JOURNAL OF
PUBLIC
ECONOMICS

Dynamic scoring: Alternative financing schemes ☆

Eric M. Leeper *, Shu-Chun Susan Yang

Indiana University and NBER, Institute of Economics, Academia Sinica, Taiwan

Abstract

Neoclassical growth models predict that reductions in capital or labor income tax rates are expansionary when lump-sum transfers are used to balance the government budget. This paper explores the consequences of bond-financed tax reductions that bring forth a range of possible offsetting policies, including future government consumption, capital tax rates, or labor tax rates. Through the resulting intertemporal distortions, current tax cuts can be expansionary or contractionary. The paper also finds that more aggressive responses of offsetting policies to debt engender less debt accumulation and less costly tax cuts.
© 2007 Elsevier B.V. All rights reserved.

1. Introduction

Can tax cuts pay for themselves? If not, to what extent do tax cuts expand the tax base to offset revenue losses? These questions are under active consideration by U.S. fiscal authorities who are studying dynamic scoring to assess the budgetary cost of tax changes. Dynamic scoring computes the revenue effects of a tax proposal using macroeconomic models in which tax changes can affect aggregate income and feedback to revenues through the tax base.[1] Recent academic research employs calibrated neoclassical growth models to bring modern quantitative analysis to bear on the questions in fully general equilibrium environments (Mankiw and Weinzierl, 2006; Trabandt and Uhlig, 2006).

---

 * Corresponding author.
   E-mail addresses: eleeper@indiana.edu (E.M. Leeper), ssyang@econ.sinica.edu.tw (S.-C.S. Yang).
 [1] See Auerbach (2005) for a useful overview and Furman (2006) for a review of recent dynamic analyses performed by government agencies.

This paper pursues two themes that are important for dynamic scoring but are abstracted from in existing academic work. First, how do the fiscal costs of tax cuts vary with alternative assumptions about financing methods: reducing transfers or purchases, raising other taxes, or increasing borrowing? Second, if tax cuts are financed through borrowing, how do the costs vary with the aggressiveness of the offsetting fiscal reaction to debt growth? The first theme figures prominently in practical analyses by fiscal agencies (Congressional Budget Office, 2005; Joint Committee on Taxation, 2005; U.S. Department of Treasury, 2006), but tend to be handled in stark ways in academic studies. The second theme is implicit in fiscal agencies' studies in which debt accumulation is tracked, but overlooked in academic work.

Mankiw and Weinzierl (2006) examine dynamic scoring in a neoclassical growth model, assuming that contemporaneous lump-sum transfers adjust to balance the budget. A version of the model calibrated to U.S. data suggests that permanent reductions in capital (labor) tax rates can expand the tax base enough to offset 53% (17%) of the revenue loss. As the authors themselves point out, however, their analysis does not address several factors that are potentially important for dynamic scoring, including the possibility that financing schemes may distort economic behavior. Trabandt and Uhlig (2006) consider a distorting financing method-reductions in government consumption—but assume that government debt evolves exogenously; hence, their paper does not study the consequences of permanent or transitory changes in the state of government indebtedness induced by tax changes.

We analyze a conventional neoclassical growth model that is a discrete-time version of Mankiw and Weinzierl's model. Government issues debt to finance a tax cut, and has access to lump-sum and distorting financing schemes to maintain fiscal solvency. To the extent that a reduction in one fiscal distortion is replaced by a change in some other distortion, or combination of distortions, the results derived from lump-sum financing are likely to change.[2] Specifically, we consider permanent reductions in capital or labor tax rates. Fiscal sustainability is ensured by one of three instruments: (1) lower government transfer-output ratios, (2) lower government consumption-output ratios, or (3) increases in other tax rates. The budgetary cost of tax cuts is measured by changes in tax revenues net of interest payments on outstanding debt.[3]

The paper studies how permanent cuts in capital and labor tax rates affect the economy, both in long-run steady states and along the transition path to a new steady state. Two conclusions emerge. First, the expansionary effects of a tax cut depend crucially on the choice of which fiscal instrument adjusts and on the magnitude of the adjustment in response to a deteriorating budget. The stronger is the response, the less debt accumulates, and the more favorable are the expansionary effects of a tax cut.[4] Second, government indebtedness matters for the budgetary cost of a tax cut especially in the long(er) run: a more aggressive response to a deteriorating budget yields a smaller debt-output ratio and makes a tax cut less costly. This result holds even when the fiscal adjustment is non-distorting.

---

[2] This point echoes a theme that appears in Baxter and King (1993) and Sims (1998).

[3] In contrast to Mankiw and Weinzierl, we do not compute revenue feedback measures, which are defined as the proportion of revenue losses offset by an expanded tax base. When a cut in one tax rate is offset by an increase in another tax rate, there is no change in the static score–the change in revenues holding the tax base fixed–and revenue feedback is undefined. In addition, when a tax cut is debt-financed, interest payments should be factored into computing the budgetary impact.

[4] In a model with monopolistic competition and nominal price rigidity, Kirsanova and Wren-Lewis (2007) find that clearing the government budget through very gradual adjustment of government consumption to debt is nearly optimal. Their model, however, has a fixed capital stock and distortions not present in the current analysis, so differences between their findings and this analysis are not comparable.

2. Budget solvency and tax cuts

Neoclassical growth models, such as Baxter and King (1993), take the long-run growth rate of the economy as exogenous and impose the restriction that a debt-financed tax cut inevitably involves some offsetting policies to ensure budget solvency. Offsetting policies, however, may be unnecessary when long-run growth rates are endogenous. King and Rebelo (1990) find that lower income tax rates produce higher long-run economic growth. Ireland (1994) further demonstrates that when the long-run growth rate after a tax cut outpaces the growth rate of government debt, the expansionary effects of a debt-financed tax cut can pay off debt without any further fiscal adjustments. Subsequent studies by Bruce and Turnovsky (1999) and Novales and Ruiz (2002), however, find that tax cuts can improve the long-run budget only when the elasticity of intertemporal substitution of consumption is implausibly high. Although some doubt remains about whether a deficit-financed tax cut can actually be self-financing, this paper focuses on circumstances in which tax cuts induce current or future fiscal adjustments that maintain a sustainable budget.

In the U.S. economy, state governments quickly initiate offsetting policies because many state constitutions require balancing the budget within a couple of years. No analogous statutory requirement constrains federal behavior, and offsetting policy actions can take much longer to be implemented. For example, when the debt-output ratio rose rapidly in the early and mid-1980s (partly due to the large tax cuts in the Economic Recovery Act of 1981), the Gramm–Rudman–Hollings balanced-budget law was enacted in 1985 to reduce deficits. In addition, the Omnibus Budget Reconciliation Acts of 1990 and 1993, which increased individual and corporate income tax rates, were passed to reduce government debt. A rapidly rising debt-GDP ratio since 2001 again has spurred calls for cutting federal deficits (Greenspan, 2005a,b).

Aside from anecdotal examples, some econometric evidence finds that policy makers systematically take corrective measures in response to rising debt levels. Using long-term U.S. data from 1916 to 1995, Bohn (1998) concludes that the primary surplus responds positively to the debt-GDP ratio and makes the debt ratio mean-reverting, after controlling for war-time spending and for cyclical fluctuations. Davig and Leeper (2006) estimate a regime-switching rule for tax policy over the post-war period in the U.S. and find that policy swings between periods when taxes are unresponsive to debt and periods when they respond aggressively. Davig (2005) uses a Markov-switching model to test the global sustainability of U.S. post-war policy; he finds that threats to long-run sustainability posed by expanding periods of discounted debt are mitigated by the expectation of returning to a regime where debt is repaid. This evidence underscores the empirical relevance of considering postponed offsetting policies to ensure budget solvency following a tax cut.

Throughout the analysis, we maintain the assumption that private agents are endowed with all the information needed to form rational expectations. Agents know the rules governing fiscal instruments and they anticipate future offsetting policies during periods of expanding debt. Budget solvency in the model means that the intertemporal government budget constraint is satisfied both *ex ante* and *ex post*. While the debt-output ratio after a tax cut can be permanently higher, debt cannot permanently grow faster than the economy.

3. The model

The model economy consists of a representative competitive household, a representative competitive firm, and a government.

3.1. The private sector

The household chooses consumption, C_t, capital, K_t, hours worked, L_t, and one-period government bonds, B_t, to maximize expected utility, given by

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{C_t^{1-\gamma} - 1}{1 - \gamma} + \chi \frac{(1 - L_t)^{1-\theta} - 1}{1 - \theta} \right],$$

subject to the budget constraint

$$C_t + K_t + B_t = (1 - \tau_t^K)\rho_t K_{t-1} + (1 - \tau_t^L)W_t L_t + (1 - \delta)K_{t-1} + B_{t-1}R_{t-1} + T_t,$$

taking all prices and policies as given. E_t is the mathematical expectation conditional on the household's information set at t. β is the discount factor ($0 < \beta < 1$). γ and θ are the inverses of elasticities of intertemporal substitution of consumption and leisure ($\gamma > 0$ and $\theta \geq 0$). τ_t^K and τ_t^L are proportional tax rates levied on capital and labor income. T_t is lump-sum transfers if positive (taxes if negative). δ is the capital depreciation rate ($0 \leq \delta \leq 1$). W_t is the real wage, ρ_t is the capital rental rate, and R_{t-1} is the gross real interest rate on government bonds.

A representative firm rents capital and labor from the household to maximize profit

$$K_{t-1}^{\alpha}(h^t L_t)^{1-\alpha} - W_t L_t - \rho_t K_{t-1},$$

where h is the constant growth rate of labor augmenting technology ($h \geq 1$), and α is the share of capital in output ($0 < \alpha < 1$). The firm takes prices parametrically.

Total goods produced each period are $Y_t = K_{t-1}^{\alpha}(h^t L_t)^{1-\alpha}$.

3.2. The government

This paper is a positive analysis of the budgetary consequences of tax cuts which are financed in various ways. To study the implications of alternative financing schemes, we posit the simplest possible rules for policy instruments that are consistent with fiscal solvency. Fiscal instruments are chosen as a function of the state of government indebtedness, as measured by the debt-output ratio. The rules adopted here are abstractions designed to capture the practice of offsetting policy: when the fiscal budget deteriorates and debt rises, explicit fiscal actions are taken to improve the budget situation.

The fiscal rules are:

$$\ln\left(\frac{\tau_t^K}{\tau^K}\right) = q_K \ln\left(\frac{s_{t-1}^B}{s^B}\right), \qquad q_K \geq 0 \tag{1}$$

$$\ln\left(\frac{\tau_t^L}{\tau^L}\right) = q_L \ln\left(\frac{s_{t-1}^B}{s^B}\right), \qquad q_L \geq 0 \tag{2}$$

$$\ln\left(\frac{s_t^T}{s^T}\right) = q_T \ln\left(\frac{s_{t-1}^B}{s^B}\right), \qquad q_T \leq 0 \tag{3}$$

and

$$\ln\left(\frac{s_t^G}{s^G}\right) = q_G \ln\left(\frac{s_{t-1}^B}{s^B}\right), \qquad q_G \leq 0 \tag{4}$$

where $s_t^B \equiv \frac{B_t}{Y_t}$, $s_t^T \equiv \frac{T_t}{Y_t}$, $s_t^G \equiv \frac{G_t}{Y_t}$, and variables without time subscripts denote steady state values. The rules build in a one-year delay for the response of an offsetting policy.[5]

We refer to the q's in rules (1)–(4) as the "fiscal adjustment parameters." Sign restrictions on q_K, q_L, q_T, and q_G are straightforward. When the debt-output ratio rises above its initial steady-state level, one of the future distorting tax rates is raised, the government consumption-output is reduced, or the transfers-output ratio is lowered to maintain fiscal solvency. To isolate the impacts of each financing instrument, one of the q's is non-zero in each experiment. For example, if the transfers-output ratio is adjusted, $q_T < 0$, $q_G = q_K = q_L = 0$. The magnitudes of the q's characterize how strongly the offsetting policy reacts to debt.

Policy choices must satisfy rules (1)–(4) and the government's budget constraint at each date:

$$B_t = G_t + R_{t-1}B_{t-1} - \tau_t^L W_t L_t - \tau_t^K \rho_t K_{t-1} + T_t, \tag{5}$$

where for simplicity we assume all government debt is one-period and indexed for inflation.

Any equilibrium must satisfy both the first-order conditions for the household and the firm and the transversality conditions for debt and capital accumulation. For debt, this condition is $E_t \lim_{T \to \infty} \left(\frac{\beta}{h}\right)^{t+T} u'(c_{t+T}) B_{t+T} = 0$, which essentially ensures that in any optimum the household does not overaccumulate government liabilities. Writing the government's flow budget constraint, (14), in terms of shares of output, iterating forward, and imposing transversality yields the government's intertemporal budget constraint:

$$\frac{B_t}{Y_t} = s_t^B = \sum_{j=1}^{\infty} d_{t,t+j}[(1 - \alpha)\tau_{t+j}^L + \alpha\tau_{t+1}^K - s_{t+j}^G - s_{t+j}^T]. \tag{6}$$

$d_{t,t+j}$ is the growth-adjusted stochastic discount factor given by $d_{t,t+j} \equiv \Pi_{i=0}^{j-1} R_{t+i}^{-1} \frac{Y_{t+i+1}}{Y_{t+i}}$.

In equilibrium, (6) determines the value of government debt. It also imposes restrictions on dynamic interactions between current debt and expected future policies. A debt-financed tax cut that raises B_t / Y_t requires some combination of fiscal variables and/or discount factors in the future to be expected to adjust. Of course, there are many expected sequences of fiscal policies that satisfy (6). The policy rules (1)–(4) serve to specify one of many paths of fiscal variables. Feasibility is ensured by the judicious choice of response magnitude parameters—the q's in the rules.[6] Note that, as written, (6) holds in realizations. Taking expectations at t and imposing the asset-pricing relation for government bonds reveals that the value of debt at t depends on the expected present values of future fiscal instruments.

3.3. The solution method

Following King et al. (2002), the model, which has a deterministic growth trend h, is scaled by the factor of h^t. This creates a new discount factor, $\beta* \equiv \beta h^{1-\gamma}$, such that the steady state of the economy has constant output growth and constant consumption-output, investment-output, and debt-output ratios. An analytical solution is not available; the

---

[5] Longer delays can be easily handled. We only present results under one-year delay; the results under five-year delay are very similar.

[6] At the end of the paper, we consider another set of policy rules.

Table 1
Benchmark parameter settings

Parameter value		Parameter value		Parameter value	
α	0.36	δ	0.1	s^T	0.07
β	0.96	h	1.02	τ^K	0.35
γ	1	χ	3	τ^L	0.25
θ	1	s^G	0.2	s^B	0.376

equilibrium conditions are log-linearized around the steady state growth path and analyzed in terms of percentage deviations from that growth path. The model is solved using Sims's (2001) algorithm.[7]

3.4. The equilibrium

A competitive rational expectations equilibrium is defined as the agent's decisions, $\{C_t, L_t, K_t, B_t\}_{t=0}^{\infty}$, the firm's decisions, $\{L_t, K_t\}_{t=0}^{\infty}$, prices, $\{\rho_t, W_t, R_t\}_{t=0}^{\infty}$, and policy variables, $\{B_t, G_t, \tau_t^L, \tau_t^K, T_t\}$, such that, given initial levels of capital and debt, K_{-1} and B_{-1}, the optimality conditions for agents' and firms' problems are satisfied in each period; the goods, capital, labor, and bond markets clear; the transversality conditions for capital and debt hold; and the government budget constraint and the policy rules (Eqs. (1)–(4)) are satisfied. The analysis focuses on the ranges of the fiscal adjustment parameters–the q's–that are consistent with the existence of a rational expectations equilibrium.

3.5. Model calibration

The model is calibrated at an annual frequency. Table 1 reports the benchmark values of parameters and steady state values of variables before a permanent tax rate change. The choices of the values for structural parameters are comparable to those in similar models with distorting capital and labor income taxation (Braun, 1994; McGrattan, 1994; Jones, 2002; Yang, 2005). The model implies that in the original steady state, the fraction of time spent working is 0.20, the consumption-output ratio is 0.63, and the investment-output ratio is 0.17. The debt-output ratio in the steady state before a tax cut is 0.376, roughly corresponding to the ratio of federal debt held by the public to GDP in 2005 (Table 78, Economic Report of the President, 2006).

Benchmark settings of the q's are presented in the left column of Table 2.[8] These values are chosen so that after a permanent 1% reduction in the capital or labor tax rate, the economy evolves to a new steady state in which the debt-output ratio is 0.442, the postwar average for the ratio of

---

[7] We examine permanent tax cuts. The use of log-linearization may raise concerns about the quality of the first-order approximation when the equilibrium is away from the original steady state. Such concerns are alleviated by the facts that the equilibrium system for the model is nearly log-linear and that the size of tax cuts considered here is fairly small (a reduction of 1% of tax rates from their original steady state levels).

[8] Small values of q imply that following a tax cut, the debt-output ratio grows rapidly and the new steady state value for s^B can be quite distant from its initial steady state value. Of course, as s_{t-1}^B / s^B increases, even small values of q imply large offsetting policy adjustments, which imply larger contractionary effects.

Table 2
Fiscal adjustment parameters under various policy rules

Long-run s^B	0.442 (benchmark)		1	
Tax shock	$\Delta\tau^K=-1\%$	$\Delta\tau^L=-1\%$	$\Delta\tau^K=-1\%$	$\Delta\tau^L=-1\%$
q_G	−0.119	−0.130	−0.086	−0.088
q_T	−0.341	−0.371	−0.246	−0.251
q_L	0.149	–	0.108	–
q_K	–	0.206	–	0.140

The q's are chosen to allow the debt-output ratio to rise from an initial level of 0.376 to a new long-run level of 0.442 (second column) or 1.0 (third column).

privately held federal debt to GDP (1947–2005, Table 78, Economic Report of the President (2006)).[9]

4. Dynamic impacts of permanent tax rate cuts

This section reports the dynamic impacts of permanent reductions in capital and labor tax rates and shows how those impacts change when the financing schemes vary among permanently higher lump-sum transfers, a lower government consumption-output ratio, and increases in other proportional tax rates.

4.1. Tax-rate cuts financed by lump-sum transfers

To show that the government financing rule is an important determinant of the effects of permanent tax cuts, first we examine the consequences of tax rate cuts financed by lump-sum transfers. The policy rule for the transfer-output share, (3), is operative, so debt-financed deficits reduce expected future transfers. Fiscal adjustment parameters are $q_T=-0.341$ for a capital tax cut and $q_T=-0.371$ for a labor tax cut (Table 2). Fig. 1 reports the responses to a capital tax rate cut (solid lines), and to a permanent cut in the labor tax rate (dashed-dotted lines).

Both tax cuts have strong expansionary effects on output (the tax base), with higher investment and hours worked along the transition path. In the short run, substitution effects created by lower tax rates entice agents to invest more and work harder, raising output. As the economy converges to the new steady state, wealth effects from higher disposable income begin to dominate, raising consumption and leisure; investment and hours worked subside somewhat, but remain above their original steady state levels.

Although Mankiw and Weinzierl (2006) finance the tax-rate reductions with contemporaneous lump-sum transfer cuts, rather than debt, Ricardian equivalence ensures the two exercises produce identical effects on C, K, L, Y, and the prices. The qualitative patterns for permanent capital or labor tax cuts are the same in this model as in Mankiw and Weinzierl's model. The tax base expands along the transition path and in the new steady state for either tax cut (Fig. 1). Revenues from capital and labor income taxes are permanently lower (bottom right panel) and the shortfall is absorbed by permanently lower lump-sum transfers (bottom left panel). Our model implies

---

[9] Section 5.1 reports the sensitivity of outcomes to variations in the strength of fiscal responses.
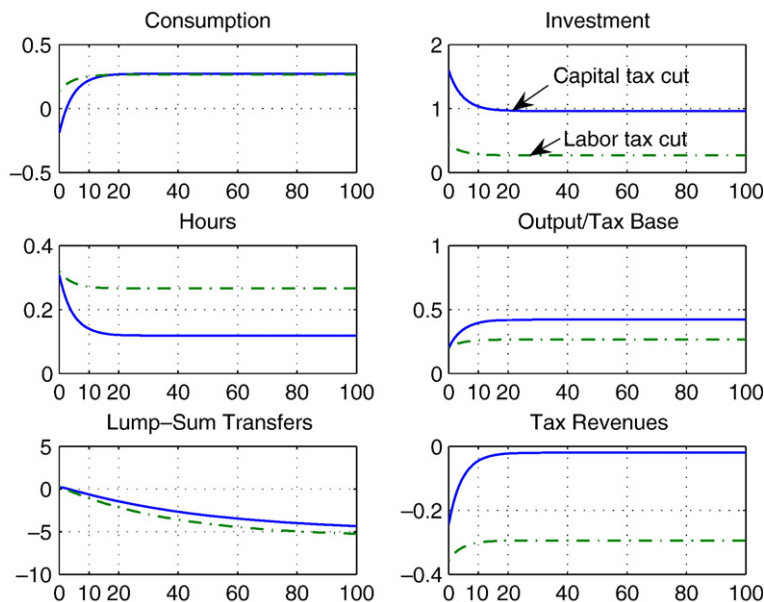
Fig. 1. Lump-sum financing. Impulse responses to a permanent 1% capital or labor tax rate reduction when lump-sum transfers adjust to balance the budget (in percent). The surprise tax cut occurs at period 0. Responses are plotted over a 100-year horizon when the economy has approximately reached its new steady state path.

95% (47%) of the revenue losses associated with a capital (labor) tax rate cut are offset by an expanded tax base in the long run when transfers finance the deficits.[10]

   When the government has access to a non-distorting tax instrument, lower tax rates appear to be expansionary and tax cuts are self-financing to a large degree.

4.2. Alternative financing schemes

   We turn now to the transitional dynamics following a permanent reduction in capital (or labor) tax rates, when the tax cuts are financed initially by government debt and eventually by permanent reductions in government consumption or permanent increases in labor (or capital) tax rates. Fig. 2 plots the dynamic responses of macroeconomic and budgetary variables to a permanent, unexpected 1% cut in the capital tax rate. Dashed-dotted lines are the impacts with $q_G = -0.119$ and $q_T = q_K = q_L = 0$; solid lines are the impacts with $q_L = 0.149$ and $q_G = q_T = q_K = 0$;

---

[10] Differences in revenue feedback between our result and Mankiw and Weinizerl's stem from model calibrations. Changing three aspects of our calibration helps to reconcile the differences: (1) reducing the original steady state capital tax rate from 0.35 to 0.25; (2) increasing the steady state time share spent working from 20 to 34%; and (3) reducing the intertemporal elasticity of substitution from 1 to 0.5. Under this alternative calibration, our model implies 67% and 25% of revenue loss for a capital and labor tax cut is offset by an expanded tax base under lump-sum transfer financing. Reducing the steady state capital tax rate plays the most important role in moving our results towards Mankiw and Weinizerl's. The average U.S. capital tax rate between 1947 and 2004 is about 0.39, according to Jones's (2002) method.
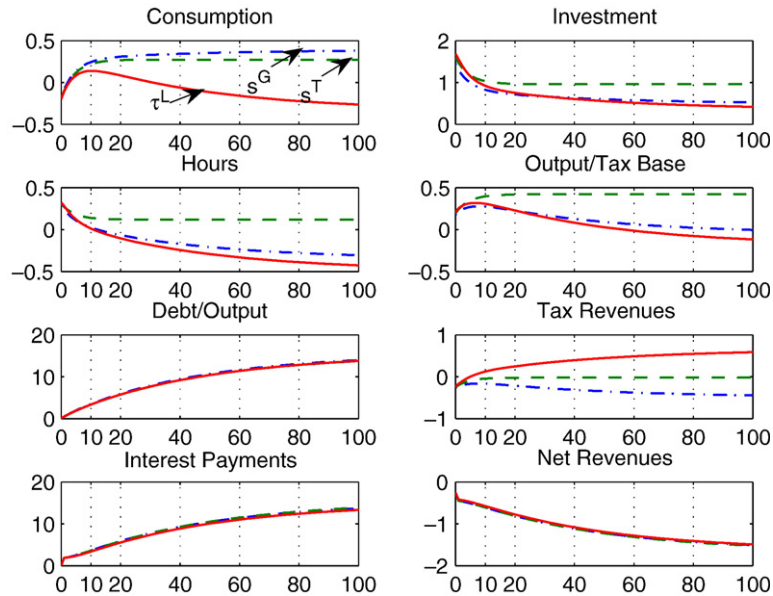
Fig. 2. Capital taxes: alternative financing schemes. Responses to a permanent 1% capital tax rate reduction (in percent). The surprise tax cut occurs at period 0. Responses are plotted over a 100-year horizon when the economy has approximately reached its new steady state path. Government consumption adjusts: dotted-dashed line; labor tax rates adjust: solid line; lump-sum transfers adjust: dashed line.

for reference, we repeat part of the responses from Fig. 1, which are dashed lines obtained when $q_T = -0.341$ and $q_G = q_K = q_L = 0$.[11]

When the capital tax rate is permanently cut, it increases the expected rate of return to investment. Regardless of which policy rule is used, agents sacrifice consumption in order to invest more in the first few years; consumption initially falls below the level in the original steady state path. Lower consumption raises the marginal utility of consumption, raising the benefit of working and the supply of labor. Higher labor and higher capital stock produce more output.

On the government financing side, the capital tax rate cut drives up the government debt-output ratio. When lump-sum transfers fall with debt, the tax reduction has its largest positive effects on investment, hours, and output (dashed lines in Fig. 2). This outcome is not surprising, as a distorting source of tax revenues is replaced by a non-distorting source.

Alternative financing schemes, however, involve changing some other distortion, with important implications for the impacts of tax changes. Reductions in the government consumption-output ratio (dotted-dashed lines) raise wealth as the government absorbs a smaller share of output. Wealthier households consume more leisure, reducing hours worked both along the transition path and in the new steady state. In the long run, the reduction in the government consumption ratio crowds in private consumption, raising consumption above its original steady state level. Ultimately, a higher after-tax return on investment raises the steady state capital stock and output, though by less than when lump-sum transfers adjust to clear the government budget.

---

[11] We do not allow a tax rate to adjust in response to its own shock so that the tax rate being shocked can be permanently held at 1% below its original steady state level.
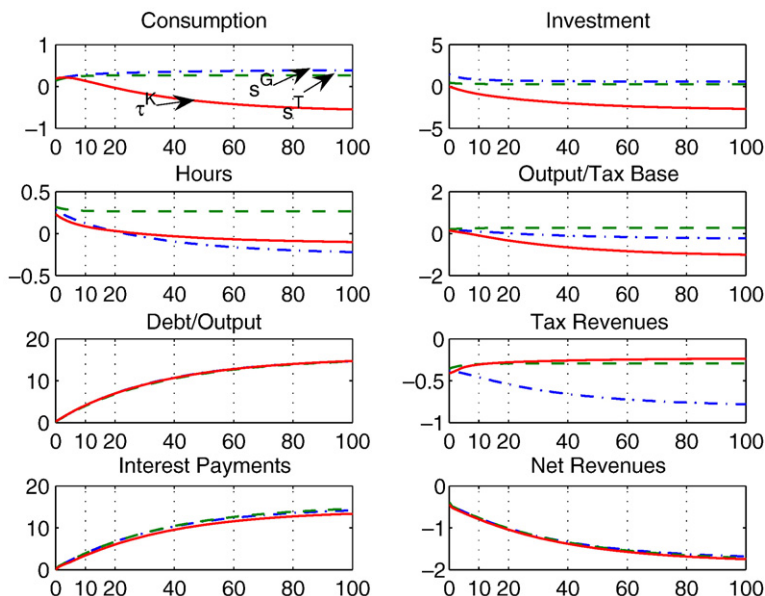
Fig. 3. Labor taxes: alternative financing schemes. Responses to a permanent 1% labor tax rate reduction. The surprise tax cut occurs at period 0. Responses are plotted over a 100-year horizon when the economy has approximately reached its new steady state path. Government consumption adjusts: dotted-dashed line; capital tax rates adjust: solid line; lump-sum transfers adjust: dashed line.

When the labor income tax rate (solid lines) rises to compensate for the lower capital tax rate, the permanently lower after-tax return to labor reduces hours worked in the new steady state. After rising initially, output declines to about 0.2% below its original steady state level. This negative outcome on the long-run tax base is strikingly different from the case when lump-sum transfers are used to respond to higher debt. Permanently higher investment, coupled with a fixed government consumption-output ratio, implies that consumption is lower in the new steady state.

Total revenues derived from capital and labor income taxes are permanently lower when government consumption or lump-sum transfers adjust, while revenues rise when labor tax rates adjust. Because permanently higher revenues after a capital tax cut arise from higher future labor tax rates, it would be misleading to infer that capital tax cuts *per se* generate permanently higher revenues.

To measure the budgetary cost of a tax cut, we also compute revenues net of interest payment (net revenues) to service debt. Regardless of which policy rule is used, interest payments rise and net revenues fall steadily as the debt-output ratio gradually climbs to a permanent higher level (bottom panels of the figure). Although a capital tax cut financed by a labor tax rate increase generates more revenues, net revenues still fall as the increased tax revenues are insufficient to compensate for the additional interest payment due to the debt-financed tax cut.

Analogous, but different, patterns of results emerge when a permanent labor tax rate reduction is financed by three alternative schemes. Fig. 3 reports responses to a 1% labor tax rate cut. Dashed-dotted lines are the impacts with $q_G=-0.130$ and $q_T=q_K=q_L=0$; solid lines give the responses when capital taxes adjust with $q_K=0.206$ and $q_T=q_G=q_L=0$; dashed lines report effects under $q_T=-0.371$ and $q_G=q_K=q_L=0$.

Once again, the tax impacts on investment, hours worked, and output are largest when lump-sum transfers respond to debt to satisfy the government budget constraint. Permanently lower labor tax rates raise the return to labor and increase equilibrium hours and output for the first few years. The deficit-financed tax cut raises debt as a share of output.

When future government consumption is reduced in response to the rising debt, the positive wealth effect offsets the substitution effect induced by a higher after-tax real wage and, within 18 years of the tax cut, hours worked fall as the economy converges to a new steady state with lower employment and output. As before, the reduced steady state government share crowds in private consumption.

If higher debt raises expected capital taxes, the long-run negative output effects are still more pronounced; output falls about 1% below the original steady state level in the new steady state. Lower expected returns to investment sharply reduce investment, output, and consumption.[12] After an initial increase, hours worked rapidly fall below their original steady state level. When capital taxes are expected to adjust to balance the budget, a permanent cut in labor taxes produces only an ephemeral expansionary effect; in the long run, the tax base falls.

Like a capital tax cut, net revenues fall under all financing schemes for a debt-financed labor tax cut. The differences in net revenues are quite small among the three financing schemes despite some differences in revenues and the interest rate. As the three financing schemes yield nearly identical paths for the debt-output ratio, it is clear that government indebtedness is important in determining the budgetary cost of a tax cut.

Mankiw and Weinizerl show that the elasticity of intertemporal substitution of leisure plays an important role in determining revenue feedback numbers. We consider two alternative settings for this parameter $-\theta = 2$ and $\theta = 5$—implying the smaller elasticities of 0.5 and 0.2. While the responses of key macroeconomic variables to either tax rate shock vary somewhat, the qualitative patterns are the same as those under the benchmark values. Importantly, the paper's message–that the ultimate source of fiscal financing matters to conclusions about dynamic scoring–is unaltered by different assumptions about labor elasticity.

Fiscal adjustments operating through different financing instruments (government consumption or one of the two distorting income taxes) can generate permanent changes in important macroeconomic variables. In particular, the expansionary effects of a tax cut can be reversed in the longer run. Moreover, even if a tax cut raises the tax base and total revenues, it may reduce revenues net of interest payments on the debt. This result is an outgrowth of the permanent increase in the debt-output ratio induced by the permanent tax cuts.

5. Changes in government indebtedness and the impacts of tax cuts

The above analysis focuses on the consequences of varying which fiscal instrument adjusts to maintain budget solvency. In this section, we focus on how changes in government indebtedness affect the expansionary effects and the budgetary costs of tax cuts.

5.1. Transition dynamics under two long-run debt-output ratios

Fig. 4 compares the tax base, net revenues, and debt-output ratios under two sets of settings of the fiscal adjustment parameters for a permanent 1% reduction in the capital tax rate.[13] The offsetting

---

[12] Similar results appear in Gordon and Leeper's (2005) study of countercyclical fiscal policies.
[13] A very similar picture emerges when labor taxes are permanently reduced.
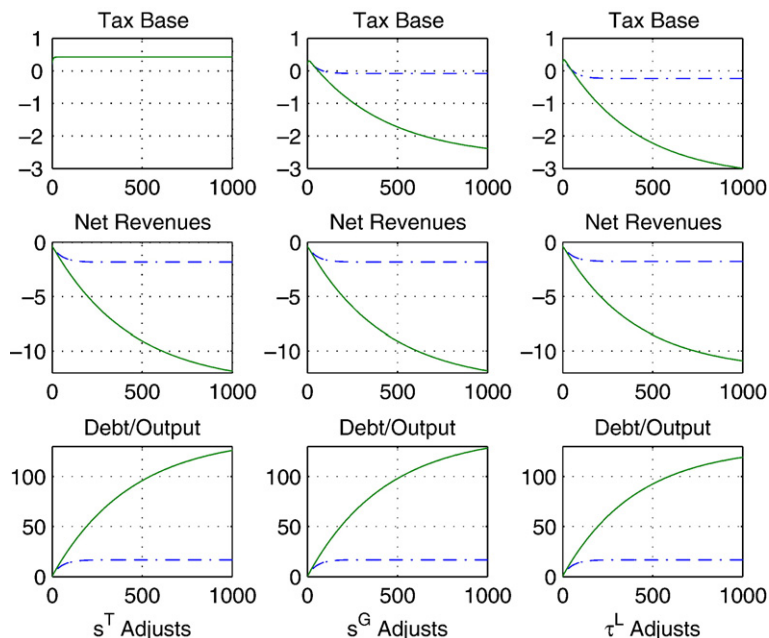
Fig. 4. Government indebtedness and fiscal adjustments: permanent 1% capital tax rate reduction. Responses plotted over a 1000-year horizon. Solid line allows long-run debt-output ratio to rise to 1.0; dotted-dashed line allows ratio to rise to 0.442. First column—transfers adjust: dotted-dashed ($q_T=-.341$), solid ($q_T=-.246$). Second column—government consumption adjusts: dotted-dashed ($q_G=-.119$), solid ($q_G=-.086$). Third column—labor taxes adjust: dotted-dashed ($q_L=.149$), solid ($q_L=.108$).

policy used to maintain fiscal solvency is labeled at the bottom of each column. The first set of q's yields a long-run debt-output ratio of 0.442, as in the earlier analysis. The second set of q's are selected such that the long-run debt-output ratio rises to 1 (the approximate upper bound for the ratio of federal debt to GDP in postwar U.S. data). Values of the q's are presented in Table 2. Notice that higher long-run debt-output ratios are associated with smaller magnitudes of fiscal adjustment parameters.

Several observations emerge from the figure. First, less debt is accumulated along a transition path and in the final steady state when the response magnitude of a fiscal adjustment parameter is relatively large (dotted-dashed lines). Second, more positive expansionary or less contractionary effects are associated with a smaller long-run debt-output ratio (except, of course, when transfers adjust). For example, when government consumption adjusts in response to a capital tax rate cut, the tax base in the new steady state falls only slightly when $q_G=-0.119$. With $q_G=-0.086$, in contrast, the tax cut produces stronger negative effects on the tax base (column 2 of Fig. 4). When labor taxes adjust in response to a capital tax rate cut (column 3), although the long-run expansionary effect is negative under both q_L's examined, the larger the q_L, the smaller the reduction in the tax base. Finally, tax cuts are less expensive (net revenues fall less) when they are associated with smaller long-run debt-output ratios. This holds even when lump-sum transfers adjust (column 1 of the figure).

5.2. Steady state analysis

Fig. 4 suggests that how aggressively fiscal instruments adjust after a permanent tax cut, with the inevitable consequences for debt accumulation, matters for the fiscal costs of the tax

reductions. We probe this phenomenon more deeply by turning to a steady state analysis in which the debt-output ratio is permitted to vary continuously from 0.376–its 2005 level–to 1.0-near its postwar peak.

A change in the steady state is triggered by a permanent 1% reduction in either the capital or the labor tax rate. Associated with the new tax rate are steady state values of endogenous variables, indexed by the new steady state value of the debt-output ratio. Let Δx denote the change in x across the two steady states. The government budget constraint in the two steady states implies a restriction among policy variables across steady states of the form

$$(1 - \beta^{-1})\Delta s^B = \Delta s^G + \Delta s^T - (1 - \alpha)\Delta\tau^L - \alpha\Delta\tau^K, \tag{7}$$

where in one set of experiments $\Delta\tau^K = .0035$ and in the other set $\Delta\tau^L = .0025$. It is straightforward to use (7) to compute the adjustment required in other instruments as a function of the posited change in debt, Δs^B.

Given the steady state values of policy variables, $(s^T, s^G, \tau^K, \tau^L)$, equilibrium consumption, capital, and labor satisfy the following system of non-linear equations:[14]

$$1 = \beta h^{-\gamma}[\alpha(1 - \tau^K)k^{\alpha-1}L^{1-\alpha} + 1 - \delta], \tag{8}$$

$$\chi(1 - L)^{-\theta} = c^{-\gamma}(1 - \tau^L)(1 - \alpha)k^\alpha L^{-\alpha}, \tag{9}$$

and

$$c + (h - 1 + \delta)k = (1 - s^g)k^\alpha L^{1-\alpha}, \tag{10}$$

where variables in lower cases are those scaled by the growth factor h^t.

Fig. 5 summarizes the relationship between the debt-output ratio and various budgetary variables for three distorting fiscal adjustments under the benchmark parameter values in Table 1. The x-axis in each of the nine plots has debt-output ratios in the new steady state varying from 0.376 to 1. The offsetting policy used is labeled on the top of each column. The first row of the figure reports magnitudes of fiscal instruments in levels in the new steady state. The second and last rows plot percent changes in the tax base and net revenues relative to their levels in a steady state without a tax cut. Solid lines are the effects of a capital tax cut, and the dotted-dashed lines are the effects of a labor tax cut. The vertical gray lines correspond to the debt-output ratio 0.442, as analyzed in Section 4.

The message is clear: across the three distorting financing schemes, a higher debt-output ratio is associated with (1) larger required fiscal adjustments, (2) less favorable expansionary effects, and (3) more costly tax cuts. Since a higher debt-output ratio means that a larger share of government resources is devoted to debt service, either government consumption or transfers have to be permanently lower, or one of the two tax rates has to be permanently higher to sustain a higher debt-output ratio. As analyzed in Section 4, reductions in government consumption or increases in a capital or labor tax rate have contractionary effects, offsetting the impacts of the tax rate cuts; with larger fiscal adjustments, contractionary effects are more likely. Finally, if the tax base falls, declines in net revenues are exacerbated by the higher interest payments associated with higher long-run debt-output ratios.

---

[14] Analytical results for a steady state are obtainable but do not lend themselves to intuitive interpretations for our analysis. Steady state analytics are reported in Appendix A.
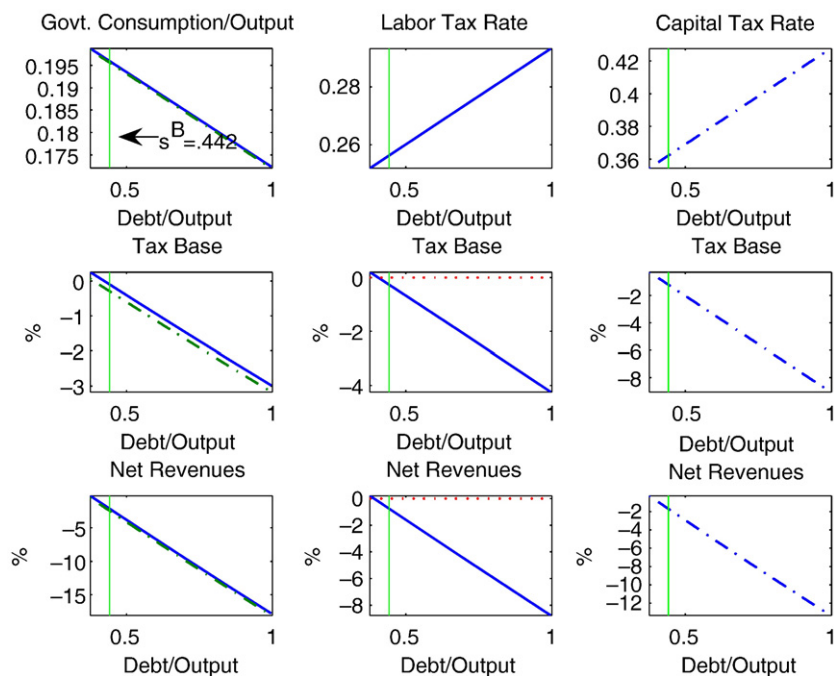
Fig. 5. Steady state analysis. Solid lines—a permanent 1% capital tax rate cut; dotted-dashed lines—a permanent 1% labor tax rate cut. First column—government consumption adjusts; second column—labor tax rate adjusts; third column—capital tax rate adjusts. Fiscal instruments are in levels; tax base and net revenues are percent changes relative to pre-tax cut steady state levels.

Combining the analyses of transition paths and steady states, we find that the systematic relationship between the response magnitude of fiscal adjustments to debt and long-run expansionary outcomes has important policy implications. While tax policy can be expansionary, debt management policy also matters. A relatively small response in the short run when the budget starts to deteriorate can be more costly in the long run.

6. Sensitivity analysis

Transitional dynamics have been analyzed under simple assumptions about policy rules. These rules serve as a tool for tracking the transition path and quantifying the aggressiveness of fiscal adjustments to debt. The qualitative conclusions obtained under these rules about the relationships among the aggressiveness of debt management policy, government indebtedness, and the expansionary effects and budget cost of a tax cut, however, are not sensitive to the particular policy rule, as long as the rule delivers a sustainable budget.

We check the sensitivity of the transitional dynamics to the specification of policy rules by considering a different set of rules, similar to the ones adopted in Trabandt and Uhlig (2006). In their setup, debt accumulates at the exogenously given long-run growth rate of the economy, h. One of the fiscal instruments adjusts endogenously to ensure the budget constraint is satisfied each period.[15] Figs. 6 and 7 contain the transitional dynamics and the steady state after a 1% permanent reduction in capital and labor tax rates under the parameters in Table 1.

---

[15] Trabandt and Uhlig (2006) only consider the rule where government consumption adjusts to balance the budget.
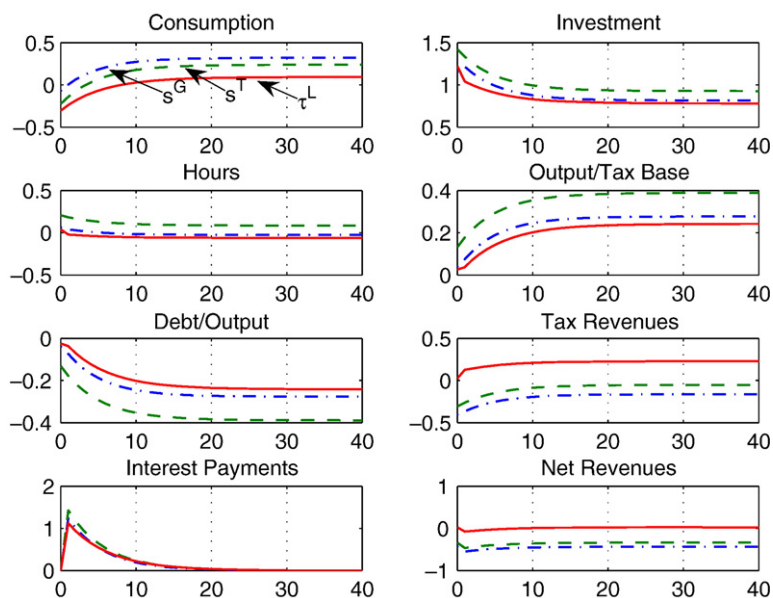
Fig. 6. Exogenous debt growth rule. Responses to a permanent 1% capital tax rate reduction (in percent). The surprise tax cut occurs at period 0. Responses plotted over a 40-year horizon. Government consumption adjusts in dotted-dashed lines; labor tax rates adjust in solid lines; lump-sum transfers adjust in dashed lines.

With a constant debt growth rule, while the debt-output ratio can deviate from the pre-tax cut level each period, the magnitude of the deviation is small because relatively strong fiscal adjustment is triggered at the time of a permanent tax cut. As a result, the expansionary effects of either tax cut are more favorable and the fiscal cost of the tax cuts are smaller, compared to the delayed fiscal adjustments examined in Section 4.

For example, under a delayed labor tax rate adjustment, the tax base eventually falls below the original steady state level for a capital tax rate cut (Fig. 2) but stays positive under the constant debt growth rule (Fig. 6). Because the debt rule keeps the debt-output ratio much smaller throughout the horizon, the labor tax rate rises only slightly to maintain budget solvency. Unlike the case of the delayed fiscal adjustments, the expansionary effects from the permanent capital tax rate cut are never outweighed by the contractionary effects of the increase in the labor tax rate. Similar comparative results are found for the labor tax rate cut. When the capital tax rate adjusts, the tax base falls 0.3% below the path without a tax cut (Fig. 7), much smaller than the same experiment under the earlier policy rule—1% (Fig. 3).

When debt grows exogenously, it cannot change with either tax cut. However, interest payments rise in most cases because of the higher interest rate, except for the labor tax rate cut under capital tax adjustments (the bottom left panel in Fig. 3). As the capital tax rate rises to balance the budget, agents substitute away from capital into bonds; the interest rate must fall to clear the bond market.

Comparing net revenues in Figs. 2 and 6, we see that the fiscal costs of same-sized capital tax rate cuts can be substantially different: when government pursues a more aggressive debt management policy by making debt growth exogenous, the tax cut is much less costly. In the case of a capital tax rate cut financed by higher labor tax rates, net revenues are even slightly above the
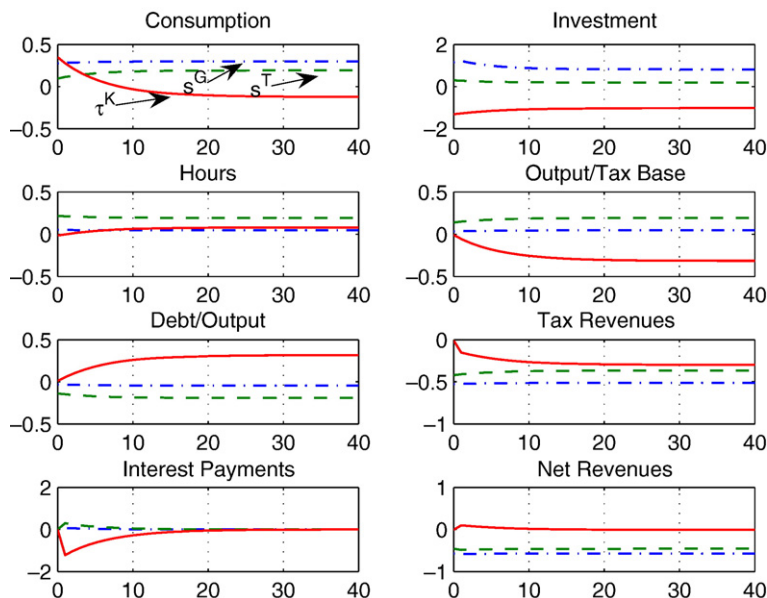
Fig. 7. Exogenous debt growth rule. Responses to a permanent 1% labor tax rate reduction (in percent). The surprise tax cut occurs at period 0. Responses plotted over a 40-year horizon. Government consumption adjusts in dotted-dashed lines; capital tax rates adjust in solid lines; lump-sum transfers adjust in dashed lines.

path without a tax cut in the long run. This is because there are few additional interest payments to offset the revenue gains from the higher labor tax rates.

The results obtained under the constant debt growth rule further highlight our previous conclusion under the earlier policy rule: when debt is well managed, a tax cut is more likely to be expansionary, making it less costly both along a transition path and in the long run.

Finally, the model assumes that government expenditures do not yield utility or enter the production function. Although not an uncommon assumption, it is hard to argue that government expenditure is completely wasteful, as it is in the model. If government expenditures are productive (such as useful government investment) then balancing the budget by cutting expenditures can make a tax cut more contractionary because less capital is available for production. If government expenditure enters the utility function as a (partial) substitute to private consumption, then reductions in government expenditures increase private consumption, which has a negative impact on saving, leading to less capital accumulation and output growth. On the other hand, if government expenditures enter the utility function as a complement, then reductions in government expenditures may increase investment, which in turn mitigates the contractionary effects resulting from a decrease in government expenditures. The precise role that government spending plays in the macro economy remains an open question with important implications for the budgetary costs of tax reductions.

7. Concluding remarks

Dynamic scoring is a complex business. This paper has maintained the assumption that the true model of the economy, including parameter values, is known with certainty. Despite that heroic assumption, the model predicts a wide range of expansionary effects and revenue consequences

from permanent cuts in tax rates. Those consequences depend on two critical aspects of fiscal behavior: which fiscal instruments agents expect will adjust to any revenue shortfalls and the extent to which shortfalls are financed with new debt issuances.

Previous work has made simplifying assumptions about these two aspects of fiscal policy to conclude that permanent tax cuts may, to a large extent, be self-financing. This paper points out, in contrast, that the range of possible dynamic scoring results mirrors the broad range of financing options actually available to policymakers.

As long as fiscal authorities are not committed–or cannot commit–to specific financing schemes, the response of private agents to tax cuts will be conditioned on expectations of the full range of possible schemes. The analysis in this paper argues that a complete assessment of the revenue costs of tax changes produces a matrix of predicted consequences. Rows of the matrix represent the offsetting fiscal instruments and columns represent alternative changes in steady state debt levels. Analyses that include the two dimensions of the matrix can help inform policy choices.

Appendix A. Steady state analytics

This appendix describes the steady state analytics. We begin with a general analysis that reveals the mechanisms through which government indebtedness matters for the expansionary effects and the budgetary costs of tax cuts. Then we derive the analytical solution under the benchmark parameterization, which is used to produce the (numerical) results presented in Section 5 of the paper.

A.1. General analysis

Write the steady state of the model as

$$\frac{1}{\beta}h^\gamma - (1 - \delta) = (1 - \tau^K)F_k(k, L), \tag{11}$$

$$v'(1 - L) = u'(c)(1 - \tau^L)F_L(k, L), \tag{12}$$

$$\text{and} \quad c + \delta^* k = (1 - s^G)F(k, L). \tag{13}$$

where v' is the marginal utility of leisure, u' is the marginal utility of consumption (consumption and leisure are assumed to enter utility separably), F is the production function, F_X is the marginal product of input X, and $\delta^* = h - 1 + \delta$. In (11)–(13) and in what follows, lower case letters refer to variables on the steady state growth path; these are upper case variables scaled by the exogenous growth factor, h. The government budget constraint is given by

$$B_t = G_t + R_{t-1}B_{t-1} - \tau_t^L W_t L_t - \tau_t^K \rho_t K_{t-1} + T_t. \tag{14}$$

Rewriting the government budget constraint in terms of shares of output and substituting out equilibrium expressions for factor prices, the totally differentiated constraint is

$$(1 - \beta^{-1})ds^B = ds^G + ds^T - (1 - \alpha)d\tau^L - \alpha d\tau^K. \tag{15}$$

Given steady state settings of policy, $(\tau^K, \tau^L, s^G, s^T)$, steady state values of (c, k, L, s^B) satisfy (11), (13), and (15).

In this appendix we examine how changes in steady state policy variables that are consistent with fiscal solvency–that is, satisfy (15)–alter the steady state levels of variables in the economy.

Given that $F(\cdot)$ is constant returns to scale, we can re-express the system in terms of the capital–labor ratio. Let

$$z \equiv \frac{k}{L} \tag{16}$$

and define the new production function

$$f(z) \equiv \left(\frac{k}{L}\right)^{\alpha}, \tag{17}$$

so that

$$y \equiv F(k, L) = Lf(z), \tag{18}$$

$$F_L(k, L) = (1 - \alpha)f(z), \tag{19}$$

$$\text{and } F_k(k, L) = \alpha \frac{f(z)}{z}. \tag{20}$$

Note that the Euler equation for capital, (11), can be written entirely in terms of the capital–labor ratio, z:

$$\left[\frac{1}{\beta}h^{\gamma} - (1 - \delta)\right] = \alpha(1 - \tau^K) \cdot \frac{f(z)}{z}. \tag{21}$$

Totally differentiating (21) and simplifying

$$dz = \frac{f'(z)}{(1 - \tau^K)f''(z)} d\tau^K. \tag{22}$$

Expression (22) reports that the capital–labor ratio changes if and only if the capital income tax rate changes.

Rewrite (13) in terms of z as

$$c = L[(1 - s^G)f(z) - \delta^* z] \tag{23}$$

and totally differentiate to get

$$dc = [(1 - s^G)f(z) - \delta^* z]dL + L[(1 - s^G)f'(z) - \delta^*]dz - Lf(z)ds^G. \tag{24}$$

Rewrite (12) in terms of z

$$v'(1 - L) = (1 - \alpha)(1 - \tau^L)f(z)u'(c), \tag{25}$$

and totally differentiate

$$-v''dL = (1 - \alpha)[-f(z)u'(c)d\tau^L + (1 - \tau^L)u'(c)f'(z)dz + (1 - \tau^L)f(z)u''(c)dc], \tag{26}$$

which, using (25) and multiplying through by $(1-L)$, can be written as

$$dL = \frac{1}{\theta}\left[-\frac{1 - L}{1 - \tau^L}d\tau^L + \frac{\alpha}{z}(1 - L)dz + \frac{u''}{u'}(1 - L)dc\right], \tag{27}$$

where $\frac{1}{\theta} = -v'/[v''(1 - L)]$ is the intertemporal elasticity of substitution of leisure.

In a steady state $(1 - s^G)f(z) - \delta^* z = c/L$, so using (22) to substitute for dz, dc in (24) yields

$$dc = \frac{c}{L}dL - Lf(z)ds^G + L[(1 - s^G)f'(z) - \delta^*]dz. \tag{28}$$

Substitute (28) into (27) and note that $\gamma = -u''(c)c/u'(c)$ to get

$$dL = \frac{1}{\Delta}\left\{-\frac{1}{1 - \tau^L}d\tau^L + \left[\frac{\alpha}{z} - \gamma\frac{L}{c}[(1 - s^G)f'(z) - \delta^*]\right]dz + \gamma\frac{L}{c}f(z)ds^G\right\}, \tag{29}$$

where $\Delta \equiv \left(\frac{\gamma}{L} + \frac{\theta}{1-L}\right) > 0$ and $\frac{1}{\gamma}$ is the elasticity of intertemporal substitution of consumption. From (29) we have the unambiguous partial derivatives

$$\frac{\partial L}{\partial \tau^L} < 0, \qquad \frac{\partial L}{\partial s^G} > 0. \tag{30}$$

Let nr denote net revenues, defined as

$$nr = [\alpha\tau^K + (1 - \alpha)\tau^L]Lf(z) - (r - 1)b, \tag{31}$$

so that

$$d(nr) = [\alpha\tau^K + (1 - \alpha)\tau^L][f(z)dL + Lf'(z)dz] + y[\alpha d\tau^K + (1 - \alpha)d\tau^L] - (r - 1)db, \tag{32}$$

where $r = \frac{h}{\beta}$.

Turning to the government budget constraint,

$$\left(\frac{1 - \beta^{-1}}{y}\right)(db - s^B dy) = ds^G + ds^T - [\alpha d\tau^K + (1 - \alpha)d\tau^L], \tag{33}$$

so that

$$db = \frac{y}{1 - \beta^{-1}}\{ds^G + ds^T - [\alpha d\tau^K + (1 - \alpha)d\tau^L]\} + s^B dy. \tag{34}$$

Use the restrictions from the government budget constraint in (34) in the expression for $d(nr)$ in (32) to obtain

$$d(nr) = [\alpha\tau^K + (1 - \alpha)\tau^L - (r - 1)s^B]dy + \frac{r - 1}{\beta^{-1} - 1}y(ds^G + ds^T)$$
$$+ y\left(\frac{r - \beta^{-1}}{1 - \beta^{-1}}\right)[\alpha d\tau^K + (1 - \alpha)d\tau^L], \tag{35}$$

where we use the facts that the tax base is

$$y = Lf(z) \tag{36}$$

and

$$dy = f(z)dL + Lf'(z)dz. \tag{37}$$

We now have four equations—(22), (29), (35) and (37)—in the four total derivatives dz, dL, $d(nr)$, and dy, which can be expressed in terms only of changes in fiscal policy variables. Our interest is to trace out how government indebtedness affects the tax base and net revenues in the long run. We first use (15) to obtain how a change in the debt-output ratio affects the magnitudes of adjustment in an offsetting policy. Then expressions (22), (29), (35), and (37) imply how an

adjustment in the offsetting policy influences the tax base and net revenues in the new steady state. Three examples illustrate the mechanisms at work.

In the first example, the labor income tax rate is permanently cut and government transfers adjust to maintain budget solvency. This corresponds to the financing scheme employed by Mankiw and Weinzierl (2006).[16] After setting $ds^G=d\tau^K=0$, (15) reduces to

$$ds^T = (1 - \beta^{-1})ds^B + (1 - \alpha)d\tau^L.$$

Note that $\frac{\partial s^T}{\partial s^B} = 1 - \beta^{-1} < 0$, which says a higher debt-output ratio requires a bigger reduction in the transfers-output ratio. Note that ds^T does not show up in (22), (29), and (37) but it does appear in (35). Since transfers are non-distorting, they do not affect steady state labor, capital, and hence the tax base. However, a transfer change has an effect on net revenues. (35) shows that $\frac{\partial nr}{\partial s^T} = \frac{r-1}{\beta^{-1}-1} > 0$, which says that the smaller is the transfers-output ratio, the smaller are net revenues. Combining with the earlier result that $\frac{\partial s^T}{\partial s^B} < 0$, we find that with a non-distorting financing instrument a higher debt-output ratio has no impact on the tax base but leads to a more costly tax cut, as implied by the first column of Fig. 4.

In the second example, the labor income tax rate is permanently cut and government consumption adjusts to maintain budget solvency, so $ds^T=d\tau^K=0$. Again, (15) reduces to

$$ds^G = (1 - \beta^{-1})ds^B + (1 - \alpha)d\tau^L, \tag{38}$$

which implies $\frac{\partial s^G}{\partial s^B} = 1 - \beta^{-1} < 0$. By (22), $dz=0$, and (29) simplifies to

$$dL = -\frac{1}{\Delta(1 - \tau^L)}d\tau^L + \gamma\frac{L}{\Delta c}f(z)ds^G. \tag{39}$$

Using (39) and (37), the change in the tax base is

$$dy = \frac{-f(z)}{\Delta(1 - \tau^L)}d\tau^L + \frac{\gamma L[f(z)]^2}{\Delta c}ds^G \tag{40}$$

so that (35) yields the change in net revenues

$$d(nr) = \left\{[\alpha\tau^K + (1 - \alpha)\tau^L - (r - 1)s^B]\frac{\gamma L[f(z)]^2}{\Delta c} + \frac{r - 1}{\beta^{-1} - 1}y\right\}ds^G$$
$$+ \left\{\frac{-f(z)}{\Delta(1 - \tau^L)}[\alpha\tau^K + (1 - \alpha)\tau^L - (r - 1)s^B] + (1 - \alpha)y\left(1 - \frac{r - 1}{\beta^{-1} - 1}\right)\right\}d\tau^L.$$

Note that

$$\frac{\partial y}{\partial s^G} = \frac{\gamma L[f(z)]^2}{\Delta c} > 0 \tag{41}$$

[16] To be more precise, Mankiw and Weinzierl also assume $ds^B=0$, though this assumption is irrelevant for the tax base once it is assumed that transfers are the only policy that adjusts.

and

$$\frac{\partial nr}{\partial s^G} = [\alpha\tau^K + (1-\alpha)\tau^L - (r-1)s^B]\frac{\gamma L[f(z)]^2}{\Delta c} + \frac{r-1}{\beta^{-1}-1}y > 0.^{[17]} \tag{42}$$

Eq. (38) implies that the higher is the debt-output ratio, the bigger is the reduction in the government consumption-output ratio required to maintain budget solvency. Because $\frac{\partial y}{\partial s^G} > 0$ and $\frac{\partial nr}{\partial s^G} > 0$, a smaller government consumption-output ratio makes the tax base and net revenues fall still more. This result appears in the dashed lines in the first column of Fig. 5 in the paper.

The third example permanently cuts the capital income tax rate and government consumption adjusts to maintain budget solvency: $ds^T = d\tau^L = 0$. Define $D \equiv \frac{\alpha}{z} - \gamma\frac{L}{c}[(1-s^G)f'(z) - \delta^*]$. Then (15), (29), (35), and (37) yield the expressions

$$ds^G = (1 - \beta^{-1})ds^B + \alpha d\tau^K, \tag{43}$$

$$dL = \frac{Df'(z)}{\Delta(1-\tau^K)f''(z)}d\tau^K + \gamma\frac{L}{\Delta c}f(z)ds^G, \tag{44}$$

$$dy = \frac{f'(z)}{(1-\tau^L)f''(z)}\left[\frac{Dfz}{\Delta} + Lf'(z)\right]d\tau^K + \frac{\gamma L[f(z)]^2}{\Delta c}ds^G, \tag{45}$$

and

$$d(nr) = \left\{[\alpha\tau^K + (1-\alpha)\tau^L - (r-1)s^B]\frac{\gamma L[f(z)]^2}{\Delta c} + \frac{r-1}{\beta^{-1}-1}y\right\}ds^G$$
$$+\left\{\frac{f'z}{(1-\tau^L)f''(z)}\left[\frac{Df(z)}{\Delta}+Lf'(z)\right][\alpha\tau^K + (1-\alpha)\tau^L - (r-1)s^B]+\alpha y\left(1-\frac{r-1}{\beta^{-1}-1}\right)\right\}d\tau^K.$$

$\frac{\partial s^G}{\partial s^B} < 0$ indicates that a higher debt-output ratio requires further reductions in the government consumption-output ratio. $\frac{\partial y}{\partial s^G} > 0$ and $\frac{\partial nr}{\partial s^G} > 0$ imply that the smaller is the government consumption-output, the less expansionary and more costly is the capital tax cut (as suggested by the solid line in the first column of Fig. 5).

A.2. Solution for the benchmark parameterization

In the benchmark parameterization, we use logarithmic preferences for consumption and leisure to obtain explicit analytical solutions. Steady state Eqs. (11)– (13) now are

$$\frac{h}{\beta} = \alpha(1-\tau^K)z^{\alpha-1} + 1 - \delta, \tag{46}$$

$$\frac{\chi}{1-L} = \frac{1}{c}(1-\alpha)(1-\tau^L)z^\alpha, \tag{47}$$

---

[17] Given the parameter values, even if $s^B=1$, the upperbound of debt-output ratio we consider in the paper, $\alpha\tau^K + (1-\alpha)\tau^L - (r-1)s^B > 0$.

and

$$c = L[(1 - s^G)z^\alpha - \delta^* z].$$ (48)

Solving (46) for z

$$z = \left[\frac{\frac{h}{\beta} - 1 + \delta}{\alpha(1 - \tau^K)}\right]^{\frac{1}{\alpha-1}}.$$ (49)

Substituting (48) into (47), labor can be expressed as

$$L = \left\{\chi\left[\frac{(1 - s^G) - \delta^*\left(\frac{\alpha(1-\tau^K)}{\frac{h}{\beta}-1+\delta}\right)}{(1-\alpha)(1-\tau^L)}\right] + 1\right\}^{-1},$$ (50)

consumption is

$$c = \left\{\chi\left[\frac{(1 - s^G) - \delta^*\left(\frac{\alpha(1-\tau^K)}{\frac{h}{\beta}-1+\delta}\right)}{(1-\alpha)(1-\tau^L)}\right] + 1\right\}^{-1}$$
$$\times \left[(1 - s^G)\left[\frac{\frac{h}{\beta} - 1 + \delta}{\alpha(1 - \tau^K)}\right]^{\frac{\alpha}{\alpha-1}} - \delta^*\left[\frac{\frac{h}{\beta} - 1 + \delta}{\alpha(1 - \tau^K)}\right]^{\frac{1}{\alpha-1}}\right],$$ (51)

and the capital stock, $k=zL$, is

$$k = \left[\frac{\frac{h}{\beta} - 1 + \delta}{\alpha(1 - \tau^K)}\right]^{\frac{1}{\alpha-1}}\left\{\chi\left[\frac{(1 - s^G) - \delta^*\left(\frac{\alpha(1-\tau^K)}{\frac{h}{\beta}-1+\delta}\right)}{(1-\alpha)(1-\tau^L)}\right] + 1\right\}^{-1}.$$ (52)

Eqs. (50)–(52) express L, c, and k in terms of exogenous parameters and policy variables. Therefore, the tax base and net revenues can also be expressed in terms of exogenous parameters and policy variables only.

The analysis begins with an exogenous debt-output ratio in a new steady state. For a given s^B, if the capital income tax rate is permanently reduced by 1% and government consumption is reduced to maintain budget solvency, then s^G is

$$s^G = \left(1 - \frac{1}{\beta}\right)s^B - s^T + (1 - \alpha)\tau^L + \alpha\tau^K,$$ (53)

where τ^K is set at 1% below its initial steady state level, and s^T and τ^L are set at their initial steady state values.

Use (49), (50), and (53) in (31) and (36) to rewrite the tax base as

$$y = \left\{ \chi \left[\frac{\left[1 - \left(1 - \frac{1}{\beta}\right)s^B - s^T + (1-\alpha)\tau^L + \alpha\tau^K\right] - \delta^* \frac{\alpha(1-\tau^K)}{\frac{h}{\beta} - 1 + \delta}}{(1-\alpha)(1-\tau^L)} \right] + 1 \right\}^{-1}$$
$$\times \left[\frac{\frac{h}{\beta} - 1 + \delta}{\alpha(1-\tau^K)} \right]^{\frac{\alpha}{\alpha-1}}.$$

and net revenue is

$$nr = [\alpha\tau^K + (1-\alpha)\tau^L - (r-1)s^B]z^\alpha L$$
$$= [\alpha\tau^K + (1-\alpha)\tau^L - (r-1)s^B] \times \left[\frac{\frac{h}{\beta} - 1 + \delta}{\alpha(1-\tau^K)} \right]^{\frac{\alpha}{\alpha-1}}$$
$$\times \left\{ \chi \left[\frac{\left[1 - \left(1 - \frac{1}{\beta}\right)s^B - s^T + (1-\alpha)\tau^L + \alpha\tau^K\right] - \delta^* \frac{\alpha(1-\tau^K)}{\frac{h}{\beta} - 1 + \delta}}{(1-\alpha)(1-\tau^L)} \right] + 1 \right\}^{-1}.$$

Changes in the tax base and net revenues arising when the debt-output ratio changes are given by

$$\frac{\partial y}{\partial s^B} = \frac{\chi\left(1 - \frac{1}{\beta}\right)}{(1-\alpha)(1-\tau^L)} L^2 z^\alpha \tag{54}$$

and

$$\frac{\partial nr}{\partial s^B} = \left\{ (1-r) + \frac{\chi\left(1 - \frac{1}{\beta}\right)[\alpha\tau^K + (1-\alpha)\tau^L + (1-r)s^B]}{(1-\alpha)(1-\tau^L)} L \right\} L z^\alpha, \tag{55}$$

where z and L are defined as in (49) and (50). The analytical results for other experiments can be derived analogously by the above steps.

Although (54) and (55) are the analytical solutions to the questions of interest, they are not terribly effective at illuminating the relationships between government indebtedness and the tax base or the cost of a tax cut. As a consequence, the paper presents numerical results, such as those summarized in Fig. 5.

References

Auerbach, A.J., 2005. Dynamic Scoring: An Introduction to the Issues. American Economic Review 95 (2), 421–425.

Baxter, M., King, R.G., 1993. Fiscal policy in general equilibrium. American Economic Review 86, 1154–1174.

Bohn, H., 1998. The behavior of U.S. public debt and deficits. Quarterly Journal of Economics 113 (3), 949–963.

Braun, R.A., 1994. Tax disturbances and real economic activity in the postwar United States. Journal of Monetary Economics 33, 441–462 (June).

Bruce, N., Turnovsky, S.J., 1999. Budget balance, welfare, and the growth rate: 'dynamic scoring' of the long-run government budget. Journal of Money, Credit and Banking 31 (2), 162–186.

Congressional Budget Office, 2005. Analyzing the Economic and Budgetary Effects of a 10 Percent Cut in Income Tax Rates. CBO, Washington, D.C. December 1.

Davig, T., 2005. Periodically expanding discounted debt: a threat to fiscal policy sustainability? Journal of Applied Econometrics 20 (7), 829–840.

Davig, T., Leeper, E.M., 2006. Fluctuating Macro Policies and the Fiscal Theory. In: Acemoglu, Daron, Rogoff, Kenneth, Michael Woodford (Eds.), NBER Macroeconomics Annual 2006, vol. 21. MIT Press, Cambridge, MA, pp. 247–316.

Economic Report of the President (2006). United States Government Printing Office, Washington, D.C.

Furman, J., 2006. A short guide to dynamic scoring. Center for Budget and Policy Priorities. August 24.

Gordon, D.B., Leeper, E.M., 2005. Are Countercyclical Fiscal Policies Counterproductive? NBER Working Paper 11869.

Greenspan, A. (2005a). "Remarks by Chairman Alan Greespan, Globalization, at the Council on Foreign Relations," accessed on 3/24/2005.

Greenspan, A. (2005b). "Testimony of Chairman Alan Greenspan, Future of the Social Security Program and Economics of Retirement, before the Special Committee on Aging, U.S. Senate," accessed on 3/24/2005.

Ireland, P.N., 1994. Supply-side economics and endogenous growth. Journal of Monetary Economics 33, 559–571.

Joint Committee on Taxation, 2005. Macroeconomic Analysis of Various Proposals to Provide $500 Billion in Tax Relief. JCT, U.S. Congress, Washington, D.C.. JCX-4-05, March 1.

Jones, J.B., 2002. Has fiscal policy helped stabilize the postwar U.S. economy? Journal of Monetary Economics 49, 709–746 (May).

King, R.G., Rebelo, S., 1990. Public policy and economic growth: developing neoclassical implications. Journal of Political Economy 98 (5), S126–S150.

King, R.G., Plosser, C.I., Rebelo, S.T., 2002. Production, growth and business cycles: technical appendix. Computational Economics 20 (1–2), 87–116.

Kirsanova, T., Wren-Lewis, S., 2007. "Optimal Fiscal Feedback on Debt in an Economy with Nominal Rigidities," Manuscript. University of Exeter.

Mankiw, N.G., Weinzierl, M., 2006. Dynamic scoring: a back-of-the-envelope guide. Journal of Public Economics 90 (8–9), 1415–1433.

McGrattan, E.R., 1994. The macroeconomic effects of distortionary taxation. Journal of Monetary Economics 33 (3), 573–601.

Novales, A., Ruiz, J., 2002. Dynamic Laffer curves. Journal of Economic Dynamics and Control 27 (2), 181–206.

Sims, C.A., 1998. Econometric implications of the government budget constraint. Journal of Econometrics 83 (1–2), 9–19.

Sims, C.A., 2001. Solving linear rational expectations models. Journal of Computational Economics 20 (1–2), 1–20.

Trabandt, M., Uhlig, H., 2006. How far are we from the slippery slope? The Laffer curve revisited. SFB 649 Discussion Paper 2006-023. Humboldt University.

U.S. Department of Treasury, 2006. A Dynamic Analysis of Permanent Extension of the President's Tax Relief. Office of Tax Analysis, Washington, D.C. July 25.

Yang, S.-C.S., 2005. Quantifying tax effects under policy foresight. Journal of Monetary Economics 52 (8), 1557–1568.