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Dynamic Scoring Through Creative Destruction*

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Abstract

We examine the dynamic feedback effects of fiscal policies on the government budget and economy activity in a calibrated general equilibrium framework featuring endogenous growth through creative destruction. For several European countries, we find that making tax incentives with respect to research effort more generous is the least costly way, in terms of the impact on the government budget, to promote economic growth. It is almost three times as cost effective as lowering the tax rate on capital income. When non-distorting financing options are excluded, adjusting the consumption tax to finance more generous tax incentives for research effort leads to the smallest loss in economic efficiency and the largest welfare gain.

JEL Classification: E62; H2; H3; 038

Keywords: Dynamic Scoring; Creative Destruction; Endogenous Growth; Calibration; Taxation

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1 Introduction

Governments face the challenge to set fiscal policies such that they result in sufficient revenues to deal with long-run budget challenges and promote economic growth at the same time. This challenge is especially relevant for governments currently proposing fiscal reforms to reduce their fiscal deficits and bring down their debt. Scoring exercises, which are analyses of the impact of fiscal policies on the long-run budget balance of the government and the economy, are useful tools to see whether these two goals can be satisfied simultaneously. These scoring exercises increasingly take place in dynamic general equilibrium frameworks and are referred to as dynamic scoring exercises.

Most dynamic scoring exercises use models where economic activity is solely determined by traditional factors of production such as physical capital and labor.[1] So far, less attention is being paid to the use of models where economic activity is the result of intentional investment in research and development (R&D) by firms. However, scoring exercises are especially interesting in these models since they feature monopolistic distortions and usually some form of externalities (e.g., research spillovers). Therefore, they lend themselves to studying active government involvement. More important, the question whether the government is able to deal with these distortions and externalities remains largely unanswered when either only a part of government activities is taken into account or when it is assumed that the government can raise funds at no cost to economy activity. Such an analysis requires a calibrated framework in which the government plays a prominent role. This paper addresses these issues and performs dynamic scoring exercises in an economic model with intentional innovation by firms. We do this by examining the dynamic feedback effects of fiscal policies on the government budget in a calibrated general equilibrium framework featuring endogenous growth through creative destruction.

The production side of the closed economy takes standard "Schumpeterian" growth models (cf. Aghion and Howitt, 1998; Acemoglu, 2009) as a basis. Expenditures of the government consist of interest payments on debt, public consumption, and lump-sum transfers to house-

[1]See Ireland (1994), Agell and Persson (2001), Mankiw and Weinzierl (2006), Trabandt and Uhlig (2011), Van Oudheusden (2009), and Strulik and Trimborn (2010).

holds. The government finances these expenditures by issuing debt and collecting taxes on capital income, labor income, and consumption. Moreover, the government provides tax incentives with respect to research effort to affect the economy (e.g., investment tax credits and depreciation allowances for research and development expenditures). To prevent the government from raising revenues in a non-distorting way, we assume labor supply is elastic. Finally, we calibrate the model to resemble the economies of the United Kingdom and three major European continental countries, which are France, Germany, and Italy.

We use this calibrated framework to perform dynamic scoring analyses for more generous tax incentives with respect to research effort, lower tax rates on capital income, labor income and consumption, and a higher share of government expenditures in output. From these dynamic scoring analyses it follows that more generous tax incentives with respect to research effort is the least costly way, in terms of the impact on the government budget, to stimulate economic activity. This policy is almost three times as cost effective as lowering the tax rate on capital income, which is the next best policy. We never obtain a dynamic Laffer effect, which is an improvement in the long-run government budget balance, for the fiscal policies considered. This last finding can be explained by the relatively large deterioration of the government budget balance in the short run compared to the resulting efficiency gains of these policies in the long run. Finally, when non-distorting financing options are unavailable, more generous tax incentives with respect to research effort can best be financed by cutting government expenditures and raising the tax rate on consumption.

The framework we develop in this paper has characteristics that makes it suitable to also address other issues besides dynamic scoring analyses. The model has closed form solutions in equilibrium, features tractable transitional dynamics, and comes with a graphical apparatus that provides a clear insight in the mechanisms that are at work after a change in a fiscal instrument. Moreover, the inclusion of a wide array of fiscal instruments available to the government makes it possible to include almost all government expenditures and revenues that are found in the national accounts of countries. Because of these characteristics, the framework is useful to study, for example, optimal taxation questions. Although these questions are interesting on their own, we do not address them here and leave them for future research.

Our analysis is closely related to Trabandt and Uhlig (2011) who perform dynamic scoring analyses for the United States and several European countries in a neoclassical growth model. We mainly differ from this study by looking at a framework where economic activity results from intentional innovation by firms and by analyzing a wider variety of financing schemes.[2] Other related papers in the dynamic scoring literature are Ireland (1994), Bruce and Turnovsky (1999), Agell and Persson (2001), and Van Oudheusden (2009), who look at the conditions under which a dynamic Laffer effect can be obtained. Mankiw and Weinzierl (2006) and Strulik and Trimborn (2010) perform dynamic scoring analyses in a standard neoclassical growth model and focus on the degree of self-financing of fiscal policy reforms. None of these papers considers economic activity to be the result of intentional research by firms, and all papers limit the number of financing schemes. Our paper is also related to Jones (1995), Jones and Williams (2000), Zeng and Zhang (2007), and Grossmann et al. (2010), who calibrate R&D-based models of economic growth but differ substantially in their treatment of the elasticity of labor supply and coverage of fiscal instruments available to the government.

The remainder of the paper is structured as follows. Section 2 sets out the analytical framework. Section 3 presents the analytical results. Section 4 discusses the numerical results. Section 5 concludes.

2 Analytical Framework

The building block of the model is a "Schumpeterian growth model" similar to those discussed by Aghion and Howitt (1998), Barro and Sala-i-Martin (1999), and Acemoglu (2009).[3] We consider a closed economy where the production side consists of a final goods sector, an intermediate goods sector, and a research sector. Other economic actors are households and the government.

[2]We consider three financing schemes: i) a non-distorting financing scheme, ii) a non-distorting scheme where debt is allowed to adjust, and iii) a distorting financing scheme.

[3]More specifically, the model contains elements of but is not identical to the models described by Aghion and Howitt (1998, Chapter 3), Barro and Sala-i-Martin (1999, Chapter 7), and Acemoglu (2009, Chapter 14).

2.1 The Final Goods Sector

The final goods sector operates under perfect competition and produces a homogeneous output good $Y(t)$ using a continuum of intermediate goods, normalized to unity, and aggregate labor:

$$Y(t) = \alpha^{-1} \left(\int_0^1 Q_i(t)^\theta x_i(t|Q_i(t))^{\frac{\epsilon_\beta - 1}{\epsilon_\beta}} di \right)^{\frac{\alpha \epsilon_\beta}{\epsilon_\beta - 1}} H(t)^{1-\alpha}, \tag{1}$$

where $0 < \alpha < 1$, $\theta > 0$, $\epsilon_\beta > 1$, $x_i(t|Q_i(t))$ is the quantity of intermediate good i at time t with quality $Q_i(t)$, θ measures how this quality affects the productivity of the intermediate good, and ϵ_β is the elasticity of substitution between the differentiated intermediate goods. Aggregate labor is given by $H(t)$ and its production elasticity is $1 - \alpha$.

We take output as the numeraire and normalize its price to unity. Profits of the final goods sector are given by $(1-\tau_X)(Y(t) - w(t)H(t)) - \int_0^1 p_i(t|Q_i(t))x_i(t|Q_i(t))di$, where τ_X is the tax rate on capital income, w_t is the wage rate, and $p_i(t|Q_i(t))$ is the price of intermediate good i at time t with quality $Q_i(t)$.[4] Profit maximization gives demand functions for intermediate goods and aggregate labor, respectively:

$$x_i(t|Q_i(t)) = \left(\frac{p_i(t|Q_i(t))}{Q_i(t)^\theta} \right)^{-\epsilon_\beta} P(t)^{\epsilon_\beta - \frac{1}{1-\alpha}} H(t)(1-\tau_x)^{\frac{1}{1-\alpha}}, \tag{2}$$

$$H(t) = \left(\int_0^1 Q_i(t)^\theta x_i(t|Q_i(t))^{\frac{\epsilon_\beta - 1}{\epsilon_\beta}} di \right)^{\frac{\epsilon_\beta}{\epsilon_\beta - 1}} \left(\frac{1-\alpha}{\alpha} \right)^{\frac{1}{\alpha}} w(t)^{-\frac{1}{\alpha}}, \tag{3}$$

and $P(t)$ is a price index given by $P(t) \equiv \left(\int_0^1 p_i(t|Q_i(t))^{1-\epsilon_\beta} Q_i(t)^{\theta \epsilon_\beta} di \right)^{\frac{1}{1-\epsilon_\beta}}$.

2.2 The Intermediate Goods Sector

The intermediate good i with quality $Q_i(t)$ is produced by a representative firm that owns a potentially infinitely lived patent for the use of that good. This patent can be bought from the research sector and its value is given by

$$V_i(t|Q_i(t)) = \int_t^\infty \pi_i(t'|Q_i(t)) e^{\int_t^{t'} (r(t'') + z_i(t''|Q_i(t)))dt''} dt'.$$

[4] Hence, the intermediate goods can be seen as capital; see Acemoglu (2009).

This equation can be written in a more convenient way by taking the time derivative and rearranging terms:[5]

$$r(t)V_i(t|Q_i(t)) = \pi_i(t|Q_i(t)) + \dot{V}_i(t|Q_i(t)) - z_i(t|Q_i(t))V_i(t|Q_i(t)). \tag{4}$$

Equation (4) says that the per period expected income of owning a patent $r(t)V_i(t|Q_i(t))$ equals the profit in that period $\pi_i(t|Q_i(t))$, plus the change in the value of the patent $\dot{V}_i(t|Q_i(t))$, and minus the expected loss of losing the patent $z_i(t|Q_i(t))V_i(t|Q_i(t))$ by being replaced; see Section 2.3 for the last effect. In this equation, $r(t)$ is the market interest rate, and $z_i(t|Q_i(t))$ is the Poisson arrival rate of innovations, also called the flow rate of innovations, on intermediate good i with quality $Q_i(t)$.

Per period profits are given by $\pi_i(t|Q_i(t)) = p_i(t|Q_i(t))x_i(t|Q_i(t)) - \psi Q_i(t)^\theta x_i(t|Q_i(t))$, where the marginal costs $\psi Q_i(t)^\theta$, with $\psi > 0$, are increasing in the quality of the intermediate good, which captures the idea that it is more expensive to produce intermediate goods of higher quality. Firms in the intermediate sector act like monopolists when maximizing their profits. Assuming firms are small and charge the unconstrained monopoly price, firms set their price as a markup over marginal costs:

$$p_i(t|Q_i(t)) = \frac{\epsilon_\beta}{\epsilon_\beta - 1}\psi Q_i(t)^\theta, \tag{5}$$

so that profits are given by[6]

$$\pi_i(t|Q_i(t)) = \left(\frac{\epsilon_\beta}{\epsilon_\beta - 1}\frac{\psi}{1-\tau_X}\right)^{\frac{\alpha}{\alpha-1}} Q_i(t)^\theta \left(\int_0^1 Q_i(t)^\theta di\right)^{\frac{1}{1-\epsilon_\beta}\left(\epsilon_\beta - \frac{1}{1-\alpha}\right)} \frac{H(t)}{\epsilon_\beta}(1-\tau_X). \tag{6}$$

[5]The result is the Hamilton-Jacobi-Bellman representation of the value of the patent; see Acemoglu (2009, p. 244).

[6]Equation (5) is obtained by substituting equation (2) into the expression for per period profits and maximizing with respect to $p_i(t|Q_i(t))$, where the effect of $p_i(t|Q_i(t))$ on $P(t)$ is neglected since the size of firms is small. Equation (6) is obtained by substituting equation (5) into $P(t)$, and subsequently substituting the result and equation (2) into the expression for per period profits.

2.3 The Research Sector

Each intermediate good sector has it own research sector where firms compete to discover the next quality improvement of that good. The quality of intermediate good i at time t is given by the following quality ladder:

$$Q_i(t) = Q_i(0)e^{\frac{S_i(t)}{v-1}},$$

where $v > 1$, $Q_i(0) > 0$, and S_i is the total number of innovations on intermediate good i between time 0 and time t. The total number of innovations depends on the flow rate of innovations; $\dot{S}_i(t) = z_i(t)$. Since $z_i(t|Q_i(t))$ is the Poisson arrival rate of innovations, quality improvements of a particular intermediate good are stochastic. For an incumbent, $z_i(t|Q_i(t))$ is the probability of being replaced by an entrant.

Firms in the research sector spend $Z_i(t|Q_i(t))$ units of the final good on research effort, where a successful innovation gives the firm a patent with value $V_i(t|Q_i(t))$. The relation between the flow rate of innovations $z_i(t|Q_i(t))$ and research effort is given by

$$z_i(t|Q_i(t)) = \eta\Phi(Q_i(t))Z_i(t|Q_i(t)),$$

where $\eta > 0$ is the productivity of research effort, and $\Phi(\cdot)$ with $\partial\Phi(\cdot)/\partial Q_i(t) < 0$ captures the idea that it becomes harder to obtain a successful innovation when the quality of the intermediate good is higher.

Expected profits of research are given by $z_i(t|Q_i(t))V_i(t|Q_i(t)) - (1-s_Z)Z_i(t|Q_i(t))$, where we assume the government provides tax incentives, denoted by s_Z, to stimulate research effort. The parameter s_Z captures the generosity of the tax incentives with respect to research effort, which may capture exemptions, allowances, credits, tax deferrals and rate reliefs. Since these tax incentives can be seen as an implicit subsidy to research effort, we model them accordingly.

Free entry in the research sector implies zero profits, which leads to the following conditions:

$$V_i(t|Q_i(t)) = \frac{1 - s_Z}{\eta\Phi(Q_i(t))} \quad \text{if} \quad Z_i(t|Q_i(t)) > 0,$$
$$V_i(t|Q_i(t)) < \frac{1 - s_Z}{\eta\Phi(Q_i(t))} \quad \text{if} \quad Z_i(t|Q_i(t)) = 0,$$

where the first equation is the free entry condition when research effort takes place and implies that $\dot{V}_i(t|Q_i(t)) = 0$ since $Q_i(t)$ is constant over time until there is a new innovation. This free entry condition can be rewritten as[7]

$$z_i(t|Q_i(t)) = \pi_i(t|Q_i(t))\frac{\eta\Phi(Q_i(t))}{1 - s_Z} - r(t),$$

which is affected by the quality of the intermediate good in two opposite ways. The first effect is captured by $\pi_i(t|Q_i(t))$ and says that the return on research effort increases with $Q_i(t)$ since profits depends positively on the quality of the intermediate good; see equation (6). The second effect is captured by $\Phi(Q_i(t))$ and says it becomes harder to obtain a successful innovation when the quality of the intermediate good is higher, which means the return on research effort decreases with $Q_i(t)$.

If the first effect dominates the second, then the return on research effort increases with quality, and research effort will focus on the intermediate goods with the highest quality. Conversely, research effort shifts to the intermediate goods with the lowest quality if the second effect dominates. In both cases, research effort depends on the quality of the intermediate goods. Since quality improvements are stochastic, the model becomes analytically intractable. The only situation in which we can say something about the growth process is when research effort is independent of the quality of intermediate goods, which is the case when the two effects exactly offset each other.

Because we do not want to limit our attention to this particular case, we need to adjust the model in such a way that research effort is the same for all intermediate goods regardless of which effect dominates. We do this by following Aghion and Howitt (1992, 1998). Suppose

[7] This result is obtained by substituting $V_i(t|Q_i(t)) = \frac{1-s_Z}{\eta\Phi(Q_i(t))}$ into (4), taking into account that $\dot{V}_i(t|Q_i(t)) = 0$, and rearranging terms.

now that after a successful innovation at time t, the quality of an intermediate good does not follow the quality ladder given above but instead jumps to the leading-edge quality in the whole economy at that time, which is denoted by $Q(t)$. Any innovation then leads to a discontinuous jump of the quality that is currently being used in the production of that good to this leading-edge quality. More specifically, a new firm now produces the intermediate good using the leading-edge quality and replaces the old firm that uses the old quality. Moreover, suppose now that the flow rate of innovation is given by

$$z_i(t|Q(t)) = \eta\Phi(Q(t))Z_i(t|Q(t)) = \eta Q(t)^{-\phi}Z_i(t|Q(t)),$$

where we defined $\Phi(Q(t)) \equiv Q(t)^{-\phi}$, and $\phi > 0$ indicates that the effectiveness of research effort decreases with the leading-edge quality. The free entry condition changes into

$$z_i(t|Q(t)) = \pi_i(t|Q(t))\frac{\eta Q(t)^{-\phi}}{1-s_Z} - r(t). \tag{7}$$

which again says that the return on research effort on intermediate good i is still affected in two opposite ways, though not by the quality of the intermediate good itself but by the leading-edge quality in the economy. Moreover, equation (7) implies that research effort will be the same for all intermediate goods.

We follow Aghion and Howitt (1998) and assume that the evolution of the leading-edge quality over time is proportional to the aggregate flow rate of innovations:[8]

$$\frac{\dot{Q}(t)}{Q(t)} = \frac{z(t)}{v-1}, \tag{8}$$

with $z(t) = \int_0^1 z_i(t)di$. A graphical representation of this process of quality improvements of the intermediate goods is given in Figure 1.

Enter Figure 1 approximately here.

Figure 1 shows that both the distribution of qualities and the leading-edge quality change

[8] For more detail see Aghion and Howitt (1998, p. 88). The derivation of equation (8) is given in Appendix A.

over time. However, it can be shown that the distribution of relative qualities $q_i \equiv Q_i/Q$ is independent of the leading-edge quality and thus time independent: $J(q) = q^{v-1}$. This property implies that intermediate goods can be classified according to their relative qualities so that the sum of qualities used in the production of intermediate goods at time t is given by[9]

$$\int_0^1 Q_i(t)^\theta di = \frac{v-1}{v-1+\theta} Q(t)^\theta. \tag{9}$$

2.4 Households

The economy consists of a set of infinitely lived identical households, where for convenience the number of households is normalized to unity. The size of the representative household is given by $N(t)$, which evolves according to $N(t) = N(0)e^{nt}$, where $N(0) = 1$, and $n \geq 0$ is the growth rate. Each household has the same felicity function so that lifetime utility of the representative household is given by

$$\Lambda(0) \equiv \int_0^\infty N(t)u(t)e^{-\rho t}dt = \int_0^\infty N(t)\frac{[c(t)^{\epsilon_C}(1-L(t))^{\epsilon_L}]^{1-\sigma}-1}{1-\sigma}e^{-\rho t}dt, \tag{10}$$

where $\rho > 0$ is the pure rate of time preference, $u(t)$ represents the felicity function, and $c(t)$ is per capita consumption of the final good. We normalize the total amount of time to unity so that $1 - L(t)$ reflects leisure. The parameter $\sigma > 0$ represents the inverse of the intertemporal elasticity of substitution. Preference weights for consumption and leisure are given by $\epsilon_C > 0$ and $\epsilon_L > 0$, respectively. The felicity function is assumed to be jointly concave in per capita consumption and leisure.

The representative household receives income from labor and claims on assets $A(t)$ and government bonds $B(t)$.[10] Since we have a closed economy, assets equal the sum of patent values $A(t) \equiv \int_0^1 V_i(t|Q_i(t))di$. Moreover, households receive lump-sum transfers $T(t) > 0$

[9]This result is given in Appendix A.

[10]Government bonds are assumed to be perpetuities that every period pay out a coupon equal to one unit of output. The nominal value of the stock of bonds $B(t)$ is defined as the number of bonds multiplied by their price $p_B(t)$ defined in terms of the numeraire. The return on bonds is given by $r_B(t) \equiv (1 + \dot{p}_B(t))/p_B(t)$. We choose this specification to abstract from transitional dynamics in portfolio shares associated with fixed-price bonds; see Turnovsky (2000b, p. 438).

from the government. The budget constraint of the household is then given by

$$\dot{A}(t) + \dot{B}(t) = r(t)A(t) + r_B(t)B(t) + (1 - \tau_L)w(t)H(t) - (1 + \tau_C)C(t) + T(t), \quad (11a)$$

where $r_B(t)$ is the rate of return on government bonds, $C(t) \equiv c(t)N(t)$ is aggregate consumption, and $H(t) \equiv L(t)N(t)$ is aggregate labor. Labor income is taxed at rate τ_L and consumption at rate τ_C. The per capita budget constraint of the household is given by

$$\dot{a}(t)+\dot{b}(t) = (r(t)-n)a(t)+(r_B(t)-n)b(t)+(1-\tau_L)w(t)L(t)-(1+\tau_C)c(t)+T(t)/N(t), \quad (11b)$$

where $a(t) \equiv A(t)/N(t)$ and $b(t) \equiv B(t)/N(t)$, are assets per capita and government bonds per capita, respectively. Households choose consumption, labor, assets, and government bonds to maximize utility (10) subject to the per capita budget constraint (11b). The first-order conditions for this problem are

$$\epsilon_C c(t)^{-1} \left(c(t)^{\epsilon_C}(1 - L(t))^{\epsilon_L}\right)^{1-\sigma} = \lambda(t)(1 + \tau_C), \quad (12a)$$

$$\epsilon_L(1 - L(t))^{-1} \left(c(t)^{\epsilon_C}(1 - L(t))^{\epsilon_L}\right)^{1-\sigma} = \lambda(t)(1 - \tau_L)w(t), \quad (12b)$$

$$\lambda(t)(r(t) - n) = \lambda(t)(\rho - n) - \dot{\lambda}(t), \quad (12c)$$

$$\lambda(t)(r_B(t) - n) = \lambda(t)(\rho - n) - \dot{\lambda}(t), \quad (12d)$$

where $\lambda(t)$ is the shadow price of assets and government bonds. The transversality conditions are given by

$$\lim_{t\to\infty} \lambda(t)A(t)e^{-\rho t} = 0, \quad \text{and} \quad \lim_{t\to\infty} \lambda(t)B(t)e^{-\rho t} = 0. \quad (13)$$

Combining equations (12c) and (12d) gives the no-arbitrage condition $r_B(t) = r(t)$, which says the return on assets should equal the return on government bonds.

2.5 Government

Government expenditures are interest payments on outstanding bonds $r_B(t)B(t)$, lump-sum transfers to households $T(t)$, and other expenditures defined by $G(t) \equiv \omega_G Y(t)$, which says that $G(t)$ is a constant fraction of output ($0 < \omega_G < 1$). Revenues of the government consist of taxes on consumption $\tau_C C(t)$, capital income $\tau_X(Y(t) - w(t)H(t))$, and labor income $\tau_L w(t)H(t)$. Moreover, $s_Z Z(t)$ measures the amount of foregone revenues by research effort stimulating tax incentives. Any fiscal deficit has to be financed by issuing bonds. Taking into account the no-arbitrage condition $r_B(t) = r(t)$, the periodic budget constraint of the government becomes

$$\dot{B}(t) = r(t)B(t) + T(t) + \omega_G Y(t) - \tau_L w(t)H(t) - \tau_C C(t) - \tau_X(Y(t) - w(t)H(t)) + s_Z Z(t). \quad (14)$$

2.6 Balanced Growth Equilibrium

We define the balanced growth equilibrium as a situation where aggregate consumption, research expenditures, intermediate goods expenditures, and output all grow at the same rate while labor supply is constant:

$$g = \frac{\dot{C}(t)}{C(t)} = \frac{\dot{Z}(t)}{Z(t)} = \frac{\dot{X}(t)}{X(t)} = \frac{\dot{Y}(t)}{Y(t)}, \quad \text{and} \quad \dot{L}(t) = 0,$$

where g is the constant growth rate of the economy in the balanced growth equilibrium and $X(t) \equiv \int_0^1 \psi Q_i(t)^\theta x_i(t|Q_i(t))di$. The evolution of labor supply over time is given by[11]

$$\dot{L}(t) = \frac{(v-1)(\alpha-1)(1-\epsilon_\beta) + \theta\alpha(1-(1-\sigma)\epsilon_C)}{(\alpha-1)(1-\epsilon_\beta)(1-(1-\sigma)(\epsilon_C+\epsilon_L))}(L(t)-1)(\gamma_P - \gamma_Q) \quad (15)$$

[11] The derivation of equation (15) is given in Appendix A.

with

$$\gamma_P \equiv \frac{(\alpha-1)(1-\epsilon_\beta)}{(v-1)(\alpha-1)(1-\epsilon_\beta)+\theta\alpha(1-(1-\sigma)\epsilon_C)}\left(\xi\frac{1-\tau_X}{1-s_Z}\frac{v-1+\theta}{\epsilon_\beta}Q_N(t)L(t)-\rho\right), \tag{16a}$$

$$\gamma_Q \equiv \frac{\xi}{\alpha}Q_N(t)L(t)\left(1-\omega_G-\alpha(1-\tau_X)\frac{\epsilon_\beta-1}{\epsilon_\beta}-\frac{\epsilon_C}{\epsilon_L}\frac{1-\tau_L}{1+\tau_C}(1-\alpha)\frac{1-L(t)}{L(t)}\right), \tag{16b}$$

where $\xi \equiv \frac{\eta}{v-1}\left(\frac{v-1}{v-1+\theta}\right)^{\frac{\alpha}{(\alpha-1)(1-\epsilon_\beta)}}\left(\frac{\epsilon_\beta}{\epsilon_\beta-1}\frac{\psi}{1-\tau_X}\right)^{\frac{\alpha}{\alpha-1}}$ and

$$Q_N(t) \equiv Q(t)^{\frac{\theta\alpha}{(\alpha-1)(1-\epsilon_\beta)}-\phi}N(t). \tag{17}$$

From equation (15) it can be seen that $\dot{L}(t)=0$ when $\gamma_P=\gamma_Q$. Using equations (1), (2), (5), (8), and $P(t)=\left(\int_0^1 p_i(t|Q_i(t))^{1-\epsilon_\beta}Q_i(t)^{\theta\epsilon_\beta}di\right)^{\frac{1}{1-\epsilon_\beta}}$, output can be given by

$$Y(t)=\left(\frac{v-1}{v-1+\theta}\right)^{\frac{\alpha}{(\alpha-1)(1-\epsilon_\beta)}}\left(\frac{\epsilon_\beta}{\epsilon_\beta-1}\frac{\psi}{1-\tau_X}\right)^{\frac{\alpha}{\alpha-1}}\frac{L(t)}{\alpha}Q(t)^{\frac{\theta\alpha}{(\alpha-1)(1-\epsilon_\beta)}}N(t).$$

Given that γ_Q denotes the growth rate of the leading-edge quality $\frac{\dot{Q}(t)}{Q(t)}$, the growth rate of output in the balanced growth equilibrium is $g=\frac{\theta\alpha}{(\alpha-1)(1-\epsilon_\beta)}\gamma_Q+n$, which is only constant as long as $Q_N(t)$ is constant; see equations (16a) and (16b). The evolution of $Q_N(t)$ over time is as follows:

$$\dot{Q}_N(t)=\left(\left(\frac{\theta\alpha}{(\alpha-1)(1-\epsilon_\beta)}-\phi\right)\gamma_Q+n\right)Q_N(t), \tag{18}$$

which implies that there are two cases in which $\dot{Q}_N(t)=0$.

In the first case, $\phi>\frac{\theta\alpha}{(\alpha-1)(1-\epsilon_\beta)}$ and $n>0$. For $\dot{Q}_N(t)$ to be zero, $\gamma_Q=n\left(\phi-\frac{\theta\alpha}{(\alpha-1)(1-\epsilon_\beta)}\right)^{-1}$ must hold. The growth rate of the economy in the balanced growth equilibrium is then given by $g=\phi n\left(\phi-\frac{\theta\alpha}{(\alpha-1)(1-\epsilon_\beta)}\right)^{-1}$. In this case, g does not depend on fiscal instruments of the government, for example, the tax incentives related to research effort s_Z, so that government policies cannot influence the growth rate of the economy in the balanced growth equilibrium. Let $\tilde{L}$ and $\tilde{Q}_N$ be the equilibrium values for which $\gamma_P=\gamma_Q$. Equations (16a) and (16b) show that these values are affected by fiscal instruments of the government, which means the government can affect the level of output, so government policies have *temporary* effects on the growth rate of the economy during the transition toward the balanced growth equilibrium; this will be discussed in Section 2.7.

In the second case, $\phi = \frac{\theta\alpha}{(\alpha-1)(1-\epsilon_\beta)}$ and $n = 0$ so that $\tilde{Q}_N = 1$, and the growth rate of the economy in the balanced growth equilibrium is $g = \frac{\theta\alpha}{(\alpha-1)(1-\epsilon_\beta)}\gamma_P(\tilde{L}) = \frac{\theta\alpha}{(\alpha-1)(1-\epsilon_\beta)}\gamma_Q(\tilde{L})$. The equilibrium value of labor supply $\tilde{L}$ follows from equating (16a) and (16b). In this case, g depends on $\tilde{L}$, which can be influenced by the government so that government policies have *permanent* effects on the growth rate of the economy.

The balanced growth equilibrium in which government policies have temporary effects on growth (TEG) and the one in which they have permanent effects on growth (PEG) are respectively described by[12]

$$\left.\begin{aligned} g &= \phi n \left(\phi - \tfrac{\theta\alpha}{(\alpha-1)(1-\epsilon_\beta)}\right)^{-1}, \\ &\gamma_P = \gamma_Q = n\left(\phi - \tfrac{\theta\alpha}{(\alpha-1)(1-\epsilon_\beta)}\right)^{-1} \Rightarrow \tilde{Q}_N, \\ &\gamma_P = \gamma_Q = n\left(\phi - \tfrac{\theta\alpha}{(\alpha-1)(1-\epsilon_\beta)}\right)^{-1} \Rightarrow \tilde{L}, \end{aligned}\right\} \quad \text{for TEG,} \tag{19a}$$

$$\left.\begin{aligned} g &= \tfrac{\theta\alpha}{(v-1)(\alpha-1)(1-\epsilon_\beta)+\theta\alpha(1-(1-\sigma)\epsilon_C)}\left(\xi\tfrac{1-\tau_X}{1-s_Z}\tfrac{v-1+\theta}{\epsilon_\beta}\tilde{L} - \rho\right), \\ \tilde{Q}_N &= 1, \\ &\gamma_P = \gamma_Q \Rightarrow \tilde{L}, \end{aligned}\right\} \quad \text{for PEG.} \tag{19b}$$

Figure 2 gives a graphical representation of the equilibrium described by (19a). The dashed lines in the graphs, indicated by Γ_P, correspond to γ_P and are associated with portfolio balance equilibrium. Along these lines the return on consumption always equals the return on investment. The solid lines, indicated by Γ_Q, correspond to γ_Q and are associated with good market equilibrium. Along these lines, the aggregate resource constraint $Y(t) = C(t)+G(t)+X(t)+Z(t)$ and the intratemporal optimality condition between consumption and leisure are always satisfied.[13]

[12] Basically, the TEG and PEG equilibria correspond to an endogenous growth model without and with scale effects, respectively.

[13] The intratemporal optimality condition between consumption and leisure says that the marginal rate of substitution between consumption and leisure equals its relative price.

Enter Figure 2 approximately here.

The top panel of the figure shows the two loci describing the relationship between γ_i and L conditional on Q_N, for $i \in \{P, Q\}$. When the two loci intersect, labor supply is constant over time. Figures 2a and 2b only differ in the way these loci intersect, which determines the stability of the equilibrium. The bottom panel presents two loci describing the relationship between Q_N and L conditional on $\gamma_P = \gamma_Q = n\left(\phi - \frac{\theta\alpha}{(\alpha-1)(1-\epsilon_\beta)}\right)^{-1}$, both for γ_P and γ_Q. The top and bottom panel together determine the equilibrium values $\tilde{Q}_N$ and $\tilde{L}$.

Figure 3 shows the graphical representation of the equilibrium described by (19b). Since $\tilde{Q}_N = 1$ by the choice of parameter values, the equilibrium is solely represented by the two loci describing the relationship between γ_i and L, for $i \in \{P, Q\}$. The growth rate of the economy and corresponding equilibrium value of labor supply $\tilde{L}$ are determined by the intersection of these loci.

Enter Figure 3 approximately here.

2.7 Transitional Dynamics

Using equations (15)–(18) and $\gamma_P = \gamma_Q$ in equilibrium, the linearized dynamics are described by

$$\begin{bmatrix} \dot{L}(t) \\ \dot{Q}_N(t) \end{bmatrix} = \Delta \begin{bmatrix} L(t) - \tilde{L} \\ Q_N(t) - \tilde{Q}_N \end{bmatrix}, \tag{20}$$

where Δ is the Jacobian matrix with typical element δ_{ij}:

$$\begin{aligned}
\delta_{11} &\equiv \frac{(v-1)(\alpha-1)(1-\epsilon_\beta) + \theta\alpha(1-(1-\sigma)\epsilon_C)}{(\alpha-1)(1-\epsilon_\beta)(1-(1-\sigma)(\epsilon_C+\epsilon_L))}(\tilde{L}-1)\left(\left.\frac{\partial\gamma_P}{\partial L}\right|_{\tilde{L},\tilde{Q}_N} - \left.\frac{\partial\gamma_Q}{\partial L}\right|_{\tilde{L},\tilde{Q}_N}\right), \\
\delta_{12} &\equiv \frac{(v-1)(\alpha-1)(1-\epsilon_\beta) + \theta\alpha(1-(1-\sigma)\epsilon_C)}{(\alpha-1)(1-\epsilon_\beta)(1-(1-\sigma)(\epsilon_C+\epsilon_L))}(\tilde{L}-1)\left(\left.\frac{\partial\gamma_P}{\partial Q_N}\right|_{\tilde{L},\tilde{Q}_N} - \left.\frac{\partial\gamma_Q}{\partial Q_N}\right|_{\tilde{L},\tilde{Q}_N}\right) < 0, \\
\delta_{21} &\equiv \left(\frac{\theta\alpha}{(\alpha-1)(1-\epsilon_\beta)} - \phi\right)\left(\left.\frac{\partial\gamma_Q}{\partial L}\right|_{\tilde{L},\tilde{Q}_N}\right)\tilde{Q}_N < 0, \\
\delta_{22} &\equiv -n < 0.
\end{aligned}$$

Since δ_{12}, δ_{21}, and δ_{22} are all negative, the TEG equilibrium is saddle path stable if the following condition holds:[14]

$$\frac{(v-1)(\alpha-1)(1-\epsilon_\beta)+\theta\alpha(1-(1-\sigma)\epsilon_C)}{(\alpha-1)(1-\epsilon_\beta)(1-(1-\sigma)(\epsilon_C+\epsilon_L))}(\tilde{L}-1)\left(\frac{\partial\gamma_P}{\partial L}\bigg|_{\tilde{L},\tilde{Q}_N}-\frac{\partial\gamma_Q}{\partial L}\bigg|_{\tilde{L},\tilde{Q}_N}\right)-n>0. \quad (21)$$

The condition in equation (21) also determines the stability of the PEG equilibrium where $\phi=\frac{\theta\alpha}{(\alpha-1)(1-\epsilon_\beta)}$ and $n=0$. In this case, the elements δ_{12}, δ_{21}, and δ_{22} are all zero so that the dynamics of the balanced growth equilibrium are given by $\dot{L}(t)=\delta_{11}(L(t)-\tilde{L})$. If $\delta_{11}>0$, then a positive deviation of labor supply from its steady-state value leads to a permanent deviation from this value. The balanced growth equilibrium is then locally unstable and, thus, locally determinate. Moreover, the economy is then always in its balanced growth equilibrium and there are no transitional dynamics. If $\delta_{11}<0$, then a positive deviation will force labor supply back to its initial steady-state value so that the balanced growth equilibrium is locally stable and, thus, locally indeterminate. Figures 3a and 3b give the situations in which the PEG equilibrium is locally determinate and indeterminate, respectively.

3 Analytical Results

In this section, we discuss the effects of changes in the fiscal instruments on the economy and the long-run government budget balance of the government, respectively.

3.1 Effects of Fiscal Policy on the Economy

We define fiscal policies as changes in tax rates τ_C, τ_L, and τ_X, changes in government expenditures ω_G, and changes in the generosity of the tax incentives with respect to research effort s_Z. From the definitions in (19), it follows that L and Q_N in the respective balanced

[14] When $\delta_{11}-n>0$, the determinant and trace of Δ are negative and positive, respectively, which means the equilibrium is saddle path stable.

growth equilibria are given by

$$\left.\begin{aligned} \tilde{L} &= \tilde{l}_{\text{TEG}}(\alpha, \epsilon_\beta, \epsilon_C, \epsilon_L, \rho, \sigma, v, \tau_C, \tau_L, \tau_X, s_Z, \omega_G, \theta, \phi, n,) \\ \tilde{Q}_N &= \tilde{q}_{\text{TEG}}(\alpha, \epsilon_\beta, \epsilon_C, \epsilon_L, \rho, \sigma, v, \tau_C, \tau_L, \tau_X, s_Z, \omega_G, \theta, \phi, n, \eta, \psi, \tilde{L}) \end{aligned}\right\} \quad \text{for TEG,}$$

$$\left.\begin{aligned} \tilde{L} &= \tilde{l}_{\text{PEG}}(\alpha, \epsilon_\beta, \epsilon_C, \epsilon_L, \rho, \sigma, v, \tau_C, \tau_L, \tau_X, s_Z, \omega_G, \theta, \eta, \psi) \\ \tilde{Q}_N &= 1 \end{aligned}\right\} \quad \text{for PEG.}$$

The steady-state, or long-run, effects of fiscal policies are obtained by fully differentiating the functions $\tilde{l}_{\text{TEG}}(\cdot)$, $\tilde{q}_{\text{TEG}}(\cdot)$, and $\tilde{l}_{\text{PEG}}(\cdot)$.[15] For now, we assume changes in government revenues or expenditures that follow from these fiscal policies are offset in a non-distorting way by adjusting lump-sum transfers to keep the budget balance of the government unchanged. For the TEG equilibrium, the effects are

$$\begin{aligned} &\frac{d\tilde{L}}{di} < 0 \quad \text{and} \quad \frac{d\tilde{Q}_N}{di} > 0 \quad \text{for } i \in \{\tau_C, \tau_L, \tau_X\}, \\ &\frac{d\tilde{L}}{di} > 0 \quad \text{and} \quad \frac{d\tilde{Q}_N}{di} < 0 \quad \text{for } i \in \{\omega_G, s_Z\}, \end{aligned}$$

which says that increases in tax rates lead to a decrease in labor supply and a decrease in the relative quality used in production.[16] On the other hand, an increase in government expenditures and more generous tax incentives with respect to research effort lead to an increase in both labor supply and the relative quality of intermediate goods used in production.

The effects for the PEG equilibrium are less straightforward. In general, the effects of fiscal policies on labor supply are given by $\frac{d\tilde{L}}{di} = \left(\frac{\partial \gamma_Q}{\partial i}\Big|_{\tilde{L}} - \frac{\partial \gamma_P}{\partial i}\Big|_{\tilde{L}} \right) \left(\frac{\partial \gamma_P}{\partial L}\Big|_{\tilde{L}} - \frac{\partial \gamma_Q}{\partial L}\Big|_{\tilde{L}} \right)^{-1}$ for $i \in \{\tau_C, \tau_L, \tau_X, \omega_G, s_Z\}$; see equation (19b). If the condition in equation (21) is satisfied, then the effects of fiscal policies for the PEG equilibrium are in line with those of the TEG

[15] From (19) it follows that $\tilde{L}$ and $\tilde{Q}_N$ are described by two equations with two unknowns in the TEG equilibrium and by one equation with one unknown in the PEG equilibrium. Although we can solve explicitly for $\tilde{L}$ and $\tilde{Q}_N$ in both equilibria, the resulting expressions are too large to show them here.

[16] An increase in $\tilde{Q}_N$ corresponds to a decrease in the leading-edge quality Q relative to N; see equation (17).

equilibrium:

$$\frac{d\tilde{L}}{di} < 0 \quad \text{and} \quad \frac{dg}{di} < 0 \quad \text{for } i \in \{\tau_C, \tau_L, \tau_X\},$$
$$\frac{d\tilde{L}}{di} > 0 \quad \text{and} \quad \frac{dg}{di} > 0 \quad \text{for } i \in \{\omega_G, s_Z\}.$$

In this case, increases in tax rates lead to a decrease in labor supply and, in contrast to the TEG equilibrium, a permanent lower growth rate of the economy. An increase in government expenditures or more generous tax incentives with respect to research effort lead to an increase in both labor supply and the growth rate of the economy. The effects are the opposite if equation (21) is not satisfied.

For the calibrated model and numerical illustrations in Section 3, equation (21) is always satisfied.[17] Henceforth, we assume that this equation is satisfied. In this case, there are no transitional dynamics in the PEG equilibrium, and transitional dynamics in the TEG equilibrium are given by solving (20):

$$L(t) = \left(1 - e^{\mu t}\right) \tilde{L}(\infty) + e^{\mu t} L(0),$$
$$Q_N(t) = \left(1 - e^{\mu t}\right) \tilde{Q}_N(\infty) + e^{\mu t} Q_N(0),$$

where μ is the stable characteristic root of matrix Δ, and $\tilde{L}(\infty)$ and $\tilde{Q}_N(\infty)$ are long-run equilibrium values. Moreover, $L(0) = L(\infty) + (Q_N(0) - \tilde{Q}_N(\infty))\frac{\delta_{12}}{\mu - \delta_{11}}$ so that the short-run response of labor supply is larger in absolute terms than its long-run response. We proceed by discussing the effects in more detail.

For the TEG equilibrium, the short-run and long-run qualitative effects of more generous tax incentives with respect to research effort are given in Figures 4a and 4b, respectively. In the short run, an increase in s_Z leads to an increase in the return on research effort for the given leading-edge quality, which results in an upward rotation of Γ_P in the upper panel of Figure 4a. The higher return on research effort leads to a shift of resources from consumption

[17] Itaya (2008), however, shows that in an endogenous growth model with elastic labor supply and environmental externalities that are more than proportionally increasing with output an indeterminate balanced growth equilibrium may occur.

to research effort, and labor supply increases accordingly to ensure that both the aggregate resource constraint and the intratemporal optimality condition between consumption and leisure are satisfied.[18] The increase in labor supply leads to an increase in the growth rate in the short run. From the bottom panel of Figure 4a, it can be seen that both the short-run leading-edge quality and labor supply are incompatible with a balanced growth equilibrium under the more generous tax incentives.

Enter Figure 4 approximately here.

The short-run increase in research effort leads to a higher growth of the leading-edge quality and, since population growth does not change, a decrease in Q_N. The return on research effort, however, decreases with the leading-edge quality since $\phi > \frac{\theta\alpha}{(\alpha-1)(1-\epsilon_\beta)}$, which is reflected by the downward rotation of Γ_P in the upper panel of Figure 4d. This decrease in the return on research effort also means that more labor is needed to produce the same amount of research effort, which results in a clockwise rotation of Γ_Q in the upper panel of Figure 4b. Both effects imply a shift of resources from research effort to consumption and a corresponding reduction in labor supply so that research effort and the decline in Q_N decrease over time until the new equilibrium is reached; see the bottom panel of Figure 4b. In the new equilibrium, the growth rate of the economy returns to its balanced growth level.

The qualitative effects of a lower tax rate on labor income, or equivalently a lower tax rate on consumption, are as follows. A decrease in τ_L makes consumption relatively cheap compared to leisure so that, for the current amount of labor supply, consumption has to increase to satisfy the aggregate resource constraint and the intratemporal optimality condition between consumption and leisure, which is represented by a downward rotation of Γ_Q in the upper panel of Figure 4c. As a consequence of the rise in consumption for the given amount of labor supply, the return on consumption falls below the return on research effort, which leads to a shift of resources from consumption to research effort and a corresponding increase in

[18]The intratemporal optimality condition between consumption and leisure is obtained by dividing equations (12a) by (12b). In general, there is a inverse relationship between consumption and labor supply, which depends among others on the relative utility weights of consumption and leisure, the relative taxation of consumption and wage income, and the production elasticity of labor. This relationship is captured by the slope of Γ_Q in the upper panel of Figure 4a. The relationship is not necessarily strictly linear though; see Turnovsky (2000a) and Van Oudheusden (2009).

labor supply and the growth rate of the economy in the short run. The short-run leading-edge quality and labor supply are again incompatible with a balanced growth equilibrium under the lower tax rate on labor income; see the lower panel of Figure 4c.

The transition toward the long-run equilibrium is the same as described above and is presented in Figure 4d. Recall that the mechanism behind the transitional dynamics follows from the negative relationship between the return on research effort and the leading-edge quality; see the discussion in Section 2.3. In the PEG equilibrium, this is not the case since $\phi = \frac{\theta\alpha}{(\alpha-1)(1-\epsilon_\beta)}$, which implies that the return on research effort is independent of the leading-edge quality. This independency implies that the effects of fiscal policies in the PEG equilibrium are the same as the short-run effects in the TEG equilibrium; see Figures 5a and 5b. For a higher government expenditures-to-output ratio and a lower tax rate on capital income, we therefore limit the analysis of the qualitative effects to the PEG equilibrium.

Enter Figure 5 approximately here.

A higher government expenditures-to-output ratio increases the claim of the government on resources from the private sector. Given labor supply, and consumption following from the intratemporal optimality condition between consumption and leisure, this results in too little research effort given its return. This situation is represented by a downward rotation of Γ_Q in Figure 5c. As a result, resources flow from consumption to research effort and labor supply increases accordingly, leading to an increase in the growth rate of the economy.

The qualitative effects of a decrease in the capital income tax rate are given in Figure 5d. A decrease in τ_X leads to a higher return on research effort, which is shown by the upward rotation of Γ_P. Moreover, it increases the demand for intermediate goods, which results in too little research effort given labor supply. This situation is represented by the downward and counterclockwise rotation of Γ_Q. Both effects lead to a shift of resources from consumption toward research effort, which implies an increase in labor supply and the growth rate of the economy.

3.2 Effects of Fiscal Policy on the Government Budget Balance

The fiscal policies, and resulting changes in consumption, research effort, and labor supply also, effect the budget balance of the government. Studies that look at the feedback effects of fiscal policies using calibrated general equilibrium frameworks differ in the way they include the budget balance of the government. They assume either a periodically balanced government budget or an intertemporal government budget constraint that has to be satisfied, where the former has the disadvantage that it rules out financing schemes involving changes in the debt of the government.[19] We follow the latter approach since we want to analyze the consequences of the fiscal policies on the sustainability of the government budget in the long run. The long-run government budget balance is given by the intertemporal budget constraint of the government:

$$D \equiv \frac{\tau_C C(0) + \tau_L w(0)H(0) + \tau_X(Y(0) - w(0)H(0)) - s_Z Z(0) - \omega_G Y(0) - T(0)}{\tilde{r} - \tilde{g}} - B(0),$$

where we make use of the customary No-Ponzi Game condition $\lim_{t\to\infty} B(t)e^{-\int_0^t r(t')dt'} = 0$.[20] If $D < 0$, then the net present value of government revenues minus the net present value of government expenditures is insufficient to pay off the initial public debt, and vice versa. The intertemporal budget constraint of the government is balanced if $D = 0$.

There are different approaches in the dynamic scoring literature to measure the feedback effects of fiscal policies on the government budget. Mankiw and Weinzierl (2006), Trabandt and Uhlig (2009), Strulik and Trimborn (2010), and Scrimgeour (2010) analyze the degree of self-financing of tax cuts and focus on the dynamic feedback effects on government revenues. In these analyses, government budgets are balanced by letting lump-sum transfers adjust, where lower transfers imply a replacement of distortionary taxes with lump-sum taxes. Bruce and Turnovsky (1999) take a different approach and measure the feedback effects as the change in the present discounted value of lump-sum taxes needed for the intertemporal budget to be balanced. This approach shifts the attention from the effects on government revenues

[19]For example, studies that assume a periodically balanced government budget are Mankiw and Weinzierl (2006), Zeng and Zhang (2007), and Itaya (2008), and analyses that look at the intertemporal budget balance of the government are Ireland (1994), Bruce and Turnovsky (1999), and Novales and Ruiz (2002).

[20]Variables with tildes, like $\tilde{r}$ and $\tilde{g}$, are equilibrium values.

toward the effects on the government budget in general, including the effects on government expenditures and the growth rate of the economy.

One way we measure the feedback effects is by κ, which is defined as the percentage change in the transfer-to-output ratio T/Y needed for the intertemporal budget to be balanced. More specifically,

$$\kappa \equiv \frac{T(\infty)}{Y(\infty)} \left(\frac{T(0)}{Y(0)} \right)^{-1} - 1 \quad \text{such that} \quad \frac{\partial D}{\partial i} = 0 \quad \text{for} \quad i \in \{\tau_C, \tau_L, \tau_X, \omega_G, s_Z\},$$

where we assume that initially $D = 0$ and that the debt-to-output ratio cannot change. Since this approach takes into account the effects on both government revenues and expenditures, the return on assets, and the growth rate of the economy, it is in line with the approach of Bruce and Turnovsky (1999).

The above measure gives a good indication of the dynamic feedback effects of fiscal policies on the government budget. However, it is restrictive since the financing scheme is limited to the adjustment of transfers. Ireland (1994) proposes an alternative financing scheme where the path of transfers is predetermined but requires the assumption of a fixed debt-to-output ratio to be relaxed. If the path of transfers is predetermined, growth enhancing fiscal policies, such as lower distortionary tax rates, lead to a decline in the transfer-to-output ratio over time. This process frees up resources in the future that can be used to cover the initial loss in revenues caused by the lower tax rates. Since these resources come available over time, government debt is used to finance short-term fiscal deficits. If the present discounted value of these resources equals or is larger than the deterioration of the government budget and additional interest payments, the intertemporal budget of the government remains balanced or may even improve. In the latter situation, the fiscal policies lead to a dynamic Laffer effect. This financing scheme seems to be used only in frameworks where fiscal policies have permanent effects on growth, though the idea naturally extends to frameworks where they have only temporary effects.

Although it has the advantage that government expenditures do not have to decrease, the alternative finance scheme described above does not always lead to an improvement in the long-run government budget and may even lead to a situation where the intertemporal budget constraint is not satisfied.[21] Leeper and Yang (2008) introduce financing schemes where the intertemporal budget constraint is satisfied without having to rely on adjustments of transfers. More specifically, changes in the government budget as a result of fiscal policies are offset with a range of possible responses, such as changes in government expenditures or other distorting taxes. These offsetting policies may dampen or reverse the stimulating effects on the economy that the initial fiscal policies have brought forth.

We analyze the dynamic feedback effects of fiscal policies on the government budget under these three financing schemes. The first is the non-distorting financing scheme, where we adjust the transfer-to-output ratio to ensure the intertemporal budget constraint of the government is satisfied. In this case, we assume the debt-to-output ratio cannot be changed. Under the second financing scheme, the path of transfers is predetermined so that transfers cannot be lowered to improve the budget balance of the government. Temporary changes in the debt-to-output ratio, however, are allowed. We call this the non-distorting finance scheme with debt. Finally, we consider the distorting finance scheme, where we finance changes in the government budget by adjusting government expenditures or other distorting taxes.

Changes in welfare as a result of a fiscal policy are calculated as the percentage change in consumption, corresponding to the initial balanced growth equilibrium, necessary to obtain the same present discounted value of utility that follows from the fiscal policy. This percentage change is given by

$$\upsilon \equiv \frac{C_A(0)}{C(0)} \left(\frac{1-\tilde{L}_A}{1-\tilde{L}} \right)^{\frac{\epsilon_L}{\epsilon_C}} \left(\frac{\rho - \epsilon_C(1-\sigma)g}{\rho - \epsilon_C(1-\sigma)g_A} \right)^{\frac{1}{(1-\sigma)\epsilon_C}} - 1,$$

where the subscript A corresponds to values of the new balanced growth equilibrium. If υ is positive, then fiscal policies lead to a gain in welfare. A negative value of υ implies a deterioration in welfare as a result of fiscal policies.

[21]See Van Oudheusden (2009) for an overview of the mechanisms behind the dynamic Laffer effect and the conditions under which it may occur.

4 Numerical Results

To quantify the dynamic feedback effects of fiscal policies on the government budget, we perform several numerical analyses for different economies. We want these economies to differ in the way they set tax rates since this allows us to verify whether our model is able to replicate fiscal stylized facts and, thus, can be used for quantitative analyses. Mendoza and Tesar (2005) use similar arguments for the choice of their economies, we therefore choose the same economies. More specifically, we calibrate our model for both the United Kingdom and an average of three major continental European economies, namely France, Germany, and Italy; hereafter defined as Continental Europe. These two economies differ in how they tax factor income. Our choice of parameters and variables, representative for these countries, is based on data over the period 1995–2006. We take averages over this period to control for business-cycle effects, and we calibrate the model at an annual frequency.

4.1 Calibration and Stylized Facts

All fiscal parameters and variables are taken from the data, while for the structural parameters of the model we refer to literature when data are unavailable.[22]

To pin down the initial tax rates for the economies, we use data on implicit tax rates, which are based on the method of Mendoza et al. (1994). The benefits of these tax rates are that they take into account various features of the tax system, such as the combined effects of tax credits, tax deductions, and statutory rates.[23] The tax rate on consumption is the same for both economies and is 18.90 percent. The economies, however, differ in their tax rates on factor income. In Continental Europe, labor income and capital income are taxed at 41.16 and 20.01 percent, respectively, and for the United Kingdom these rates are 25.04 and 23.81 percent, respectively.

We measure the generosity of the tax incentives with respect to research effort by making use of data on the B-index, which captures the elements of these tax incentives such as

[22]The data are given in Table A.1, and the corresponding definitions and data sources are given in Table A.2. The data and their sources are in line with the calibration as performed by Trabandt and Uhlig (2011).

[23]See European Commission (2011, pp. 392–422) for a detailed overview of the exact definitions of the implicit tax rates and Trabandt and Uhlig (2011) for arguments for the use of these tax rates rather than marginal tax rates.

exemptions, allowances, credits, tax deferrals and rate reliefs. The index reflects before-tax income required to break even on one unit of research expenditures. We take one minus this index as the value for the parameter s_Z, which is 4.10 percent for Continental Europe and 7.85 percent for the United Kingdom; see Warda (2001) for details on the construction of the B-index.

The remaining fiscal parameters are the public expenditures-to-output ratio and the debt-to-output ratio. When restricted to consumption expenditures only, the public expenditures-to-output ratio is 20.51 percent for Continental Europe and 19.53 percent for the United Kingdom. Including investment expenditures of the government increases these ratios to 22.85 and 20.98 percent, respectively, which are used for the calibration. The debt-to-output ratio is 77.63 percent for Continental Europe, but it is only 43.73 percent for the United Kingdom. This difference can be explained by Italy, which has a debt-to-output ratio of over one hundred percent. However, the debt-to-output ratio of both France and Germany exceeds that of the United Kingdom, so the inclusion of Italy does not change their relative position.

For Continental Europe, the population growth rate and the production elasticity of aggregate labor are 0.80 percent and 0.6467, respectively, and for the United Kingdom these values are 1.08 percent and 0.7083, respectively. Here, we use that the value of the production elasticity of aggregate labor equals the income share of labor since there is perfect competition in the final goods sector. Krueger (1999), however, argues that there is a lot of variation in the income share of labor depending on which definition of labor income is used. Therefore, we do not always restrict the value of the production elasticity of aggregate labor to be equal to the observed income shares of labor, but let it vary to match other variables with the data; see also Grossmann et al. (2010).

We set the inverse of the intertemporal elasticity of substitution σ to 2, which falls well within the range of estimates found by Attanasio and Weber (1993) and is a common value used in the literature.[24] The choice for the elasticity of substitution between intermediate goods ϵ_β is less straightforward. A number of studies relates this elasticity directly to the

[24] For example, Turnovsky (2000a), Mendoza and Tesar (2005), Itaya (2008) and Trabandt and Uhlig (2011) use the same value for σ. In contrast, Mankiw and Weinzierl (2006) and Leeper and Yang (2008) set σ equal to unity, which falls outside the range of Attanasio and Weber (1993). Our model, however, is also compatible with this value for the intertemporal elasticity of substitution.

production elasticity of capital α, resulting in either unrealistic high markups or implausible income shares of production factors when calibrating the model; see Romer (1990), Jones (1995), Zeng and Zhang (2007), and Long and Pelloni (2011). We follow the literature that calibrates the parameters ϵ_β and α separately (i.e., Jones and Williams, 2000; Grossmann et al., 2010). These studies choose a value for ϵ_β such that the implied markup lies between 1.05 and 1.40. We set ϵ_β to 20 and aim at the lower bound of this range since Basu (1996) argues that estimates of mark-ups may be too large when failing to take into account variable utilization rates of production factors.

The parameters ϵ_C, ϵ_L, ϕ, ρ, η, ψ, and v have no real-world observable counterparts. We set ϵ_C to 1 and let ϵ_L adjust so that the share of the time endowment allocated to labor resulting from the model matches with the share observed in the data.[25] In general, the relative weight of leisure to consumption ϵ_L/ϵ_C is used to obtain a value of $\tilde{L}$ of around 20 percent (Mendoza and Tesar, 2005, p. 190). Differences in the values of α, or the tax rate on consumption and labor, then lead to differences in the value of ϵ_L/ϵ_C. For example, Novales and Ruiz (2002), Mendoza and Tesar (2005), and Leeper and Yang (2008), who all have in common that α is 0.36, set ϵ_L/ϵ_C between 2 and 3. In contrast, Turnovsky (2000a) sets ϵ_L/ϵ_C to 0.3 and works with a value of α of 0.92.

We set ρ so that the interest payments of the government match with the data. The parameters η and ψ are chosen such to ensure that, at least initially, the share of the time endowment allocated to labor in the TEG and PEG equilibrium coincides; see $\tilde{l}_{\text{TEG}}(\cdot)$ and $\tilde{l}_{\text{PEG}}(\cdot)$. Finally, we use ϕ, v, and θ to match the output share of research expenditures and the growth rate of output per capita with the data. The parameter v, which is inversely related to the size of quality improvements on the quality ladder of an intermediate good, has to be large enough for monopoly pricing to exist, so we set v equal to 2.[26]

Enter Table 1 approximately here.

[25]The share of time endowment allocated to labor L is calculated as the amount of hours per capita worked divided by the time endowment, which is set to 7200 (=20 $\times$ 360). Other calculations are possible, though the current share is similar to those aimed for in the literature; see Turnovsky (2000a), Mendoza and Tesar (2005), Leeper and Yang (2008), and Trabandt and Uhlig (2011).

[26]More specifically, the condition for monopoly pricing to exist is $v \leq \theta \left(\frac{1}{\epsilon_\beta - 1}\right) \left(\ln\left(\frac{\epsilon_\beta}{\epsilon_\beta - 1}\right)\right)^{-1} + 1$. See also Barro and Sala-i-Martin (1999, p. 244) and Acemoglu (2009, p. 461).

Table 1 summarizes the choices of parameters. The table compares the outcomes of our model with stylized facts observed in the data for different scenarios. These scenarios differ as follows. In the first scenario (I) , $1-\alpha$ is chosen under the assumption that the value of the production elasticity of labor equals the income share of labor, whereas in the second scenario (II), $1-\alpha$ adjusts so that the output share of consumption matches the data. In the third (III) and fourth (IV) scenario, we vary $1-\alpha$ to match output shares of the capital income tax revenues and labor income tax revenues, respectively.

By adjusting ϵ_L, the share of time endowment allocated to labor resulting from the model always matches with the one observed in the data. The resulting values of ϵ_L/ϵ_C lie between 2 and 3, which are common values in the literature. Moreover, the implied values of the Frisch elasticity of labor supply vary between 1.41 and 1.58. These values are close to one, which is the value used by House and Shapiro (2006), Strulik and Trimborn (2010), and Trabandt and Uhlig (2011). In contrast to these analyses, however, our value for the Frisch elasticity of labor supply follows endogenously from the model and cannot be picked.[27] Although the values implied by the model are higher than estimates based on micro data, we think they are plausible given the "major discrepancies between the micro evidence and the assumptions on which the stylized dynamic models are based" (Browning et al., 1999, p. 545) and the downward bias in the micro estimates (Domeij and Flodén, 2006).

To match the growth rate of output per capita to the data, we adjust ϕ, v, and θ in such a way that the output share of research expenditures also matches with the data.[28] Given that these parameters have no real-world counterparts, we look at the corresponding expected lifetime of a patent, which ranges from six years to 15.5 years. These values are well in the range of values found by Mansfield et al. (1981) and Caballero and Jaffe (1993); see also Jones and Williams (2000). An alternative strategy would be to fix the expected lifetime of a patent and compare the corresponding output share of research expenditures with the data. However, we do not pursue this approach since Jones and Williams (2000) and Grossmann

[27]More precisely, House and Shapiro (2006) have separable preference and Strulik and Trimborn (2010) and Trabandt and Uhlig (2011) use constant Frisch elasticity preferences. Trabandt and Uhlig (2011) also consider the case where the Frisch elasticity of labor supply does depend on the share of time endowment allocated to labor and has value of 3 in line with Prescott (1996). We can replicate this case in our model by setting $\sigma = 1$.

[28]Basically, we fix one of the parameters, v, and let the other vary. Changing the value of v leads to a change in the value of the other parameters but does not influence the outcomes of the model.

et al. (2010) argue that statistics on research expenditures do not completely capture the true amount of research expenditures.

By construction, we cannot replicate the share of consumption and investment in output exactly since our model assumes a closed economy. More specifically, the observed sum of consumption, government expenditures, and investment in Continental Europe falls short of output when not taking into account net exports. This means the sum of output shares of consumption and investment resulting from the model will always differ from the observed sum in the data. For Continental Europe, this difference amounts to 2.00 percentage points, and for the United Kingdom this is -1.39 percentage points.

In general, we find that our model underpredicts the output share of consumption. Since the output share of government expenditures is determined by the data, we overpredict the investment share of output. This outcome may be explained by the inclusion of durable consumption goods in the data on consumption, which could be seen as investment; see Trabandt and Uhlig (2011). The best fit in terms of the consumption and investment shares in output is obtained in the scenarios where we choose $1 - \alpha$ such that the output share of consumption exactly matches. The implied income share of labor in this case is on average 79.86 percent for Continental Europe and on average 86.30 percent for the United Kingdom.

To measure the fit of our model in terms of the fiscal side of the economy, we calculate the transfer-to-output ratio necessary for the long-run government budget to be balanced and compare this ratio with its real-world counterpart. In addition, we look at the implied revenue shares in output for the various taxes and see whether they are in line with the shares as observed in the data. Note that by construction, we cannot replicate exact shares of all the fiscal parameters since we capture on average 95 percent of all expenditures but only 90 percent of all revenues.[29] This situation is incompatible with a positive stock of initial debt and a long-run government budget that is balanced. Given this problem, however, the model has a relatively good fit when comparing the implied and actual transfer-to-output ratio.

For the interest payments of the government to match the data, we adjust ρ. This leads to

[29] For example, the sum of interest payments, transfers, consumptive government expenditures, and investment expenditures of the government are 94.19 percent of all government expenditures in the United Kingdom. At the same time, revenues from consumption taxes and taxes on labor income and capital income only make up 88.45 percent of all revenues. See Table A.1 for the data used in these calculations.

a value of 0.0360 for Continental Europe and 0.0245 for the United Kingdom. Both values are in the range of 0.02 (Agell and Persson, 2001; Mendoza and Tesar, 2005) and 0.04 (Turnovsky, 2000a; Mankiw and Weinzierl, 2006; Leeper and Yang, 2008) used in the literature. Since our model underpredicts the output share of consumption, it underpredicts the output share of consumption tax revenues as well. In general, the model overpredicts the output share of labor income tax revenues. We can remove this bias by adjusting $1 - \alpha$, but the implied income share of labor is 54.18 percent, which seems rather low.[30] The overprediction of the output share of labor income tax revenues, however, is not a bias specific to our model, but it seems to be shared by a wider class of calibrated dynamic general equilibrium models; see Van Oudheusden (2009) and Trabandt and Uhlig (2011). There is no general pattern in the prediction of the output share of capital income tax revenues. To be certain that the tax bases following from our model correspond to the actual tax bases, we look at different scenarios when analyzing the dynamic feedback effects of fiscal policies on the government budget.

4.2 Feedback Effects of Fiscal Policies

Given our choice of parameters and variables for the different scenarios, we analyze the dynamic feedback effects of fiscal policies on the government budget. More specifically, we look at the effects of an unexpected and permanent one percentage point change in each of the fiscal instrument available to the government separately. Hereby, we look at a decrease in the various tax rates and an increase in the government expenditures-to-output share and generosity of tax incentives with respect to research effort.[31] When analyzing these fiscal policies, we make a distinction between a non-distorting financing scheme, a non-distorting financing scheme where we allow for debt-to-output ratio changes over time, and a distorting finance scheme where changes in the budget balance of the government are financed by adjusting expenditures or other distorting taxes.

[30] The overprediction of the output share of labor income tax revenues is not too problematic since it mitigates the problem of the discrepancy between the government expenditures and revenues as described above.

[31] Changes in the government expenditures-to-output ratio are henceforth referred to as changes in government expenditures for ease of notation.

4.2.1 Non-distorting Financing Scheme

Table 2 gives an overview of the effects on the economy of the fiscal policies in the case of the non-distorting financing scheme. For the TEG equilibrium, the table gives both the short-run and long-run effects on the growth rate per capita, a measure of the leading-edge quality used in production Q_N, the share of time endowment allocated to labor, and both the output shares of consumption and research expenditures. Since transitional dynamics are absent in the PEG equilibrium, these effects represent changes in balanced growth equilibrium values. For each fiscal policy, the model predicts the short-run effects in the TEG equilibrium to be the same as the effects in the PEG equilibrium. Any deviations between the two are caused by linearization of the dynamics around the balanced growth equilibrium. Table 2 shows that the magnitude of these deviations are around one-hundredths of a percent, so we are confident we capture the dynamics well.

Enter Table 2 approximately here.

Lowering the tax rate on capital income gives the largest increase in economic activity measured by the impact on the growth rate, either temporary or permanent, or the use of a relatively higher leading-edge quality in the new balanced growth equilibrium. This fiscal policy is followed by an increase in government expenditures, a lower tax rate on labor income, and more generous tax incentives with respect to research effort. A lower tax rate on consumption is the least effective way to boost the economy.

Changes in labor supply are the largest for an increase in government expenditures, followed by lower taxes on labor income, capital income, and consumption. More generous tax incentives with respect to research effort lead to the smallest changes in the share of time endowment allocated to labor. In the TEG equilibrium, the long-run effects are smaller than the short-run effects, which is in line with the theoretical predictions of the model, although the differences are rather small.

The impact on the government budget is measured by κ, where in its calculation we use the actual transfer-to-output ratio rather than the ones implied by the model since the latter differ across the scenarios and may bias the results. Making tax incentives with respect to research effort more generous leads to the smallest impact on the long-run government budget balance, in terms of a lower transfer-to-output ratio. This fiscal policy is followed by the lower tax rates on capital income, consumption, and labor income. The largest impact on the budget balance of the government is caused by the increase in government expenditures.

Welfare effects are measured by υ. The largest welfare gain is obtained by lowering the tax rate on labor income, followed by a lower tax rate on capital income and consumption. More generous tax incentives for research effort lead to the smallest welfare gain. Increasing government expenditures lead to a loss in welfare, which can be explained by government expenditures being modeled as pure waste. A larger claim of the government on the private sector then means a larger part of private activity is crowded out.

For comparison, we normalize the effect such that all fiscal policies lead to an increase in the growth rate per capita of one percent for the PEG equilibrium and to a decrease in Q_N of one percent for the TEG equilibrium. The results are given in Table 3 and suggest that the least costly way, in terms of the impact on the government budget, to promote economic growth is by making tax incentives with respect to research effort more generous. This fiscal policy is followed by lower tax rates on capital income and labor income. Higher government expenditures and a lower tax rate on consumption are the most expensive policies to boost economic activity. The corresponding changes in labor supply follow a similar pattern.

Enter Table 3 approximately here.

The above results hold for both economies and are robust across the different scenarios. To stimulate economic activity, more generous tax incentives with respect to research effort are almost three times as effective as lowering the tax rate on capital, which in turn is at least three times as effective as lowering the tax rate on labor income. An explanation of this result may be the relative size of the initial tax bases of the instruments. For example, the tax base of tax incentives with respect to research effort, which is the output share of research expenditures, is relatively small compared to the bases of the other instruments. A relatively small initial tax base causes smaller losses in revenues when tax rates are lowered. Of course, this effect has to be compared with the resulting efficiency gains of changes in the fiscal policy instruments, which may be independent of their corresponding initial tax bases.

4.2.2 Non-distorting Financing Scheme with Debt

Under the previous financing scheme, the transfers to households are adjusted to ensure the intertemporal budget constraint of the government is satisfied. At the same time, the debt-to-output ratio is assumed to be constant. As an alternative finance scheme, we assume the path of transfers to households to be predetermined so that transfers cannot be lowered to improve the budget balance of the government. We do, however, allow for temporary changes in the debt-to-output ratio now. Figure 6 gives the impulse response functions of more generous tax incentives with respect to research effort for both economies under the second scenario. We choose this scenario because it has the highest κ, and the possibility of obtaining a dynamic Laffer effect is the largest of all scenarios.

Enter Figure 6 approximately here.

For Continental Europe, the debt-to-output ratio increases over time (see Figure 6a), which means the resources that come available in the future, as a result of the predetermined path of transfers, are insufficient to cover the initial deterioration of the budget balance of the government and the temporary increase in government debt. The same result is obtained for the United Kingdom. None of the fiscal policies lead to a dynamic Laffer effect, which can be explained by the relatively large deterioration of the government budget balance in the short run compared to the resulting efficiency gains of these policies; see Van Oudheusden (2009).

4.2.3 Distorting Financing Scheme

As a final financing scheme, we consider the case where changes in the budget balance of the government, as a result of fiscal policies, are offset by adjusting expenditures or other distorting taxes. In addition, we assume constant output shares of lump-sum transfers and debt. The previous results already suggest what to expect. We know that adjusting government expenditures or the consumption tax are the most expensive way, in terms of their impact on the budget balance of the government, to promote economic activity; see Table 3. Thus, they should be the least expensive way, in terms of their impact on economic activity, to offset changes in the budget balance of the government. This expectation is confirmed in Table 4.

Enter Table 4 approximately here.

For tax incentives with respect to research effort, offsetting changes in the government budget balance with the consumption tax leads to an increase in the growth rate per capita that is on average 94 percent of the increase under the non-distorting finance scheme. Adjusting the tax rate on labor income or capital income are less efficient with percentages of around 92 and 65, respectively. When financing a lower tax rate on capital income by adjusting the consumption tax rate, the increase in the growth rate per capita is only 82 percent of the increase under the non-distorting finance scheme. In all cases, changes in the share of time endowment allocated to labor are relatively small. Adjustments of the consumption tax rate also lead to the largest gain in welfare.[32]

In general, making tax incentives with respect to research effort more generous is the least costly way to boost economic activity. If non-distorting finance options are excluded, then adjusting government expenditures and the consumption tax to finance this policy lead to the smallest loss in efficiency. The last result may be changed when giving government expenditures a more prominent role in the framework. In our framework, government expenditures are modeled as waste. Including them in the utility function in a separable way may be useful for welfare analysis, but it does not change the results; see Agell and Persson (2001) and Trabandt and Uhlig (2011). When included in a non-separable way, government expenditures affect the effective intertemporal elasticity of substitution (Agell and Persson, 2001; Van Oudheusden, 2009) and possibly transitional dynamics (Van Oudheusden, 2009).[33] The general findings, however, should remain valid.

[32] Financing with government expenditures does lead to a higher gain in welfare, but this is the results of government expenditures being modeled as waste. Lower expenditures then imply that waste is lower and welfare is higher.

[33] Transitional dynamics are influenced in the case where the PEG equilibrium is locally stable, which is not the case in our analysis. See Leeper and Yang (2008) for an additional discussion on including government expenditures in dynamic scoring analyses.

5 Conclusions

Using a calibrated dynamic general equilibrium framework featuring endogenous growth through creative destruction, we analyze dynamic feedback effects of fiscal policies on the government budget balance for several European countries. Making tax incentives with respect to research effort more generous is the least costly way, in terms of the impact on the government budget, to boost economic activity. Moreover, this policy is almost three times as cost effective as the next best policy, which is a lower tax rate on capital income. A dynamic Laffer effect is never possible for any of the fiscal policies. If financing with non-distorting means is excluded, adjusting government expenditures and the consumption tax rate are the preferred policies to keep the long-run government budget balanced. Governments that face the challenge to set fiscal policies such that they result in sufficient revenues to deal with long-run budget challenges and promote economic growth at the same time could possible benefit by taking into account the above findings.

Future research could usefully focus on extending the framework with additional growth engines; for example, the inclusion of human capital accumulation or a more elaborate process of the investment and depreciation of physical capital. However, explicitly modeling intermediate good specific capital stocks may change research effort incentives by introducing an additional element of competition. Firms then not only compete on basis of their relative quality but also have to take into account the stock of machines of competitors. This may create an additional role for government policies in the form of directed R&D subsidies or sector specific depreciation allowances. Including public R&D expenditures in addition to private R&D expenditures may be another avenue for future research.

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A Appendix

This appendix describes the derivations of equations (8), (9), and (15). Moreover, it provides the data, and corresponding sources, we use in the calibration of the model.

A.1 Derivation of Equations

Derivation of (8)

Assume that the leading-edge quality at time t and time $t + \Delta t$ is given by

$$Q(t) = Q(0)e^{\frac{S(t)}{v-1}},$$
$$Q(t + \Delta t) = Q(0)e^{\frac{S(t+\Delta t)}{v-1}},$$

so that

$$\frac{\ln Q(t + \Delta t) - \ln Q(t)}{\Delta t} = \frac{S(t + \Delta t) - S(t)}{\Delta t(v - 1)}.$$

Taking the limit as $\Delta t \to 0$ then gives

$$\frac{\dot{Q}(t)}{Q(t)} = \frac{\dot{S}(t)}{v - 1} = \frac{z(t)}{v - 1},$$

where $v > 1$, $Q(0) > 0$, $S(t)$ is the total number of innovations between time 0 and time t, and $\dot{S}(t) = z(t)$ is the aggregate flow of innovations.

Derivation of (9)

In deriving equation (9), we follow Aghion and Howitt (1998, p.115). We define $\Theta(t) \equiv F(\bar{Q}, t)$ as the mass of intermediate goods that are produced with quality lower than $\bar{Q} > 0$, where $F(\cdot, t)$ is the cumulative distribution function of absolute qualities at time t, and $\bar{Q}$ is the leading-edge quality at time $t_0 \geq 0$. This means that $Q(t_0) = \bar{Q}$ and $\Theta(t_0) = 1$. As a result of innovations, intermediate goods that are being produced with qualities lower than $\bar{Q}$ jump to the leading-edge quality so that $\Theta(t)$ decreases over time. More specifically, this process is given by $\dot{\Theta}(t) = -\Theta(t)z(t)\ \forall\ t \geq t_0$, which says that the decline in $\Theta(t)$ equals the number of intermediate goods with quality lower than $\bar{Q}$ times the aggregate flow rate of new innovations $z(t)$. From equation (8), we know that in general the leading-edge quality evolves over time according to $\dot{Q}(t) = z(t)(1-v)^{-1}Q(t)$. We solve these two differential equations to get

$$\Theta(t) = e^{-\int_{t_0}^{t} z(t')dt'},$$
$$Q(t) = \bar{Q}\left(e^{\int_{t_0}^{t} z(t')dt'}\right)^{\frac{1}{v-1}},$$

and combining the solutions gives

$$\Theta(t) = \left(\frac{\bar{Q}}{Q(t)}\right)^{v-1} = q^{v-1},$$

with $0 \leq q \leq 1$ and $q \equiv \bar{Q}/Q(t)$. Since $\Theta(t)$ is the mass of intermediate goods that are produced with quality lower than $qQ(t)$ at time t, the distribution function of quality $Q_i(t)$ with relative quality q can be given by $J(q) \equiv q^{v-1}$. This means that the distribution function of any quality $Q_i(t)$ is independent of the leading-edge quality. Moreover, intermediate goods can be classified according to their relative qualities so that the sum of qualities at any time is given by

$$\int_0^1 Q_i(t)^\theta di = Q(t)^\theta \int_0^1 q^\theta \frac{\partial J(q)}{\partial q} dq = \frac{v-1}{v-1+\theta} Q(t)^\theta.$$

Derivation of (15)

The derivation of equation (15) is standard though quite tedious. Basically, we combine the intratemporal optimality condition between consumption and leisure, the intertemporal optimality condition that says the return on consumption should equal the return on investment, and the aggregate resource constraint.

The intratemporal optimality condition between leisure and per capita consumption is obtained by dividing equation (12b) by equation (12a) and says that at each point in time the marginal rate of substitution between leisure and per capita consumption should equal its relative price:

$$\frac{\epsilon_L}{\epsilon_C}\frac{c(t)}{1-L(t)} = \frac{1-\tau_L}{1+\tau_C}w(t)$$
$$= \frac{1-\tau_L}{1+\tau_C}\frac{1-\alpha}{\alpha}\left(\frac{\epsilon_\beta}{\epsilon_\beta-1}\frac{\psi}{1-\tau_X}\right)^{\frac{\alpha}{\alpha-1}}\left(\frac{\upsilon-1}{\upsilon-1+\theta}Q(t)^\theta\right)^{\frac{\alpha}{(\alpha-1)(1-\epsilon_\beta)}},$$

where we rewrite $w(t)$ by using $P(t) \equiv \left(\int_0^1 p_i(t|Q_i(t))^{1-\epsilon_\beta}Q_i(t)^{\theta\epsilon_\beta}di\right)^{\frac{1}{1-\epsilon_\beta}}$ and equations (2), (3), (5), and (8). Taking the logarithm and subsequently the time derivative of this intratemporal optimality condition and rearranging terms gives

$$\frac{\dot{c}(t)}{c(t)} = \frac{\theta\alpha}{(\alpha-1)(1-\epsilon_\beta)}\frac{\dot{Q}(t)}{Q(t)} - \frac{\dot{L}(t)}{1-L(t)}. \tag{15a}$$

The return on consumption is given by

$$\rho - \frac{\dot{\lambda}(t)}{\lambda(t)} = \rho + (1-(1-\sigma)\epsilon_C)\frac{\dot{c}(t)}{c(t)} + (1-\sigma)\epsilon_L\frac{\dot{L}(t)}{1-L(t)}, \tag{15b}$$

where the expression for $\dot{\lambda}(t)/\lambda(t)$ is obtained by taking the logarithm and subsequently the time derivative of equation (12a). The return on investment is given by

$$r(t) = \frac{\eta}{\epsilon_\beta}\frac{1-\tau_X}{1-s_Z}\left(\frac{\epsilon_\beta}{\epsilon_\beta-1}\frac{\psi}{1-\tau_X}\right)^{\frac{\alpha}{\alpha-1}}\left(\frac{\upsilon-1}{\upsilon-1+\theta}\right)^{\frac{1}{1-\epsilon_\beta}\left(\epsilon_\beta-\frac{1}{1-\alpha}\right)}Q_N(t)L(t) - (\upsilon-1)\frac{\dot{Q}(t)}{Q(t)}, \tag{15c}$$

where we use equations (6)–(9), and $z_i(t) = z(t)$ since the return on research effort is the same for all intermediate goods and the total number of intermediate goods is normalized to unity. Moreover,

$$Q_N(t) \equiv Q(t)^{\frac{\theta\alpha}{(\alpha-1)(1-\epsilon_\beta)}-\phi}N(t). \tag{15d}$$

The intertemporal optimality condition is given by equation (12c):

$$\rho - \frac{\dot{\lambda}}{\lambda} = r(t), \tag{15e}$$

which says that the return on consumption should equal the return on investment.

The derivation of the condition corresponding to the aggregate resource constraint is as follows. First, we multiply the per capita budget constraint (11b) by $N(t)$, add up the resource constraint of the government (14). Now, we use that $A(t) \equiv \int_0^1 V_i(t|Q_i(t))di$ since we have a closed economy. We further use that perfect competition in the research sector implies $z_i(t|Q_i(t))V_i(t|Q_i(t) = (1-s_Z)Z_i(t|Q_i(t))$, perfect competition in the final good sector implies $\int_0^1 \pi_i(t|Q_i(t))di + w(t)H(t) = Y(t) - \int_0^1 \psi Q_i(t)^\theta x_i(t|Q_i(t)) = Y(t) - X(t)$, and $G(t) = \omega_G Y(t)$ so that the aggregate resource constraint is given by $Y(t) = C(t) + G(t) + X(t) + Z(t)$. We know that

$$
\begin{aligned}
Y(t) &= \left(\frac{v-1}{v-1+\theta}\right)^{\frac{\alpha}{(\alpha-1)(1-\epsilon_\beta)}} \left(\frac{\epsilon_\beta}{\epsilon_\beta - 1}\frac{\psi}{1-\tau_X}\right)^{\frac{\alpha}{\alpha-1}} Q_N(t)Q(t)^\phi \frac{L(t)}{\alpha}, \\
C(t) &= \left(\frac{v-1}{v-1+\theta}\right)^{\frac{\alpha}{(\alpha-1)(1-\epsilon_\beta)}} \left(\frac{\epsilon_\beta}{\epsilon_\beta - 1}\frac{\psi}{1-\tau_X}\right)^{\frac{\alpha}{\alpha-1}} Q_N(t)Q(t)^\phi \frac{\epsilon_C}{\epsilon_L}\frac{1-\tau_L}{1+\tau_C}\frac{1-\alpha}{\alpha}(1-L(t)), \\
G(t) &= \left(\frac{v-1}{v-1+\theta}\right)^{\frac{\alpha}{(\alpha-1)(1-\epsilon_\beta)}} \left(\frac{\epsilon_\beta}{\epsilon_\beta - 1}\frac{\psi}{1-\tau_X}\right)^{\frac{\alpha}{\alpha-1}} Q_N(t)Q(t)^\phi \frac{L(t)}{\alpha}\omega_G, \\
X(t) &= \left(\frac{v-1}{v-1+\theta}\right)^{\frac{\alpha}{(\alpha-1)(1-\epsilon_\beta)}} \left(\frac{\epsilon_\beta}{\epsilon_\beta - 1}\frac{\psi}{1-\tau_X}\right)^{\frac{\alpha}{\alpha-1}} Q_N(t)Q(t)^\phi \frac{\epsilon_\beta - 1}{\epsilon_\beta}L(t), \\
Z(t) &= (v-1)\frac{\dot{Q}(t)}{Q(t)}\eta^{-1}Q(t)^\phi,
\end{aligned}
$$

where we used $P(t) = \left(\int_0^1 p_i(t|Q_i(t))^{1-\epsilon_\beta} Q_i(t)^{\theta\epsilon_\beta} di\right)^{\frac{1}{1-\epsilon_\beta}}$, $Z(t) = z(t)\eta^{-1}Q(t)^\phi$, and equations (1), (2), (3), (8), (9), (12a), and (12b). The aggregate resource constraint can then be written as

$$
\frac{\dot{Q}(t)}{Q(t)} = \frac{\xi}{\alpha}Q_N(t)L(t)\left(1 - \omega_G - \alpha(1-\tau_X)\frac{\epsilon_\beta - 1}{\epsilon_\beta} - \frac{\epsilon_C}{\epsilon_L}\frac{1-\tau_L}{1+\tau_C}(1-\alpha)\frac{1-L(t)}{L(t)}\right), \quad (15f)
$$

with $\xi \equiv \frac{\eta}{v-1}\left(\frac{v-1}{v-1+\theta}\right)^{\frac{\alpha}{(\alpha-1)(1-\epsilon_\beta)}}\left(\frac{\epsilon_\beta}{\epsilon_\beta-1}\frac{\psi}{1-\tau_X}\right)^{\frac{\alpha}{\alpha-1}}$. Combining equation (15a)–(15f) and rearranging terms gives equation (15).

A.2 Data

The data are on the next pages.

Table A.1: Calibration Data

	Economy	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	Average
L	France	1651	1655	1649	1637	1630	1591	1578	1537	1532	1561	1557	1536	1593
	Germany	1534	1518	1509	1503	1492	1473	1458	1445	1439	1442	1434	1430	1473
	Italy	1859	1873	1863	1880	1876	1861	1843	1831	1826	1826	1819	1815	1848
	Continental Europe	1681	1682	1673	1673	1666	1642	1627	1604	1599	1610	1603	1593	1638
	United Kingdom	1631	1630	1630	1624	1613	1602	1605	1587	1570	1565	1569	1564	1599
n	France	0.0088	0.0038	0.0044	0.0151	0.0200	0.0265	0.0176	0.0062	0.0013	0.0011	0.0055	0.0098	0.0100
	Germany	0.0023	-0.0027	-0.0009	0.0119	0.0134	0.0186	0.0044	-0.0056	-0.0095	0.0040	-0.0012	0.0062	0.0034
	Italy	-0.0020	0.0057	0.0031	0.0098	0.0108	0.0192	0.0200	0.0170	0.0149	0.0044	0.0057	0.0194	0.0107
	Continental Europe	0.0030	0.0022	0.0022	0.0123	0.0147	0.0214	0.0140	0.0058	0.0022	0.0031	0.0034	0.0118	0.0080
	United Kingdom	0.0122	0.0093	0.0178	0.0102	0.0138	0.0116	0.0082	0.0076	0.0095	0.0106	0.0101	0.0087	0.0108
$g - n$	France	0.0156	0.0122	0.0195	0.0216	0.0131	0.0102	-0.0024	0.0017	0.0099	0.0232	0.0129	0.0116	0.0124
	Germany	0.0165	0.0126	0.0188	0.0082	0.0065	0.0130	0.0079	0.0056	0.0073	0.0080	0.0087	0.0270	0.0117
	Italy	0.0282	0.0075	0.0142	0.0047	0.0091	0.0183	0.0004	-0.0081	-0.0064	0.0115	0.0050	0.0048	0.0074
	Continental Europe	0.0201	0.0108	0.0175	0.0115	0.0096	0.0138	0.0020	-0.0003	0.0036	0.0143	0.0088	0.0145	0.0105
	United Kingdom	0.0179	0.0191	0.0148	0.0253	0.0203	0.0268	0.0161	0.0132	0.0182	0.0185	0.0114	0.0188	0.0184
$1 - \alpha$	France	0.6726	0.6744	0.6686	0.6609	0.6667	0.6615	0.6601	0.6632	0.6622	0.6618	0.6619	0.6588	0.6644
	Germany	0.6633	0.6602	0.6522	0.6501	0.6549	0.6633	0.6594	0.6546	0.6541	0.6448	0.6358	0.6246	0.6514
	Italy	0.6324	0.6315	0.6379	0.6289	0.6261	0.6167	0.6139	0.6157	0.6190	0.6167	0.6231	0.6298	0.6243
	Continental Europe	0.6561	0.6554	0.6529	0.6466	0.6492	0.6472	0.6445	0.6445	0.6451	0.6411	0.6403	0.6377	0.6467
	United Kingdom	0.7125	0.6929	0.6914	0.7021	0.7068	0.7193	0.7254	0.7152	0.7130	0.7087	0.7069	0.7054	0.7083
C	France	0.5661	0.5692	0.5584	0.5564	0.5542	0.5573	0.5599	0.5593	0.5644	0.5662	0.5686	0.5680	0.5623
as share of Y	Germany	0.5773	0.5818	0.5825	0.5788	0.5840	0.5887	0.5956	0.5895	0.5937	0.5894	0.5911	0.5836	0.5863
	Italy	0.5841	0.5791	0.5847	0.5919	0.5985	0.5992	0.5908	0.5870	0.5909	0.5863	0.5904	0.5907	0.5895
	Continental Europe	0.5758	0.5767	0.5752	0.5757	0.5789	0.5817	0.5821	0.5786	0.5830	0.5806	0.5834	0.5808	0.5794
	United Kingdom	0.6346	0.6401	0.6410	0.6461	0.6509	0.6555	0.6585	0.6577	0.6513	0.6476	0.6499	0.6414	0.6479
$X + Z$	France	0.1493	0.1473	0.1455	0.1508	0.1584	0.1639	0.1647	0.1584	0.1577	0.1619	0.1665	0.1746	0.1582
as share of Y	Germany	0.1972	0.1925	0.1916	0.1928	0.1942	0.1967	0.1827	0.1666	0.1631	0.1607	0.1605	0.1680	0.1806
	Italy	0.1701	0.1679	0.1676	0.1698	0.1725	0.1799	0.1795	0.1918	0.1790	0.1811	0.1837	0.1875	0.1775
	Continental Europe	0.1722	0.1692	0.1683	0.1711	0.1750	0.1802	0.1756	0.1722	0.1666	0.1679	0.1703	0.1767	0.1721
	United Kingdom	0.1456	0.1516	0.1546	0.1647	0.1612	0.1593	0.1532	0.1524	0.1479	0.1489	0.1602	0.1529	0.1544

(Continued)

Table A.1: Calibration Data (continued)

	Economy	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	Average
τ_C	France	0.2154	0.2210	0.2222	0.2195	0.2207	0.2089	0.2028	0.2033	0.1996	0.2011	0.2005	0.1987	0.2095
	Germany	0.1883	0.1831	0.1806	0.1832	0.1903	0.1890	0.1851	0.1854	0.1864	0.1821	0.1808	0.1827	0.1847
	Italy	0.1741	0.1709	0.1735	0.1780	0.1799	0.1791	0.1731	0.1712	0.1655	0.1685	0.1671	0.1733	0.1728
	Continental Europe	0.1926	0.1917	0.1921	0.1936	0.1970	0.1924	0.1870	0.1866	0.1839	0.1839	0.1828	0.1849	0.1890
	United Kingdom	0.1965	0.1956	0.1949	0.1920	0.1940	0.1894	0.1860	0.1849	0.1875	0.1868	0.1811	0.1799	0.1890
τ_L	France	0.4117	0.4143	0.4174	0.4220	0.4242	0.4199	0.4167	0.4119	0.4150	0.4145	0.4192	0.4188	0.4171
	Germany	0.3944	0.3961	0.4057	0.4061	0.4037	0.4074	0.4050	0.4039	0.4039	0.3918	0.3883	0.3894	0.3997
	Italy	0.3819	0.4185	0.4347	0.4328	0.4268	0.4216	0.4213	0.4201	0.4187	0.4164	0.4134	0.4110	0.4181
	Continental Europe	0.3960	0.4096	0.4193	0.4203	0.4182	0.4163	0.4143	0.4120	0.4125	0.4076	0.4070	0.4064	0.4116
	United Kingdom	0.2575	0.2484	0.2438	0.2504	0.2511	0.2533	0.2501	0.2410	0.2431	0.2491	0.2563	0.2602	0.2504
τ_X	France	0.1572	0.1753	0.1793	0.1811	0.2019	0.2079	0.2146	0.1984	0.1867	0.1929	0.1979	0.2206	0.1928
	Germany	0.1721	0.2005	0.1954	0.2072	0.2348	0.2378	0.1739	0.1610	0.1606	0.1648	0.1761	0.1972	0.1901
	Italy	0.1803	0.1938	0.2188	0.2001	0.2237	0.2245	0.2238	0.2121	0.2412	0.2183	0.2174	0.2548	0.2174
	Continental Europe	0.1699	0.1899	0.1978	0.1961	0.2202	0.2234	0.2041	0.1905	0.1962	0.1920	0.1971	0.2242	0.2001
	United Kingdom	0.2057	0.2074	0.2254	0.2415	0.2566	0.2675	0.2767	0.2404	0.2107	0.2207	0.2414	0.2630	0.2381
τ_C revenues	France	0.1205	0.1242	0.1228	0.1209	0.1213	0.1157	0.1126	0.1126	0.1114	0.1124	0.1124	0.1113	0.1165
as share of Y	Germany	0.1032	0.1015	0.1002	0.1009	0.1053	0.1054	0.1046	0.1036	0.1047	0.1017	0.1013	0.1013	0.1028
	Italy	0.1038	0.1008	0.1034	0.1072	0.1095	0.1094	0.1040	0.1019	0.0990	0.1001	0.0997	0.1036	0.1035
	Continental Europe	0.1092	0.1088	0.1088	0.1097	0.1120	0.1101	0.1070	0.1061	0.1050	0.1047	0.1045	0.1054	0.1076
	United Kingdom	0.1201	0.1205	0.1201	0.1189	0.1205	0.1182	0.1162	0.1152	0.1156	0.1146	0.1115	0.1093	0.1167
τ_L revenues	France	0.2271	0.2291	0.2289	0.2275	0.2315	0.2297	0.2288	0.2275	0.2292	0.2285	0.2306	0.2290	0.2290
as share of Y	Germany	0.2403	0.2432	0.2456	0.2437	0.2424	0.2452	0.2422	0.2415	0.2408	0.2309	0.2260	0.2212	0.2386
	Italy	0.1825	0.1991	0.2085	0.2078	0.2036	0.1988	0.2019	0.2022	0.2033	0.2011	0.2040	0.2048	0.2015
	Continental Europe	0.2166	0.2238	0.2277	0.2263	0.2258	0.2246	0.2243	0.2237	0.2244	0.2202	0.2202	0.2183	0.2230
	United Kingdom	0.1372	0.1299	0.1278	0.1344	0.1357	0.1397	0.1398	0.1334	0.1333	0.1356	0.1402	0.1408	0.1357
τ_X revenues	France	0.0401	0.0438	0.0455	0.0472	0.0513	0.0535	0.0554	0.0494	0.0459	0.0472	0.0477	0.0542	0.0484
as share of Y	Germany	0.0429	0.0500	0.0501	0.0531	0.0576	0.0570	0.0420	0.0398	0.0405	0.0440	0.0494	0.0583	0.0487
	Italy	0.0754	0.0823	0.0875	0.0761	0.0820	0.0832	0.0841	0.0762	0.0848	0.0767	0.0738	0.0842	0.0805
	Continental Europe	0.0528	0.0587	0.0610	0.0588	0.0637	0.0646	0.0605	0.0551	0.0571	0.0560	0.0570	0.0655	0.0592
	United Kingdom	0.0530	0.0566	0.0630	0.0666	0.0649	0.0654	0.0661	0.0583	0.0559	0.0584	0.0647	0.0720	0.0621

(*Continued*)

Table A.1: Calibration Data (continued)

	Economy	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	Average
τ_C revenues	France	0.2822	0.2828	0.2782	0.2748	0.2702	0.2621	0.2570	0.2612	0.2596	0.2602	0.2576	0.2535	0.2666
as share of total	Germany	0.2594	0.2495	0.2463	0.2467	0.2525	0.2517	0.2616	0.2622	0.2640	0.2624	0.2614	0.2587	0.2564
	Italy	0.2591	0.2412	0.2364	0.2525	0.2577	0.2619	0.2508	0.2493	0.2395	0.2466	0.2468	0.2466	0.2490
	Continental Europe	0.2669	0.2578	0.2536	0.2580	0.2601	0.2586	0.2565	0.2576	0.2544	0.2564	0.2553	0.2529	0.2573
	United Kingdom	0.3466	0.3505	0.3447	0.3314	0.3331	0.3221	0.3187	0.3298	0.3334	0.3261	0.3095	0.2971	0.3286
τ_L revenues	France	0.5318	0.5217	0.5188	0.5172	0.5156	0.5205	0.5225	0.5276	0.5342	0.5290	0.5285	0.5213	0.5241
as share of total	Germany	0.6040	0.5980	0.6038	0.5960	0.5810	0.5857	0.6058	0.6108	0.6072	0.5961	0.5831	0.5647	0.5947
	Italy	0.4554	0.4760	0.4767	0.4895	0.4793	0.4760	0.4868	0.4947	0.4920	0.4956	0.5050	0.4876	0.4846
	Continental Europe	0.5304	0.5319	0.5331	0.5343	0.5253	0.5274	0.5384	0.5444	0.5445	0.5402	0.5388	0.5245	0.5344
	United Kingdom	0.3958	0.3779	0.3667	0.3745	0.3749	0.3804	0.3837	0.3818	0.3846	0.3860	0.3894	0.3827	0.3815
τ_X revenues	France	0.0938	0.0998	0.1032	0.1074	0.1142	0.1213	0.1266	0.1145	0.1070	0.1093	0.1092	0.1234	0.1108
as share of total	Germany	0.1078	0.1229	0.1232	0.1298	0.1382	0.1362	0.1051	0.1006	0.1021	0.1136	0.1274	0.1487	0.1213
	Italy	0.1881	0.1969	0.2000	0.1794	0.1931	0.1993	0.2028	0.1864	0.2053	0.1890	0.1827	0.2004	0.1936
	Continental Europe	0.1299	0.1398	0.1421	0.1388	0.1485	0.1523	0.1448	0.1339	0.1381	0.1373	0.1398	0.1575	0.1419
	United Kingdom	0.1530	0.1646	0.1807	0.1854	0.1795	0.1782	0.1813	0.1670	0.1613	0.1661	0.1795	0.1955	0.1743
s_Z	France					0.0850	0.0850				0.1340		0.1890	0.1233
	Germany					-0.0410	-0.0410				-0.0240		-0.0300	-0.0340
	Italy					-0.0270	-0.0270				0.2120		-0.0230	0.0338
	Continental Europe					0.0057	0.0057				0.1073		0.0453	0.0410
	United Kingdom					0.0560	0.0560				0.1010		0.1010	0.0785
Z	France												0.0459	0.0459
as share of Y	Germany												0.0431	0.0431
	Italy												0.0283	0.0283
	Continental Europe												0.0391	0.0391
	United Kingdom												0.0432	0.0432
B	France	0.5548	0.5800	0.5928	0.5943	0.5881	0.5733	0.5688	0.5882	0.6291	0.6487	0.6636	0.6366	0.6015
as share of Y	Germany	0.5560	0.5843	0.5966	0.6032	0.6090	0.5974	0.5883	0.6044	0.6394	0.6576	0.6799	0.6755	0.6160
	Italy	1.2155	1.2089	1.1806	1.1494	1.1370	1.0917	1.0879	1.0569	1.0442	1.0390	1.0594	1.0665	1.1114
	Continental Europe	0.7754	0.7911	0.7900	0.7823	0.7780	0.7542	0.7483	0.7498	0.7709	0.7818	0.8009	0.7929	0.7763
	United Kingdom	0.5123	0.5130	0.4978	0.4666	0.4368	0.4102	0.3773	0.3746	0.3904	0.4087	0.4251	0.4345	0.4373

(*Continued*)

Table A.1: Calibration Data (continued)

	Economy	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	Average
G_c	France	0.2369	0.2392	0.2387	0.2310	0.2315	0.2290	0.2279	0.2339	0.2373	0.2372	0.2367	0.2337	0.2344
as share of Y	Germany	0.1957	0.1981	0.1939	0.1915	0.1925	0.1900	0.1894	0.1921	0.1926	0.1881	0.1871	0.1828	0.1912
	Italy	0.1796	0.1826	0.1831	0.1811	0.1823	0.1845	0.1897	0.1921	0.1969	0.1985	0.2034	0.2015	0.1896
	Continental Europe	0.2041	0.2066	0.2053	0.2012	0.2021	0.2012	0.2023	0.2060	0.2089	0.2079	0.2091	0.2060	0.2051
	United Kingdom	0.1951	0.1903	0.1815	0.1780	0.1827	0.1863	0.1904	0.1976	0.2043	0.2087	0.2138	0.2147	0.1953
G_p	France	0.0318	0.0316	0.0291	0.0283	0.0293	0.0308	0.0301	0.0293	0.0307	0.0311	0.0330	0.0320	0.0306
as share of Y	Germany	0.0218	0.0206	0.0184	0.0181	0.0187	0.0178	0.0174	0.0168	0.0156	0.0143	0.0135	0.0139	0.0172
	Italy	0.0206	0.0215	0.0215	0.0232	0.0238	0.0233	0.0237	0.0173	0.0245	0.0240	0.0236	0.0234	0.0225
	Continental Europe	0.0247	0.0246	0.0230	0.0232	0.0240	0.0240	0.0237	0.0211	0.0236	0.0231	0.0234	0.0231	0.0235
	United Kingdom	0.0199	0.0152	0.0120	0.0127	0.0129	0.0119	0.0149	0.0155	0.0159	0.0177	0.0071	0.0181	0.0145
T	France	0.1793	0.1802	0.1808	0.1771	0.1765	0.1713	0.1705	0.1735	0.1753	0.1758	0.1766	0.1763	0.1761
as share of Y	Germany	0.1761	0.1883	0.1885	0.1860	0.1862	0.1841	0.1859	0.1946	0.1976	0.1938	0.1916	0.1834	0.1880
	Italy	0.1629	0.1650	0.1695	0.1667	0.1686	0.1641	0.1620	0.1653	0.1681	0.1687	0.1695	0.1698	0.1667
	Continental Europe	0.1728	0.1778	0.1796	0.1766	0.1771	0.1732	0.1728	0.1778	0.1803	0.1794	0.1793	0.1765	0.1769
	United Kingdom	0.1504	0.1455	0.1407	0.1340	0.1282	0.1259	0.1289	0.1284	0.1281	0.1284	0.1287	0.1258	0.1327
$r_B B$	France	0.0347	0.0359	0.0347	0.0334	0.0302	0.0292	0.0305	0.0296	0.0283	0.0278	0.0267	0.0258	0.0306
as share of Y	Germany	0.0349	0.0348	0.0338	0.0336	0.0314	0.0315	0.0305	0.0292	0.0297	0.0282	0.0279	0.0282	0.0312
	Italy	0.1159	0.1152	0.0929	0.0818	0.0664	0.0637	0.0633	0.0567	0.0517	0.0480	0.0470	0.0463	0.0707
	Continental Europe	0.0618	0.0620	0.0538	0.0496	0.0427	0.0415	0.0414	0.0385	0.0366	0.0346	0.0339	0.0335	0.0442
	United Kingdom	0.0357	0.0357	0.0356	0.0347	0.0283	0.0271	0.0233	0.0200	0.0198	0.0196	0.0210	0.0206	0.0268
$G + T + r_B B$	France	0.4826	0.4870	0.4834	0.4697	0.4676	0.4603	0.4590	0.4662	0.4716	0.4718	0.4731	0.4679	0.4717
as share of Y	Germany	0.4287	0.4418	0.4346	0.4291	0.4287	0.4235	0.4232	0.4328	0.4355	0.4245	0.4201	0.4083	0.4276
	Italy	0.4789	0.4843	0.4671	0.4528	0.4411	0.4355	0.4387	0.4314	0.4413	0.4391	0.4435	0.4410	0.4496
	Continental Europe	0.4634	0.4710	0.4617	0.4505	0.4458	0.4398	0.4403	0.4434	0.4495	0.4451	0.4456	0.4391	0.4496
	United Kingdom	0.4011	0.3866	0.3698	0.3594	0.3521	0.3513	0.3575	0.3614	0.3680	0.3744	0.3706	0.3791	0.3693
Expenditures	France	0.4966	0.5028	0.5002	0.4882	0.4845	0.4771	0.4774	0.4883	0.4937	0.4920	0.4916	0.4866	0.4899
as share of Y	Germany	0.4469	0.4607	0.4537	0.4491	0.4493	0.4443	0.4423	0.4488	0.4533	0.4420	0.4401	0.4267	0.4464
	Italy	0.4802	0.4876	0.4686	0.4547	0.4425	0.4359	0.4385	0.4376	0.4399	0.4379	0.4405	0.4370	0.4501
	Continental Europe	0.4745	0.4837	0.4742	0.4640	0.4588	0.4524	0.4527	0.4582	0.4623	0.4573	0.4574	0.4501	0.4621
	United Kingdom	0.4072	0.3978	0.3861	0.3762	0.3703	0.3732	0.3792	0.3882	0.3956	0.4037	0.4140	0.4131	0.3921

Notes: Continental Europe is the average of France, Germany, and Italy. The exact definitions of the data are used for the calibration are given in Table A.2.

Table A.2: Data Sources

Variable	Source	Description
L	TED	Total annual hours worked
	AMECO: NETD	Employment, persons: all domestic industries
n	AMECO: NETD	Employment, persons: all domestic industries
$g-n$	AMECO: RVGDE	Gross domestic product at 2000 market prices per person employed
$1-\alpha$	AMECO: ALCD2	Adjusted wage share of total economy as percentage of GDP at current factor cost
Y	AMECO: UVGD	Gross domestic product at current market prices
C	AMECO: UCPH	Private final consumption expenditure at current prices
$X+Z$	AMECO: UIGP	Gross fixed capital formation at current prices: private sector
G_c	AMECO: UCTG	Final consumption expenditure of general government at current prices
G_p	AMECO: UIGG	Gross fixed capital formation at current prices: general government
T	AMECO: UYTGH	Social benefits other than social transfers in kind: general government
B	AMECO: UDGG	General government consolidated gross debt: Excessive deficit procedure
$r_B B$	AMECO: UUCG	Total current expenditure: general government
	AMECO: UUCGI	Total current expenditure excluding interest: general government
τ_C	TTEU: ITR C	Implicit tax rates in percentage - Consumption
τ_L	TTEU: ITR L	Implicit tax rates in percentage - Labour
τ_X	TTEU: ITR KI	Implicit tax rates in percentage - Capital and business income
revenues: τ_C	TTEU: C.1_G	Taxes on Consumption as percentage of GDP - Total
revenues: τ_L	TTEU: C.2_G	Taxes on Labour as percentage of GDP - Total
revenues: τ_X	TTEU: C.3.1_G	Taxes on Capital as percentage of GDP - Capital and business income
revenues: τ_C	TTEU: C.1_T	Taxes on Consumption as percentage of Total Taxation - Total
revenues: τ_L	TTEU: C.2_T	Taxes on Labour as percentage of Total Taxation - Total
revenues: τ_X	TTEU: C.3.1_T	Taxes on Capital as percentage of Total Taxation - Capital and business income
Z	MIANP: Chapter 1	Software, databases, R&D, and other intellectual property rights as percentage of GDP
s_Z	STIS: A12.1/C.3.1/2.37	One minus B-index: 2005/2007/2009

Notes: Data sources are
TED: http://www.conference-board.org/data/economydatabase/
AMECO: http://ec.europa.eu/economy_finance/db_indicators/ameco/index_en.htm
TTEU: http://ec.europa.eu/taxation_customs/taxation/gen_info/economic_analysis/tax_structures/index_en.htm
MIANP: Measuring Innovation: A New Perspective - OECD 2010 - ISBN 9789264059467
STIS: http://www.oecd-ilibrary.org/science-and-technology/oecd-science-technology-and-industry-scoreboard-2009_sti_scoreboard-2009-en

Figure 1: The Process of Quality Improvements

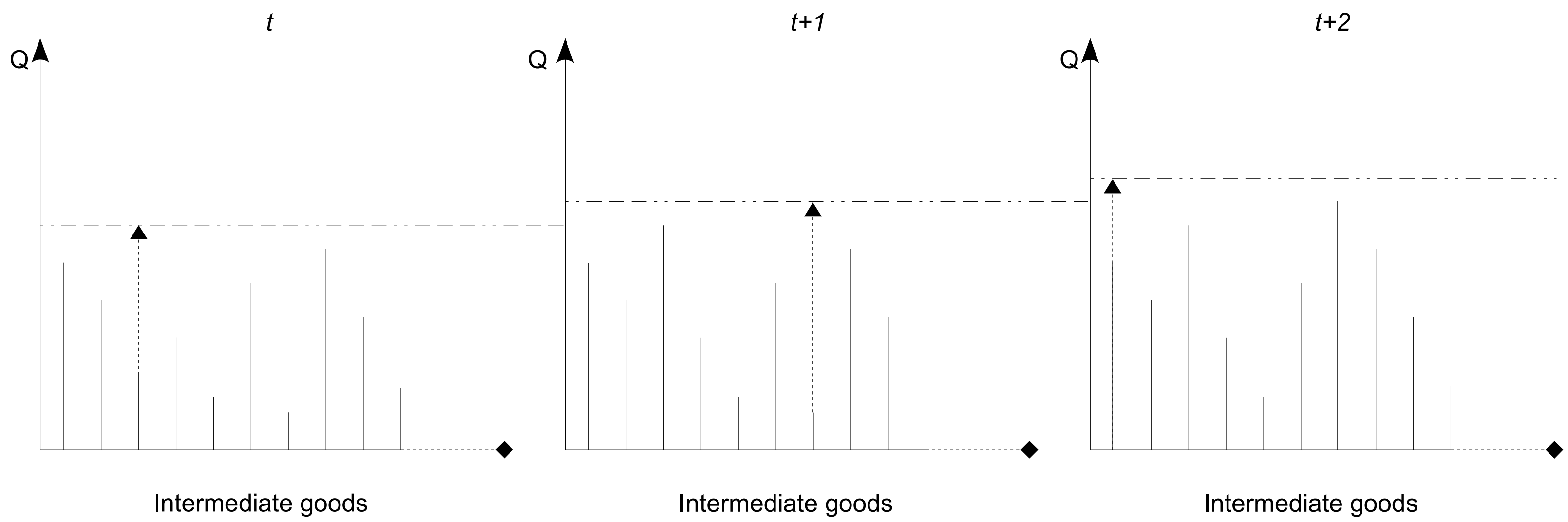
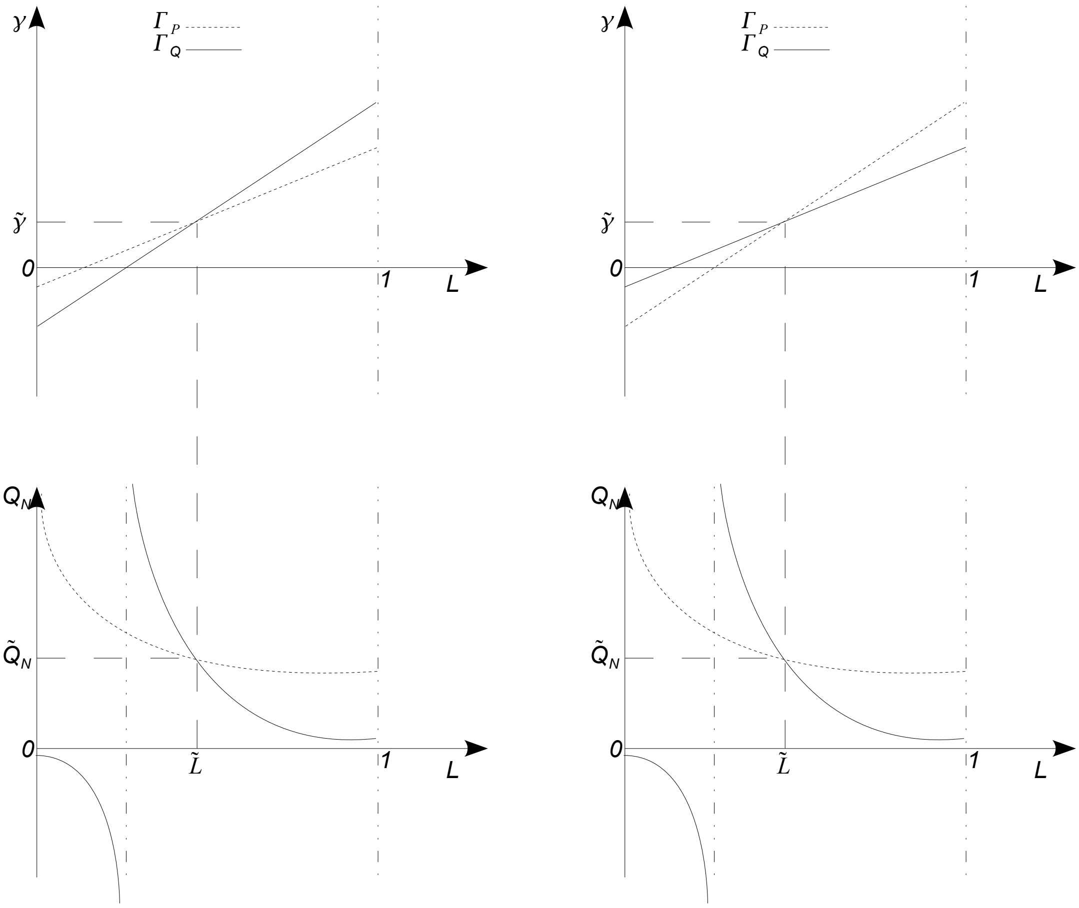


Figure 2: TEG Equilibrium: $\phi > \frac{\theta\alpha}{(\alpha-1)(1-\epsilon_\beta)}$ and $n > 0$

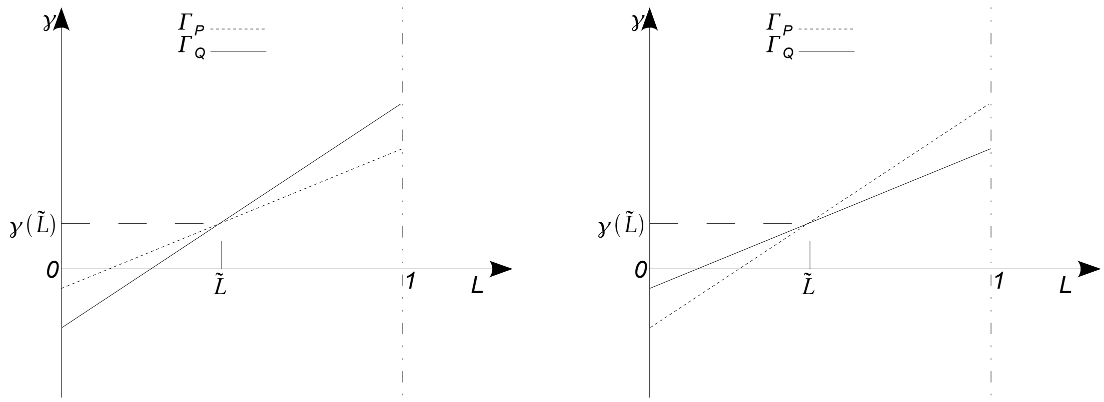
(a) Locally Determinate (b) Locally Indeterminate



Notes: The dashed lines in the graphs correspond to γ_P and are associated with portfolio balance equilibrium. The solid lines correspond to γ_Q and are associated with good market equilibrium. In the balanced growth equilibrium $\tilde{\gamma} = n\left(\phi - \frac{\theta\alpha}{(\alpha-1)(1-\epsilon_\beta)}\right)^{-1}$.

Figure 3: PEG Equilibrium: $\phi = \frac{\theta\alpha}{(\alpha-1)(1-\epsilon_\beta)}$ and $n = 0$

(a) Locally Determinate (b) Locally Indeterminate



Notes: The dashed lines in the graphs correspond to γ_P and are associated with portfolio balance equilibrium. The solid lines correspond to γ_Q and are associated with good market equilibrium.

Figure 4: TEG Equilibrium: Short-run and Long-run Effects of Fiscal Policies

(a) $ds_Z > 0$: $t = 0$ (b) $ds_Z > 0$: $t = \infty$

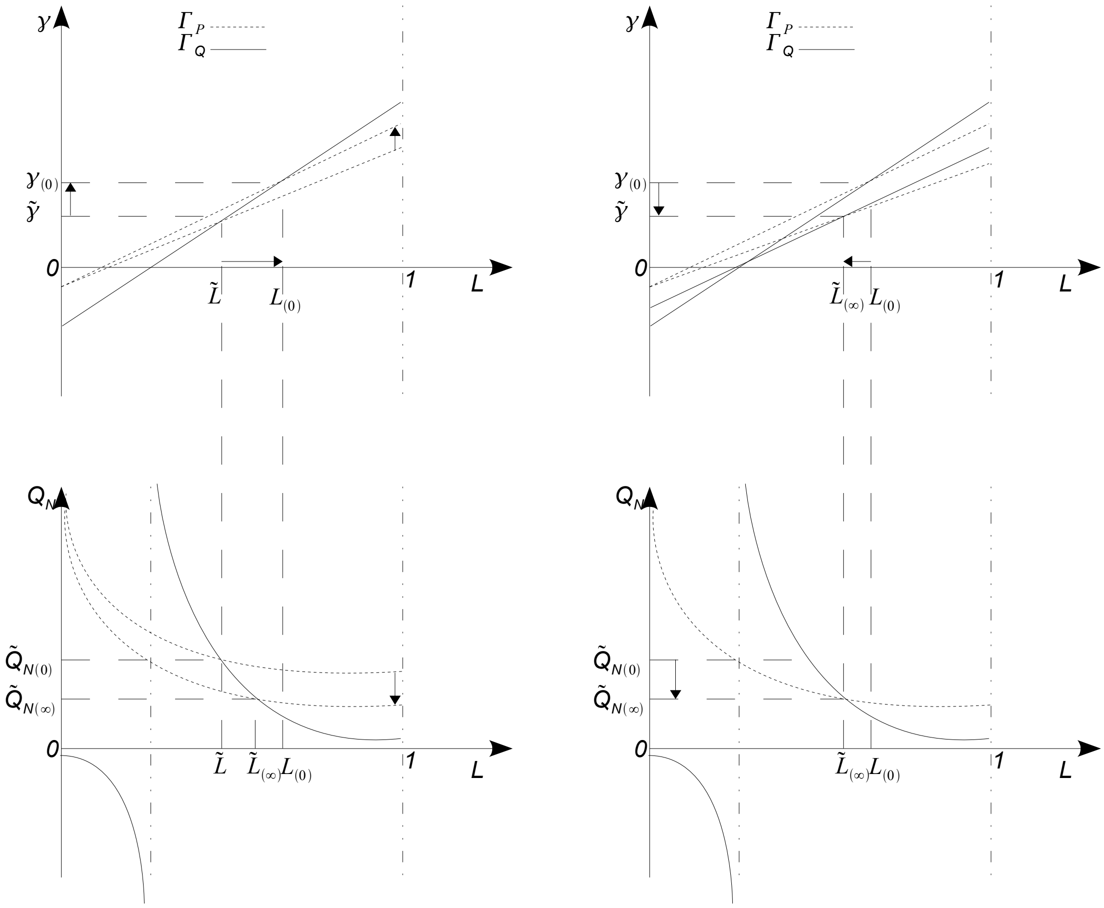
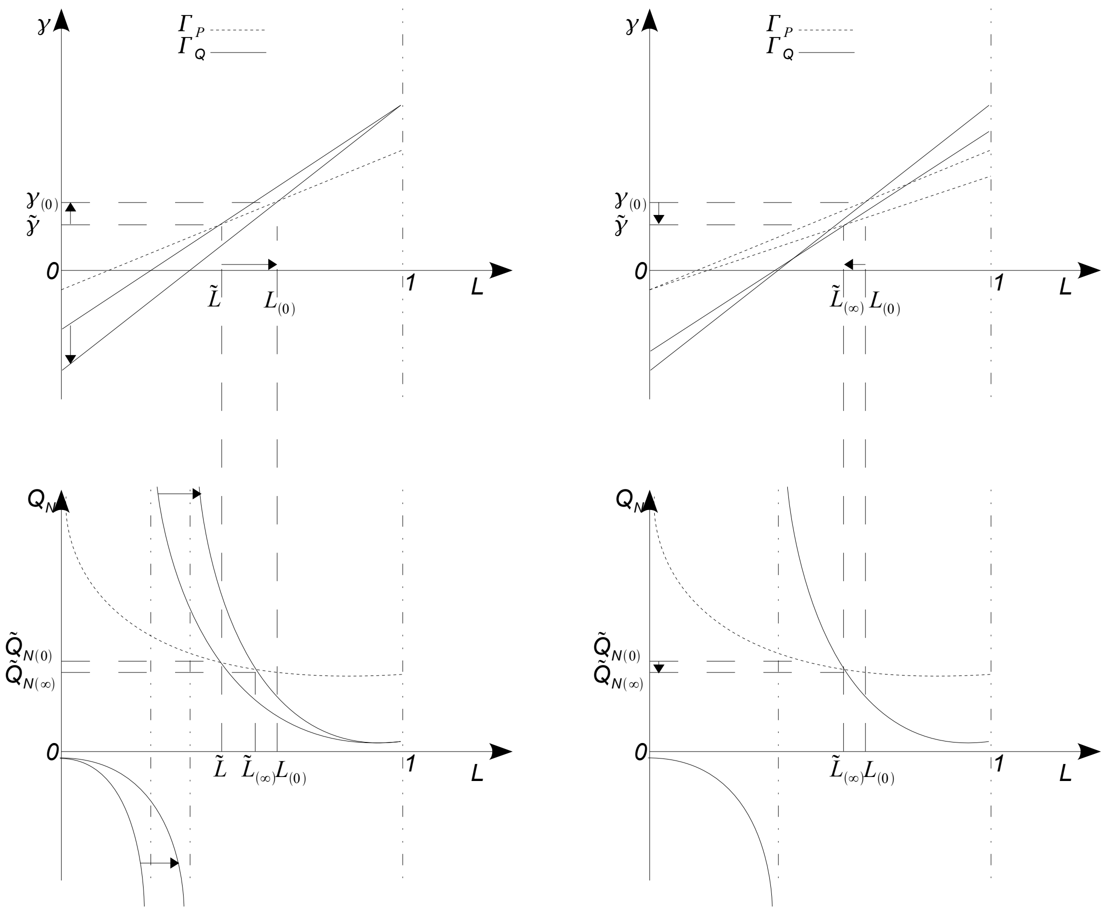


Figure 4: TEG Equilibrium: Short-run and Long-run Effects of Fiscal Policies (continued)

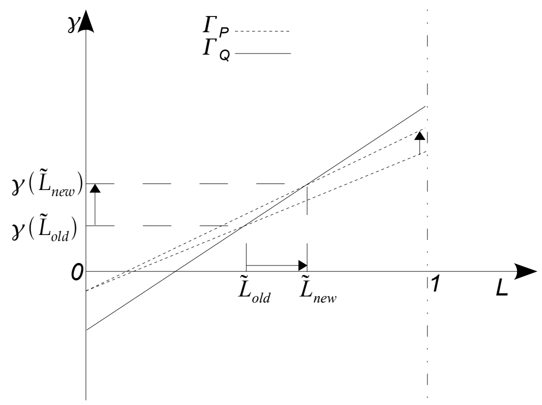
(c) $d\tau_L < 0$: $t = 0$ (d) $d\tau_L < 0$: $t = \infty$



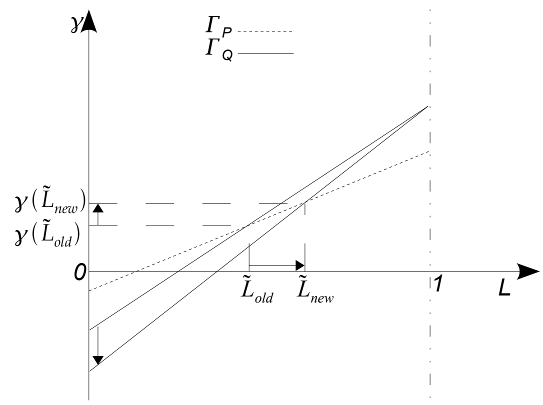
Notes: The dashed lines in the graphs correspond to γ_P and are associated with portfolio balance equilibrium. The solid lines correspond to γ_Q and are associated with good market equilibrium. In the balanced growth equilibrium $\tilde{\gamma} = n\left(\phi - \frac{\theta\alpha}{(\alpha-1)(1-\epsilon_\beta)}\right)^{-1}$. Figures 4c and 4d also capture the effects of a lower tax rate on consumption.

Figure 5: PEG Equilibrium: Short-run and Long-run Effects of Fiscal Policies

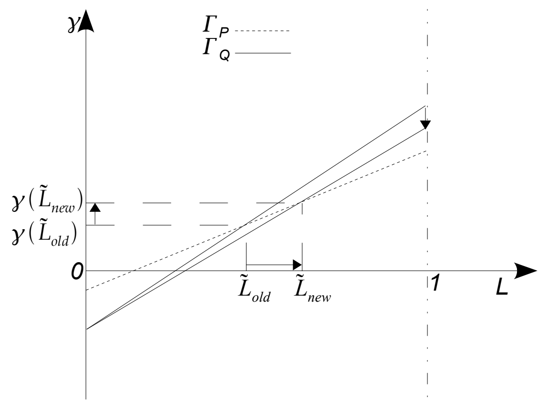
(a) $ds_Z > 0$



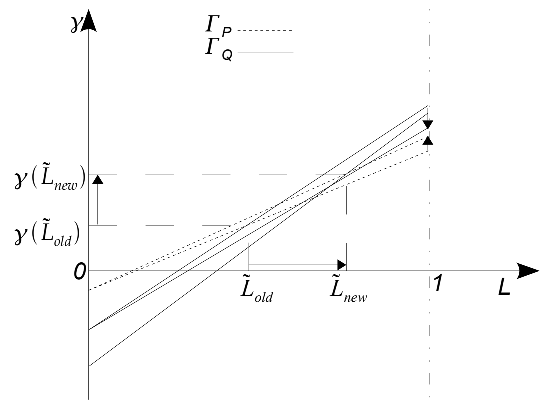
(b) $d\tau_L < 0$, $d\tau_C < 0$



(c) $d\omega_G > 0$



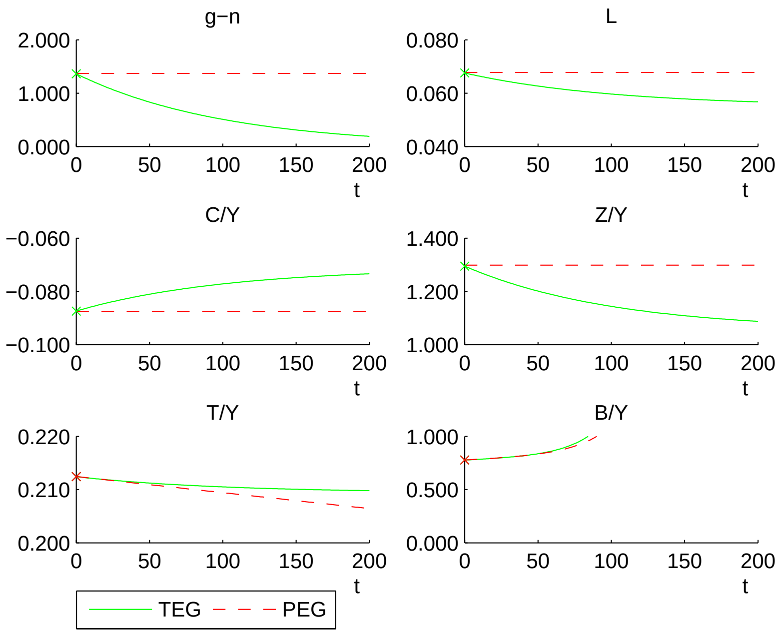
(d) $d\tau_X < 0$



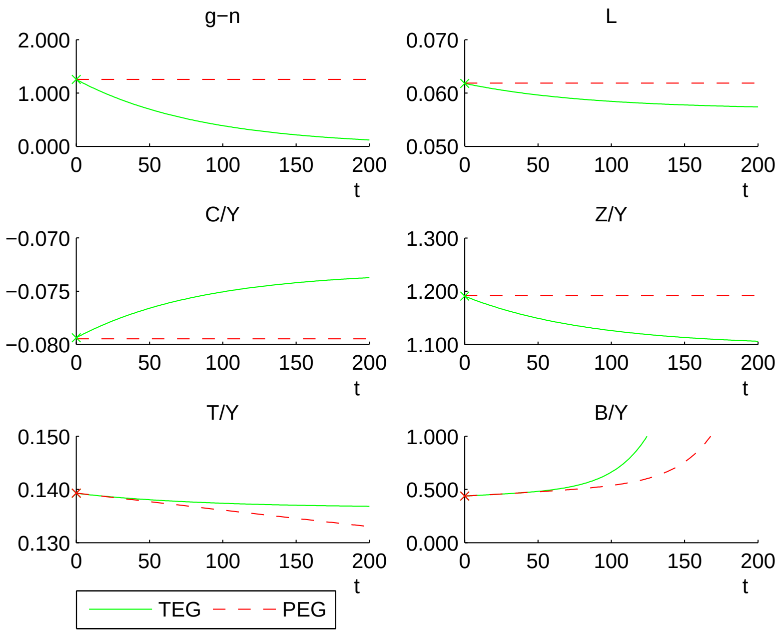
Notes: The dashed lines in the graphs correspond to γ_P and are associated with portfolio balance equilibrium. The solid lines correspond to γ_Q and are associated with good market equilibrium.

Figure 6: Impulse Response Functions of Fiscal Policies

(a) Continental Europe II: $\Delta s_Z = 0.01$



(b) United Kingdom II: $\Delta s_Z = 0.01$



Notes: Impulse responses of an unexpected and permanent shock at time 0 for both the TEG equilibrium (solid line) and PEG equilibrium (dashed line). The vertical axes show ratios, and the horizontal axes show time in years. Based on scenario II.

Table 1: Comparing Stylized Facts

Economy	τ_C	τ_L	τ_X	s_Z	ω_G	B/Y	n	ρ	$1-\alpha$	EPL	ϵ_L	ϵ_F
Continental Europe I	0.1890	0.4116	0.2001	0.0410	0.2285	0.7763	0.0080	0.0360	0.6467	13.600	2.3423	1.5640
Continental Europe II	0.1890	0.4116	0.2001	0.0410	0.2285	0.7763	0.0080	0.0360	0.7986	12.250	2.3163	1.5734
Continental Europe III	0.1890	0.4116	0.2001	0.0410	0.2285	0.7763	0.0080	0.0360	0.7041	13.000	2.3312	1.5680
Continental Europe IV	0.1890	0.4116	0.2001	0.0410	0.2285	0.7763	0.0080	0.0360	0.5418	15.500	2.3699	1.5541
United Kingdom I	0.1890	0.2504	0.2381	0.0785	0.2098	0.4373	0.0108	0.0245	0.7083	6.5000	2.9201	1.4246
United Kingdom II	0.1890	0.2504	0.2381	0.0785	0.2098	0.4373	0.0108	0.0245	0.8630	6.0600	2.9431	1.4179
United Kingdom III	0.1890	0.2504	0.2381	0.0785	0.2098	0.4373	0.0108	0.0245	0.7391	6.4150	2.9259	1.4229
United Kingdom IV	0.1890	0.2504	0.2381	0.0785	0.2098	0.4373	0.0108	0.0245	0.5418	7.4400	2.8822	1.4356
												(Continued)
Constraint	Data	Data	Data	Data	Data	Data	Data	r_B	Various	Z/Y	L	Implied

Table 1: Comparing Stylized Facts (continued)

	Continental Europe					United Kingdom				
	Actual	I	II	III	IV	Actual	V	VI	VII	VIII
L	0.2275	0.2275	0.2275	0.2275	0.2275	0.2275	0.2275	0.2275	0.2275	0.2275
$g-n$	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105	0.0105
Output shares:										
C	0.5794	0.4640	0.5794	0.5075	0.3842	0.6497	0.5359	0.6479	0.5581	0.4153
$X+Z$	0.1721	0.3075	0.1921	0.2640	0.3873	0.1544	0.2543	0.1423	0.2321	0.3749
Z	0.0391	0.0391	0.0391	0.0391	0.0391	0.0432	0.0432	0.0432	0.0432	0.0432
T	0.1769	0.1584	0.2123	0.1787	0.1211	0.1327	0.1162	0.1392	0.1207	0.0913
$r_B B$	0.0442	0.0442	0.0442	0.0442	0.0442	0.0268	0.0268	0.0268	0.0268	0.0268
$T+r_B B+G$	0.4262	0.4311	0.4850	0.4515	0.3938	0.3548	0.3528	0.3758	0.3573	0.3279
revenues: τ_C	0.1076	0.0877	0.1095	0.0959	0.0726	0.1167	0.1013	0.1224	0.1055	0.0785
revenues: τ_L	0.2230	0.2662	0.3287	0.2898	0.2230	0.1357	0.1774	0.2161	0.1851	0.1357
revenues: τ_X	0.0592	0.0707	0.0403	0.0592	0.0917	0.0621	0.0695	0.0326	0.0621	0.1091
revenues: total	0.3898	0.4246	0.4785	0.4449	0.3873	0.3145	0.3481	0.3712	0.3527	0.3233

Notes: Continental Europe is the average of France, Germany, and Italy. The data used for the calibration are based on the average over the period 1995–2006; see Table A.1. The term *EPL* denotes expected patent life. The parameters ϵ_C, ϵ_L, ϕ and ρ do not have observable equivalents in the data. We use the parameter ϕ to match the growth rate of our model, and the parameter ρ to match interest payments of the government. The parameters η and ψ are used to ensure L is the same in the TEG and PEG equilibrium. The values of ϵ_C, ϵ_L, σ, and L are used to determine the Frisch-elasticity of labor supply, which is given by $\epsilon_F \equiv \frac{\partial L}{\partial w}\frac{w}{L}\Big|_{\partial U/\partial C} = \frac{1-L}{L}\frac{1-(1-\sigma)\epsilon_C}{1-(1-\sigma)(\epsilon_C+\epsilon_L)}$. In scenario (I), (II), (III), and (IV), $1-\alpha$ varies to match respectively the income share of labor, the output share of consumption, the output share of capital income tax revenues, and the output share of labor income tax revenues with the data.

Table 2: Effects of Fiscal Policies – Continental Europe

	$\Delta\tau_C = -0.01$			$\Delta\tau_L = -0.01$			$\Delta\tau_X = -0.01$			$\Delta s_Z = 0.01$			$\Delta\omega_G = 0.01$		
	TEG		PEG	TEG		PEG	TEG		PEG	TEG		PEG	TEG		PEG
	$t=0$	$t=\infty$		$t=0$	$t=\infty$		$t=0$	$t=\infty$		$t=0$	$t=\infty$		$t=0$	$t=\infty$	
Continental Europe I															
g	0.8214	0	0.8231	1.6411	0	1.6461	3.2486	0	3.2692	1.4088	0	1.4139	2.1149	0	2.1319
Q_N	0	-0.6497	0	0	-1.2909	0	0	-2.5308	0	0	-1.1106	0	0	-1.6650	0
L	0.6642	0.6540	0.6643	1.3281	1.3078	1.3284	0.6841	0.6443	0.6853	0.0861	0.0686	0.0864	1.7194	1.6932	1.7205
C/Y	-0.0132	0	-0.0133	-0.0260	0	-0.0264	-0.8795	-0.8287	-0.8811	-0.1113	-0.0887	-0.1117	-2.1881	-2.1554	-2.1895
Z/Y	0.1562	0	0.1578	0.3089	0	0.3135	1.8534	1.2502	1.8725	1.3216	1.0537	1.3263	0.3888	0	0.4044
κ		-2.9297	-2.9806		-4.0836	-4.1862		-2.7025	-2.9060		-0.3091	-0.3981		-7.5080	-7.6407
υ			0.0038			0.0075			0.0074			0.0023			-0.0121
Continental Europe II															
g	0.8046	0	0.8059	1.6078	0	1.6117	2.3250	0	2.3350	1.3633	0	1.3673	1.6562	0	1.6658
Q_N	0	-0.6497	0	0	-1.2909	0	0	-1.8590	0	0	-1.0971	0	0	-1.3334	0
L	0.6614	0.6540	0.6615	1.3226	1.3078	1.3228	0.3427	0.3213	0.3431	0.0676	0.0550	0.0678	1.3667	1.3514	1.3672
C/Y	-0.0096	0	-0.0097	-0.0190	0	-0.0192	-0.4420	-0.4146	-0.4427	-0.0874	-0.0711	-0.0876	-1.7453	-1.7261	-1.7459
Z/Y	0.1423	0	0.1435	0.2814	0	0.2851	1.6565	1.2502	1.6660	1.2949	1.0537	1.2987	0.2856	0	0.2946
κ		-2.7289	-2.7657		-3.7616	-3.8356		-1.1719	-1.2792		-0.2308	-0.2941		-5.6005	-5.6770
υ			0.0038			0.0076			0.0051			0.0024			-0.0096
Continental Europe III															
g	0.8140	0	0.8155	1.6264	0	1.6309	2.8460	0	2.8615	1.3888	0	1.3934	1.9144	0	1.9279
Q_N	0	-0.6497	0	0	-1.2909	0	0	-2.2426	0	0	-1.1048	0	0	-1.5221	0
L	0.6629	0.6540	0.6630	1.3257	1.3078	1.3259	0.5358	0.5048	0.5367	0.0780	0.0628	0.0783	1.5666	1.5456	1.5674
C/Y	-0.0116	0	-0.0117	-0.0229	0	-0.0232	-0.6899	-0.6502	-0.6910	-0.1009	-0.0812	-0.1013	-1.9967	-1.9703	-1.9977
Z/Y	0.1501	0	0.1515	0.2968	0	0.3010	1.7652	1.2502	1.7796	1.3097	1.0537	1.3141	0.3424	0	0.3549
κ		-2.8395	-2.8840		-3.9393	-4.0288		-2.0157	-2.1728		-0.2742	-0.3514		-6.6522	-6.7580
υ			0.0038			0.0075			0.0064			0.0024			-0.0110
Continental Europe IV															
g	0.8442	0	0.8465	1.6864	0	1.6929	4.2685	0	4.3073	1.4663	0	1.4731	2.6288	0	2.6577
Q_N	0	-0.6497	0	0	-1.2909	0	0	-3.2186	0	0	-1.1248	0	0	-2.0108	0
L	0.6678	0.6540	0.6680	1.3354	1.3078	1.3358	1.0519	0.9833	1.0547	0.1070	0.0830	0.1075	2.0950	2.0521	2.0971
C/Y	-0.0178	0	-0.0181	-0.0353	0	-0.0359	-1.3475	-1.2604	-1.3511	-0.1383	-0.1074	-0.1390	-2.6563	-2.6030	-2.6589
Z/Y	0.1752	0	0.1774	0.3465	0	0.3524	2.1046	1.2502	2.1398	1.3579	1.0537	1.3641	0.5228	0	0.5491
κ		-3.1724	-3.2420		-4.4741	-4.6143		-4.5561	-4.9121		-0.4049	-0.5282		-9.8186	-10.038
υ			0.0037			0.0074			0.0098			0.0023			-0.0148

(Continued)

Table 2: Effects of Fiscal Policies – United Kingdom

	$\Delta\tau_C=-0.01$			$\Delta\tau_L=-0.01$			$\Delta\tau_X=-0.01$			$\Delta s_Z=0.01$			$\Delta\omega_G=0.01$		
	TEG		PEG	TEG		PEG	TEG		PEG	TEG		PEG	TEG		PEG
	$t=0$	$t=\infty$		$t=0$	$t=\infty$		$t=0$	$t=\infty$		$t=0$	$t=\infty$		$t=0$	$t=\infty$	
United Kingdom I															
g	0.7195	0	0.7200	1.1302	0	1.1312	2.5678	0	2.5735	1.2737	0	1.2754	1.6060	0	1.6105
Q_N	0	-0.6543	0	0	-1.0242	0	0	-2.2998	0	0	-1.1532	0	0	-1.4517	0
L	0.6622	0.6586	0.6623	1.0404	1.0348	1.0405	0.4995	0.4869	0.4998	0.0751	0.0688	0.0752	1.4811	1.4731	1.4813
C/Y	-0.0046	0	-0.0046	-0.0072	0	-0.0072	-0.6388	-0.6228	-0.6392	-0.0964	-0.0883	-0.0966	-1.8759	-1.8660	-1.8762
Z/Y	0.0569	0	0.0574	0.0888	0	0.0898	1.5115	1.3125	1.5168	1.1977	1.0971	1.1993	0.1232	0	0.1273
κ		-4.6139	-4.6693		-6.0980	-6.1853		-3.0927	-3.2913		-0.4846	-0.5835		-10.237	-10.361
υ			0.0041			0.0065			0.0108			0.0046			-0.0097
United Kingdom II															
g	0.7153	0	0.7157	1.1236	0	1.1245	1.8995	0	1.9026	1.2533	0	1.2548	1.3181	0	1.3209
Q_N	0	-0.6543	0	0	-1.0242	0	0	-1.7206	0	0	-1.1415	0	0	-1.2009	0
L	0.6614	0.6586	0.6614	1.0392	1.0348	1.0392	0.2322	0.2249	0.2323	0.0618	0.0569	0.0619	1.2206	1.2155	1.2207
C/Y	-0.0036	0	-0.0036	-0.0056	0	-0.0056	-0.2978	-0.2884	-0.2980	-0.0794	-0.0731	-0.0795	-1.5500	-1.5436	-1.5501
Z/Y	0.0535	0	0.0539	0.0835	0	0.0844	1.4532	1.3125	1.4561	1.1907	1.0971	1.1922	0.0963	0	0.0989
κ		-4.6538	-4.6995		-6.1993	-6.2713		-1.2697	-1.3916		-0.4046	-0.4854		-8.5411	-8.6256
υ			0.0041			0.0064			0.0076			0.0047			-0.0081
United Kingdom III															
g	0.7187	0	0.7192	1.1289	0	1.1299	2.4126	0	2.4176	1.2694	0	1.2710	1.5397	0	1.5437
Q_N	0	-0.6543	0	0	-1.0242	0	0	-2.1660	0	0	-1.1506	0	0	-1.3940	0
L	0.6620	0.6586	0.6621	1.0402	1.0348	1.0402	0.4377	0.4264	0.4380	0.0722	0.0662	0.0723	1.4210	1.4137	1.4212
C/Y	-0.0044	0	-0.0044	-0.0068	0	-0.0069	-0.5602	-0.5458	-0.5605	-0.0927	-0.0850	-0.0928	-1.8008	-1.7918	-1.8011
Z/Y	0.0562	0	0.0567	0.0878	0	0.0888	1.4980	1.3125	1.5027	1.1963	1.0971	1.1979	0.1170	0	0.1208
κ		-4.6232	-4.6764		-6.1225	-6.2063		-2.6751	-2.8544		-0.4673	-0.5621		-9.8493	-9.9638
υ			0.0041			0.0064			0.0101			0.0046			-0.0093
United Kingdom IV															
g	0.7282	0	0.7289	1.1439	0	1.1453	3.7380	0	3.7513	1.3115	0	1.3138	2.1044	0	2.1131
Q_N	0	-0.6543	0	0	-1.0242	0	0	-3.2778	0	0	-1.1731	0	0	-1.8732	0
L	0.6638	0.6586	0.6639	1.0430	1.0348	1.0431	0.9563	0.9303	0.9573	0.0982	0.0889	0.0984	1.9239	1.9090	1.9246
C/Y	-0.0067	0	-0.0067	-0.0104	0	-0.0105	-1.2176	-1.1847	-1.2188	-0.1262	-0.1142	-0.1264	-2.4262	-2.4078	-2.4270
Z/Y	0.0640	0	0.0646	0.0998	0	0.1011	1.6284	1.3125	1.6404	1.2121	1.0971	1.2142	0.1771	0	0.1850
κ		-4.5487	-4.6208		-5.9339	-6.0476		-6.0855	-6.4576		-0.6176	-0.7488		-13.022	-13.232
υ			0.0042			0.0066			0.0165			0.0045			-0.0123

Notes: See Table 1 for a description of the different scenarios.

Table 3: Effects of Fiscal Policies: Normalized

Instrument	Continental Europe				United Kingdom			
	TEG		PEG		TEG		PEG	
	κ	L	κ	L	κ	L	κ	L
τ_C	-4.4907	1.0065	-3.6047	0.8075	-7.0452	1.0066	-6.4732	0.9188
τ_L	-3.1486	1.0131	-2.5297	0.8075	-5.9444	1.0103	-5.4546	0.9188
τ_X	-1.0031	0.2395	-0.8341	0.1973	-1.2936	0.2058	-1.2281	0.1882
s_Z	-0.2742	0.0606	-0.2768	0.0599	-0.4268	0.0607	-0.4641	0.0600
ω_G	-4.4907	1.0166	-3.5686	0.8075	-7.0452	1.0150	-6.4199	0.9188

Notes: Continental Europe is the average of France, Germany, and Italy. The effects are percent changes and are the result of a change in fiscal instruments such that Q_N decreases with one percent in the TEG equilibrium and $g - n$ increases with one percent in the PEG equilibrium. The numbers are the average of all scenarios.

Table 4: Effects of Fiscal Policies: Alternative Financing Schemes

	non-distortionary			τ_X			τ_C			τ_L			ω_G		
	TEG		PEG	TEG		PEG	TEG		PEG	TEG		PEG	TEG		PEG
	$t=0$	$t=\infty$		$t=0$	$t=\infty$		$t=0$	$t=\infty$		$t=0$	$t=\infty$		$t=0$	$t=\infty$	
Continental Europe: $\Delta s_Z = 0.01$															
g	1.3633	0	1.3673	1.0007	0	0.9302	1.2951	0	1.2812	1.2633	0	1.2419	1.2953	0	1.2812
Q_N	0	-1.0971	0	0	-0.7981	0	0	-1.0428	0	0	-1.0174	0	0	-1.0428	0
L	0.0676	0.0550	0.0678	0.0054	-0.0056	-0.0081	0.0120	0	-0.0022	-0.0139	-0.0256	-0.0341	0.0120	0	-0.0022
C/Y	-0.0874	-0.0711	-0.0876	-0.0070	0.0072	0.0104	-0.0866	-0.0711	-0.0866	-0.0862	-0.0711	-0.0861	-0.0155	0	0.0028
Z/Y	1.2949	1.0537	1.2987	1.0674	0.8822	1.0240	1.2830	1.0537	1.2834	1.2775	1.0537	1.2764	1.2832	1.0537	1.2834
instrument					0.2015	0.2017		0.1898	0.1901		0.4122	0.4124		0.2281	0.2280
v			0.0024			0.0013			0.0020			0.0018			0.0029
Continental Europe: $\Delta \tau_X = -0.01$															
g	2.3250	0	2.3350				1.9766	0	1.9575	1.8143	0	1.7851	1.9779	0	1.9575
Q_N	0	-1.8590	0				0	-1.5843	0	0	-1.4559	0	0	-1.5843	0
L	0.3427	0.3213	0.3431				0.0595	0.0413	0.0381	-0.0724	-0.0891	-0.1012	0.0595	0.0413	0.0381
C/Y	-0.4420	-0.4146	-0.4427				-0.4380	-0.4146	-0.4382	-0.4362	-0.4146	-0.4362	-0.0769	-0.0534	-0.0493
Z/Y	1.6565	1.2502	1.6660				1.5972	1.2502	1.5998	1.5693	1.2502	1.5695	1.5984	1.2502	1.5998
instrument								0.1933	0.1936		0.4147	0.4149		0.2264	0.2262
v			0.0051						0.0033			0.0025			0.0072
United Kingdom: $\Delta s_Z = 0.01$															
g	1.2533	0	1.2548	0.8467	0	0.7940	1.1908	0	1.1805	1.1789	0	1.1665	1.1909	0	1.1805
Q_N	0	-1.1415	0	0	-0.7702	0	0	-1.0852	0	0	-1.0744	0	0	-1.0852	0
L	0.0618	0.0569	0.0619	-0.0040	-0.0080	-0.0136	0.0046	0	-0.0060	-0.0063	-0.0109	-0.0188	0.0046	0	-0.0060
C/Y	-0.0794	-0.0731	-0.0795	0.0052	0.0103	0.0175	-0.0791	-0.0731	-0.0791	-0.0790	-0.0731	-0.0790	-0.0059	0	0.0078
Z/Y	1.1907	1.0971	1.1922	0.9323	0.8658	0.8996	1.1862	1.0971	1.1866	1.1853	1.0971	1.1855	1.1862	1.0971	1.1866
instrument					0.2398	0.2401		0.1899	0.1900		0.2511	0.2512		0.2093	0.2092
v			0.0047			0.0026			0.0043			0.0042			0.0051
United Kingdom: $\Delta \tau_X = -0.01$															
g	1.8995	0	1.9026				1.7025	0	1.6883	1.6650	0	1.6480	1.7028	0	1.6883
Q_N	0	-1.7206	0				0	-1.5448	0	0	-1.5112	0	0	-1.5448	0
L	0.2322	0.2249	0.2323				0.0524	0.0459	0.0373	0.0183	0.0118	0.0006	0.0524	0.0459	0.0373
C/Y	-0.2978	-0.2884	-0.2980				-0.2968	-0.2884	-0.2969	-0.2966	-0.2884	-0.2967	-0.0674	-0.0589	-0.0479
Z/Y	1.4532	1.3125	1.4561				1.4390	1.3125	1.4402	1.4363	1.3125	1.4372	1.4393	1.3125	1.4402
instrument								0.1917	0.1920		0.2524	0.2526		0.2083	0.2082
v			0.0076						0.0064			0.0062			0.0089