tax credit rate, taking into account differences arising depending on tax change implementation methods. Calibrating the model with U.S. data, we obtain the following main results. First, a dividend tax cut reduces the level of welfare irrespective of implementation method. After the tax cut is implemented, it is detrimental to in-house R&D and aggregate growth. However, the anticipation of a dividend tax cut stimulates in-house R&D and aggregate growth during the announcement phase. Although the overall welfare effect remains negative, pre-announcement of the tax cut mitigates the resultant welfare losses. Second, the policy effect of a corporate tax cut depends upon whether or not in-house R&D expenditures are tax deductible. If in-house R&D expenditures are not deductible, a corporate tax cut leads to higher economic growth and welfare gains irrespective of implementation. However, if they are fully (or partially) deductible, the policy effect mirrors that observed for the dividend tax cut. On the other hand, a capital gains tax cut and a rise in the R&D tax credit rate improve the level of welfare irrespective of implementation method. After implementation, they stimulate in-house R&D and aggregate growth. However, these anticipated tax changes are detrimental to in-house R&D and aggregate growth during the announcement phase. Therefore, although the overall welfare effect remains positive, pre-announcement of these tax changes worsens their effectiveness.

Our results have implications regarding the following important channels. First, tax changes have a direct but different effect on both after-tax gross cash flow and firms' cost of in-house R&D. For example, during the announcement phase, the anticipated dividend tax cut increases future after-tax gross cash flow, whereas it does not change the cost of in-house R&D. As a result, firms dynamically adjust the timing of in-house R&D investments in reaction to the tax schedule. Second, tax changes also affect incentives to create a new firm and thus impinge on endogenous firm entry. This determines the scale of production at the individual-firm level given an aggregate market size, which in turn affects incentives for firms to engage in R&D in-house. In addition, households can dynamically adjust the timing of consumption (saving), resulting in a general equilibrium effect.

Peretto (2007, 2011) examined the policy effect of tax changes relevant to corporate R&D activities. In particular, Peretto (2007, 2011) mainly focuses on the policy effect of a dividend tax cut such as the U.S.'s Jobs Growth and Taxpayer Relief Reconciliation Act of 2003. Specifically, Peretto (2007) analyzes the revenue-neutral tax changes in an environment where the dividend tax rate is endogenously determined to balance the government's budget constraint and shows that lowering the corporate tax rate and capital gains tax rate or increasing the R&D tax credit rate can lead to higher economic growth and improve welfare levels. Peretto (2011) analyzes the case where the government can finance the outlay required by tax changes via debt, and quantitatively shows that a dividend tax cut leads to the slowdown of in-house R&D and aggregate growth, and thus leads to substantial welfare losses. The differences between our study and that of Peretto (2011) are as follows. First, Peretto (2007, 2011) focuses only on unanticipated and permanent tax changes. On the other hand, we also consider anticipated and temporary tax changes in an environment where firms dynamically react to these tax changes. Second, we examine the effectiveness of alternative policy instruments rather than the dividend tax cut in an environment where the government finances with debt as just in Peretto (2011).

Our study is also related to the following previous studies. Zeng and Zhang (2002) and Peretto (2003) also study the effects of tax changes on the basis of a non-scale R&D-based growth model. However, both these studies analyze only unanticipated and permanent tax changes and do not consider transitional dynamics and welfare implications. Summers (1981) and Abel (1982) analyze how anticipated and temporary tax changes affect firms' forward-looking investment decisions by using the framework of adjustment costs for investment. However, their analysis are based on the partial equilibrium approach. As a result, they can not consider the impacts on aggregate growth and welfare. Strulik and Trimborn (2010) study the effects of anticipated and temporary tax changes in a general equilibrium setting. Their model is based on the neoclassical growth model with endogenous corporate finance, making the steady-state growth rate exogenous in this setting.

The remainder of this paper is as follows. Section 2 describes the model. Section 3 characterizes the dynamic system and the steady-state equilibrium of the market economy. Section 4 quantitatively analyzes the transitional adjustment of macroeconomic variables to tax changes and welfare consequences, calibrating the model with U.S. data. Section 5 analyzes the sensitivity of the numerical analysis. Finally, Section 6 concludes the study.

2 The model

In this section, we establish our model, which is based on that of Peretto (2011). Time is continuous. The economy is closed and consists of a final goods sector, an intermediate goods sector, households, and government. Perfect competition prevails in the final goods sector, while monopolistic competition prevails in the intermediate goods sector. Both the labor and asset markets are competitive. All fiscal variables either change only at discrete events or remain static. Thus, we can treat them parametrically and omit the time index t.

2.1 Final goods sector

The price of final goods is set to be the numeraire. Final goods are consumed by households and used as only one factor of production and investment by the intermediate goods sector. The final goods, Y_t is produced by the following production function:

$$Y_t = \int_0^{N_t} X_{it}^{\theta} \left(Z_{it}^{\alpha} \bar{Z}_t^{1-\alpha} L_{it} \right)^{1-\theta} di, \quad 0 < \alpha, \theta < 1, \tag{1}$$

where N_t is the variety of intermediate goods (the number of intermediate goods firms), X_{it} is the input of intermediate goods $i \in [0, N_t]$ (produced by firm i), and L_{it} is the input of labor that uses intermediate goods i. The productivity of L_{it} depends not only on the quality of intermediate good i, Z_{it}, but also on the average quality level across all intermediate goods, $\bar{Z}_t \equiv \int_0^{N_t} \frac{1}{N_t} Z_{jt} dj$. Therefore, we obtain the following optimal conditions:

$$X_{it} = \left(\frac{\theta}{P_{it}} \right)^{\frac{1}{1-\theta}} \left(Z_{it}^{\alpha} \bar{Z}_t^{1-\alpha} L_{it} \right), \tag{2}$$

$$L_{it} = \left(\frac{1-\theta}{W_t} \right)^{\frac{1}{\theta}} X_{it} \left(Z_{it}^{\alpha} \bar{Z}_t^{1-\alpha} \right)^{\frac{1-\theta}{\theta}}, \tag{3}$$

where P_{it} and W_t represent the price of intermediate good i and the labor wage rate, respectively.

2.2 Intermediate goods sector

Firm i exclusively produces its differentiated good at quality, Z_{it}. Each firm's monopoly is permanently protected by perfect patent protection. Producing one unit of intermediate goods requires one unit of final goods. Firms improve the quality of their specific product through their in-house R&D. In contrast to Peretto (2007, 2011), however, we assume that given increases in firm-specific quality level, $R_{it} \geq 0$, involve adjustment costs associated with innovation, following à la Hayashi (1982) specification. Specifically, the law of motion pertaining to firm-specific quality is

$$\dot{Z}_{it} = R_{it}, \tag{4}$$

and the amount of R&D expenditure is given by

$$\Phi(R_{it}, Z_{it}) = R_{it} + \frac{h}{2} \frac{R_{it}^2}{Z_{it}}, \tag{5}$$

where $h > 0$ reflects the extent of adjustment costs associated with in-house R&D and the case of $h = 0$ corresponds to the specification of Peretto (2007, 2011).[5]

At each point in time, fixed operating costs, $\phi \bar{Z}_t$ ($\phi > 0$), are imposed. Accordingly, the gross cash flow is $F_{it} = (P_{it} - 1) X_{it} - \phi \bar{Z}_t$, where the first term represents revenue minus variable production costs and the second term represents fixed operating costs. Let σ represent the rate of R&D tax credits (the fraction of R&D expenditure that firms are allowed to deduct from their corporate taxable amount).[6] The total amount of corporate tax is $\tau_{\Pi} \left[F_{it} - \sigma \Phi(R_{it}, Z_{it}) \right]$, where τ_{Π} represents the corporate tax rate. The gross cash

[5] This functional form is based on Turnovsky (2000).

[6] Although σ is assumed to be zero for simplification in Peretto (2011), we follow the specification of Peretto (2007) so that we can consider the effects of the tax credit policy for R&D investment as well.

flow must therefore be distributed as follows:

$$F_{it} = \tau_{\Pi}\left[F_{it} - \sigma\Phi(R_{it}, Z_{it})\right] + E_{it}d_{it} + J_{it},$$

where E_{it} is the number of equities, d_{it} is the pre-tax dividends on a per-share basis, and J_{it} is the retained earnings. A firm's financial constraint is written by $J_{it}+\dot{E}_{it}v_{it} = \Phi(R_{it}, Z_{it})$, where $\dot{E}_{it}$ and v_{it} represent the number of newly issued equities and the equity price on a per-share basis, respectively. Since we do not consider here the case where in-house R&D is financed by a bond issue, the above identity indicates that in-house R&D investments must be financed by retaining earnings, newly issued equities, or both.[7] Along the lines of Peretto (2011), we focus only on the scenario where the marginal source of in-house R&D is limited only to retaining earnings. The scenario is called "New view" in the corporate finance literature. In this scenario, $\Phi(R_{it}, Z_{it}) = J_{it}$ because $\dot{E}_{it} = 0$.

Let $V_{it} \equiv E_{it}v_{it}$ and $D_{it} \equiv E_{it}d_{it}$. Without loss of generality, E_{it} is normalized to one. Dividends is given by

$$D_{it} = (1-\tau_{\Pi})F_{it} - (1-\sigma\tau_{\Pi})\Phi(R_{it}, Z_{it}). \tag{6}$$

The return on equity can be rewritten by

$$r_t = (1-\tau_D)\frac{D_{it}}{V_{it}} + (1-\tau_V)\frac{\dot{V}_{it}}{V_{it}}. \tag{7}$$

where τ_D is the dividend tax rate and τ_V is the capital gains tax rate.

Integrating (7) yields the value of firm i as follows:

$$V_{it} = \int_t^{\infty} \exp\left(\int_t^s -\frac{1}{1-\tau_V} r_v dv\right)\left(\frac{1-\tau_D}{1-\tau_V}\right)\left[(1-\tau_{\Pi})F_{is} - (1-\sigma\tau_{\Pi})\Phi(R_{is}, Z_{is})\right] ds.$$

Throughout this exercise, we consider a symmetric equilibrium by assuming that any new firm starts with the same technology level as incumbents so that the subscript i can be dropped. In the equilibrium, $Z_t = \bar{Z}_t$ holds. Each firm maximizes its value, subject to

[7] See Turnovsky (1990) for a detailed discussion.

(2) and (4), given $\bar{Z}$. To solve the inter-temporal maximization problem, we define the following current-value Hamiltonian as

$$H \equiv \frac{1-\tau_D}{1-\tau_V}\left[(1-\tau_\Pi)F_t - (1-\sigma\tau_\Pi)\Phi(R_t, Z_t)\right] + q_t\left[R_t\right],$$

where the co-state variable, q_t, represents a shadow value for in-house R&D. We obtain the following optimal conditions:

$$P_t = \frac{1}{\theta}, \tag{8}$$

$$q_t = \frac{(1-\tau_D)(1-\sigma\tau_\Pi)}{(1-\tau_V)}\left[1 + h\frac{R_t}{Z_t}\right], \tag{9}$$

$$r_t = (1-\tau_D)(1-\tau_\Pi)\frac{\partial F_t}{\partial Z_t}\frac{1}{q_t} + (1-\tau_D)(1-\sigma\tau_\Pi)\frac{h}{2}\left(\frac{R_t}{Z_t}\right)^2\frac{1}{q_t} + (1-\tau_V)\frac{\dot{q}_t}{q_t}. \tag{10}$$

The transversality condition is $\lim_{s\to\infty}\exp\left(-\frac{1}{1-\tau_V}\int_t^s r_v dv\right)Z_s q_s = 0$. From (4) and (9), the quality growth rate is given by

$$\hat{z}_t \equiv \frac{\dot{Z}_t}{Z_t} = \begin{cases} \frac{1}{h}\left[\frac{(1-\tau_V)}{(1-\tau_D)(1-\sigma\tau_\Pi)}q_t - 1\right] \equiv \frac{1}{h}\left[\tilde{q}_t - 1\right], & \text{if } \tilde{q}_t > 1, \\ 0, \quad \text{if } \tilde{q}_t \leq 1. \end{cases} \tag{11}$$

(8) represents the pricing rule with constant mark-up. (9) indicates that firms invest in-house R&D up to the point where the shadow value of in-house R&D (RHS) equals the actual cost of in-house R&D (LHS). Since in-house R&D is funded only by retaining earnings, the outlay of one dollar for in-house R&D decreases dividend payments for shareholders by $\frac{(1-\tau_D)(1-\sigma\tau_\Pi)}{(1-\tau_V)}$. Thus, reductions in the dividend tax rate and corporate tax rate increase the cost of in-house R&D, whereas reductions in the capital gains tax rate and a higher R&D tax credit rate lowers the cost of in-house R&D.[8] (10) represents the no-arbitrage condition between the return on equity and that on in-house R&D. Hereafter, we call $\tilde{q}_t \equiv \frac{(1-\tau_V)}{(1-\tau_D)(1-\sigma\tau_\Pi)}q_t$ as modified q along the lines of Hayashi (1982). If there are no

[8] If $\sigma = 0$, a decrease in the corporate tax does not change the cost of in-house R&D.

adjustment costs ($h = 0$), modified q always pins down to one.[9] By contrast, in our setting, modified q is endogenously determined and has a transitional process in equilibrium. (11) shows that the rate of quality growth is an increasing function of modified q. Since modified q is derived from firms' intertemporal optimization problem, all informations relevant to in-house R&D decisions are summarized by modified q.

Developing new products requires βZ_t ($\beta > 1$). New entry firms are financed by issuing equity. Free-entry conditions yields

$$V_t = \beta Z_t \;\Leftrightarrow\; \dot{N}_t > 0. \tag{12}$$

From (6) and (12), the return on equity, (7), can be rewritten by

$$r_t = (1-\tau_D)\left[(1-\tau_\Pi)\frac{F_t}{\beta Z_t} - (1-\sigma\tau_\Pi)\frac{\Phi(R_t, Z_t)}{\beta Z_t}\right] + (1-\tau_V)\frac{\dot{Z}_t}{Z_t}. \tag{13}$$

2.3 Households

The model's economy has identical households. Each individual household member is identically endowed with one unit of time and provides labor supply elastically. The population grows at a constant rate, $\lambda > 0$. Without loss of generality, the population size at time 0 is normalized to one. Hence, the number of population at time t is given by $e^{\lambda t}$. Households maximize the following utility function:

$$U_t = \int_t^\infty e^{-(\rho-\lambda)(s-t)}\left[\log C_s e^{-\lambda s} + \zeta \log(1-l_s)\right] ds,$$

where C_t is the aggregate consumption, l_t is the fraction of time allocated to work per capita, $\zeta > 0$ is the measure of preference for leisure, and ρ ($> \lambda$) is the rate of the time preference. The household budget constraint is given by

$$\dot{N}_t V_t = N_t\left[(1-\tau_D)D_t - \tau_V \dot{V}_t\right] + (1-\tau_L)W_t l_t e^{\lambda t} - (1+\tau_C)C_t - T_t,$$

[9] See Peretto (2007, 2011).

where τ_L is the labor income tax rate, τ_C is the consumption tax rate, and T_t is the lump-sum tax. Solving the inter-temporal optimization problem yields the following optimal conditions:

$$\frac{\dot{C}_t}{C_t} = r_t - \rho + \lambda, \tag{14}$$

$$l_t = 1 - \frac{(1+\tau_C)\zeta C_t}{(1-\tau_L)W_t e^{\lambda t}}. \tag{15}$$

The transversality condition is $\lim_{s\to\infty} e^{-(\rho-\lambda)(s-t)} a_s \mu_s = 0$, where μ_t represents the shadow value of holdings assets.

2.4 Government

Government spending is given by $G_t = gY_t$ $(0 < g < 1)$, where the share of the government spending to outputs is assumed to be exogenously given. Along the lines of Peretto (2007, 2011), it is assumed that government spending does not affect a household's utility or the efficiency of production activities. This allows the effects of distortionary taxes to be isolated from the effects of government expenditure. The government's budget constraint is given by

$$G_t = \tau_L W_t e^{\lambda t} l_t + \tau_C C_t + \tau_\Pi N_t \left[F_t - \sigma \Phi(Z_t, R_t)\right] + \tau_D N_t D_t + \tau_V N_t \dot{V}_t + T_t.$$

Since the Ricardian equivalence holds, the same equilibrium dynamics occurs as in the economy with public debt.

3 Market equilibrium

3.1 Equilibrium dynamics

In this section, we derive the dynamic system of market equilibrium. The market equilibrium condition of final goods is given by

$$Y_t = G_t + C_t + N_t \left[X_t + \phi Z_t + \Phi(Z_t, R_t)\right] + \beta Z_t \dot{N}_t. \tag{16}$$

Define the number of firms per capita as $n_t \equiv N_t/e^{\lambda t}$ and the ratio of the aggregate consumption to outputs as $c_t \equiv C_t/Y_t$. With full proof presented in Appendix 1, the labor supply per capita is given by

$$l(c_t) = \frac{1}{1+\Gamma c_t}, \quad \Gamma \equiv \frac{(1+\tau_C)\zeta}{(1-\tau_L)(1-\theta)} > 0. \tag{17}$$

The reduced-form aggregate production function of final goods is given by

$$Y_t = \Omega l(c_t) e^{\lambda t} Z_t, \quad \Omega \equiv \theta^{\frac{2\theta}{1-\theta}}. \tag{18}$$

For simplifying the notation, we hereafter define

$$S \equiv \frac{(1-\tau_V)}{(1-\tau_D)(1-\sigma\tau_\Pi)} \quad \text{and} \quad \eta \equiv \frac{1-\sigma\tau_\Pi}{1-\tau_\Pi}.$$

In Appendix 2, we provide proof for the following simultaneous differential equation, which constitutes the economy's dynamical system (in the case where $\tilde{q}_t > 1$):

$$\dot{n}_t = \left[1-\theta^2-g-c_t\right]\frac{\Omega l(c_t)}{\beta} - \left[\phi + \frac{(Sq_t)^2-1}{2h} + \beta\lambda\right]\frac{n_t}{\beta}, \tag{19}$$

$$\dot{c}_t = c_t\left[1+\Gamma c_t\right]\left[r_t - \rho - \frac{Sq_t - 1}{h}\right], \tag{20}$$

$$\dot{q}_t = \frac{1}{1-\tau_V} r_t q_t - \frac{\alpha\theta(1-\theta)}{S\eta}\frac{\Omega l(c_t)}{n_t} - \frac{(Sq_t-1)^2}{2Sh}, \tag{21}$$

where the interest rate (return on equity) is given by

$$r_t = \frac{(1-\tau_V)}{\beta S\eta}\left[\theta(1-\theta)\frac{\Omega l(c_t)}{n_t} - \phi - \eta\frac{(Sq_t)^2-1}{2h}\right] + (1-\tau_V)\frac{Sq_t-1}{h}. \tag{22}$$

See Appendix 3 for proof of the dynamic system in the case where $\tilde{q}_t \le 1$.

3.2 Steady-state equilibrium

Let $y_t \equiv Y_t/(l_t e^{\lambda t})$, which represents the output per worker. From (18), the growth rate of output per worker is given by $\hat{y}_t \equiv \dot{y}_t/y_t = \hat{z}_t = (\tilde{q}_t - 1)/h$. In what follows, we characterize the steady-state equilibrium, $\{n^*, c^*, \tilde{q}^*(\equiv Sq^*), l^*, r^*, \hat{y}^*\}$. From (20), $\dot{c}_t = 0$ and $c^* > 0$ implies (if $\tilde{q}^* > 1$)

$$r^* = \rho + \frac{\tilde{q}^* - 1}{h}. \tag{23}$$

From (21), $\dot{q}_t = 0$ and $\tilde{q}^* > 1$ implies

$$r^* = (1-\tau_V)\frac{\alpha\theta(1-\theta)}{\eta}\frac{\Omega l(c^*)}{n^*}\frac{1}{\tilde{q}^*} + (1-\tau_V)\frac{(\tilde{q}^*-1)^2}{2h}\frac{1}{\tilde{q}^*}. \tag{24}$$

This equation represents the no-arbitrage condition between the return on in-house R&D and that on equity in the steady-state equilibrium. Other things being equal, a dividend tax cut has no direct impact on the return from in-house R&D. A dividend tax cut boosts a firm's after-tax gross cash flow and thus enhances the benefit derived from quality growth through in-house R&D. But the tax cut also increases the cost of in-house R&D, as previously discussed. As described in public finance literature [e.g. Summers (1981) and Hassett and Hubbard (2002)], the effects of the dividend tax cut cancel each other out. On the other hand, a corporate tax cut, a capital gains tax cut, and an increase in the R&D tax credit rate directly enhance the return on in-house R&D. From (23) and (24), we can determine that eliminating r^* yields (if $\tilde{q}^* > 1$)

$$\frac{\Omega l(c^*)}{n^*} = \frac{\eta}{\alpha\theta(1-\theta)}\left\{\frac{1}{1-\tau_V}\left[\rho + \frac{\tilde{q}^*-1}{h}\right]\tilde{q}^* - \frac{(\tilde{q}^*-1)^2}{2h}\right\}. \tag{25}$$

Substituting (23) and (25) in (22), we find that $\tilde{q}^*$ is derived by solving $f(\tilde{q}) = 0$ with respect to $\tilde{q}$ where

$$f(\tilde{q}) \equiv \begin{cases} \dfrac{1}{1-\tau_V}\left[\rho + \dfrac{\tilde{q}-1}{h}\right](S\alpha\beta - \tilde{q}) + \dfrac{(\tilde{q}-1)^2}{2h} + \alpha\dfrac{\tilde{q}^2-1}{2h} \\ -S\alpha\beta\dfrac{\tilde{q}-1}{h} + \dfrac{\alpha\phi}{\eta}, \quad \text{if} \quad \tilde{q} > 1, \\ \dfrac{\rho}{1-\tau_V}(S\alpha\beta - \tilde{q}) + \dfrac{\alpha\phi}{\eta}, \quad \text{if} \quad \tilde{q} \leq 1. \end{cases} \tag{26}$$

If $S\alpha\beta \leq 1 - \frac{(1-\tau_V)\alpha\phi}{\eta\rho} < 1$, $f(1) \leq 0$ and $f'(\tilde{q}) < 0$. In such a case, no steady-state equilibrium exists with a positive quality growth rate. If $1 - \frac{(1-\tau_V)\alpha\phi}{\eta\rho} < S\alpha\beta$, $f(1) > 0$. In such a case, $f(\tilde{q})$ is depicted, as shown in Figure 1. Figure 1 shows that if $1 - \frac{(1-\tau_V)\alpha\phi}{\eta\rho} < S\alpha\beta$, then $\tilde{q}^*$ is uniquely determined at the point where $\tilde{q}^*$ is higher than 1. In what follows, we focus on the case where $1 - \frac{(1-\tau_V)\alpha\phi}{\eta\rho} < S\alpha\beta$. In such a case, there exists a unique steady-state equilibrium with a positive rate of quality growth. See Appendix 4 for proof.

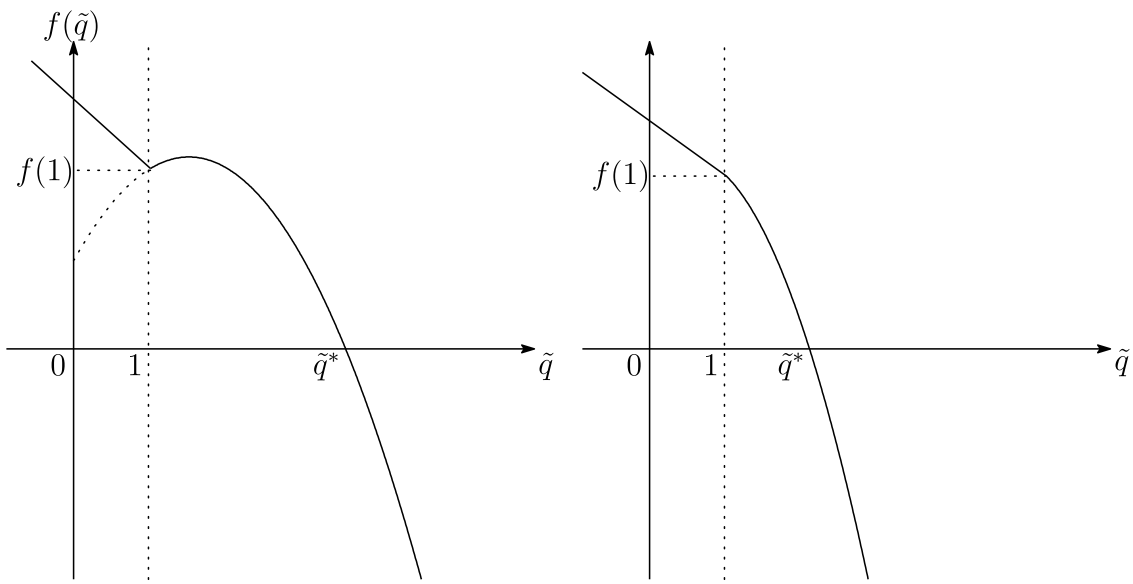


Figure 1: The steady-state equilibrium: the left (right) figure represents the case where $f(\tilde{q})$ is inverted U-shapes (monotonically decreasing in $\tilde{q}$) for $\tilde{q} > 1$.

Since the Jacobian matrix derived from the linear approximation of (19)-(21) in the neighborhood of the steady-state equilibrium is complicated, we cannot analytically examine the dynamic system's local stability. However, our numerical simulations confirm that the unique steady state is locally saddle-point stable in the benchmark setting and in the subsequent sensitivity analysis, as shown below.[10]

[10] Since the dynamic system has one state variable (n_t) and two jump variables (c_t and q_t), it must have two positive characteristic roots and one negative characteristic root to assure that the unique steady state is saddle-point stable. Our numerical simulation reports that the value of three characteristic root corresponding to the dynamic system are -0.4129, 0.2240, and 0.1478 in the benchmark parameter setting.

From (19) and (25), $\dot{n}_t = 0$ and $n^* > 0$ implies

$$c^* = \left[1 - \theta^2 - g\right] - \frac{\alpha\theta(1-\theta)}{\varphi(\tilde{q}^*)}\left[\phi + \frac{\tilde{q}^{*2} - 1}{2h} + \beta\lambda\right],$$

where

$$\varphi(\tilde{q}^*) \equiv \frac{\eta}{1-\tau_V}\left[\rho + \frac{\tilde{q}^* - 1}{h}\right]\tilde{q}^* - \eta\frac{(\tilde{q}^* - 1)^2}{2h}.$$

Rewriting (25) yields

$$n^* = \frac{\alpha\theta(1-\theta)\Omega l(c^*)}{\varphi(\tilde{q}^*)}.$$

The mechanism that eliminates the scale effect on the steady-state growth rate of output is consistent with the case where adjustment costs are absent [Peretto (2007, 2011)]. In the steady-state equilibrium, modified q is independent of the scale factor for the economy, $l(c^*)$ [see (26)]. Increases in the economy's scale factor lead to higher aggregate demand for intermediate goods at the individual firm level. This larger scale of production at the individual firm level allows in-house R&D expenditures to be spread over a greater number of units of goods, thus having a direct positive effect on incentives for a firm to engage in R&D in-house. This effect is called the cost-spreading effect. However, higher aggregate demand for intermediate goods also attracts new firms to enter the market as firm values rise. Thus, the per-firm market share of intermediate goods demand shrinks. This reduces the scale of production at the individual firm level, which in turn lowers incentives to conduct in-house R&D activities. This effect is called the market share effect. In the steady-state equilibrium, the market share effect derived from higher aggregate demand for intermediate goods perfectly cancels out the cost-spreading effect [see discussion in Peretto (2007)].[11]

[11] Furthermore, we confirm that the comparative statics of the parameters in the steady-state equilibrium obtain similar results to those in Peretto (2007, 2011). Increases in α, β, and ϕ enhance the steady-state growth rate of outputs, respectively. Increases in α allow each firm to more intensely internalize positive returns derived from its own in-house R&D activities. Increases in β and ϕ make it more difficult for potential new firms to enter the market, thus reallocating resources from product proliferation to quality improving. An increase in h reduce the steady-state growth rate of output because it directly increases the cost of in-house R&D. On the other hand, the effect of ρ upon the steady-state growth rate of outputs is ambiguous.

3.3 Steady-state effect of tax changes

The manner in which a permanent change of tax variables affects quality growth in the steady-state equilibrium is also consistent with Peretto (2007, 2011). We summarize those findings as follows:

Quality growth in the steady-state equilibrium is increasing in the rates of dividend tax and corporate tax (if $\sigma \geq 1$) and R&D tax credit rate. On the other hand, it is decreasing in the rate of the corporate tax (if $\sigma = 0$). Increases in the corporate tax rate (if $\sigma \in (0, 1)$) and capital gains tax rate have ambiguous effects upon the steady-state quality growth rate.

Proofs can be found in Appendix 5. A dividend tax cut has no direct impact on a firms' incentive to pursue in-house R&D, as previously discussed. On the other hand, a dividend tax cut directly enhances the returns on equity. Given the aggregate market demand for intermediate goods, the number of firms per capita increases. The resulting product proliferation lowers incentives to conduct in-house R&D through the market share effect. Thus, a dividend tax cut unambiguously has an unambiguously negative effect on quality growth.[12]

On the other hand, a higher R&D tax credit rate has an unambiguously positive effect on quality growth. It reduces the cost of conducting in-house R&D, which dominates the other effect so that it functions like a direct subsidy for in-house R&D.

Both a corporate tax cut (if $\sigma \in (0, 1)$) and a capital gains tax cut have ambiguous effects on quality growth. These tax cuts directly enhance both the returns on in-house R&D and on equity. However, if $\sigma = 0$, it is shown that a corporate tax cut unambiguously enhances quality growth in the steady state. Furthermore, if α and β are sufficiently low, a capital gains tax cut enhances quality growth in the steady state.

[12] If $\sigma = 1$, a corporate tax cut also has the same qualitative effect as a dividend tax cut. When in-house R&D expenditures are fully deductible against corporate tax, no qualitative difference exists between the dividend tax and corporate tax.

4 Numerical analysis

4.1 Data and methodology

Since analytically examining the transitional adjustment of aggregate economy in response to various tax changes is complicated, we calibrate the model with U.S. data by using relaxation algorithm method developed by Trimborn, Koch, and Steger (2008).[13]

As the benchmark, we use the value of all tax variables, following the methodology in Peretto (2011).[14] The values of θ and ρ are set to 0.30 and 0.04, respectively, which are conventional values in the macroeconomic literature. The value of λ is set to 0.01, which is consistent with the average annual population growth rate in the U.S. economy. The parameter choice associated with adjustment costs, h, is less clear. According to Schubert and Turnovsky (2011), the parameter of adjustment costs for physical capital investment is generally assumed to fall within 10-15 in the literature [e.g., Ortigueira and Santos (1997) and Auerbach and Kotlikoff (1987)]. Bernstein and Nadiri (1989) and Himmelberg and Petersen (1994) report the extent to which adjustment costs associated with R&D investment equals or surpasses than that associated with physical capital investment. Therefore $h = 12.0$ is employed as the benchmark. The parameter associated with entry costs, β, is also less clear. Following Peretto (2011), we employ $\beta = 6.55$ as the benchmark.[15] The values of α and ϕ are set to 0.141 and 0.266, respectively, so that the consumption ratio and growth rate of output in the steady state are 0.69 and 0.02, respectively. ζ is set to 1.459 so that the fraction of time devoted to labor supply is 0.33.

Table 1 summarizes the benchmark parameter values. Table 2 reports the values of key endogenous variables in the steady-state equilibrium, $\{n^*, c^*, \tilde{q}^*, l^*, r^*, \hat{y}^*\}$, which are characterized under the benchmark parameter setting.

[13] Trimborn, Koch, and Steger (2008) details the relaxation algorithm. They also provide MATLAB programs for the relaxation algorithm, which are downloadable for free at http://www.wiwi.uni-siegen.de/vwli/forschung/relaxation/matlab_applications.html?lang=de. Using this method, Strulik and Trimborn (2010) examine how both anticipated and temporary tax reforms affect the aggregate economy within the framework of the neoclassical (exogenous) growth model.

[14] R&D costs are in fact fully deductible against corporate tax liability in the U.S. tax code. However, setting $\sigma = 0$ allows us to clearly see the fundamental distinction between corporate and dividend taxes. If R&D costs are assumed to be fully deductible ($\sigma = 1.0$), then a corporate tax cut has the same qualitative effects upon the economy as a dividend tax cut.

[15] See Peretto (2011) for a detailed explanation of this estimation.

Table 1: Benchmark parameter setting

Parameter	Benchmark Value	Description
g	0.143	Government expenditure share
τ_D	0.35	Dividend tax rate
σ	0.0	R&D tax credit rate
τ_Π	0.335	Corporate tax rate
τ_V	0.20	Capital gains tax rate
τ_C	0.05	Consumption tax rate
τ_L	0.256	Labor income tax rate
α	0.141	Appropriable quality
$1-\theta$	0.7	Labor share
h	12.0	The extent of adjustment costs
ϕ	0.266	The extent of fixed operating costs
β	6.55	The extent of entry costs
ζ	1.459	Preference for leisure
ρ	0.04	Time discount rate
λ	0.01	Population growth rate

Table 2: Steady-state equilibrium values (benchmark)

n^*	c^*	$\tilde{q}^*$	l^*	r^*	$\hat{y}^*$
0.0256	0.69	1.24	0.33	0.06	0.02

In what follows, we investigate the specific transitional adjustments in key macro variables and welfare induced by the following specific tax changes: (a) a 10% point reduction in the dividend tax rate, (b) a 10% point reduction in the corporate tax rate, (c) a 10% point reduction in the capital gains tax rate, and (d) a 20% point rise in the R&D tax credit rate. In addition, we consider the following three different implementation scenarios: (1) an unanticipated and permanent tax change, (2) an anticipated and permanent tax change, and (3) an unanticipated and temporary tax change. In every scenario, the economy initially (at $t = 0$) remains in the steady-state equilibrium before the tax change. In implementation scenario (1), each tax change suddenly comes into effect at $t = 5$ and lasts forever from that point forward. In implementation scenario (2), all economic agents expect at $t = 0$ that each tax change will be implemented at $t = 5$ and last forever from that point on. In implementation scenario (3), each tax change comes into effect unexpectedly at $t = 0$ and but reverts to its initial level after $t = 10$. This reversion is expected by all economic agents at $t = 0$.

Figures 2-5 show the transitional path of key macro variables in response to each tax change within the different implementation scenarios as given above. Specifically, each panel of these figures represents the transitional path of: (1) the number of firms per capita (n_t), (2) the consumption ratio (c_t), (3) modified q ($\tilde{q}_t$), (4) hours worked per capita (l_t), (5) the interest rate (r_t), (6) the growth rate of outputs per workers ($\hat{y}_t$), (7) the ratio of after-tax dividend payments to firm value, and (8) the ratio of distortionary tax revenue to outputs. The horizontal axes in each panel measures years. In the vertical axes, r_t and $\hat{y}_t$ are measured by their actual values, whereas all the other variables are measured by their percentage deviation from pre-reform levels.

Table 3 reports welfare consequences arising from the tax changes. Welfare level is measured as a consumption equivalent: what constant relative increases in annual consumption per capita must be induced so that households' pre-reform utility levels equal the household utility levels in the case where the economy moves to a new steady-state equilibrium due to the tax change.[16]

Table 3: Welfare gains of tax changes (benchmark)

Policy change	Unanticipated (Permanent)	Anticipated (Permanent)	Temporary
$\Delta t_D = -0.1$	-14.0	-11.17	-8.19
$\Delta t_\Pi = -0.1$	5.03	5.67	0.64
$\Delta t_V = -0.1$	13.56	10.78	7.86
$\Delta \sigma = 0.2$	10.86	9.58	4.87

Note: Welfare gains are measured in consumption equivalent and expressed in percentage points.

[16] More formally, welfare differences are evaluated as follows. $U_0^O(c^O, l^O, \hat{y}^O, n^O)$ is defined as a household's level of the utility in the case where the economy remains in the initial steady-state equilibrium before a tax change. We define $U_0^N(c_t^N, l_t^N, \hat{y}_t^N, n_t^N)$ as in the case when the economy moves to the new steady-state equilibrium due to the tax changes. Here, we measure the consumption equivalent by δ, which is defined as the value that satisfies $U_0^O(c^O(1+\delta), l^O, \hat{y}^O, n^O) = U_0^N(c_t^N, l_t^N, \hat{y}_t^N, n_t^N)$. See Appendix 6 for details on how to calculate household utility levels.

4.2 Dividend tax cut

Figure 2-(a) shows the impulse responses by key macro variables to the 10% point permanent dividend tax cut under the benchmark parameter setting. The dashed lines in the panels of Figure 2-(a) plot the impulse responses in the case where the permanent tax cut is unanticipated. When the tax cut is implemented (at $t = 5$), the consumption ratio and modified q instantaneously fall, whereas the number of firms per capita starts to rise. These variables gradually converge to the new steady-state level. Hours worked reacts in a contrary manner against the consumption ratio. The growth rate of output per worker falls from 0.02 to 0.0148 at $t = 5$ before it converges to 0.0152. The tax cut is detrimental to quality growth during all transition phases. Since the tax cut proportionally and permanently increases both after-tax gross cash flows and the cost of in-house R&D at the same time, it therefore has no direct effect on a firm's incentive to conduct in-house R&D. It only directly increases dividend payments and returns on equity, which lead to product proliferation.[17] This negatively impacts the incentives to in-house R&D.

Table 3 shows that the tax cut carries welfare costs of around 14% points of per capita annual consumption. The negative welfare consequence results from the decline of consumption and household leisure times as well as the slowdown of quality growth.

If the permanent tax cut is anticipated, then the impulse responses, which are plotted by the solid lines in Figure 2-(a), become quite different. When the news arrives (at $t = 0$), households and firms can incorporate the future tax cut and change their intertemporal behavior. At $t = 0$, all variables rather than the state variable (the number of firms per capita) instantaneously changes. The consumption ratio falls, whereas modified q jumps up and the growth rate of per worker output rises from 0.02 to 0.025. During the announcement phase, the consumption ratio further decreases, whereas modified q increases and the growth rate of per worker output continues to rise. The number of firms per capita gradually rises through the general equilibrium effect. After the tax cut is implemented (at $t = 5$), both the consumption ratio and the number of firms per capita

[17] The interest rate (returns to equity) jumps at $t = 5$ as the tax cut directly increases after-tax dividend payments. During the transition, however, the interest rate gradually decreases, eventually falling below the pre-reform level because product proliferation lowers both pre-tax dividend payments as well as capital gains (which equals rate of quality growth) at the individual-firm level.

gradually increase to converge to a new steady-state level. On the other hand, at $t = 5$, modified q and the growth rate of output per worker drastically drops lower than they were pre-reform values. Then they also converge to a new steady-state level.

Why does a lag in implementing the tax cut have a positive impact on quality growth during the announcement phase? Recall that the dividend tax cut proportionally increases both after-tax gross cash flows and the cost of in-house R&D. However, during the announcement phase, anticipated future tax cuts increases the future after-tax gross cash flows but do not change the cost of in-house R&D. Since firms can adjust their investment plan dynamically, the anticipated tax cut has a direct positive effect on a firm's incentive to conduct in-house R&D activities up to the point when the tax cut is actually implemented. This positive effect outweighs the negative effect derived from product proliferation during the announcement phase.

Table 3 shows that the tax cut is estimated to impose the loss of around 11.17% points of annual consumption per capita, indicating that the welfare costs are mitigated compared to the welfare effect of an unanticipated tax cut. This outcome reflects the fact that the rate of quality growth temporarily increases during the announcement phase, whereas consumption and hours worked adjust more smoothly.

Figure 2-(b) shows the impulse responses to a temporary 10% point dividend tax cut under the benchmark setting. When the tax cut is implemented (at $t = 0$), all variables other than the state variable instantaneously change. After the tax cut is terminated (at $t = 10$), all variables gradually revert to their pre-reform levels. Remarkably, during implementation, modified q declines more sharply compared to the case of the permanent tax cut. At $t = 0$, the growth rate of output per worker falls to 0.0125 and then decrease further until the tax cut is terminated, in reaction to the temporary increase in the cost of conducting in-house R&D. As Table 3 shows, the temporary dividend tax cut yields welfare costs of an estimated 8.2% points of per capita annual consumption.

4.3 Corporate tax cut

Figures 3-(a, b) show the impulse responses to a 10% point corporate tax cut under the benchmark parameter setting. Except for modified q and the growth rate of output per workers, the impulse responses are qualitatively similar to those found in the case of the dividend tax cut. If the tax cut is unanticipated, then at $t = 5$, modified q jumps up and the growth rate of output per workers rises to 0.0219. These variables then further increase to the new steady-state level. If the tax cut is anticipated, then at $t = 0$, modified q jumps up and the growth rate of output per workers rises to 0.0210. Again, these variables then further increase to the new steady-state level. If the tax cut is temporary, the effect on quality growth is also positive during all transitional phases.

Why does the tax cut unambiguously exert a positive impact on the quality growth during all phases of the transition irrespective of implementation? Recall that under the benchmark parameter setting, in-house R&D expenditures are not deductible against corporate tax ($\sigma = 0$). Therefore, while tax cut directly increases after-tax gross cash flows, it does not change the cost to conduct in-house R&D. Hence, the tax cut has a direct positive effect on incentives to conduct in-house R&D, and also leads to product proliferation, which results in a negative effect on incentives to conduct in-house R&D. However, the former positive direct effect outweighs the latter negative effect. Table 3 shows that the welfare effect is positive irrespective of implementation method.

4.4 Capital gains tax cut

Figure 4-(a) shows the impulse the responses to the unanticipated (or anticipated) and permanent 10% point capital gains tax cut under the benchmark parameter setting. Although the steady-state effect of a capital gains tax cut on quality growth is qualitatively ambiguous, our calibration shows that the tax cut increases the quality growth rate in the new steady state.[18] If the permanent tax cut is unanticipated, modified q initially rises before converging to the new steady-state level. During all transition phases, the quality growth rate is higher than its pre-reform level. Table 3 shows that the tax cut yields welfare

[18]The subsequent robustness checks shows that the steady state effect on quality growth is positive.

gains of around 13.56% points of per capita annual consumption.

If the permanent tax cut is anticipated, however, quality growth slows during the announcement phase. The future capital gains tax cut reduces the future cost of conducting in-house R&D so that firms have an opportunity to dynamically adjust their investment plans and thus delay in-house R&D investments. This effect dominates the other effects. Although the overall effect of the capital gains tax cut on welfare remains positive, the temporary slowdown of quality growth has a negative effect on welfare. On the other hand, the anticipated tax cut makes household behavior more smoothly, resulting in a positive effect on welfare. However, the latter positive effect cannot outweigh the former negative effect. As a result, the anticipated tax cut reduces welfare gains by 2.77% points compared to the welfare effect of the unanticipated tax cut.

Figure 4-(b) shows the impulse response to a temporary 10% point capital gains tax cut under the benchmark parameter setting. Remarkably, quality growth accelerates during its implementation. This temporary acceleration of quality growth is more significant compared to the steady-state effect of the permanent tax cut. Mainly, this occurs because the temporary tax cut reduces the cost of conducting in-house R&D during its implementation. As Table 3 shows, the temporary tax cut also yields welfare gains of an estimated 7.86% points of per capita annual consumption.

4.5 Increases in the R&D tax credit rate

Figure 5-(a) shows impulse responses to the unanticipated (or anticipated) 20% point permanent increase in the R&D tax credit rate under the benchmark parameter setting. The tax change increases the steady-state rate of quality growth. Remarkably, in the steady state, the tax changes is shown to be self-financing: the ratio of distortionary tax revenues to output is higher than pre-reform levels. If the permanent tax change is unanticipated, then during all transition phases, both the growth rate of outputs per workers and the consumption ratio are higher than their pre-reform levels. As Table 3 shows, the tax change yields welfare gains estimated to be around 10.86% points of per capita annual consumption.

On the other hand, if the permanent tax change is anticipated, modified q and the growth rate of output per workers are lower than their pre-reform levels during the announcement phase. This findings parallel that in the case of the anticipated capital gains tax cut. Future rises of the R&D tax credit rate directly reduce the future cost of conducting in-house R&D, leading firms to delay in-house R&D investments until after the tax change is implemented. This negative effect dominates the other effects. As a result, although the tax cut has an overall positive effect on welfare, the implementation lags from the tax change reduce these welfare gains by 1.28% points of per capita annual consumption, compared to the welfare effect of the unanticipated tax change.

Figure 5-(b) shows the impulse responses to a temporary 20% point increase in the tax credit rate under the benchmark parameter setting. The effect on quality growth parallels that found in the case of the temporary capital gains tax cut. Temporary increases in the R&D tax credit rate reduce the cost of conducting in-house R&D during its implementation. Furthermore, the temporary acceleration of quality growth is more significant compared to the steady-state effect of the permanent tax change. As Table 3 shows, the temporary tax change also yields welfare gains estimated to be around 4.87% points of per capita annual consumption.

5 Sensitivity analysis

5.1 Parameter changes

We now conduct robustness checks for identified tax changes effects by changing certain parameters. First, we consider increasing or decreasing the value of the unclear parameter, β and h. Specifically, we increase or decrease the values of β and h by 50% points.[19] In all these cases, we re-estimate α and ϕ so that the consumption ratio and the growth rate of output in the pre-reform steady-state equilibrium remain the same as in the benchmark parameter setting. We find that the impulse responses are qualitatively the same as in the benchmark analysis. As Table 4 reports, the welfare consequences of tax changes are

[19] If we reduce the value of h by 50% points (i.e., we set to $h = 6.0$), the growth rate of output per workers becomes negative. To assure an interior solution, we set $h = 8.0$ alternatively.

quantitatively modified but our main findings in the benchmark analysis qualitatively hold.

Second, we consider the case of $\sigma = 1.0$. In fact, the U.S. tax code sets $\sigma = 1.0$ even though in the benchmark analysis, we set to $\sigma = 0.0$. Our analysis shows that except for the case of the corporate tax cut, the impulse responses and welfare consequences remain qualitatively the same as in the benchmark analysis. We also find that the impulse responses to the corporate tax cut are qualitatively the same as those to the dividend tax cut. As Table 4 reports, the welfare consequence is almost identical to that found in the dividend tax cut.[20] This similarity reflects the fact that a corporate tax cut has the same effects as a divided tax cut if in-house R&D investments are fully tax deductible.

We then consider the case in which labor supply is inelastic (i.e., $\zeta = 0$). The impulse responses in $\zeta = 0$ are qualitatively the same as those found in the benchmark analysis. As Table 4 reports, the welfare consequences of tax changes are quantitatively modified but our main findings in the benchmark analysis qualitatively hold.

5.2 Social returns to product variety

In the model as described thus far, and as (18) shows, the number of firms (product variety) per capita does not directly contribute to the production of final goods. Given the aggregate market demand for intermediate goods, changes in the number of firms per capita merely affect the market structure for intermediate goods firms. The policy that leads to a higher number of firms per capita indirectly distorts incentives for a firm to conduct in-house R&D. In this section, we relax this somewhat extreme feature. Along the lines of Peretto (2007, 2011), we consider the case where socially positive returns to product variety exist for the production of final goods as follows:

$$Y_t = n_t^v \int_0^{N_t} X_{it}^{\theta} \left(Z_{it}^{\alpha} \bar{Z}_t^{1-\alpha} L_{it} \right)^{1-\theta} di, \quad v > 0,$$

where the contribution of product variety on final goods output is assumed to be external to all agents. In this case, the reduced-form production function of final goods can be

[20]Note that initially, the corporate tax rate is set to 0.335, whereas the dividend tax rate is set to 0.35.

rewritten by

$$Y_t = n_t^{\kappa}\Omega l(c_t)e^{\lambda t}Z_t, \quad \kappa \equiv \frac{v}{1-\theta}.$$

The dynamic system of the economy is modified as follows:

$$\begin{aligned}
\dot{n}_t &= \left[1-\theta^2-g-c\right]\frac{\Omega l(c_t)}{\beta n_t^{-\kappa}} - \left[\phi + \frac{(Sq_t)^2-1}{2h} + \beta\lambda\right]\frac{n_t}{\beta}, \\
\dot{c}_t &= c_t\left[1+\Gamma c_t\right]\left[r_t - \rho - \frac{Sq_t-1}{h} - \kappa\frac{\dot{n}_t}{n_t}\right], \\
\dot{q}_t &= \frac{1}{1-\tau_V}r_t q_t - \frac{\alpha\theta(1-\theta)}{S\eta}\frac{\Omega l(c_t)}{n_t^{1-\kappa}} - \frac{(Sq_t-1)^2}{2Sh},
\end{aligned}$$

where

$$r_t = \frac{(1-\tau_V)}{\beta S\eta}\left[\theta(1-\theta)\frac{\Omega l(c_t)}{n_t^{1-\kappa}} - \phi - \eta\frac{(Sq_t)^2-1}{2h}\right] + (1-\tau_V)\frac{Sq_t-1}{h}.$$

The growth rate of output per workers is given by $\frac{\tilde{q}_t-1}{h} + \kappa\frac{\dot{n}_t}{n_t}$. Since the steady-state number of firms per capita is constant, the steady-state growth rate of output is only dependent of modified q, as is also the case for $\kappa = 0$. If $\kappa > 0$, then the steady-state number of firms per capita is given by $(n^*)^{\frac{1}{1-\kappa}}$, where n^* is consistent with the steady-state value in the case of $\kappa = 0$. The other steady-state values coincide with those in the case of $\kappa = 0$. That is, social returns to product variety ($\kappa > 0$) simply add to the direct positive effect on the production of final goods, and they only change the steady-state value of the number of firms per capita; thus, the steady-state effect from tax changes upon macroeconomic variables is consistent with the case of $\kappa = 0$.

The impulse responses of key macro variables not involving the growth rate of output per workers are qualitatively the same as in the case of $\kappa = 0$. The growth rate of output per workers is also dependent on the transition growth rate of the number of firms per capita. If the intensity of the growth rate for the number of firms per capita dominates that for quality growth, then the impulse response of the growth rate of output per workers is modified. As an example, Figures 6 (a, b) depict the impulse responses to a 10% point dividend tax cut in the case of $\kappa = 0.3$. The figure shows that even if the tax cut is unanticipated and permanent (or temporary), the growth rate of output per workers initially shows a sharp increase. That is, the positive growth rate in the number of firms per capita initially outweighs the slowdown in quality growth.

In the case of $\kappa > 0$, household welfare is also dependent of the number of firms per capita. Higher product variety directly increases household welfare. Table 5 reports the welfare consequences of tax changes in the cases of $\eta = 0.1, 0.3, 0.5$, and 0.7. As the intensity of social return to product variety, η, increases, welfare losses arising from the dividend tax cut are mitigated, while the welfare gains resulting from the corporate tax cut increase significantly. On the other hand, the welfare gains resulting from the capital gains tax cut increase, while the welfare gains resulting from increases in the R&D tax credit rate are reduced, but these variations are not significant compared to the impacts from cuts in the rate of dividend and corporate taxes. In any tax change, however, the sign of the welfare effect does not change, and the effect of implementation lags holds qualitatively, as in the case of the benchmark analysis.

6 Concluding remarks

We first summarize our results and then discuss their implications.

A dividend tax cut reduces the level of welfare irrespective of implementation method. After implementation, the tax cut is detrimental to both in-house R&D and aggregate growth. Consumption and household leisure time also decrease. Therefore, the tax cut yields overall welfare losses. However, an anticipated tax cut stimulates in-house R&D and aggregate growth during the pre-implementation announcement phase. Households also can adjust the timing of their consumption and leisure more smoothly. Both these effects arising from the foreknowledge of the tax cut have a positive effect on welfare. Therefore, pre-announcement mitigates the welfare losses compared to the case of an unanticipated tax cut, although the overall welfare effect still remains negative. On the other hand, the policy effect of a corporate tax cut is dependent on the specific R&D tax credit rate.

A capital gains tax cut and increases in the R&D tax credit rate lead to welfare gains irrespective of implementation method. After implementation, these tax changes stimulate in-house R&D and aggregate growth. The acceleration of quality growth yields welfare gains. However, anticipated tax changes are detrimental to in-house R&D and aggregate growth during the pre-implementation announcement phase. Although anticipated tax changes lead households to smooth their behavior, which yields a positive effect on welfare, this positive effect cannot outweigh the negative welfare effect derived from temporary slowdowns of quality growth. As a result, the pre-announcement of these tax changes worsens their effectiveness, although the overall welfare effect still remains positive.

Our analysis suggests that a capital gains tax cut and increases in the R&D tax credit rate are effective policy instruments. However, when considering their implementation in terms of scope and timing, policy makers should be careful to ensure that their effectiveness is maximized.

References

[1] Abel, A. B. (1982) "Dynamic effects of permanent and temporary tax policies in a q model of investment," *Journal of Monetary Economics*, Vol. 9, No. 3, pp. 353-373.

[2] Abel, A. B. and O. J. Blanchard (1983) "An intertemporal model of savings and investment," *Econometrica*, Vol. 51, No. 3, pp. 675-692.

[3] Adams, J. D. and A. B. Jaffe (1996) "Bounding the effects of R&D: An investigation using matched establishment-firm data," *The RAND Journal of Economics*, Vol. 27, No. 4, pp. 700-721.

[4] Ang, J. B. and J. B. Madsen (2011) "Can second-generations endogenous growth models explain the productivity and knowledge production in the asian miracle economies?," *The Review of Economics and Statistics*, Vol. 93, No. 4, pp. 1360-1373.

[5] Auerbach, A. and L. Kotilikoff (1987) "Dynamic fiscal policy," Cambridge Univ. Press.

[6] Bernstein, J. I. and M. I. Nadiri (1989) "Rates of return on physical and R&D capital and structure of the production process: Cross section and time series evidence," *Advances in Econometrics and Modelling*, Kluwer Academic Publishing, Dordrecht, pp. 169-185.

[7] Brown, J. R. and B. C. Petersen (2011) "Cash holdings and R&D smoothing," *Journal of Corporate Finance*, Vol. 17, No. 3, pp. 694-709.

[8] Cohen, W. M. and S. Klepper (1996) "Firm size and the nature of innovation within industries: The case of process and product R&D," *Review of Economics and Statistics*, Vol. 78, No. 2, pp. 232-243.

[9] Grossman, G. M. and E. Helpman (1991) "Innovation and growth in the global economy," The MIT Press.

[10] Futagami, K. and Y. Ohkusa (2003) "The quality ladder and product variety: Larger economies may not grow faster," *Japanese Economic Review*, Vol. 54, No. 3, pp. 336-351.

[11] Ha, J. and P. Howitt (2007) "Accounting for trends in productivity and R&D: A schumpeterian critique of semi-endogenous growth theory," *Journal of Money, Credit and Banking*, Vol. 39, No. 4, pp. 733-744.

[12] Hassett, K. A. and R. G. Hubbard (2002) "Chapter 20-tax policy and business investment," *Handbook of Public Economics*, Vol. 3, pp. 1293-1343.

[13] Hall, B. and J. V. Reenen (2000) "How effective are fiscal incentives for R&D? A review of the evidence," *Research Policy*, Vol. 29, No. 4-5, pp. 449-469.

[14] Hayashi, F. (1982) "Tobin's marginal q and average q: A neoclassical interpretation," *Econometrica*, Vol. 50, No. 1, pp. 213-224.

[15] Himmelberg, C. P. and B. C. Petersen (1994) "R&D and internal finance: A panel study of small firms in high-tech industries," *Review of Economics and Statistics*, Vol. 76, No. 1, pp. 38-51.

[16] Howitt, P. (1999) "Steady endogenous growth with population and R&D inputs growing," *Journal of Political Economy*, Vol. 107, No. 4, pp. 715-730.

[17] Jones, C. I. (1995a) "Time series tests of endogenous growth models," *The Quarterly Journal of Economics,* Vol. 110, No. 2, pp. 495-525.

[18] Jones, C. I. (1995b) "R&D-based models of economic growth," *Journal of Political Economy*, Vol. 103, No. 4, pp. 759-784.

[19] Laincz, C. A. and P. F. Peretto (2006) "Scale effects in endogenous growth theory: an error of aggregation not specification," *Journal of Economic Growth*, Vol. 11, No. 3, pp. 263-288.

[20] Ortigueira, S. and M. S. Santos (1997) "On the speed of convergence in endogenous growth models," *The American Economic Review*, Vol. 87, No. 3, pp. 383-399.

[21] Pagano, P. and F. Schivardi (2003) "Firm size distribution and growth," *The Scandinavian Journal of Economics*, Vol. 105, No. 2, pp. 255-274.

[22] Peretto, P. F. (1998) "Technological change and population growth," *Journal of Economic Growth*, Vol. 3, No. 4, pp. 283-311.

[23] Peretto, P. F. (2003) "Fiscal policy and long-run growth in R&D-based models with endogenous market structure," *Journal of Economic Growth*, Vol. 8, No. 3, pp. 325-347.

[24] Peretto, P. F. (2007) "Corporate taxes, growth and welfare in a schumpeterian economy," *Journal of Economic Theory*, Vol. 137, No. 1, pp. 353-382.

[25] Peretto, P. F. (2011) "The growth and welfare effects of deficit-financed dividend tax cuts," *Journal of Money, Credit, and Banking*, Vol. 43, No. 5, pp. 835-869.

[26] Romer, P. M. (1990) "Endogenous technological change," *Journal of Political Economy*, Vol. 98, No. 5, pp. S71-S102.

[27] Schubert, S. F. and S. J. Turnovsky (2011) "The impact of oil prices on an oil-importing developing economy," *Journal of Development Economics*, Vol. 94, No. 1, pp. 18-29.

[28] Segerstrom, P. S. (1998) "Endogenous growth without scale effects," *American Economic Review*, Vol. 88, No. 5, pp. 1290-1310.

[29] Summers, L. H. (1981) "Taxation and corporate investment: A q-theory approach," *Brookings Papers on Economic Activity*, Vol. 1981, No. 1, pp. 67-140.

[30] Trimborn, T., K.-J. Koch and T. M. Steger (2008) "Multi-dimensional transitional dynamics: A simple numerical procedure," *Macroeconomic Dynamics*, Vol. 12, No. 3, pp. 301-319.

[31] Trimborn, T. and T. M. Steger (2010) "Anticipated tax reforms and temporary tax cuts," *Journal of Economic Dynamics and Control*, Vol. 34, No. 10, pp. 2141-2158.

[32] Turnovsky, S. (2000) "Methods of macroeconomic dynamics," The MIT Press.

[33] Zeng, J. and J. Zhang (2002) "Long-run growth effects of taxation in a non-scale growth model with innovation," *Economic Letters*, Vol. 75, No. 3, pp. 391-403.

A Appendices

A.1 Appendix 1

The perfect distribution in the final goods sector (letting $L_{it} = L_t$) yields:

$$\theta^2 Y_t = N_t X_t, \tag{A-1}$$

$$(1-\theta) Y_t = W_t N_t L_t. \tag{A-2}$$

Using the definition of c_t, (A-2), and the market equilibrium condition of labor, $N_t L_t = e^{\lambda t} l_t$, then (15) can be rewritten as (17). Substituting (2) and the market equilibrium condition of labor to (1) yields (18).

A.2 Appendix 2

Dividing both sides of (16) by Y_t and using the definition of n_t and c_t, (A-1), and (18), we obtain

$$1 - \theta^2 - g - c_t = \frac{n_t}{\Omega l(c_t)} \left[\phi + \frac{\Phi(R_t, Z_t)}{Z_t} + \beta \left(\frac{\dot{n}_t}{n_t} + \lambda \right) \right]. \tag{A-3}$$

Dividing (5) by Z_t and using (11), we obtain

$$\frac{\Phi(R_t, Z_t)}{Z_t} = \frac{(Sq_t)^2 - 1}{2h}. \tag{A-4}$$

Substituting (A-4) to (A-3), we obtain (19).

From (A-1) together with the definition of n_t, and (18), we obtain

$$\begin{aligned}\frac{F_t}{Z_t} &= \left(\frac{1-\theta}{\theta}\right)\frac{X_t}{Z_t} - \phi, \\ &= \theta(1-\theta)\frac{\Omega l(c_t)}{n_t} - \phi. \end{aligned} \tag{A-5}$$

Using (A-4), (A-5), and (11), we can rewrite (13) as

$$\begin{aligned} r_t = &\frac{(1-\tau_D)(1-\tau_\Pi)}{\beta}\left[\theta(1-\theta)\frac{\Omega l(c_t)}{n_t} - \phi\right] - \frac{(1-\tau_D)(1-\sigma\tau_\Pi)}{\beta}\left[\frac{(Sq_t)^2-1}{2h}\right] \\ &+ (1-\tau_V)\frac{Sq_t - 1}{h}. \end{aligned}$$

Then, from the definition of S and η, rearranging the above equation yields (22).

From logarithmic differentiation of c_t with respect to time yields

$$\frac{\dot{c}_t}{c_t} = \frac{\dot{C}_t}{C_t} - \frac{\dot{Y}_t}{Y_t} = r_t - \rho + \lambda - \left\{\frac{\dot{l}(c_t)}{l(c_t)} + \lambda + \frac{\dot{Z}_t}{Z_t}\right\}.$$

Using (17) and (11), the above equation can be rewritten as

$$\frac{\dot{c}_t}{c_t} = r_t - \rho + \frac{\Gamma \dot{c}_t}{1+\Gamma c_t} - \frac{Sq_t - 1}{h}. \tag{A-6}$$

Rearranging (A-6) yields (20).

From (2), (8), and the market equilibrium condition of labor, we obtain

$$\frac{\partial F_t}{\partial Z_t} = \alpha\theta(1-\theta)\frac{\Omega l(c_t)}{n_t}. \tag{A-7}$$

Using the definition of S and η, (11), and (A-7), we can rewrite (10) as

$$\frac{\alpha\theta(1-\theta)}{S\eta}\frac{\Omega l(c_t)}{n_t}+\frac{(Sq_t-1)^2}{2Sh}=\frac{1}{1-\tau_V}r_t q_t-\dot{q}_t.$$

Then, using (17), the above equation is rewritten as (21).

A.3 Appendix 3

The dynamical system of the economy where $q_t \leq 1$ is constituted by

$$\begin{aligned}
\dot{n}_t &= \left[1-\theta^2-g-c_t\right]\frac{\Omega l(c_t)}{\beta}-[\phi+\beta\lambda]\frac{n_t}{\beta},\\
\dot{c}_t &= c_t\left[1+\Gamma c_t\right]\left[r_t-\rho\right],\\
\dot{q}_t &= \frac{1}{1-\tau_V}r_t q_t-\frac{\alpha\theta(1-\theta)}{S\eta}\frac{\Omega l(c_t)}{n_t},
\end{aligned}$$

where the interest rate is given by

$$r_t=\frac{(1-\tau_V)}{\beta S\eta}\left[\theta(1-\theta)\frac{\Omega l(c_t)}{n_t}-\phi\right].$$

A.4 Appendix 4

Differentiating (26) with respect to $\tilde{q}$ yields

$$f'(\tilde{q}) \equiv \begin{cases}\left[1+\alpha-\dfrac{2}{1-\tau_V}\right]\dfrac{\tilde{q}}{h}+\left[\dfrac{1}{1-\tau_V}-1\right]\dfrac{S\alpha\beta+1}{h}-\dfrac{\rho}{1-\tau_V}, & \text{if } \tilde{q}>1,\\[2ex] -\dfrac{\rho}{1-\tau_V}, & \text{if } \tilde{q}\leq 1.\end{cases}$$

Moreover, second order differentiation of (26) with respect to $\tilde{q}$ yields

$$f''(\tilde{q}) \equiv \begin{cases}\left[1+\alpha-\dfrac{2}{1-\tau_V}\right]\dfrac{1}{h}<0, & \text{if } \tilde{q}>1,\\[2ex] 0, & \text{if } \tilde{q}\leq 1.\end{cases}$$

Here,

$$
\begin{aligned}
f(1) &= \frac{\rho}{1-\tau_V}\left[S\alpha\beta - 1\right] + \frac{\alpha\phi}{\eta}, \\
\lim_{\tilde{q}\to 1+0} f'(\tilde{q}) &= \frac{1}{h(1-\tau_V)}\left[\tau_V(S\alpha\beta - 1) - (1-\alpha) - h\rho\right].
\end{aligned}
$$

If $S\alpha\beta \leq 1 - \frac{(1-\tau_V)\alpha\phi}{\eta\rho}$ (< 1), $f(1) \leq 0$ and $\lim_{\tilde{q}\to 1+0} f'(\tilde{q}) < 0$. Then, $f'(\tilde{q}) < 0$ for $\tilde{q} > 1$ as $f''(\tilde{q}) < 0$ for $\tilde{q} > 1$. Therefore, in this case, $f(\tilde{q})$ has only one solution of $\tilde{q}$ with a value less than one. That is, no steady-state equilibrium exists with a positive growth rate of output. On the other hand, if $1 - \frac{(1-\tau_V)\alpha\phi}{\eta\rho} < S\alpha\beta$, then $f(1) > 0$. No matter whether $\lim_{\tilde{q}\to 1+0} f'(\tilde{q}) < 0$ is positive or negative, $f(\tilde{q})$ has unique solution of $\tilde{q}$ with a value higher than one, as depicted in Figure 1.

A.5 Appendix 5

Differentiating the RHS of (26) with respect to τ_D, τ_Π, τ_V, and σ yields

$$
\begin{aligned}
\frac{\partial f(\tilde{q})}{\partial \tau_D} &= \left\{\frac{\alpha\beta}{1-\tau_V}\rho + \left[\frac{1}{1-\tau_V} - 1\right]\alpha\beta\frac{\tilde{q}-1}{h}\right\}\frac{1}{(1-\tau_D)}S > 0, \\
\frac{\partial f(\tilde{q})}{\partial \sigma} &= \left\{\frac{\alpha\beta}{1-\tau_V}\rho + \left[\frac{1}{1-\tau_V} - 1\right]\alpha\beta\frac{\tilde{q}-1}{h}\right\}\frac{\tau_\Pi}{(1-\sigma\tau_\Pi)}S + \frac{\alpha\phi}{\eta^2}\frac{\sigma}{(1-\tau_\Pi)} > 0, \\
\frac{\partial f(\tilde{q})}{\partial \tau_\Pi} &= \left\{\frac{\alpha\beta}{1-\tau_V}\rho + \left[\frac{1}{1-\tau_V} - 1\right]\alpha\beta\frac{\tilde{q}-1}{h}\right\}\frac{\sigma}{(1-\sigma\tau_\Pi)}S - \frac{\alpha\phi(1-\sigma)}{(1-\sigma\tau_\Pi)^2} \gtreqless 0, \\
&= -\alpha\phi < 0, \quad \text{if } \sigma = 0, \\
&= \left\{\frac{\alpha\beta}{1-\tau_V}\rho + \left[\frac{1}{1-\tau_V} - 1\right]\alpha\beta\frac{\tilde{q}-1}{h}\right\}\frac{1}{(1-\tau_\Pi)}S > 0, \quad \text{if } \sigma = 1, \\
\frac{\partial f(\tilde{q})}{\partial \tau_V} &= -\frac{\rho}{(1-\tau_V)^2}\tilde{q} + \frac{\tilde{q}-1}{h(1-\tau_V)}\left[S\alpha\beta - \frac{\tilde{q}}{1-\tau_V}\right] \equiv \Gamma(\tilde{q}) \gtreqless 0.
\end{aligned}
$$

Since $f(\tilde{q})$ is a decreasing function of $\tilde{q}$ in the neighborhood around the steady-state solution, the above derivations imply that $\tilde{q}^*$ is increasing in τ_D, τ_Π (if $\sigma = 1$) and is decreasing in σ, τ_Π (if $\sigma = 0$) and the effects of tax changes in τ_Π (if $\sigma \in (0,1)$) and τ_V are ambiguous.

In addition, we also find

$$\Gamma(1) = -\frac{\rho}{(1-\tau_V)^2} < 0,$$
$$\Gamma'(\tilde{q}) = \frac{1}{(1-\tau_V)^2 h}\left[-2\tilde{q} - h\rho + 1 + S\alpha\beta(1-\tau_V)\right] \gtreqless 0,$$
$$\Gamma''(\tilde{q}) = -\frac{2}{(1-\tau_V)^2 h} < 0.$$

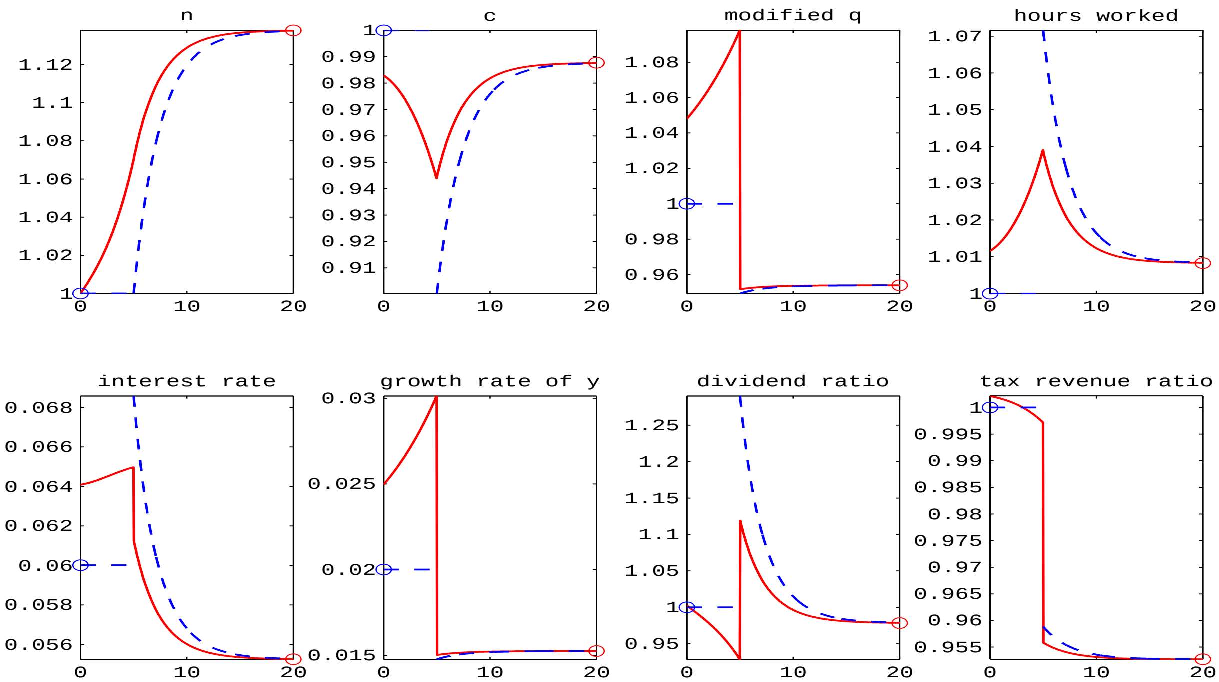
Then, if $S\alpha\beta < (1+h\rho)/(1-\tau_V)$, $\Gamma(\tilde{q}) < 0$ for $\tilde{q} > 1$. Therefore, it is shown that if $S\alpha\beta < (1+h\rho)/(1-\tau_V)$, then $\tilde{q}^*$ is a decreasing function of τ_V.

A.6 Appendix 6

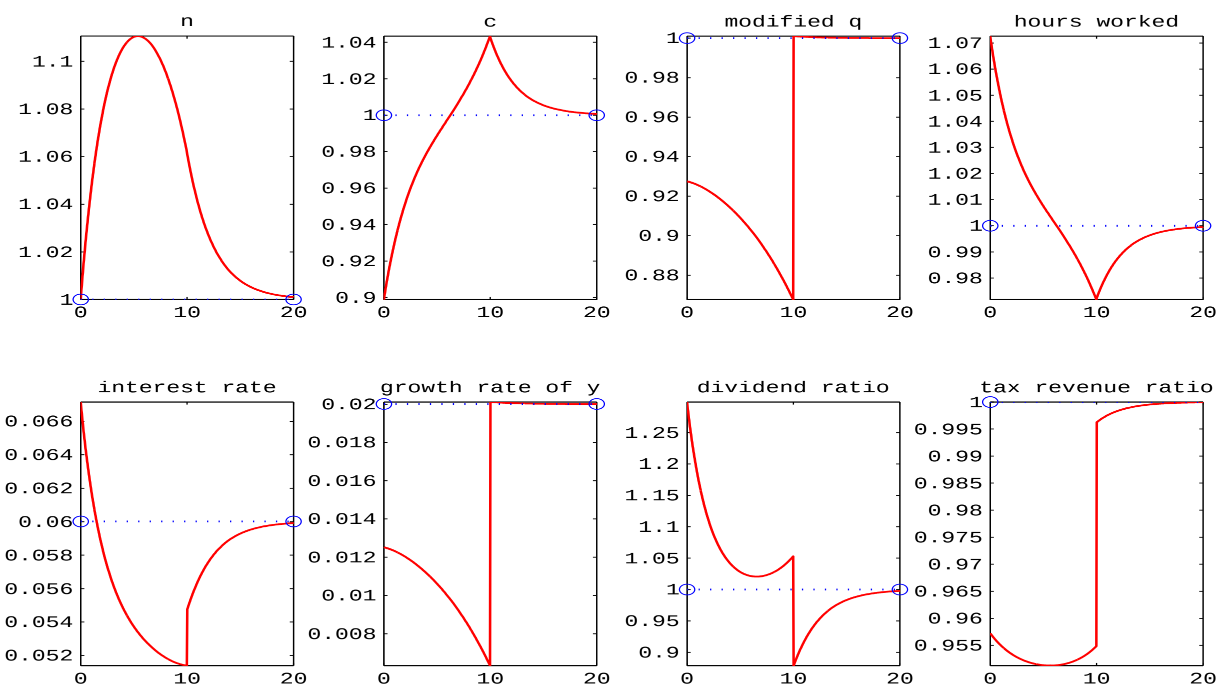
We define $\Psi_t \equiv U_t - \frac{1}{\rho-\lambda}\log Z_t$. From the definition of c_t, (11), and (18), differentiating Ψ_t with respect to time yields

$$\dot{\Psi}_t = (\rho-\lambda)\Psi_t - \log\Omega - \log c_t - \log l_t - \zeta\log(1-l_t) - \frac{1}{\rho-\lambda}\frac{Sq_t - 1}{h}.$$

In the steady state, Ψ_t is constant over time. Calculating the dynamic path of Ψ_t numerically using the relaxation algorithm, we can obtain the initial value of Ψ_t, $\Psi_0 = U_0 - \frac{1}{\rho-\lambda}\log Z_0$. Without loss of generality, Z_0 is normalized to one. Hence, we obtain $U_0 = \Psi_0$.

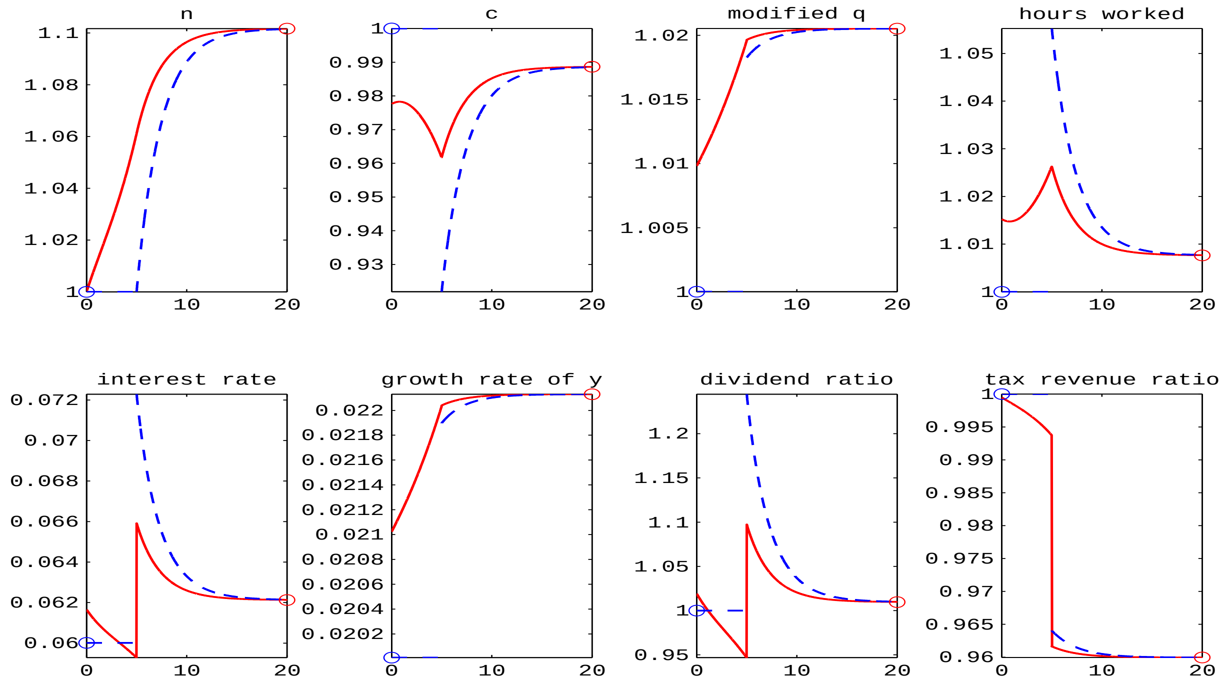


(a) **Anticipated vs. unanticipated permanent reduction in the dividend tax rate by 10 percentage points in the benchmark setting**. Solid (Dashed) lines plots the impulse response of each variable to the anticipated (unanticipated) tax cut. The circle marks on the left (right) vertical axis indicates the steady-state level before (after) the tax cut.

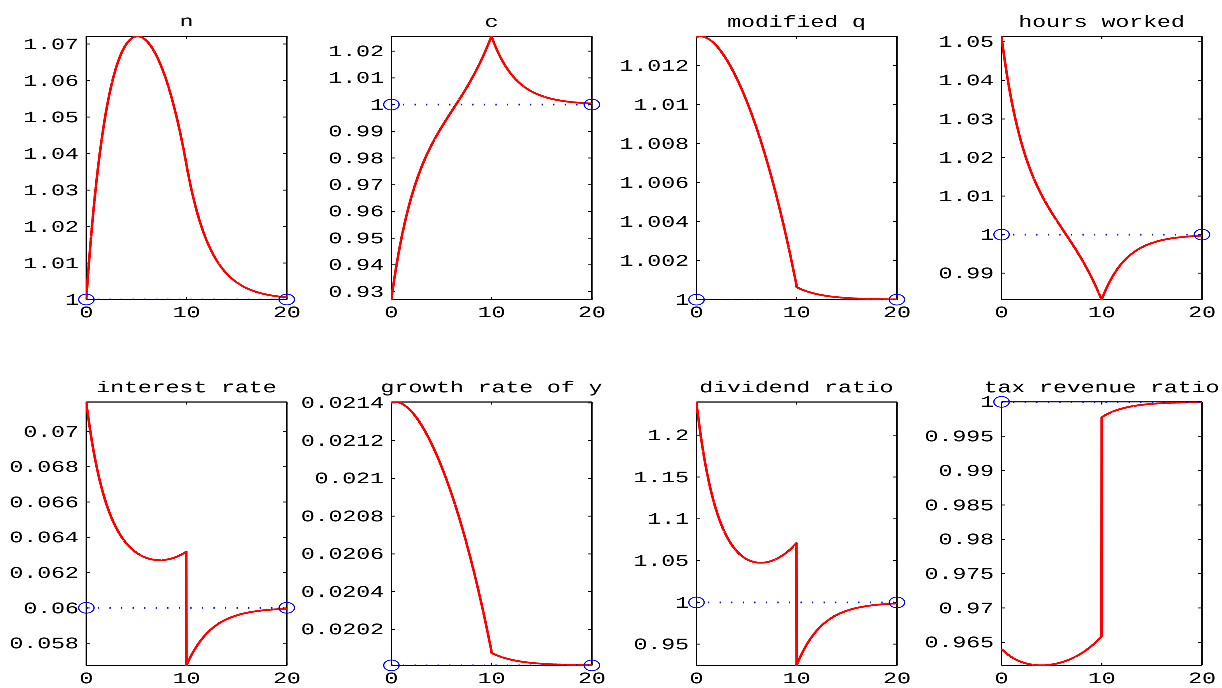


(b) **Temporary reduction in the dividend tax rate by 10 percentage points in the benchmark setting**. The circle mark on the vertical axis indicates the initial level.

Figure 2

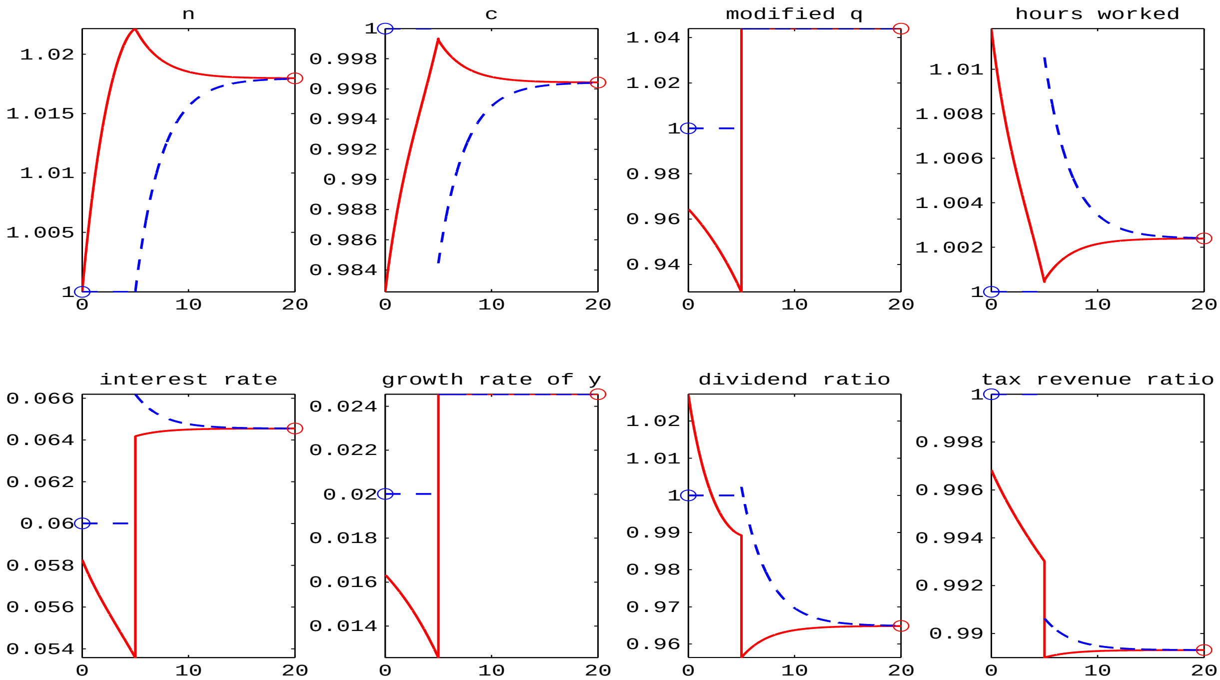


(a) **Anticipated vs. unanticipated permanent reduction in the corporate tax rate by 10 percentage points in the benchmark setting**. Solid (Dashed) lines plots the impulse response of each variable to the anticipated (unanticipated) tax cut. The circle marks on the left (right) vertical axis indicates the steady-state level before (after) the tax cut.

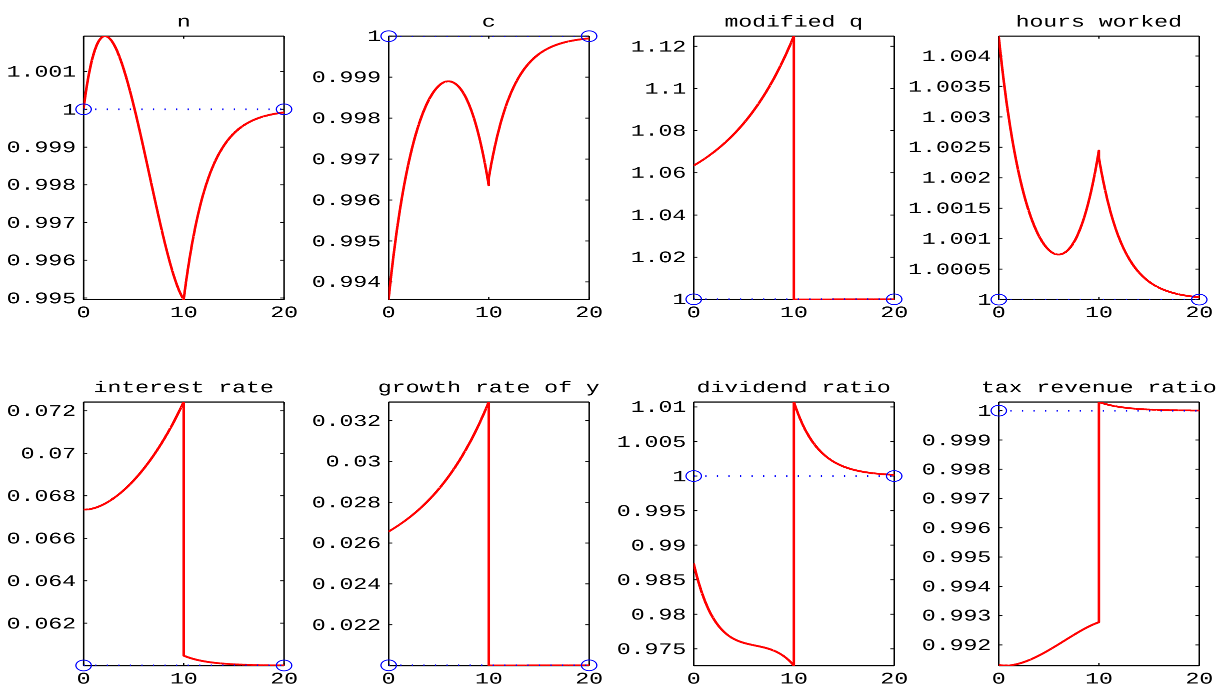


(b) **Temporary reduction in the corporate tax rate by 10 percentage points in the benchmark setting**. The circle mark on the vertical axis indicates the initial level.

Figure 3

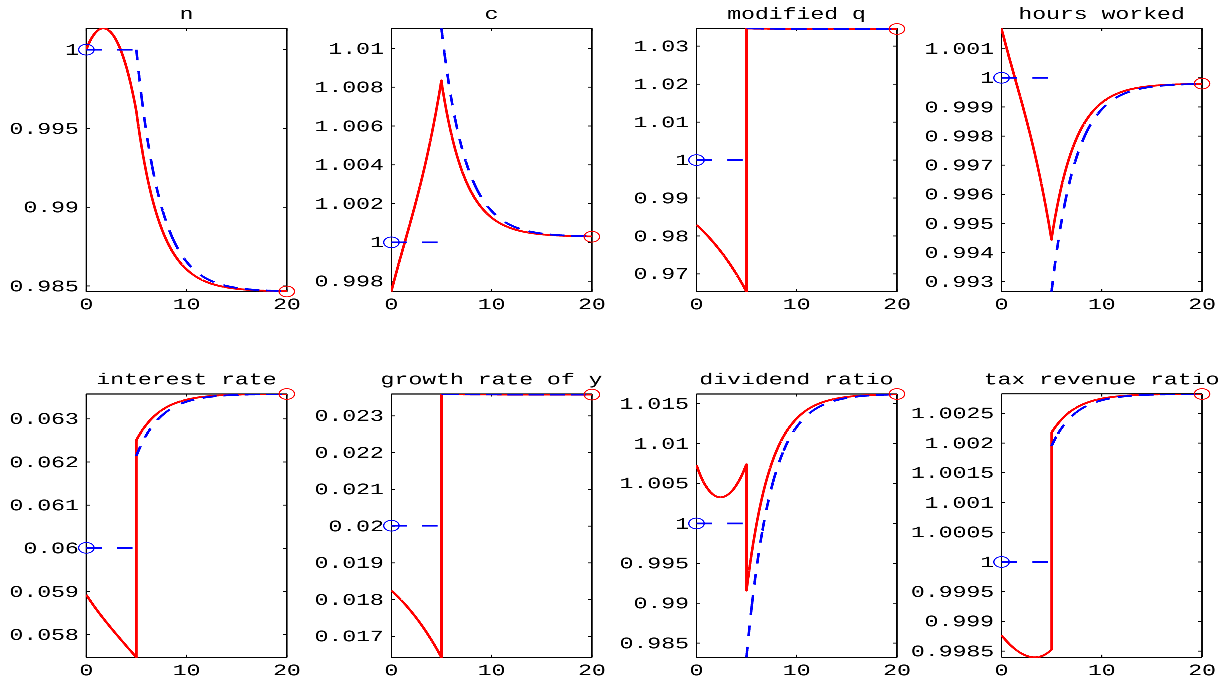


(a) **Anticipated vs. unanticipated permanent reduction in the capital gains tax rate by 10 percentage points in the benchmark setting**. Solid (Dashed) lines plots the impulse response of each variable to the anticipated (unanticipated) tax cut. The circle marks on the left (right) vertical axis indicates the steady-state level before (after) the tax cut.

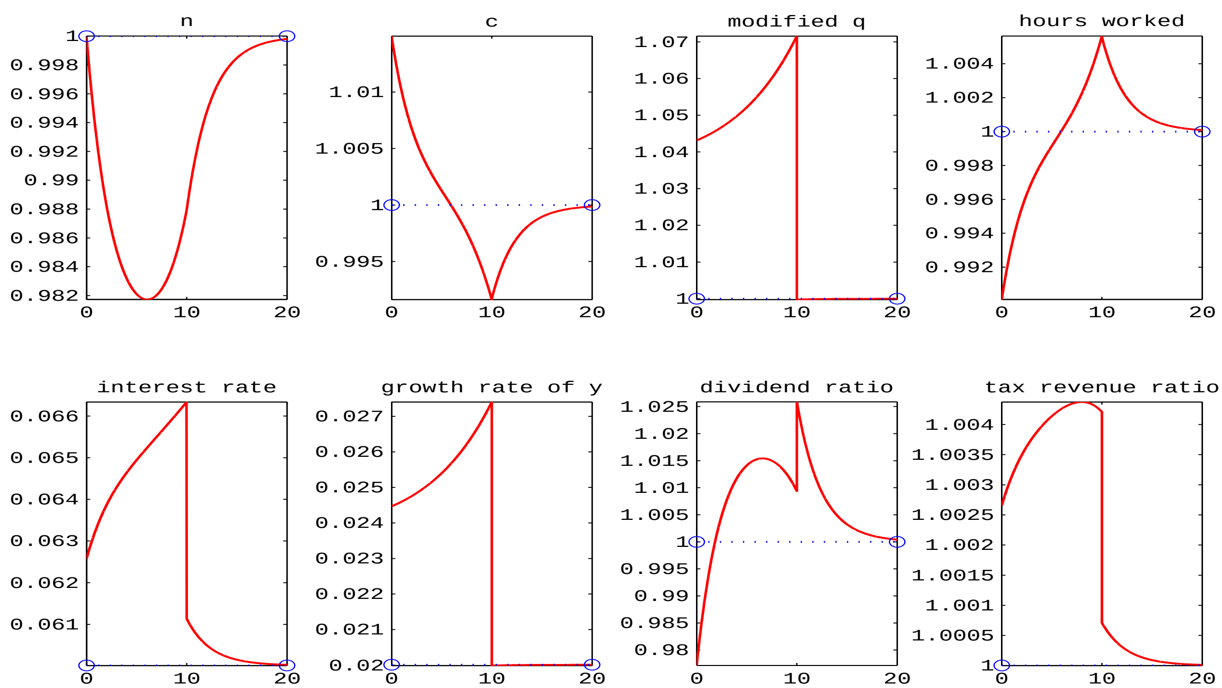


(b) **Temporary reduction in the capital gains tax rate by 10 percentage points in the benchmark setting**. The circle mark on the vertical axis indicates the initial level.

Figure 4



(a) **Anticipated vs. unanticipated permanent rise in the tax credit rate by 20 percentage points in the benchmark setting**. Solid (Dashed) lines plots the impulse response of each variable to the anticipated (unanticipated) change. The circle marks on the left (right) vertical axis indicates the steady-state level before (after) rise of the tax credit.



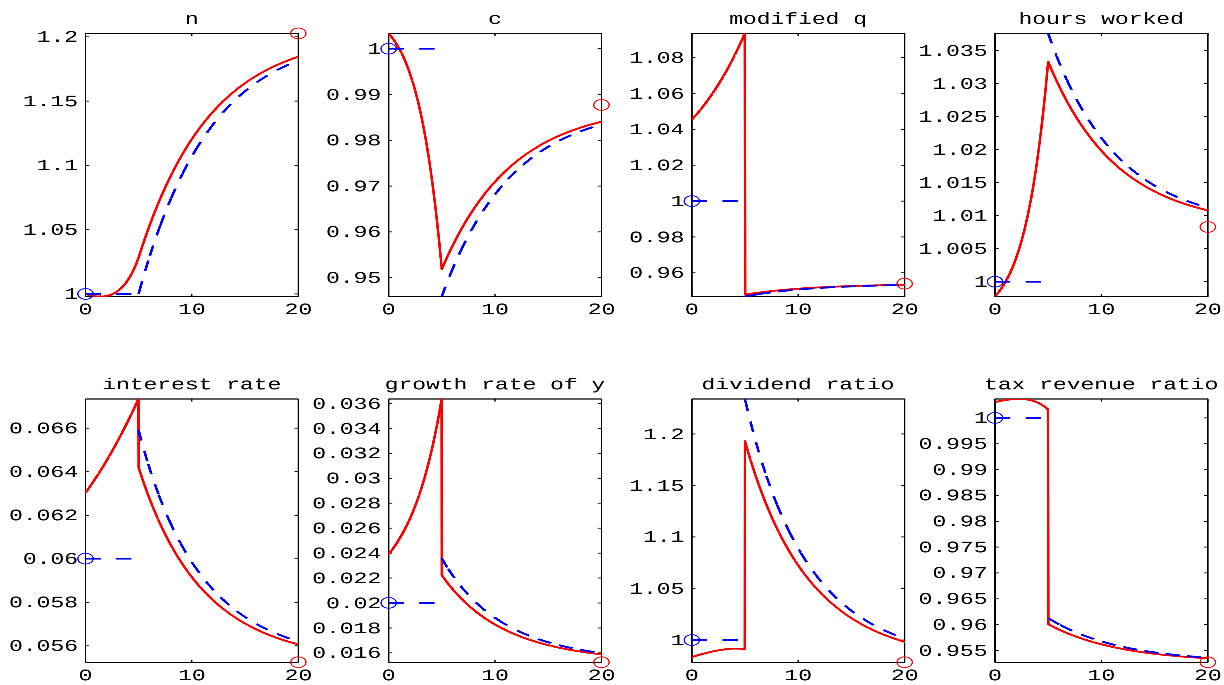
(b) **Temporary rise in the tax credit rate by 20 percentage points in the benchmark setting**. The circle mark on the vertical axis indicates the initial level.

Figure 5

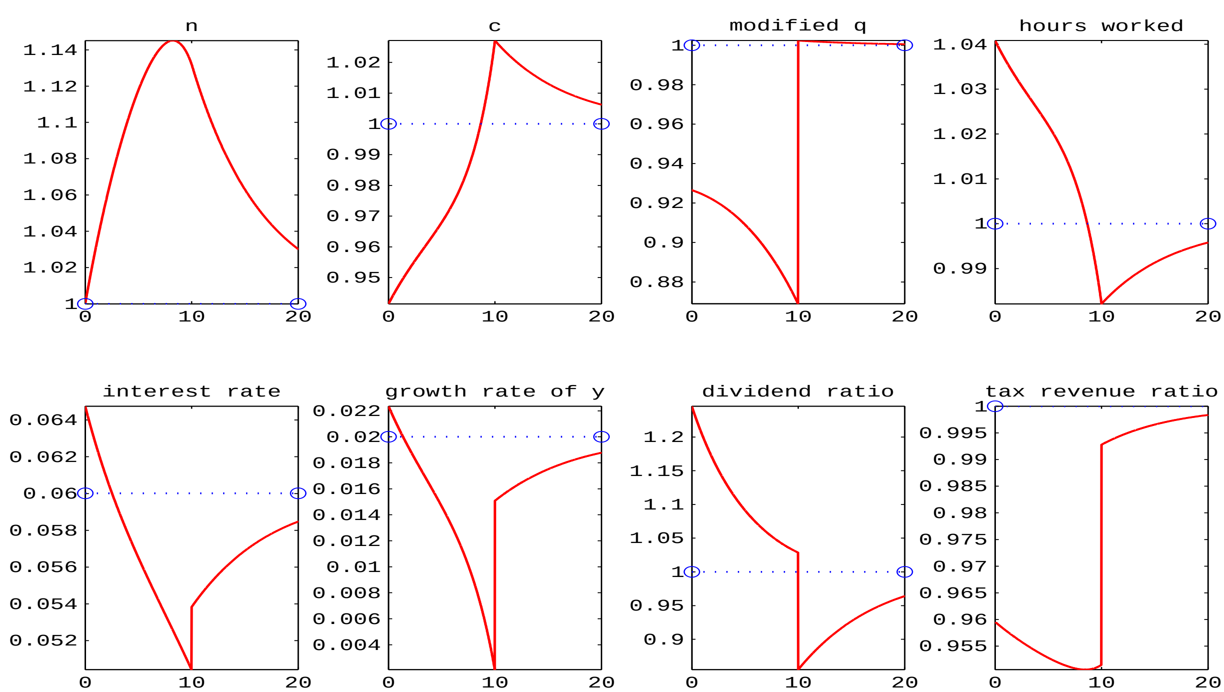
Table 4: Welfare gains of tax changes (parameter changes)

Tax change	Unanticipated (Permanent)	Anticipated (Permanent)	Temporary
$\beta = 3.275$ *(with $\alpha = 0.277$ and $\phi = 0.125$)*			
$\Delta t_D = -0.1$	-14.94	-12.21	-8.52
$\Delta t_\Pi = -0.1$	5.09	5.76	0.58
$\Delta t_V = -0.1$	15.33	12.63	8.3
$\Delta \sigma = 0.2$	11.55	10.3	5.05
$\beta = 9.825$ *(with $\alpha = 0.0945$ and $\phi = 0.408$)*			
$\Delta t_D = -0.1$	-13.7	-10.85	-8.08
$\Delta t_\Pi = -0.1$	5.03	5.65	0.66
$\Delta t_V = -0.1$	13.04	10.25	7.72
$\Delta \sigma = 0.2$	10.66	9.36	4.81
$h = 8.0$ *(with $\alpha = 0.133$ and $\phi = 0.267$)*			
$\Delta t_D = -0.1$	-15.44	-11.41	-9.98
$\Delta t_\Pi = -0.1$	5.87	6.55	0.89
$\Delta t_V = -0.1$	15.1	11.05	9.7
$\Delta \sigma = 0.2$	12.37	10.37	6.05
$h = 18.0$ *(with $\alpha = 0.153$ and $\phi = 0.265$)*			
$\Delta t_D = -0.1$	-12.5	-10.55	-6.64
$\Delta t_\Pi = -0.1$	4.2	4.77	0.44
$\Delta t_V = -0.1$	12.02	10.15	6.29
$\Delta \sigma = 0.2$	9.39	8.59	3.88
$\sigma = 1.0$ *(with $\alpha = 0.0955$ and $\phi = 0.260$)*			
$\Delta t_D = -0.1$	-13.86	-11.05	-8.08
$\Delta t_\Pi = -0.1$	-13.6	-10.83	-7.95
$\Delta t_V = -0.1$	12.95	10.15	7.69
$\Delta \sigma = 0.2$	17.06	15.0	7.55
$\zeta = 0$			
$\Delta t_D = -0.1$	-14.23	-9.93	-7.12
$\Delta t_\Pi = -0.1$	4.81	4.64	0.53
$\Delta t_V = -0.1$	13.5	9.16	6.72
$\Delta \sigma = 0.2$	10.87	8.20	4.18

Note: Welfare gains are measured in consumption equivalent and expressed in percentage points. Other values of the tax variables and parameters are sames as the benchmark setting.



(a) **Anticipated vs. unanticipated permanent reduction in the dividend tax rate by 10 percentage points in the case of $\kappa = 0.3$.** Solid (Dashed) lines plots the impulse response of each variable to the anticipated (unanticipated) tax cut. The circle marks on the left (right) vertical axis indicates the steady-state level before (after) the tax cut.



(b) **Temporary reduction in the dividend tax cut by 10 percentage points in the case of** $\kappa = 0.3$. The circle mark on the vertical axis indicates the initial level.

Figure 6

Table 5: Welfare gains of tax changes (positive social spillover of product variety)

Tax change	Unanticipated (Permanent)	Anticipated (Permanent)	Temporary
$\kappa = 0.1$			
$\Delta t_D = -0.1$	-13.08	-10.17	-7.95
$\Delta t_\Pi = -0.1$	5.88	6.59	0.83
$\Delta t_V = -0.1$	13.73	10.98	7.86
$\Delta \sigma = 0.2$	10.72	9.43	4.82
$\kappa = 0.3$			
$\Delta t_D = -0.1$	-10.75	-7.78	-7.12
$\Delta t_\Pi = -0.1$	8.07	8.88	1.42
$\Delta t_V = -0.1$	14.17	11.53	7.85
$\Delta \sigma = 0.2$	10.35	9.1	4.66
$\kappa = 0.5$			
$\Delta t_D = -0.1$	-7.57	-4.65	-5.86
$\Delta t_\Pi = -0.1$	11.08	11.93	2.35
$\Delta t_V = -0.1$	14.76	12.25	7.85
$\Delta \sigma = 0.2$	9.87	8.68	4.43
$\kappa = 0.7$			
$\Delta t_D = -0.1$	-3.07	-0.22	-4.11
$\Delta t_\Pi = -0.1$	15.34	16.22	3.61
$\Delta t_V = -0.1$	15.54	13.24	7.86
$\Delta \sigma = 0.2$	9.23	8.13	4.13

Note: Welfare gains are measured in consumption equivalent and expressed in percentage points. Other values of tax variables and parameters are same as the benchmark setting.