



## Dynamics of fiscal financing in the United States

Eric M. Leeper<sup>a,b,\*</sup>, Michael Plante<sup>c</sup>, Nora Traum<sup>a</sup>

<sup>a</sup> Department of Economics, Indiana University, Bloomington, IN 47405, USA

<sup>b</sup> National Bureau of Economic Research, Cambridge, MA 02138, USA

<sup>c</sup> Department of Economics, Ball State University, Muncie, IN 47306, USA

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### ABSTRACT

General equilibrium models that include policy rules for government spending, lump-sum transfers, and distortionary taxation on labor and capital income and on consumption expenditures are fit to US data under rich specifications of fiscal policy rules to obtain several results. First, the best-fitting model allows many fiscal instruments to respond to debt. Second, responses of aggregates to fiscal policy shocks under rich rules vary considerably from responses where only non-distortionary fiscal instruments finance debt. Third, in the short run, all fiscal instruments except labor taxes react strongly to debt, but long-run intertemporal financing comes from all components of the government's budget constraint. Fourth, debt-financed fiscal shocks trigger long-lasting dynamics; short-run and long-run multipliers can differ markedly.

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### 1. Introduction

Countries around the world combatted the recession and financial crisis of 2007–2009 with aggressive fiscal actions, both to stimulate demand with lower taxes and higher government spending and to recapitalize banks through a variety of financial “rescue” plans. In the United States, the actions will raise the federal government fiscal deficit to over 11% of GDP in fiscal year 2009 (Congressional Budget Office, 2009b). The Congressional Budget Office projects that these fiscal efforts together with the Obama administration's ambitious federal budget will push the federal debt held by the public from 40% to 80% of GDP by 2019 (Congressional Budget Office, 2009a). Large run-ups in government debt have placed issues of fiscal financing on policy makers' front burners.

Rational expectations imply that economic agents' beliefs about how debt innovations are financed by fiscal instruments play a crucial role in determining the resulting equilibrium and evolution of endogenous variables. Even in a simple real business cycle model, the impulse responses of economic variables following both fiscal policy and non-policy shocks depend on what fiscal instrument finances debt (Leeper and Yang, 2008). Understanding

which fiscal instruments have historically responded to debt and how quickly they have done so is essential to accurately predict the impacts of fiscal policy.

Although many theoretical conclusions about the effects of debt financing exist, empirical research that estimates how debt-financing policies affect the economy is scarce.<sup>1</sup> Except for recent work by Chung and Leeper (2007), the identified VAR literature has ignored this issue.<sup>2</sup> Several recent papers employ Bayesian techniques to estimate fiscal policy rules and to understand the economic effects of fiscal policy (Forni et al., 2009; Lopez-Salido and Rabanal, 2008; Kamps, 2007; Ratto et al., 2009; Coenen and Straub, 2005). However, most of this literature has focused on modeling exogenous fiscal policy, where deficits are financed by lump-sum transfer adjustments. A series of papers demonstrates that in real business cycle-style models it can be seriously misleading to set aside debt dynamics and to ignore distortionary fiscal financing (for example, Baxter and King, 1993; Sims, 1998; Leeper and Yang, 2008).

This paper uses Bayesian methods to estimate and evaluate a conventional dynamic stochastic general equilibrium (DSGE)

<sup>1</sup> Theoretical examples include Ricardian equivalence (Barro, 1974), “unpleasant monetarist arithmetic” (Sargent and Wallace, 1981), and the fiscal theory of the price level (Leeper, 1991; Sims, 1994; Woodford, 1995; Cochrane, 1999).

<sup>2</sup> Though see Favero and Giavazzi (2007) for a study that examines how including debt affects inferences from a VAR.

\* Corresponding author. Tel.: +1 812 855 9157.

E-mail addresses: [eleeper@indiana.edu](mailto:eleeper@indiana.edu) (E.M. Leeper), [mdplante@bsu.edu](mailto:mdplante@bsu.edu) (M. Plante), [ntraum@indiana.edu](mailto:ntraum@indiana.edu) (N. Traum).

model, extended to incorporate a rich description of fiscal policy, including non-trivial debt dynamics. The paper’s core contribution lies in its detailed specification of fiscal policy instruments and dynamic adjustments of fiscal instruments in response to the level of economic activity and to the state of government debt. We specify policy rules for capital, labor, and consumption taxes, government spending, and lump-sum transfers. The rules allow contemporaneous responses to output (“automatic stabilizers”) and dynamic responses to government debt. By estimating a DSGE model that incorporates a rich description of fiscal policy, we are able to estimate how government debt has been financed historically and examine how adjustments in each fiscal instrument have affected the observed equilibrium.

We estimate four versions of the model: four fiscal instruments – government spending, lump-sum transfers, and capital and labor taxes – adjust to stabilize debt; only capital and labor taxes adjust; only government spending adjusts; only lump-sum transfers adjust. We obtain several results. First, model specification tests imply that US time series prefer a rich fiscal policy specification in which all four instruments adjust to stabilize debt, with a weaker preference for having only transfers adjust. Second, responses of aggregate variables to fiscal policy shocks under rich fiscal rules can vary considerably from responses that allow only non-distortionary fiscal instruments to finance debt. Third, short-run responses of transfers, capital tax rates, and government spending to government debt are strong, while the response of labor taxes is weaker; in the long run, adjustments in all components of the government’s budget are important for ensuring that the intertemporal government budget constraint is satisfied. Fourth, debt-financed fiscal shocks trigger long-lasting dynamics so that short-run multipliers can differ markedly from long-run multipliers, even in their signs. Because inferences about policy effects depend strongly on the underlying fiscal rules, the findings underscore the importance of modeling fiscal financing dynamics.

With estimates of the model’s “deep parameters” in hand, it is possible to conduct counterfactual experiments that alter policy rules, holding private parameters fixed at their estimated values. We address three counterfactual questions: (1) How do the impacts of fiscal shocks change if future policies respond to debt more or less gradually than they have historically? (2) How do fiscal multipliers change when, instead of the historical sources of financing for debt, we imagine that only a single fiscal instrument responds to stabilize debt? (3) What are the long-run consequences of enhanced “automatic stabilizers?” Answers to questions like these can help guide policy choices.

This paper complements a large-scale global modeling effort underway at the International Monetary Fund to estimate DSGE models that incorporate fiscal policy rules that allow for both distortionary and non-distortionary sources of fiscal financing. This study, however, focuses on simpler models that are more easily interpretable and it emphasizes fresh implications that spring from explicit modeling of government debt dynamics.<sup>3</sup>

Our results are subject to an important caveat: they do not include the interactions between monetary and fiscal policies that tend to arise in practice, and certainly occurred in response to the recent recession.<sup>4</sup> Recent work finds that fiscal multipliers can change dramatically when monetary policy is passive, failing to satisfy the Taylor principle, or when the central bank’s interest rate instrument is at or near the zero lower bound (for example, Christiano et al., 2009; Davig and Leeper, 2009; Eggertsson, 2009). On the other hand, by abstracting from nominal

considerations, this paper puts empirical flesh on the multipliers that Uhlig (2009) calculates in a calibrated model.

This paper is organized as follows. Section 2 describes the estimated model, our assumptions regarding fiscal policies, and the technique used to solve the model. Section 3 outlines the techniques we use to estimate the model and our assumptions regarding prior distributions. Section 4 summarizes the estimation results, while Section 5 reports some counterfactual exercises. Section 6 concludes.

## 2. The model

The model economy is a neoclassical growth model extended to include intertemporal investment adjustment costs, variable capacity utilization, and external habit formation. The economy consists of a representative household, a representative firm, and the government. There are nine transitory shocks in the economy, denoted by  $u_t$ ’s, including two preference shocks, an investment-specific shock, neutral technology shock, and shocks to fiscal instruments.

### 2.1. Households

The representative household derives utility from consumption,  $c_t$ , relative to a habit stock. We assume that the habit stock is given by a fraction of aggregate consumption from the previous period  $hC_{t-1}$ , where  $h \in [0, 1]$ .<sup>5</sup> The household derives disutility from hours worked,  $l_t$ . In addition, there is a general preference shock,  $u_t^b$ , that affects the household’s intertemporal substitution and a preference shock specific to labor supply,  $u_t^l$ . Specifically, the household maximizes the intertemporal utility function

$$E_0 \sum_{t=0}^{\infty} \beta^t u_t^b \left[ \frac{1}{1-\gamma} (c_t - hC_{t-1})^{1-\gamma} - u_t^l \frac{l_t^{1+\kappa}}{1+\kappa} \right]$$

where  $\gamma, \kappa \geq 0$  and  $\beta \in (0, 1)$ . The shocks  $u_t^b$  and  $u_t^l$  follow AR(1) processes given by

$$\ln(u_t^b) = \rho^b \ln(u_{t-1}^b) + \sigma_b \epsilon_t^b, \quad \epsilon_t^b \sim N(0, 1) \tag{1}$$

$$\ln(u_t^l) = \rho^l \ln(u_{t-1}^l) + \sigma_l \epsilon_t^l, \quad \epsilon_t^l \sim N(0, 1). \tag{2}$$

The household’s flow budget constraint is given by

$$(1 + \tau_t^c)c_t + i_t + b_t = (1 - \tau_t^l)w_t l_t + (1 - \tau_t^k) \times R_t^k v_t k_{t-1} + R_{t-1} b_{t-1} + z_t. \tag{3}$$

Total income and wealth consists of labor income, capital income, lump-sum transfers from the government,  $z_t$ , and one-period risk-free government bonds. These assets can be used for consumption, investment in physical capital  $i_t$ , and for purchasing more government bonds. Capital income is given by the return on the effective amount of capital services supplied to firms in period  $t$ ,  $v_t k_{t-1}$ , where  $v_t$  measures capacity utilization in period  $t$ . One-period government debt outstanding at time  $t$ ,  $b_t$ , pays a gross interest rate of  $R_t$ .  $\tau_t^c$ ,  $\tau_t^l$ , and  $\tau_t^k$  are tax rates on consumption, labor income, and capital income.

The law of motion for capital is given by

$$k_t = (1 - \delta(v_t))k_{t-1} + \left[ 1 - s \left( \frac{u_t^l i_t}{i_{t-1}} \right) \right] i_t. \tag{4}$$

$s \left( \frac{u_t^l i_t}{i_{t-1}} \right) i_t$  is a cost of adjustment incurred if the household varies its investment level from the level in the previous period, as in Smets and Wouters (2003) and Christiano et al. (2005). The function  $s(\cdot)$  has the following properties at the steady state:  $s(1) = s'(1) = 0$  and  $s''(1) > 0$ . In addition, the adjustment cost is subject to a shock

<sup>3</sup> Some examples of papers flowing from the IMF effort include Laxton and Pesenti (2003), Botman et al. (2006), and Kumhof and Laxton (2008a,b).

<sup>4</sup> Traum and Yang (2009) is a recent effort to extend estimated DSGE models in that direction.

<sup>5</sup> We define  $X_t$  as the aggregate level of any variable  $x_t$  throughout the model.

$u_t^i$  which follows the AR(1) process

$$\ln(u_t^i) = \rho^i \ln(u_{t-1}^i) + \sigma_i \epsilon_t^i, \quad \epsilon_t^i \sim N(0, 1). \quad (5)$$

$u_t^i$  is an investment specific shock, similar to Greenwood et al. (1997), that captures exogenous variations in the efficiency with which investment can be transformed into physical capital. Owners of physical capital can control the intensity with which the capital stock is utilized. We assume that increasing the intensity of capital utilization entails a cost in the form of a faster rate of depreciation. Following Schmitt-Grohe and Uribe (2008), we adopt a quadratic form for the function  $\delta$ :

$$\delta(v_t) = \delta_0 + \delta_1(v_t - 1) + \frac{\delta_2}{2}(v_t - 1)^2. \quad (6)$$

The household maximizes utility subject to its budget constraint, (3), and the law of motion for capital, characterized by (4) and (6).

### 2.1.1. Firms

The representative firm rents capital and labor from the household to maximize profit given by

$$u_t^a (v_t k_{t-1})^\alpha l_t^{1-\alpha} - w_t l_t - R_t^k v_t k_{t-1} \quad (7)$$

where  $\alpha \in [0, 1]$  and  $u_t^a$  denotes a neutral technology shock that is assumed to follow the AR(1) process

$$\ln(u_t^a) = \rho^a \ln(u_{t-1}^a) + \sigma_a \epsilon_t^a, \quad \epsilon_t^a \sim N(0, 1). \quad (8)$$

Total output at period  $t$  is given by  $y_t = u_t^a (v_t k_{t-1})^\alpha l_t^{1-\alpha}$ . From the solution to the firm's problem, wages and capital rental rates are given by

$$w_t = \frac{(1-\alpha)y_t}{l_t}, \quad R_t^k v_t = \frac{\alpha y_t}{k_{t-1}}. \quad (9)$$

### 2.1.2. Fiscal policy

The government budget constraint is

$$B_t + \tau_t^k R_t^k v_t k_{t-1} + \tau_t^l w_t l_t + \tau_t^c C_t = R_{t-1} B_{t-1} + G_t + Z_t \quad (10)$$

where  $G_t$  is government expenditure. Fiscal policy follows rules that embed three features. First, there may be some "automatic stabilizer" component to movements in fiscal variables. This is modeled as a contemporaneous response to deviations of output from the steady state. Second, all instruments except consumption taxes are permitted to respond to the state of government debt. Third, since fiscal policy makers often consider changes in tax rates jointly, we allow shocks affecting one tax rate to also affect other tax rates contemporaneously. In terms of log deviations from the steady state, the policy rules are

$$\hat{G}_t = -\varphi_g \hat{Y}_t - \gamma_g \hat{B}_{t-1} + \hat{u}_t^g, \quad \hat{u}_t^g = \rho_g \hat{u}_{t-1}^g + \sigma_g \epsilon_t^g, \quad (11)$$

$$\hat{\tau}_t^k = \varphi_k \hat{Y}_t + \gamma_k \hat{B}_{t-1} + \phi_{kl} \hat{u}_t^l + \phi_{kc} \hat{u}_t^c + \hat{u}_t^k, \quad (12)$$

$$\hat{u}_t^k = \rho_k \hat{u}_{t-1}^k + \sigma_k \epsilon_t^k,$$

$$\hat{\tau}_t^l = \varphi_l \hat{Y}_t + \gamma_l \hat{B}_{t-1} + \phi_{kl} \hat{u}_t^k + \phi_{lc} \hat{u}_t^c + \hat{u}_t^l, \quad (13)$$

$$\hat{u}_t^l = \rho_l \hat{u}_{t-1}^l + \sigma_l \epsilon_t^l,$$

$$\hat{\tau}_t^c = \phi_{kc} \hat{u}_t^k + \phi_{lc} \hat{u}_t^l + \hat{u}_t^c, \quad \hat{u}_t^c = \rho_c \hat{u}_{t-1}^c + \sigma_c \epsilon_t^c, \quad (14)$$

$$\hat{Z}_t = -\varphi_z \hat{Y}_t - \gamma_z \hat{B}_{t-1} + \hat{u}_t^z, \quad \hat{u}_t^z = \rho_z \hat{u}_{t-1}^z + \sigma_z \epsilon_t^z, \quad (15)$$

where hats denote log-deviations of variables and each of the  $\epsilon$ 's is distributed i.i.d.  $N(0, 1)$ .

Consumption taxes are assumed to follow an exogenous process because US federal consumption taxes are mostly excise taxes on specific goods (gasoline, tobacco, etc.) and are used mainly for special funds. Thus, they do not adjust to changes in current output or government debt.

The other fiscal instruments follow rules that allow a response to the cyclical position of the economy ( $\varphi_i \geq 0$  for  $i = \{g, k, l, z\}$ ) and to changes in the level of government debt ( $\gamma_i \geq 0$  for  $i = \{g, k, l, z\}$ ). To capture the persistent nature of exogenous changes in instruments, we allow the shocks to be serially correlated ( $\rho_i \in [0, 1]$  for  $i = \{g, k, l, z\}$ ). In addition we augment the fiscal rules with i.i.d. error terms ( $\epsilon_t^i$  for  $i = \{g, k, l, z\}$ ) to capture unexpected changes in policy. Parameters  $\phi_{kl}$ ,  $\phi_{kc}$ , and  $\phi_{lc}$  control how much unpredicted movement in one tax rate is due to an exogenous shock to another tax rate.

## 2.2. Market equilibrium and model solution

The final goods market is in equilibrium if aggregate production equals aggregate demand for consumption and investment by the household and government:

$$Y_t = C_t + I_t + G_t. \quad (16)$$

The capital rental market and labor market are in equilibrium if both the first-order conditions for the household and the firm are satisfied. In addition, any equilibrium must satisfy the transversality conditions for debt and capital accumulation. Note that equilibrium implies  $x_t = X_t$  for any variable  $x$ .

Equilibrium conditions and their log-linearizations around the deterministic steady state are given in Appendix A. The log-linearized model is solved using the Sims (2001) gensys algorithm. The solution is of the form

$$\mathbf{x}_t = G(\Theta) \mathbf{x}_{t-1} + M(\Theta) \epsilon_t, \quad \epsilon_t \sim N(\mathbf{0}, \mathbf{I}) \quad (17)$$

where  $\Theta$  denotes the vector of structural parameters to be estimated and  $\mathbf{x}_t$  denotes the vector of model variables at time  $t$ .

## 3. Estimation

Our emphasis on government debt dynamics forces us to limit attention to federal government fiscal behavior, for which comprehensive data on the market value of publicly held government debt exists. Although this choice limits the scope of the study somewhat, because most US states have balanced-budget rules but the federal government does not, it is not obvious that it is reasonable to aggregate federal and state and local fiscal behavior.

We report results from estimates of four models that differ in which fiscal instruments are permitted to respond to debt: four fiscal instruments – government spending, lump-sum transfers, and capital and labor taxes – adjust; only capital and labor taxes adjust; only government spending adjusts; only lump-sum transfers adjust.

Models are estimated with US quarterly data from 1960Q1 to 2008Q1. We use nine time series: real consumption, real investment, hours worked, real government debt, real government spending, real capital tax revenues, real labor tax revenues, real consumption tax revenues, and real government transfers. Data are transformed to per capita terms. Appendix B describes the data construction. We detrend the logarithm of each variable independently with a linear trend.<sup>6</sup>

Let  $\mathbf{y}_t$  denote the vector of observables and define the following measurement equation relating observables to model variables:

$$\mathbf{y}_t = \mathbf{H} \mathbf{x}_t. \quad (18)$$

Using this mapping between observables and model variables, we estimate the model using Bayesian methods. First, we use

<sup>6</sup> Although many recent DSGE models allow for 1 or 2 common stochastic trends (examples include Greenwood et al., 1997, 2000; Altig et al., 2005), incorporating such features into a model with fiscal policy is nontrivial. Several fiscal variables appear to have their own trends, which require adjustments to the current model (see Schmitt-Grohe and Uribe (2008) for a model which incorporates the trend in government spending). Some fiscal variables, such as transfers, exhibit upward trends, which may require specific modeling assumptions to guarantee fiscal sustainability. We leave exploration of this topic to future research.

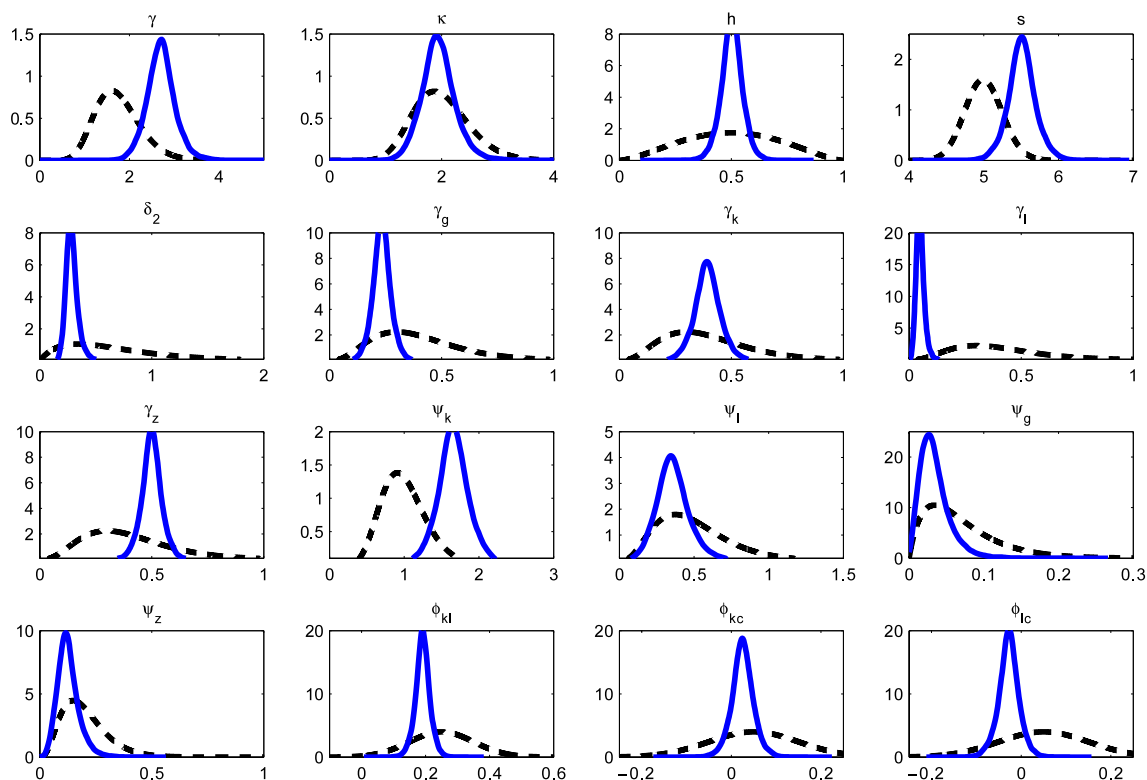


Fig. 1. Prior (dashed black) vs. posterior (solid blue) distributions. Posterior distributions are from the model where all fiscal instruments adjust to debt.

the Sims optimization routine `csmmwel` to maximize the log posterior function, which combines the priors and the likelihood of the data. Then we use the random walk Metropolis–Hastings (HM) algorithm to sample from the posterior distribution.<sup>7</sup> When performing the optimization routine, we initialize the posterior mode search with parameter values drawn at random from the prior densities. We perform several – at least 50 – searches for the mode from different starting values to determine if more than one mode exists. In all the models, the searches for the posterior mode almost always converged to the same parameter values and likelihood value.<sup>8</sup> After running the MH algorithm, we perform diagnostics to ensure convergence of the MCMC chain.<sup>9</sup>

### 3.1. Priors and calibrated values

Table 1 presents the values assigned to the calibrated parameters (which can be viewed as very strict priors). These values were kept fixed because our data set is demeaned and cannot pin down many steady state values in the estimation procedure. The discount factor,  $\beta$ , is set to equal 0.99, which implies an annual steady state

Table 1

Calibrated parameters for the estimated model.

Parameter	Value
$\beta$	0.99
$\delta_0$	0.025
$\alpha$	0.30
$G/Y$	0.0922
$B/Y$	0.3396
$\tau^k$	0.184
$\tau^l$	0.223
$\tau^c$	0.028

interest rate of 4%. We set  $\alpha$  equal to 0.3, which implies a labor share of 70%. The annual steady state depreciation rate is 10%, implying that  $\delta_0$  equals 0.025. We calibrate the parameter  $\delta_1$  to ensure that the capacity utilization,  $v$ , equals unity in the steady state. In addition, the steady state tax rates and the ratios of government spending and debt to output are set equal to the mean values of our data set.

Tables 2 and 3 shows the prior distributions for the remaining parameters, and Figs. 1 and 2 plot the probability density functions that correspond to these priors. We assume that the parameters are independent *a priori*. The priors are similar to those commonly used in the literature (see Smets and Wouters, 2007; Forni et al., 2009; An and Schorfheide, 2007, for examples). The means were set at values that correspond with estimates of other studies in the literature and the standard errors were set so that the domain covers a reasonable range of parameter values, including values estimated by previous studies.

For the preference parameters, a Gamma distribution is assumed for the coefficient of risk aversion  $\gamma$  and the inverse of the Frisch elasticity  $\kappa$ , with means of 1.75 and 2, respectively, and a standard deviation for both parameters equal to 0.5, so that both prior masses are concentrated on values higher than a logarithmic specification. The habit coefficient  $h$ , whose mean is set at 0.5, is distributed according to a Beta distribution with

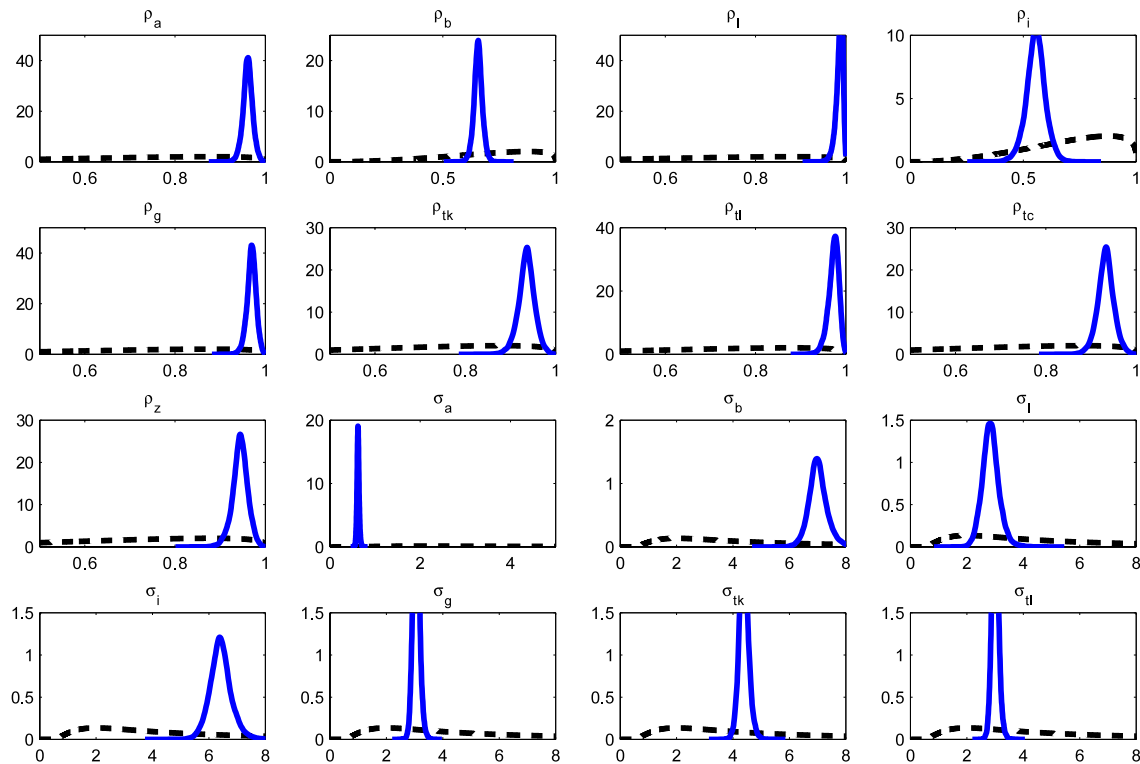
<sup>7</sup> A sample of 5,000,000 draws was created with the first 250,000 used as a burn-in period and every 200th draw was thinned. The posterior mode and the inverse Hessian at the posterior mode resulting from the optimization procedure were used to define the transition probability function. A step size of 0.3 resulted in acceptance rates between 34% and 38% for the different model specifications.

<sup>8</sup> The few exceptions were simply cases where the numerical optimization procedure failed to converge to any value. In addition, since we initialize the MH algorithm with the posterior mode and Hessian, we checked the gradient and the conditioning number of the Hessian at the mode and plotted slices of the likelihood around the mode. These details appear in an estimation appendix available upon request.

<sup>9</sup> Diagnostics include trace plots, verifying that the chain is well mixed (i.e. has low serial correlations in sample draws), and performing Geweke's (2005, pp. 149–150) Separated Partial Means tests. All results appear in an estimation appendix available upon request.

**Table 2**  
Selected prior and posterior distributions for the various models estimated.

Parameter	Prior distribution			Mean (5% & 95%) of posterior distribution			
	Density	Mean	St. dev.	All adjust	Spending adjust	Tax adjust	Transfer adjust
Risk aversion $\gamma$	$\mathcal{G}$	1.75	0.50	2.7 (2.1, 3.4)	2.68 (2.1, 3.3)	2.67 (2.1, 3.3)	2.68 (2.1, 3.3)
Inverse Frisch elast. $\kappa$	$\mathcal{G}$	2.00	0.50	1.9 (1.4, 2.6)	2.0 (1.4, 2.6)	2.0 (1.4, 2.6)	1.8 (1.3, 2.5)
Habit formation $h$	$\mathcal{B}$	0.50	0.20	0.5 (0.4, 0.6)	0.5 (0.4, 0.6)	0.5 (0.4, 0.6)	0.49 (0.4, 0.59)
Investment adj. cost $s''$	$\mathcal{G}$	5.00	0.25	5.5 (5.1, 5.9)	5.5 (5.1, 5.9)	5.5 (5.2, 5.9)	5.5 (5.1, 5.9)
Capital util. cost $\delta_2$	$\mathcal{G}$	0.70	0.50	0.29 (0.2, 0.42)	0.28 (0.2, 0.40)	0.29 (0.2, 0.42)	0.28 (0.2, 0.42)
Gov. spend debt coeff. $\gamma_g$	$\mathcal{G}$	0.40	0.20	0.23 (0.15, 0.31)	0.24 (0.17, 0.32)	–	–
Cap. tax debt coeff. $\gamma_{tk}$	$\mathcal{G}$	0.40	0.20	0.39 (0.28, 0.51)	–	0.39 (0.27, 0.5)	–
Labor tax debt coeff. $\gamma_{tl}$	$\mathcal{G}$	0.40	0.20	0.049 (0.019, 0.09)	–	0.052 (0.022, 0.092)	–
Transfer debt coeff. $\gamma_z$	$\mathcal{G}$	0.40	0.20	0.5 (0.41, 0.59)	–	–	0.5 (0.4, 0.6)
Cap. tax Y coeff. $\varphi_{tk}$	$\mathcal{G}$	1.00	0.30	1.7 (1.2, 2.1)	1.4 (0.99, 1.8)	1.6 (1.2, 2.0)	1.4 (0.98, 1.8)
Labor tax Y coeff. $\varphi_{tl}$	$\mathcal{G}$	0.50	0.25	0.36 (0.16, 0.61)	0.36 (0.16, 0.6)	0.33 (0.14, 0.56)	0.38 (0.16, 0.65)
Gov. spend Y coeff. $\varphi_g$	$\mathcal{G}$	0.07	0.05	0.034 (0.0064, 0.084)	0.033 (0.0063, 0.082)	0.031 (0.0059, 0.077)	0.033 (0.0059, 0.084)
Transfer Y coeff. $\varphi_z$	$\mathcal{G}$	0.20	0.10	0.13 (0.049, 0.24)	0.11 (0.043, 0.21)	0.11 (0.042, 0.2)	0.13 (0.048, 0.25)
Cap./Labor co-term $\phi_{kl}$	$\mathcal{N}$	0.25	0.10	0.19 (0.14, 0.24)	0.15 (0.11, 0.2)	0.19 (0.14, 0.23)	0.15 (0.11, 0.2)
Cap./cons. co-term $\phi_{kc}$	$\mathcal{N}$	0.05	0.10	0.024 (–0.025, 0.074)	0.047 (–0.0014, 0.1)	0.025 (–0.023, 0.073)	0.049 (–0.0035, 0.1)
Labor/Cons. co-term $\phi_{lc}$	$\mathcal{N}$	0.05	0.10	–0.028 (–0.077, 0.018)	–0.027 (–0.073, 0.02)	–0.029 (–0.075, 0.018)	–0.026 (–0.076, 0.024)



**Fig. 2.** Prior (dashed black) vs. posterior (solid blue) distributions. Posterior distributions are from the model where all fiscal instruments adjust to debt.

a standard deviation of 0.2. The capital utilization adjustment coefficient  $\delta_2$ , whose mean is set at 0.7, is distributed according to a Gamma distribution with standard deviation of 0.5. This gives

the prior density the most mass at values that are less than one, which is consistent with the estimates of [Schmitt-Grohe and Uribe \(2008\)](#). Beta distributions are chosen for the autoregressive

**Table 3**  
Selected prior and posterior distributions for the various models estimated.

Parameter	Prior distribution			Mean (5% & 95%) of posterior distribution			
	Density	Mean	St. dev.	All adjust	Spending adjust	Tax adjust	Transfer adjust
Tech. AR coeff. $\rho_a$	$\mathcal{B}$	0.70	0.20	0.96 (0.94, 0.98)	0.96 (0.94, 0.98)	0.96 (0.94, 0.98)	0.96 (0.94, 0.98)
Pref. AR coeff. $\rho_b$	$\mathcal{B}$	0.70	0.20	0.66 (0.62, 0.69)	0.66 (0.62, 0.69)	0.66 (0.62, 0.69)	0.66 (0.62, 0.70)
Labor AR coeff. $\rho_l$	$\mathcal{B}$	0.70	0.20	0.99 (0.97, 0.99)	0.99 (0.97, 0.99)	0.99 (0.97, 0.99)	0.98 (0.96, 0.99)
Inv. AR coeff. $\rho_i$	$\mathcal{B}$	0.70	0.20	0.55 (0.47, 0.64)	0.53 (0.45, 0.62)	0.52 (0.44, 0.61)	0.58 (0.49, 0.66)
Gov. spend AR coeff. $\rho_g$	$\mathcal{B}$	0.70	0.20	0.97 (0.95, 0.99)	0.97 (0.95, 0.99)	0.97 (0.94, 0.99)	0.96 (0.93, 0.98)
Cap. tax AR coeff. $\rho_{tk}$	$\mathcal{B}$	0.70	0.20	0.93 (0.9, 0.97)	0.91 (0.88, 0.95)	0.94 (0.9, 0.97)	0.91 (0.87, 0.93)
Labor tax AR coeff. $\rho_{tl}$	$\mathcal{B}$	0.70	0.20	0.97 (0.95, 0.99)	0.97 (0.95, 0.99)	0.97 (0.95, 0.99)	0.97 (0.94, 0.99)
Cons. tax AR coeff. $\rho_{tc}$	$\mathcal{B}$	0.70	0.20	0.93 (0.89, 0.97)	0.93 (0.89, 0.97)	0.93 (0.9, 0.97)	0.93 (0.9, 0.97)
Transfer AR coeff. $\rho_z$	$\mathcal{B}$	0.70	0.20	0.94 (0.91, 0.98)	0.97 (0.94, 0.99)	0.97 (0.94, 0.99)	0.95 (0.91, 0.98)
Tech. std $\sigma_a$	$\mathcal{IG}^3$	1	4	0.62 (0.58, 0.68)	0.63 (0.58, 0.68)	0.62 (0.58, 0.68)	0.62 (0.57, 0.68)
Pref. std $\sigma_b$	$\mathcal{IG}^3$	1	4	7 (6.4, 7.7)	7 (6.4, 7.7)	6.9 (6.3, 7.6)	7 (6.4, 7.8)
Labor std $\sigma_l$	$\mathcal{IG}^3$	1	4	2.8 (2.3, 3.5)	2.9 (2.3, 3.5)	2.9 (2.3, 3.5)	2.8 (2.2, 3.4)
Inv. std $\sigma_i$	$\mathcal{IG}^3$	1	4	6.4 (5.7, 7.2)	6.2 (5.6, 7)	6.2 (5.5, 6.9)	6.6 (5.8, 7.5)
Gov. spend std $\sigma_g$	$\mathcal{IG}^3$	1	4	3.1 (2.8, 3.3)	3.1 (2.8, 3.3)	3.1 (2.9, 3.4)	3.1 (2.9, 3.4)
Cap. tax std $\sigma_{tk}$	$\mathcal{IG}^3$	1	4	4.4 (4.1, 4.7)	4.6 (4.3, 4.9)	4.4 (4.1, 4.7)	4.6 (4.2, 5)
Labor tax std $\sigma_{tl}$	$\mathcal{IG}^3$	1	4	3 (2.8, 3.2)	3 (2.8, 3.2)	3 (2.8, 3.2)	3 (2.8, 3.3)
Cons. tax std $\sigma_{tc}$	$\mathcal{IG}^3$	1	4	4 (3.8, 4.4)	4 (3.8, 4.3)	4 (3.8, 4.4)	4 (3.7, 4.4)
Transfer std $\sigma_z$	$\mathcal{IG}^3$	1	4	3.4 (3.1, 3.7)	3.9 (3.6, 4.2)	3.9 (3.6, 4.2)	3.4 (3.1, 3.7)

<sup>a</sup> The parameters for the Inverse Gamma distribution correspond to  $s$  and  $\nu$ , where  $f(x|s, \nu) = \nu^s \Gamma^{-1}(s) x^{-s-1} \exp\left(-\frac{\nu}{x}\right)$ .

coefficients (all  $\rho_j$ 's), with means and standard deviations set at 0.7 and 0.2, respectively. The standard deviations of the innovations are assumed to be distributed as Inverse Gamma. The investment adjustment coefficient,  $s''$ , has a Gamma distribution with a mean of 5 and standard deviation equal to 0.25.<sup>10</sup>

The priors for the fiscal parameters were chosen to be fairly diffuse and cover a reasonably large range of parameter values. The fiscal responses to government debt (the  $\gamma_i$ 's) are assumed to have a Gamma distribution with a mean of 0.4 and standard deviation of 0.2 (so that they will range approximately between 0 and 1.25). The fiscal instruments' elasticities with respect to output (the  $\varphi_i$ 's) are assumed to have Gamma distributions. The mean of the government spending elasticity is 0.07 and its standard deviation is 0.05, while the mean of the transfer elasticity is 0.2 and its standard deviation is 0.1. These values ensure the domains cover the range of values estimated by past research (see Blanchard and Perotti, 2002; Giorno et al., 1995; Yang, 2005, for examples). The Blanchard and Perotti (2002) estimate of the elasticity of tax revenue with respect to output informs the priors over  $\varphi_k$  and  $\varphi_l$ . They report that a 1% increase in output leads to a 2.08% increase in tax revenue based on 1947Q1–1997Q4 US data, which implies

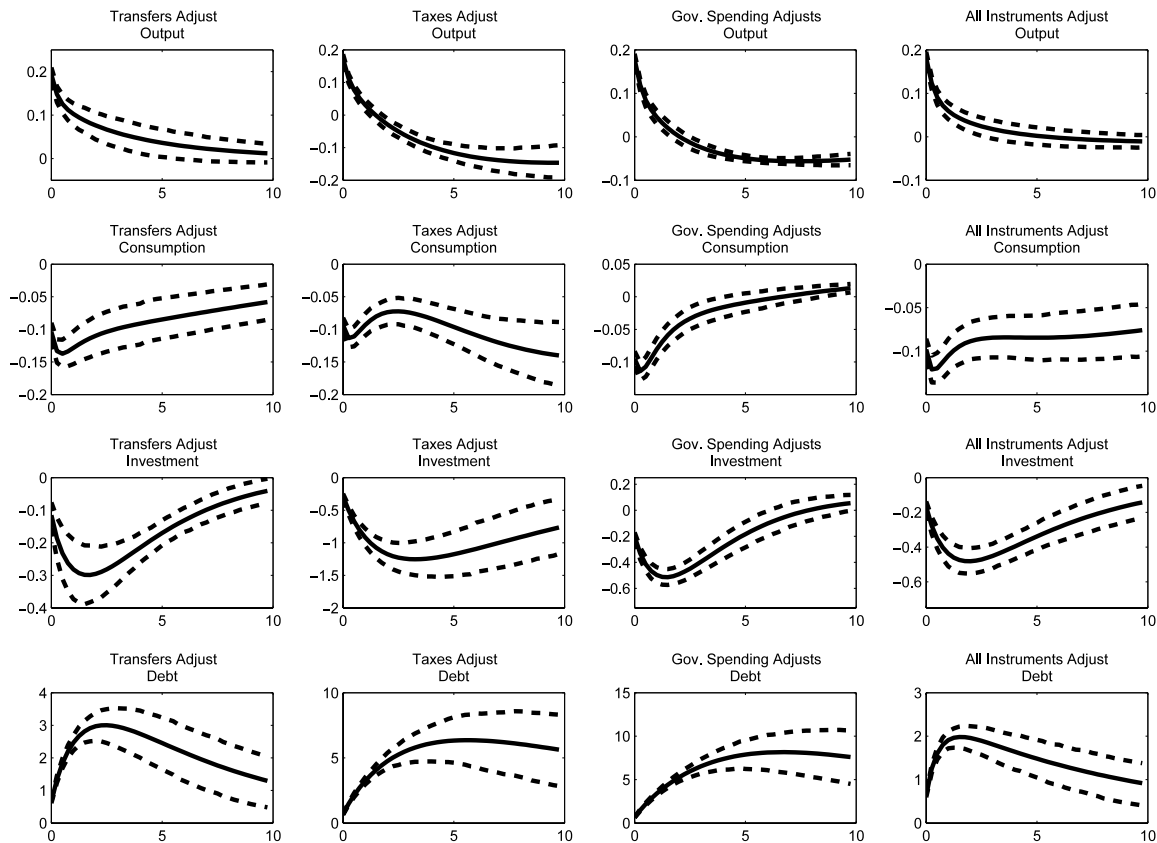
roughly a 1% increase in the average tax rate. Since we incorporate Social Security taxes in our labor tax revenue data, the labor tax rate elasticity is expected to be a value below this average because Social Security taxes are capped and are regressive. Thus, we set the labor tax rate elasticity to have a mean and standard deviation of 0.5 and 0.25, and the capital tax rate elasticity to have a mean and standard deviation of 1 and 0.3.

The parameter measuring the co-movement between the capital and labor tax rate shocks ( $\phi_{kl}$ ) is assumed to have a Normal distribution with a mean of 0.25 and a standard deviation of 0.1. Yang (2005) estimates  $\phi_{kl}$  to be 0.26. The parameters measuring the co-movement between the capital and consumption tax rate shocks and between the labor and consumption tax rate shocks ( $\phi_{kc}$  and  $\phi_{lc}$ ) are assumed to have a Normal distribution with a mean of 0.05 and a standard deviation of 0.1. To our knowledge, there is no past research estimating  $\phi_{kc}$  and  $\phi_{lc}$ . Given that consumption taxes in our US data set are mainly excise taxes used for special funds, we do not expect these values to be large.

#### 4. Estimation results

Tables 2 and 3 report the means and 5% and 95% of the posterior distribution for each of the four models estimated. With the exception of the comovement terms between consumption and labor/capital taxes, all parameters are estimated to be away from zero. Interestingly, the non-policy parameter estimates are about the same across the various model specifications and are similar to estimates in the literature. With the exception of the investment specific shock and preference shock, all the persistent

<sup>10</sup> Prior to estimation, we performed an analysis similar to An and Schorfheide (2007) to investigate the identifiability of parameters. We randomly drew several sets of parameter values from the prior distributions, simulated data, and investigated the ability to recover the underlying parameters using our estimation strategy. Results (available from the authors upon request) suggest that the inverse of the Frisch elasticity parameter,  $\kappa$ , is not well identified. In addition,  $\gamma$ ,  $\kappa$ , and  $s''$  seem to be correlated. Our tight prior on  $s''$  is a reflection of its weak identifiability.



**Fig. 3.** Estimated impulse responses to a one standard deviation increase in government spending shock in the best-fitting model. The solid line is the mean impulse response; the dashed lines are the 5% and 95% posterior intervals. The x-axis measures years.

shocks are estimated to have an autoregressive parameter which is higher than the mean of 0.7 assumed in the prior distribution. Our estimate of the intertemporal elasticity of substitution ( $1/\gamma$ ) is less than one, and the external habit stock is estimated to be about 50% of past consumption.<sup>11</sup> The estimate of the Frisch elasticity ( $1/\kappa$ ) is around 0.5.

Turning to the policy parameter estimates, the results indicate that several distortionary fiscal instruments have played an important role in financing debt innovations. Although the response of lump-sum transfers to debt innovations is the highest, the responses of capital tax rates and government spending are also important. In contrast, it appears that labor taxes have not responded strongly to debt. Note that the estimated fiscal policy parameters in Table 2 are all positive, as sign restrictions are imposed in Eqs. (11)–(15). The results also show that capital tax rates have had a highly procyclical response to the level of aggregate output, while labor tax rates are less responsive. Transfers have responded to the level of aggregate output, but the estimate here is slightly smaller than that used in previous studies; Perotti (2004), for example, uses a value of  $-0.15$  in his VAR estimation strategy. Finally, we find that exogenous changes to capital and labor tax rates affect the two rates simultaneously ( $\phi_{kl} \in [0.1, 0.25]$ ), suggesting that typical tax legislation tends to change both tax rates. In contrast, exogenous changes to consumption tax rates do not affect the capital or labor tax rates.

#### 4.1. Impulse responses

Figs. 3–7 plot the impulse responses following a temporary one standard deviation exogenous increase in each fiscal instrument. The solid line is generated with the mean estimates of the posterior distribution, while the dashed lines give the 5th and 95th percentiles based on the posterior distributions. Each row compares the responses of a variable across the various estimated models, while each column reports responses within a model. The last column shows the fiscal impacts of the best-fitting model where all fiscal instruments respond to debt. In general, the graphs demonstrate that the qualitative and quantitative effects of fiscal shocks depend on how agents perceive government debt to be financed.

Fig. 3 illustrates the responses of output, consumption, investment, and government debt following a one standard deviation shock to government spending. As is standard in an RBC-style model, an increase in government spending reduces wealth, increasing work effort and output on impact. Government spending crowds out investment and its negative wealth effect leads consumption to decline. However, these effects can be quickly reversed depending on how the government debt is financed. For instance, when only capital and labor taxes are expected to increase in the future to support the expansion in debt, the return on future capital and labor is lowered (second column). Households cut back on investment and hours worked, causing output to fall below its initial steady state level within two years of the initial fiscal expansion; output remains well below its steady state level for over 10 years. A similar result also occurs in Forni et al. (2009), which also allows only distortionary taxes to respond to debt innovations in a New Keynesian model. In contrast, when lump-sum transfers or a combination of all the fiscal instruments are allowed to respond to debt innovations, output remains above

<sup>11</sup> The results suggest the posterior of habit is quite similar to its prior. However, we estimated a different version of the model where we changed the prior on habit formation to be a beta distribution with a mean of 0.7 and standard deviation of 0.2, and in this case, the posterior estimates of the habit stock were almost identical to the ones reported here (estimates in an additional estimation appendix available upon request).

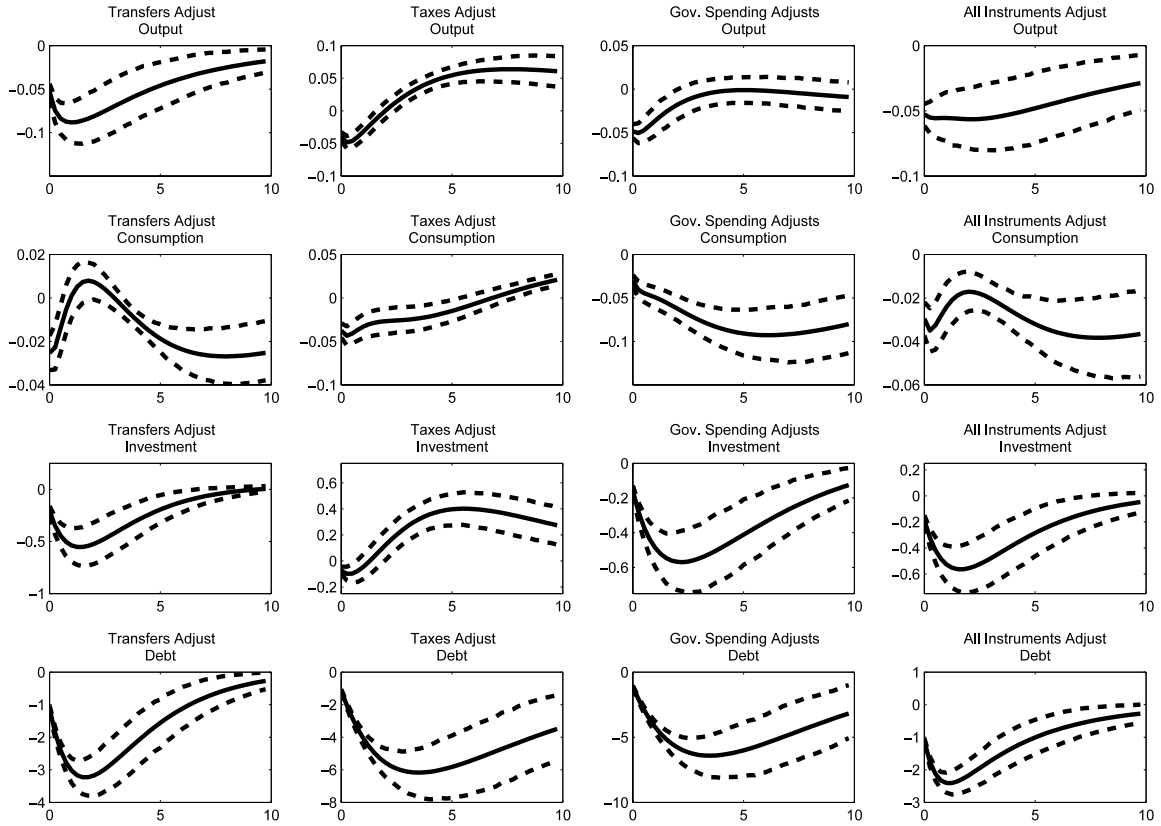


Fig. 4. Estimated impulse responses to a one standard deviation increase in the capital tax rate in the best-fitting model where all fiscal instruments respond to debt. The solid line is the mean impulse response; the dashed lines are the 5% and 95% posterior intervals. The x-axis measures years.

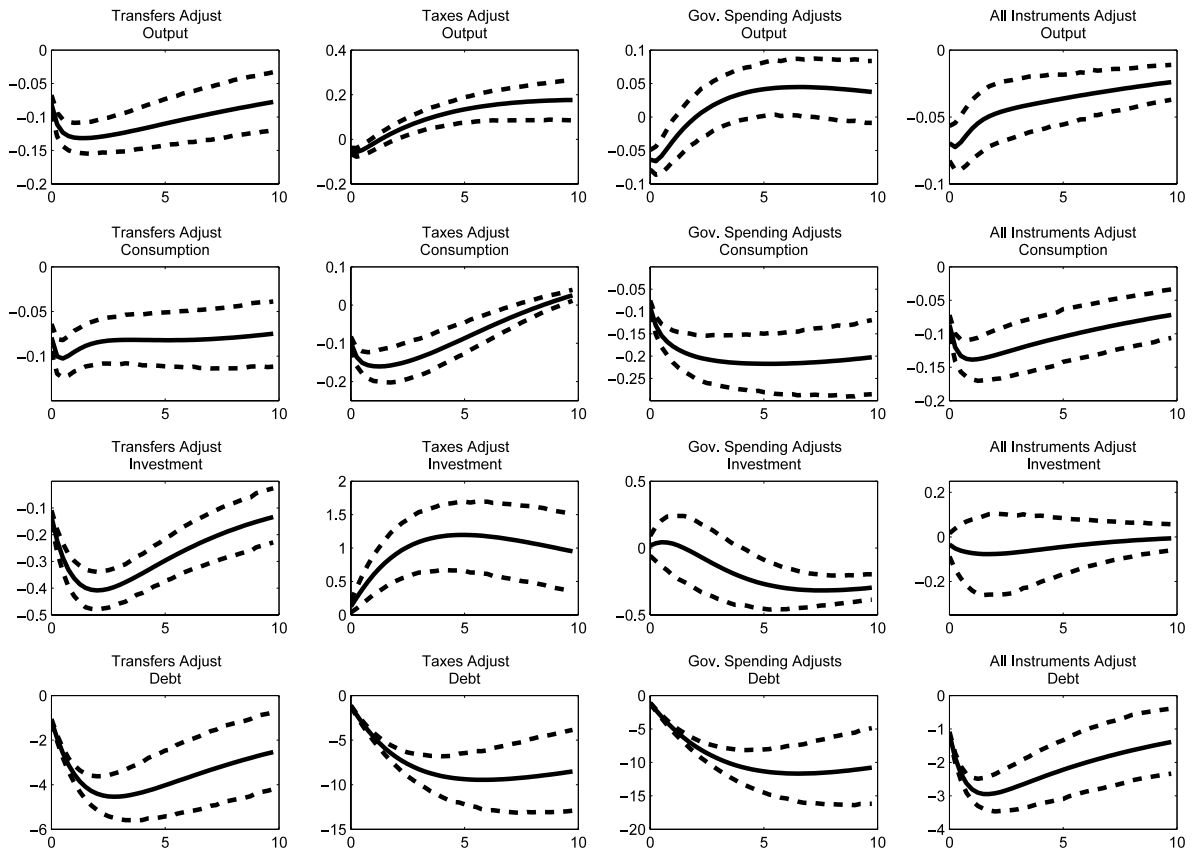
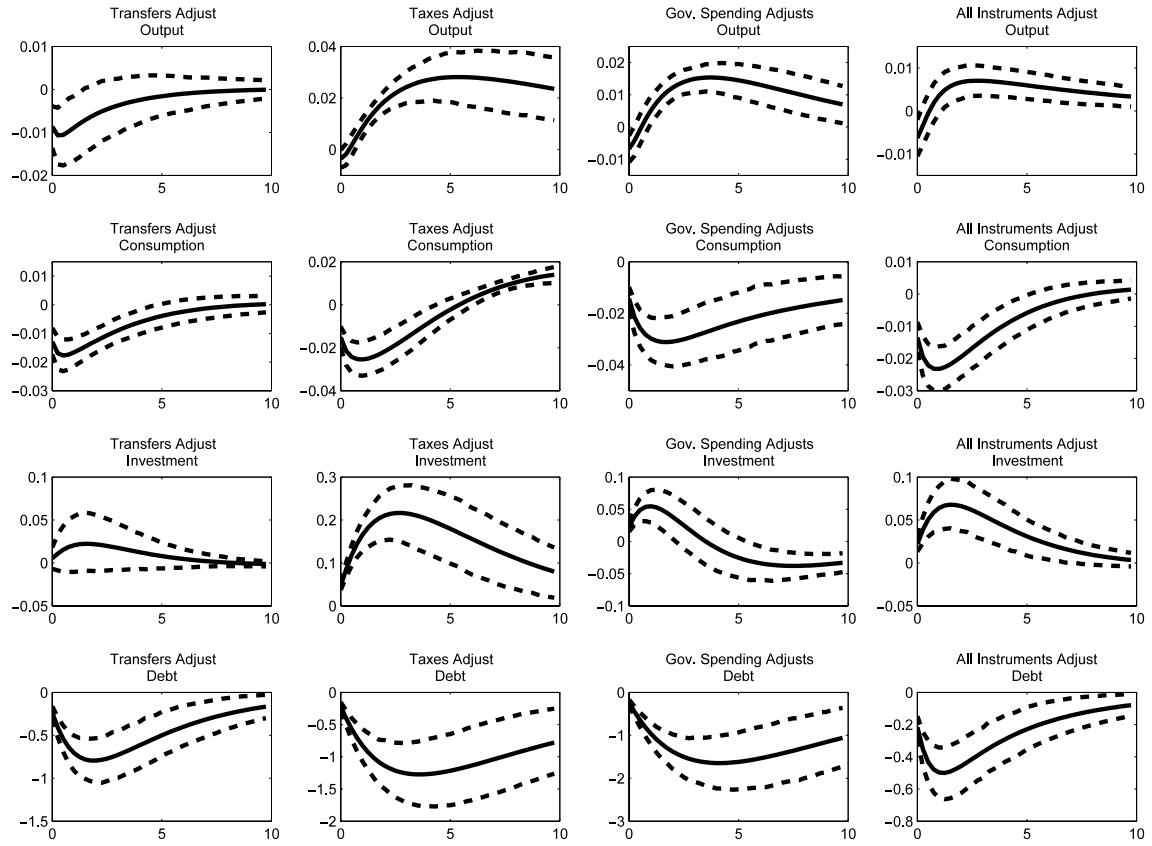
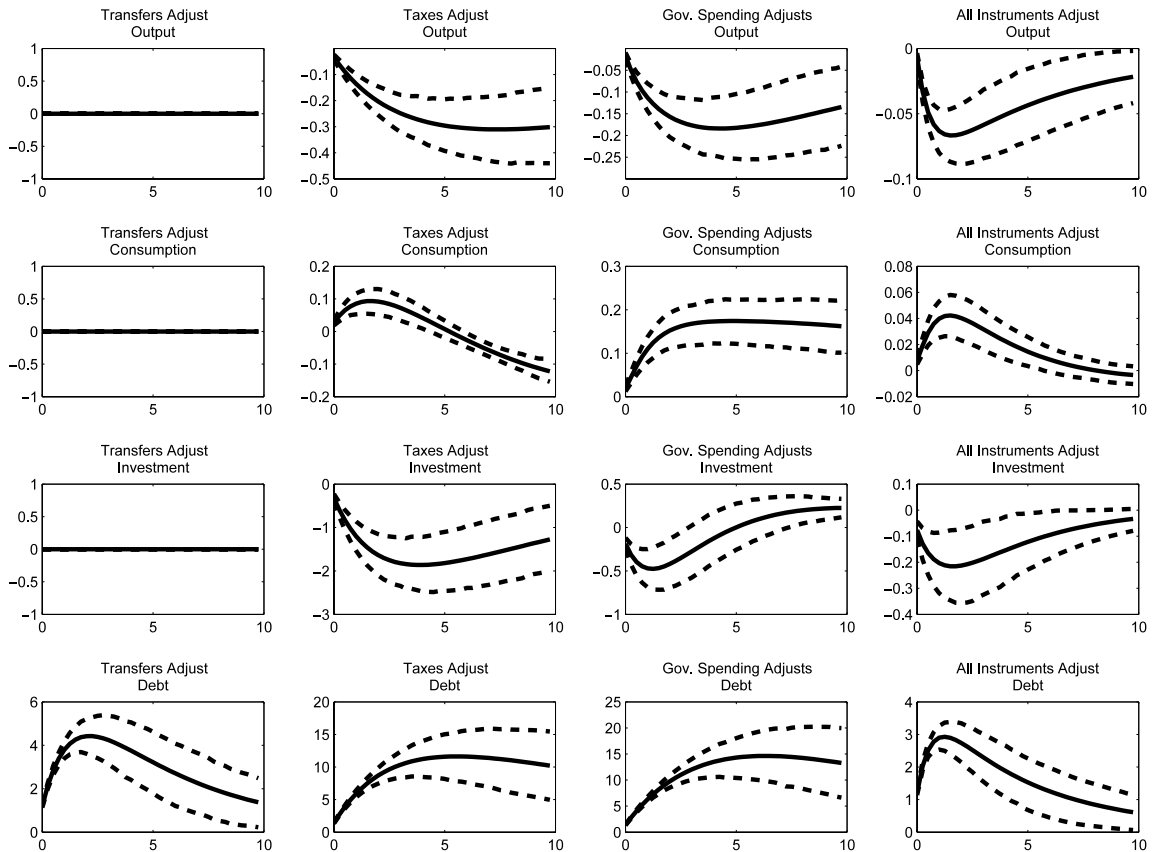


Fig. 5. Estimated impulse responses to a one standard deviation increase in the labor tax rate in the best-fitting model where all fiscal instruments respond to debt. The solid line is the mean impulse response; the dashed lines are the 5% and 95% posterior intervals. The x-axis measures years.





**Fig. 6.** Estimated impulse responses to a one standard deviation increase in the consumption tax rate in the best-fitting model where all fiscal instruments respond to debt. The solid line is the mean impulse response; the dashed lines are the 5% and 95% posterior intervals. The x-axis measures years.



**Fig. 7.** Estimated impulse responses to a one standard deviation increase in transfers in the best-fitting model where all fiscal instruments respond to debt. The solid line is the mean impulse response; the dashed lines are the 5% and 95% posterior intervals. The x-axis measures years.

**Table 4**  
Model fit comparisons.

Model specification	Log-marginal data density	Bayes factor relative to model where all adjust
All fiscal instruments adjust	−68	1.0
Only government spending adjusts	−97	exp [29]
Only taxes adjust	−102	exp [34]
Only transfers adjust	−75	exp [7]
Addendum		
Only transfers adjust, no output response or tax comovements	−86	exp [18]

its steady state level throughout its transition period (first and fourth columns).<sup>12</sup>

Impacts of a one standard deviation increase in the capital tax rate appear in Fig. 4. Standard theory suggests that when capital taxes increase, investment, labor, and output decrease immediately, while consumption rises as agents sacrifice investment for consumption (see Baxter and King, 1993; Braun, 1994; Leeper and Yang, 2008). In the estimated models, the responses of variables can differ dramatically from these conventional effects. For instance, for all four models considered, consumption *decreases* on impact following a capital tax increase. This reduction occurs because exogenous changes to capital and labor taxes are correlated; when capital taxes increase, labor taxes increase as well, which causes households to work and consume less.

The path of investment also differs qualitatively depending on which fiscal instruments respond to debt. If capital and labor taxes are expected to decrease in order to offset the reduction in debt, investment rises above its steady state level and remains positive throughout the transition path (second column). The increase in investment and hours worked (not pictured) increases output above its steady state level. In this case the capital tax rate (not pictured) actually drops below its original steady state level after approximately three years before it returns to its steady state. The resulting increase in tax revenues is more than enough to offset the change in debt, allowing the capital tax rate to fall and further spur investment and output.

Fig. 5 reports the effects of a one standard deviation increase in the labor tax rate. In all cases, the responses of output and consumption are conventional: higher labor taxes lead households to reduce their labor supply, reducing disposable income and consumption. The reduction in the labor supply lowers output. On impact, one might expect investment to decline as well, since the return to capital falls as households decrease their labor supply. However, the impulse responses demonstrate that this prediction depends crucially on which fiscal instruments adjust to debt innovations. In fact, all three models that allow distortionary fiscal instruments to adjust to debt do not rule out the possibility of investment increasing on impact (since a positive response is within the probability intervals of the impulse responses). When taxes adjust to debt, investment increases, with the mean response peaking at 1% above the steady state (second column). In this case, the capital taxes actually decrease on impact. This decrease is brought about by the capital tax rate response to output, which declines on impact. The capital taxes then continue to be consistent with declining debt, increasing the return to investment.

The effects of higher consumption taxes, shown in Fig. 6, are similar. They tend to lower consumption, but raise investment. When distorting instruments stabilize debt, output rises within a couple of years. Output falls when transfers alone adjust to debt.

Fig. 7 illustrates the responses to a one standard deviation increase in lump-sum transfers. Because lump-sum transfers are non-distortionary in our model, the responses of output, consumption, and investment are driven entirely by agents' expectations of how the resulting increase in debt will be financed. For instance, if government spending decreases to finance the higher debt, investment falls for about 5 years before rising (third column); when taxes are expected to rise, investment falls markedly over the entire forecast horizon (second column).

In summary, the results suggest that the qualitative and quantitative effects of fiscal shocks depend on how government debt is financed. Our results contrast those of Forni et al. (2009), who estimate a New Keynesian model for the Euro area and find their results do not depend qualitatively on the fiscal instruments that finance debt. Given the differences in data sets, observables, and modeling specifications, it is not obvious what causes these disparities. Investigating the source of this discrepancy could be a useful direction of future research.

#### 4.2. Posterior odds comparisons

The results of the previous section suggest that assumptions about which fiscal instruments adjust to debt innovations play critical roles in determining the transition paths of variables in response to fiscal shocks. Which scenarios are favored by the data? We use Bayes factors to evaluate the relative model fit, calculating the log-marginal data density using the modified harmonic mean estimator of Geweke (1999) with a truncation parameter of 0.5. As explained by Fernandez-Villaverde and Rubio-Ramirez (2004), the Bayes factor is the ratio of the probabilities from having observed the data given each model, as reflected by the marginal data densities. The Bayes factor is a measure of the evidence provided by the data in favor of one model over another.

Table 4 displays the log-marginal data density and Bayes factor for the four models already discussed, plus a fifth model in which only transfers respond to debt and the countercyclical parts of policy, as well as the correlation among shocks to tax rates, are shut down (labeled Addendum in the table). Richer models that include more complex fiscal adjustment perform better than the simpler models, even though the Bayes factor discriminates against complex models with more parameters. This can be seen by comparing the fit of the model where transfers adjust with and without the output responses and tax comovement terms (Addendum in Table 4). The latter specification essentially treats government spending and tax rates as exogenous processes, a practice that is common when generating theoretical predictions about fiscal impacts.

The results suggest that the models with a response of transfers to changes in debt ( $\gamma_z > 0$ ) fit better than the models without the transfer-debt response. The model allowing only taxes to adjust to debt seems to be the least favored by the data. The comparisons here suggest that transfers are important for debt stabilization, as the log-marginal data density from the model where only lump sum transfers adjust to debt is close to the value for the model with all fiscal instruments responding to debt. However, this result is largely driven by the structure of the model, and such interpretations should be made with caution. Since transfers are

<sup>12</sup> This result is, in part, model specific and might not hold if transfers were distortionary. However, the results suggest that which combination of fiscal instruments responds to debt is central for the paths of aggregate variables. Even under alternative model specifications, this general feature will hold.

**Table 5**

Present-value fiscal multipliers when all fiscal instruments respond to debt. Mean estimates of posterior draws from best-fitting model in which all fiscal instruments – government spending, capital taxes, labor taxes, and transfers – adjust to stabilize debt.

Variable	Impact	5 quarters	10 quarters	25 quarters	$\infty$
Government spending present-value multipliers					
$\frac{PV(\Delta Y)}{PV(\Delta G)}$	0.64	0.43	0.33	0.20	0.03
$\frac{PV(\Delta C)}{PV(\Delta G)}$	-0.26	-0.34	-0.35	-0.40	-0.60
$\frac{PV(\Delta I)}{PV(\Delta G)}$	-0.10	-0.23	-0.32	-0.40	-0.36
Capital tax present-value multipliers					
$\frac{PV(\Delta Y)}{PV(\Delta T^k)}$	-0.18	-0.26	-0.33	-0.50	-0.72
$\frac{PV(\Delta C)}{PV(\Delta T^k)}$	-0.076	-0.11	-0.11	-0.19	-0.47
$\frac{PV(\Delta I)}{PV(\Delta T^k)}$	-0.11	-0.30	-0.47	-0.64	-0.60
Labor tax present-value multipliers					
$\frac{PV(\Delta Y)}{PV(\Delta T^l)}$	-0.19	-0.19	-0.19	-0.19	-0.21
$\frac{PV(\Delta C)}{PV(\Delta T^l)}$	-0.17	-0.26	-0.29	-0.33	-0.37
$\frac{PV(\Delta I)}{PV(\Delta T^l)}$	-0.02	-0.03	-0.04	-0.05	-0.04
Transfers present-value multipliers					
$\frac{PV(\Delta Y)}{PV(\Delta Z)}$	-0.02	-0.16	-0.28	-0.46	-0.59
$\frac{PV(\Delta C)}{PV(\Delta Z)}$	0.01	0.07	0.13	0.18	0.12
$\frac{PV(\Delta I)}{PV(\Delta Z)}$	-0.03	-0.09	-0.15	-0.23	-0.23

non-distortionary in the model, exogenous changes to transfers have no effect on agents' consumption and savings decisions. Thus, the only way in which the model can match certain correlations between transfers and other observables is if transfers respond to endogenous variables. In particular, transfers and government debt are negatively correlated in our data, but if transfers do not respond to debt, the model cannot reproduce this feature.<sup>13</sup> This preference for transfer financing might not hold if transfers were distortionary, as they would be in a non-Ricardian model.

#### 4.3. Present-value multipliers

Quantitative effects of fiscal shocks are frequently summarized by fiscal multipliers for output, consumption, and investment. Following Mountford and Uhlig (2009), we report present-value multipliers, which are preferred over impact multipliers because they embody the full dynamics associated with fiscal disturbances and they properly discount macroeconomic effects in the future. The present value of additional output over a  $k$ -period horizon that is generated by a change in the present value of government spending is calculated as

$$\text{Present-Value Multiplier}(k) = \frac{E_t \sum_{j=0}^k \left( \prod_{i=0}^j R_{t+i}^{-1} \right) \Delta Y_{t+j}}{E_t \sum_{j=0}^k \left( \prod_{i=0}^j R_{t+i}^{-1} \right) \Delta G_{t+j}}$$

Tables 5 and 6 report the results. Note that the present-value multiplier at  $k = 0$  is equal to the initial impact multiplier; impact multipliers are widely reported in empirical studies (for example, Blanchard and Perotti (2002) and Forni et al. (2009)).

When all fiscal instruments respond to debt, as in Table 5, present-value multipliers tend to be modest; no multiplier exceeds 1. Government spending multipliers for output are substantially

<sup>13</sup> If transfers do not respond to debt, then an increase in transfers will always cause government debt to rise, making the correlation between the two positive. We thank Alejandro Justiniano for pointing out this feature.

**Table 6**

Present-value fiscal multipliers when only capital and labor taxes respond to debt. Mean estimates of posterior draws from model in which only tax instruments – capital and labor tax rates – adjust to stabilize debt.

Variable	Impact	5 quarters	10 quarters	25 quarters	$\infty$
Government spending present-value multipliers					
$\frac{PV(\Delta Y)}{PV(\Delta G)}$	0.59	0.32	0.14	-0.21	-0.99
$\frac{PV(\Delta C)}{PV(\Delta G)}$	-0.24	-0.28	-0.27	-0.33	-0.89
$\frac{PV(\Delta I)}{PV(\Delta G)}$	-0.17	-0.40	-0.59	-0.88	-1.10
Capital tax present-value multipliers					
$\frac{PV(\Delta Y)}{PV(\Delta T^k)}$	-0.14	-0.20	-0.18	0.42	-3.70
$\frac{PV(\Delta C)}{PV(\Delta T^k)}$	-0.10	-0.14	-0.18	-0.52	-0.83
$\frac{PV(\Delta I)}{PV(\Delta T^k)}$	-0.04	-0.06	0.01	0.94	-2.90
Labor tax present-value multipliers					
$\frac{PV(\Delta Y)}{PV(\Delta T^l)}$	-0.14	-0.12	-0.04	0.22	0.92
$\frac{PV(\Delta C)}{PV(\Delta T^l)}$	-0.19	-0.30	-0.34	-0.36	0.06
$\frac{PV(\Delta I)}{PV(\Delta T^l)}$	0.05	0.17	0.31	0.58	0.87
Transfers present-value multipliers					
$\frac{PV(\Delta Y)}{PV(\Delta Z)}$	-0.07	-0.19	-0.33	-0.64	-1.40
$\frac{PV(\Delta C)}{PV(\Delta Z)}$	0.04	0.10	0.14	0.11	-0.38
$\frac{PV(\Delta I)}{PV(\Delta Z)}$	-0.11	-0.30	-0.46	-0.75	-0.98

lower than those obtained in loosely identified empirical studies, which frequently are around 1.5 (Blanchard and Perotti, 2002; Monacelli and Perotti, 2008; Romer and Bernstein, 2009), but are comparable to those from real business cycle models (Uhlig, 2009).<sup>14</sup> Spending multipliers for consumption are uniformly negative, a result that is standard in real models, but has recently received much attention (Gali et al., 2007; Ravn et al., 2007; Monacelli and Perotti, 2008; Davig and Leeper, 2009). In contrast to the calibrated results of Uhlig (2009), we find that in the best-fitting model there is no tendency for tax multipliers to be larger than spending multipliers, except that, in our estimates, higher transfers reduce output.

Present-value multipliers change dramatically when only capital and labor taxes react to stabilize debt, as Table 6 reports. First, it is commonplace for long-run multipliers to have a different sign from short-run multipliers (see also Judd, 1985; Sims, 1998; Leeper and Yang, 2008; Uhlig, 2009). Higher government spending stimulates output for a couple of years, but as taxes rise, output falls and the long-run present-value multiplier is sharply negative. Lower capital taxes only weakly raise output in the short run; after a couple of years output reverses and is below the steady state until eventually returning back to the steady state. Because there is a brief time (25 quarters in the table) where output has already increased above the steady state and capital tax revenues are still above the steady state, the multiplier is positive. Eventually, though, the capital taxes must adjust to the lower level of debt and drop below the steady state. At this point, capital tax revenues drop below the steady state and in the long run the present value multiplier is strongly negative. Second, as the output multiplier of -3.70 demonstrates (second panel of Table 6), capital tax multipliers can be very large indeed in the long run.<sup>15</sup>

<sup>14</sup> As noted in the Introduction, the introduction of nominal considerations, including nominal rigidities, and monetary policy behavior can change the size of the multiplier dramatically (Christiano et al., 2009; Davig and Leeper, 2009; Eggertsson, 2009).

<sup>15</sup> Variance decompositions suggest that fiscal policy shocks contribute little to the cyclical variability of aggregate non-policy variables, but fiscal variables are affected by all policy and non-policy shocks, reflecting the influence of each fiscal instrument's response to output and debt. Forni et al. (2009) obtain similar results.

**Table 7**

Present-value financing using the mean estimates of posterior draws from the model where all fiscal instruments respond to debt. Shocks normalized to raise or lower debt by one unit. Rows for  $G$ ,  $T^k$ ,  $T^l$ ,  $T^c$ , and  $Z$  sum to Surplus; rows for  $R$  and Surplus sum to  $\Delta B$ .

Variable	Shock									
	$\epsilon_t^d$	$\epsilon_t^c$	$\epsilon_t^l$	$\epsilon_t^i$	$\epsilon_t^g$	$\epsilon_t^k$	$\epsilon_t^l$	$\epsilon_t^c$	$\epsilon_t^z$	
$G$	-9.68	14.39	17.04	2.26	-24.55	-2.30	-4.95	-2.70	3.08	
$T^k$	10.14	2.02	-19.61	-3.85	7.54	5.90	-4.41	-1.77	3.12	
$T^l$	19.18	-11.39	-35.52	-5.96	1.85	2.01	22.98	-2.74	0.25	
$T^c$	2.10	-0.49	-4.27	-0.26	-0.42	-0.01	-0.36	13.65	0.02	
$Z$	-26.42	39.9	46.43	6.11	17.23	-6.49	-13.97	-7.58	-5.49	
$R$	3.68	-43.43	-3.07	2.70	-0.65	-0.11	-0.29	0.14	0.02	
Surplus	-4.68	44.43	4.07	-1.70	1.65	-0.89	-0.71	-1.14	0.98	
$\Delta B$	-1	+1	+1	+1	+1	-1	-1	-1	+1	

4.4. Present-value financing

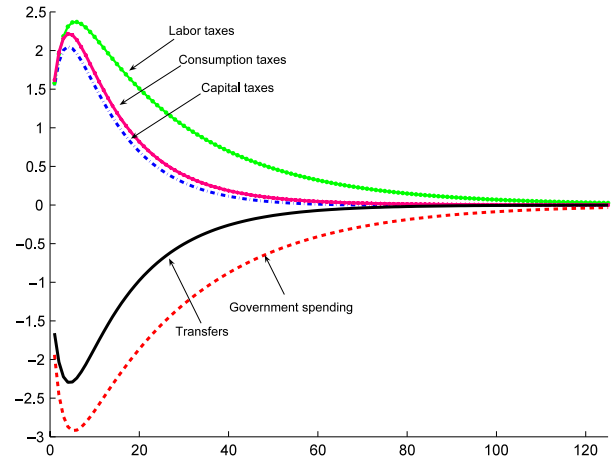
We turn now to the forward-looking aspect of government finance. We calculate present-value decompositions of debt to determine what combination of adjustments in the expected paths of fiscal policy instruments and discount rates rationalize the observed value of government debt. We also examine how adjustments depend on the nature of the fiscal policy shock. In log-linearized form, the government’s present-value relation is

$$\hat{B}_t = E_t \sum_{j=1}^{\infty} \beta^j \left[ \left( \frac{T^k}{B} \right) \hat{T}_{t+j}^k + \left( \frac{T^l}{B} \right) \hat{T}_{t+j}^l + \left( \frac{T^c}{B} \right) \hat{T}_{t+j}^c - \left( \frac{G}{B} \right) \hat{G}_{t+j} - \left( \frac{Z}{B} \right) \hat{Z}_{t+j} - \frac{1}{\beta} \hat{R}_{t+j-1} \right] \quad (19)$$

where the unsubscripted variables denote steady state values and  $\hat{T}_{t+j}^k$ ,  $\hat{T}_{t+j}^l$ , and  $\hat{T}_{t+j}^c$  denote total revenues due to capital, labor, and consumption taxes. This expression decomposes fluctuations in real debt into expected changes in the components of net-of-interest surpluses, at constant discount rates, and expected changes in real discount rates.

The present-value decompositions for the best-fitting model, in which all fiscal instruments adjust to stabilize debt, are listed in Table 7. The table shows each of the present-value components in (19) following a shock to each of the exogenous processes when the shock is calibrated to raise or lower debt by one unit of the final good. In the table, when the components have the same sign as the change in debt, the component is expected to move to support the change in debt; when the signs differ, the component is expected to move against stabilizing debt. For instance, in response to an increase in capital taxes normalized to lower debt by one unit (column six of the shocks), government spending and transfers increase while consumption tax revenue declines. Although capital and labor tax revenues increase, overall the components of the present value of surpluses move to support debt. To a smaller extent, the discount rate also moves to support debt stabilization, as it increases and causes interest rate payments to rise.

Sources of present-value financing vary substantially across the underlying exogenous shocks that perturb debt. For the capital and labor tax shocks, both the discount rate and the present value of surpluses move to support debt. With a capital tax shock, most of the work is done by changes in the present value of surpluses, whereas for labor taxes, the discount rate contributes more. In contrast, following a shock to government spending, the present value of surpluses alone moves to support debt, with taxes, spending, and transfer changes offsetting each other. The discount rate, on the other hand, resists present-value balance. Similar results hold for a technology, general preference, or labor preference shock. Following a shock to transfers, most of the present-value balancing is done by surpluses. While the same is true for consumption tax shocks, the discount rate tends to move against present-value balance. An investment-specific shock



**Fig. 8.** Government debt funding horizons for fiscal shocks using the mean estimates of posterior draws from the in the best-fitting model where all fiscal instruments respond to debt. The x-axis units are quarters.

generates movements in the discount rate that support debt, while the surplus resists present-value balance.

For each type of shock, taxes, spending, and transfers experience sizeable but offsetting movements in the present value. None of the fiscal policy instruments consistently move to support the innovation in debt in all cases. All instruments can move to support or offset debt innovations, depending on the shock.

Fig. 8 displays the present-value funding horizons of government debt innovations for various fiscal shocks using the best-fitting model in which all fiscal instruments respond to debt. The figure can answer the question, “What fraction on a one-unit innovation in government debt in quarter  $t$ , due to each of the five fiscal shocks, is financed by period  $t + K$ , where  $K$  is determined by the quarters on the x-axis?” The figure, therefore, reports the truncated sum over horizon  $K$ , denoted by  $PV_t(K)$ , and defined by

$$PV_t(K) = E_t \sum_{j=1}^K \beta^j \left[ \left( \frac{S}{B} \right) \hat{S}_{t+j} - \left( \frac{1}{\beta} \right) \hat{R}_{t+j-1} \right] \quad (20)$$

where  $S$  is the steady state net-of-interest surplus and  $\hat{S}_{t+j}$  denotes percentage deviations of the surplus from the steady state.

As the figure makes clear, it takes many years for fiscal adjustments to restore the present-value balance. Debt innovations induced by consumption taxes, capital taxes, or transfers are fully financed after 20 to 25 years. Government spending and labor tax shocks, however, can take 40 or more years to be fully financed. Over shorter horizons up to two years, serial correlation in the shocked policy instrument worsens the fiscal stance in the sense that the sum in (20), truncated at  $K \leq 8$ , moves farther from the value of  $\hat{B}_t$ .

**Table 8**  
Subsample estimates. Posterior modes and standard deviations.

	1976Q1–2008Q1		1989Q1–2008Q1		1993Q1–2008Q1	
	Mode	SD	Mode	SD	Mode	SD
$\gamma$	2.3	0.46	2.4	0.47	2.5	0.57
$\kappa$	1.8	0.4	2.1	0.45	1.9	0.43
$h$	0.52	0.079	0.5	0.095	0.69	0.085
$s''$	5.4	0.26	5.3	0.25	5.2	0.25
$\delta_2$	0.4	0.13	0.5	0.23	0.35	0.17
$\rho_a$	0.96	0.02	0.9	0.033	0.85	0.056
$\rho_c$	0.65	0.033	0.63	0.041	0.52	0.052
$\rho_l$	0.98	0.015	0.98	0.02	0.97	0.024
$\rho_i$	0.69	0.063	0.85	0.048	0.73	0.078
$\rho_g$	0.97	0.02	0.98	0.021	0.96	0.036
$\rho_{rk}$	0.91	0.033	0.88	0.06	0.8	0.085
$\rho_{r^l}$	0.93	0.033	0.94	0.037	0.91	0.055
$\rho_{r^c}$	0.90	0.038	0.9	0.053	0.73	0.1
$\rho_{rc}$	0.87	0.046	0.83	0.07	0.85	0.072
$\gamma_g$	0.12	0.056	0.58	0.13	0.38	0.16
$\gamma_{rk}$	0.21	0.1	0.38	0.18	0.91	0.25
$\gamma_{r^l}$	0.17	0.07	0.21	0.09	0.18	0.1
$\gamma_z$	0.18	0.06	0.13	0.07	0.24	0.1
$\varphi_{rk}$	1.4	0.059	1.2	0.32	0.9	0.26
$\varphi_{r^l}$	0.2	0.11	0.3	0.16	0.4	0.22
$\varphi_g$	0.035	0.034	0.03	0.033	0.035	0.038
$\varphi_z$	0.13	0.075	0.15	0.084	0.13	0.073
$\sigma_a$	0.52	0.034	0.55	0.048	0.56	0.053
$\sigma_c$	6.7	0.54	7.7	0.71	7.1	0.76
$\sigma_l$	2.5	0.39	2.2	0.33	3.1	0.57
$\sigma_i$	6.3	0.8	7.2	1.8	4.4	0.87
$\sigma_g$	2.8	0.17	2.7	0.21	3.2	0.29
$\sigma_{rk}$	4.7	0.29	4.5	0.36	4.3	0.39
$\sigma_{r^l}$	2.5	0.16	2.5	0.21	2.89	0.26
$\sigma_{r^c}$	4.3	0.27	3.4	0.28	2.8	0.26
$\sigma_z$	2.8	0.18	3.1	0.26	2.4	0.21
$\phi_{kl}$	0.12	0.035	0.15	0.043	0.22	0.051
$\phi_{kc}$	0.0074	0.04	0.03	0.05	0.07	0.05
$\phi_{lc}$	0.052	0.036	0.026	0.051	0.035	0.055

#### 4.5. Sensitivity analysis: Subsample estimates

This section examines posterior mode estimates for various subsamples in order to investigate the stability of the full sample estimates. The first subsample, 1976Q1–2008Q1, eliminates the 1973–1975 recession from the sample as well as the Tax Reduction Act of 1975 passed to provide a one-time tax rebate to stimulate the economy. The second subsample, 1989Q1–2008Q1, ignores the initial effects of the Tax Reform Act of 1986, which changed the structure of income and corporate income tax rates. Finally, the last subsample, 1993Q1–2008Q1, starts after the recession of 1990Q3–1991Q1 and begins with the implementation of the Omnibus Budget Reconciliation Act of 1993. Table 8 compares the modes of the posterior distributions over these periods.

The estimates of the structural parameters vary slightly across the subsamples. The results are consistent with Smets and Wouters (2007) in that habit formation seems to increase in the later subsamples and the capacity utilization parameter increases over the 1989Q1–2008Q1 subsample.<sup>16</sup>

The most significant differences between the three subsamples are the coefficients for the fiscal instruments' responses to debt and output. Labor tax rates responded more strongly to debt, while transfers responded less strongly over the subsamples. The capital tax and government spending responses to debt appear to be the most unstable.<sup>17</sup> The variations in the coefficients reflect differences in fiscal policy over the various years. For instance,

<sup>16</sup> Because the subsample dates considered in Smets and Wouters (2007) differ slightly from those considered here and Smets and Wouters use a different specification of capacity utilization, comparisons between our results and theirs should be made with caution.

<sup>17</sup> Davig and Leeper (2006) find evidence for regime-switching in the postwar US data, which might account for some of the instability in the estimates.

**Table 9**

Cumulative (horizon =  $\infty$ ) present-value fiscal multipliers across various subsamples, calculated from the posterior modes.

Variable	1960Q1–2008Q1	1976Q1–2008Q1	1989Q1–2008Q1	1993Q1–2008Q1
<b>Government spending present-value multipliers</b>				
$PV(\Delta Y)$	0.03	-0.13	-0.29	-0.4
$PV(\Delta G)$				
$PV(\Delta C)$	-0.6	-0.74	-0.8	-0.76
$PV(\Delta I)$				
$PV(\Delta G)$	-0.36	-0.39	-0.49	-0.64
<b>Capital tax present-value multipliers</b>				
$PV(\Delta Y)$	-0.72	-0.24	-0.29	-0.26
$PV(\Delta T^k)$				
$PV(\Delta C)$	-0.47	-0.18	-0.55	-0.63
$PV(\Delta T^k)$				
$PV(\Delta I)$	-0.6	-0.32	-0.48	-0.39
<b>Labor tax present-value multipliers</b>				
$PV(\Delta Y)$	-0.21	-0.3	-0.27	-0.26
$PV(\Delta T^l)$				
$PV(\Delta C)$	-0.37	-0.45	-0.64	-0.46
$PV(\Delta T^l)$				
$PV(\Delta I)$	-0.04	-0.09	-0.21	-0.11
<b>Transfers present-value multipliers</b>				
$PV(\Delta Y)$	-0.59	-0.53	-0.26	-0.39
$PV(\Delta Z)$				
$PV(\Delta C)$	0.12	-0.08	0.23	0.06
$PV(\Delta Z)$				
$PV(\Delta I)$	-0.23	-0.18	0.06	-0.12

the last subsample starts with the Omnibus Budget Reconciliation Act of 1993 which raised individual and corporate income taxes in order to reduce the deficit. It is not surprising that capital and labor taxes were estimated to respond more to the state of government indebtedness in this subsample. Due to fiscal policy changes enacted at the beginning of this subsample, deficits were consistently reduced, and by 1998, the US government was running a surplus.

The declines in capital tax automatic stabilizers,  $\varphi_k$ , across subsamples and the increases in labor tax automatic stabilizers,  $\varphi_l$ , are consistent with previous estimates of the elasticities of various federal taxes with respect to their tax bases. The estimates of Cohen and Follette (2000) show decreases in the progressivity of income tax rates and increases in the elasticity of social insurance contributions with respect to its tax base. The former suggests that estimates of  $\varphi_k$  should decline over time, while the latter suggests that estimates of  $\varphi_l$  might increase, as we find.

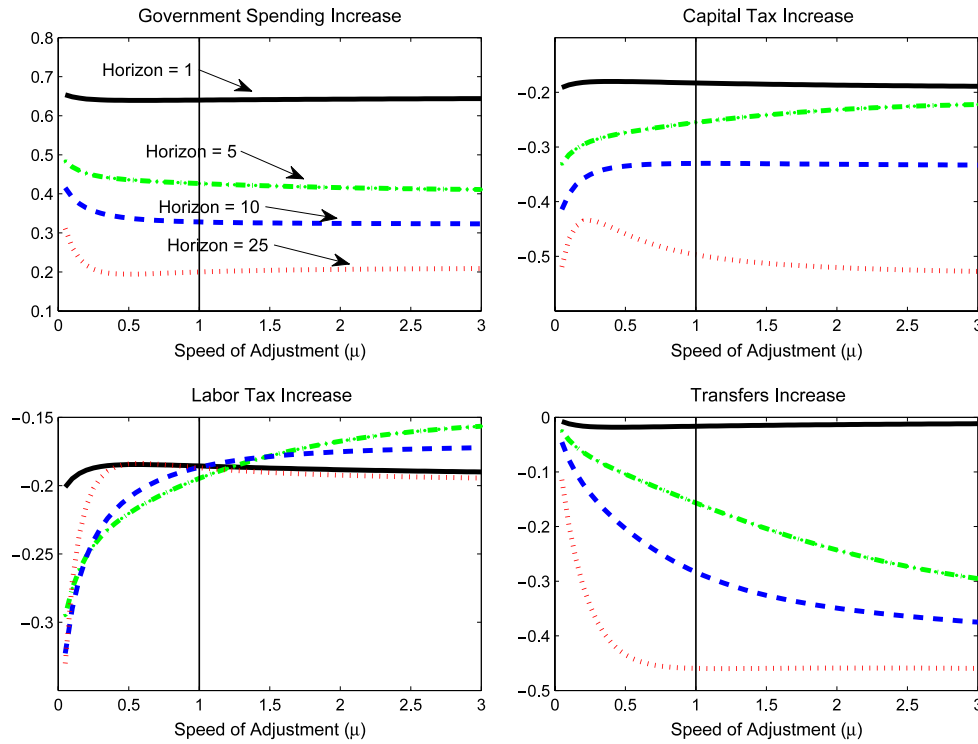
Table 9 displays the cumulative (horizon =  $\infty$ ) present-value multipliers for output, consumption, and investment calculated at the posterior modes of the various subsamples. The multipliers can differ substantially across the sample periods, even being of different signs following government spending and transfer disturbances. In the benchmark sample (1960Q1–2008Q1), there is no tendency for tax output multipliers to be larger than government spending output multipliers, while in the most recent subsample (1993Q1–2008Q1), the tax multipliers are noticeably higher. The results suggest that practitioners estimating similar models must think carefully about the sample period utilized and the effects of instabilities in policy coefficients.

## 5. Counterfactual fiscal experiments

Given estimates of the model's "deep parameters," we can consider counterfactual questions that ask how fiscal impacts might change under policies that are different from history. All three sets of counterfactuals use the private parameters from the best-fitting model in which all instruments respond to debt and then intervene in various ways on the policy rules.

### 5.1. Speed of fiscal adjustments

We consider alternative scenarios in which we scale all fiscal adjustment parameters up or down to increase or decrease the speed of adjustment of future policies to government debt.



**Fig. 9.** Present-value fiscal multipliers for output at various horizons, as a function of the speed of adjustment of future fiscal variables for shocks to government spending, capital taxes, labor taxes, and transfers. The vertical line at  $\mu = 1$  is the best-fitting parameters;  $\mu < 1$  reduces the speed at which debt is retired;  $\mu > 1$  increases the speed at which debt is retired.

The fiscal policy rules become

$$\hat{G}_t = -\varphi_g \hat{Y}_t - \mu \gamma_g \hat{B}_{t-1} + u_t^g, \tag{21}$$

$$\hat{\tau}_t^k = \varphi_k \hat{Y}_t + \mu \gamma_k \hat{B}_{t-1} + \phi_{kl} u_t^l + \phi_{kc} u_t^c + u_t^k, \tag{22}$$

$$\hat{\tau}_t^l = \varphi_l \hat{Y}_t + \mu \gamma_l \hat{B}_{t-1} + \phi_{kl} u_t^k + \phi_{lc} u_t^c + u_t^l, \tag{23}$$

$$\hat{\tau}_t^c = \phi_{kc} u_t^k + \phi_{lc} u_t^l + u_t^c, \tag{24}$$

$$\hat{Z}_t = -\varphi_z \hat{Y}_t - \mu \gamma_z \hat{B}_{t-1} + u_t^z \tag{25}$$

where  $\mu \in (0.05, 3.0)$  is the scaling parameter.  $\mu = 0.05$  is the slowest speed of adjustment consistent with equilibrium. Setting  $\mu = 1$  (vertical lines in the figure) reproduces the multipliers for the posterior mean. When  $\mu < 1$ , fiscal adjustments are slower and debt accumulates more rapidly;  $\mu > 1$  accelerates fiscal adjustments, ensuring less debt accumulation.

Fig. 9 compares present-value multipliers for output for each of the fiscal shocks – government spending, capital taxes, labor taxes, and transfers – under alternative sets of the fiscal adjustment parameters. The present-value multipliers are expressed as a function of the scaling parameter  $\mu$  at various horizons: at impact (solid lines) and at quarters 5 (dotted–dashed lines), 10 (dashed lines), and 25 (dotted lines).

Government spending multipliers are smaller at every horizon when fiscal adjustment accelerates, a pattern that also applies to labor tax multipliers (the two left-hand panels). When capital tax shocks are financed more rapidly the multiplier declines, but only at shorter horizons. The medium-run present-value multipliers (25-quarter horizon) display a non-monotonic pattern at very slow speeds of adjustment, before actually rising with the speed of adjustment once  $\mu > 0.25$ .

5.2. Alternative financing schemes

The patterns that emerge from Fig. 9, in which all instruments adjust, can change in important ways when only a single instrument takes on the burden of stabilizing debt. The second

counterfactual exercise varies both the source of fiscal financing – restricting it to adjustment by only a single instrument – and the speed of adjustment. We also eliminate the correlation among tax shocks estimated in the best-fitting model.

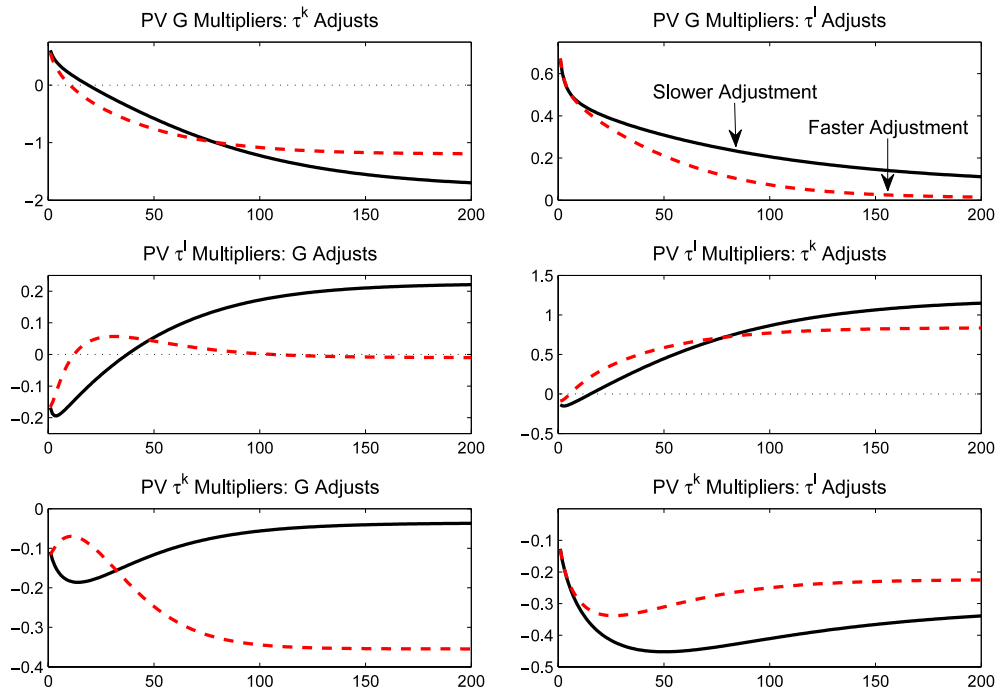
Fig. 10 reports present-value multipliers for output from changes in government spending, labor tax rates, and capital tax rates. The figure extends the forecast horizon to 50 years in order to highlight the differences between short-to-medium-run multipliers and long-run multipliers. The counterfactual allows capital taxes, labor taxes, or government spending to adjust one at a time. Slower adjustment (solid lines) scales the parameter on debt in the rule for the adjusting instrument by setting  $\mu = 0.5$ ,<sup>18</sup> while faster adjustment (dashed lines) scales the parameter by setting  $\mu = 2.0$  in the policy rules (21)–(23).

When future capital taxes alone stabilize debt, slower adjustment raises the government spending multipliers at shorter horizons, but at the cost of smaller multipliers over longer horizons (top left panel). Regardless of the speed of adjustment, when capital taxes back debt that is issued to finance government spending, the present-value multiplier rapidly turns negative and can easily exceed  $-1.0$ . When labor taxes adjust, on the other hand, there appears to be no tradeoff: slower adjustment raises the government spending multiplier over the entire 50-year horizon.

If government spending adjusts to debt following an increase in either capital or labor tax rates, interesting non-monotonicities set in (second and third panels on the left). In the short run, slower adjustment reduces the multipliers, but over longer horizons, slower adjustment enhances the present-value multipliers for taxes. In the case of labor tax shocks, the multipliers change sign, with the sign change occurring much sooner when debt stabilization is rapid.

Labor tax multipliers change sign very quickly when capital taxes adjust to debt, with higher labor taxes lowering output only

<sup>18</sup> When only the labor tax adjusts to debt, we set  $\mu = 0.75$  to ensure a unique equilibrium.



**Fig. 10.** Present-value fiscal multipliers for output as a function of the speed of adjustment of future fiscal variables and which single fiscal variable responds to debt. Uses parameters from the best-fitting model where all fiscal instruments adjust to debt, but changes fiscal rules so that only a single instrument adjusts and tax shocks are uncorrelated. Slower adjustment (solid lines) scales the relevant fiscal parameter by 0.5; faster adjustment (dashed lines) scales relevant fiscal parameter by 2.0. The x-axis measures quarters.

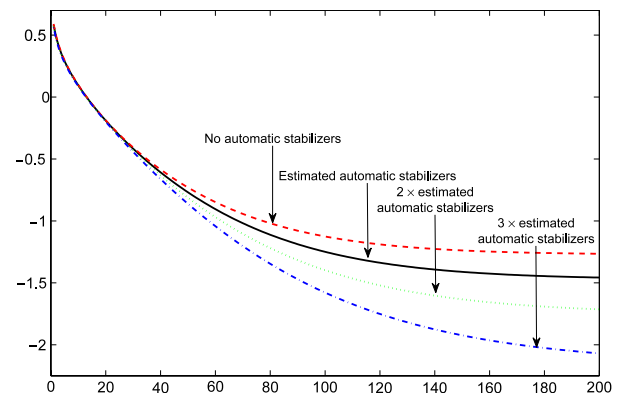
briefly (second panel on right). In the medium and long runs, higher labor taxes raise output substantially because capital taxes are persistently lower to satisfy the government’s present-value relation. Finally, when labor taxes stabilize debt following a shock to capital taxes, the present-value multiplier is uniformly larger when labor taxes adjust more slowly (bottom-right panel).

5.3. Enhanced “automatic stabilizers”

The final counterfactual exercise examines the consequences of increasing or decreasing the “automatic stabilizer” aspect of the fiscal rules—the  $\varphi$  coefficients on contemporaneous output in policy rules (11)–(13) and (15). Specifically, we ask how the government spending present-value multiplier for output changes when capital taxes alone adjust to stabilize debt, as in the top-left panel of Fig. 10, and the degree of “automatic” responsiveness of fiscal variables to output fluctuations.

Fig. 11 reports the present-value multipliers for four different settings of the  $\varphi$  coefficients: no automatic response (dashed line); estimated responses (solid line); twice the estimated responses (dotted line); three times the estimated responses (dotted-dashed line). Stronger “automatic stabilizers”, which may help to reduce the short-run fluctuations induced by various shocks, impose a long-run cost. In this example, higher government spending initially raises output, which, under the estimated policies, raises capital and labor taxes and lowers transfers.

But in this scenario, higher expected taxes on capital quickly reverse the initial stimulus to output. Naturally, “automatic stabilizers” are symmetric: when output falls, the declines in tax revenues and increases in government expenditures are amplified, reducing future surpluses still more. Capital taxes, therefore, must rise more sharply to stabilize debt. Stronger countercyclical responses exacerbate the decline in future surpluses and require more dramatic tax hikes, which drive output still lower. Although the qualitative effects of varying the size of “automatic stabilizers” are shock dependent and depend on the combination of fiscal instruments that adjust to debt, this counterfactual exercise



**Fig. 11.** Present-value government spending multipliers for output as a function of the degree of “automatic” responsiveness of fiscal variables to contemporaneous output fluctuations when only capital taxes adjust to stabilize debt. Uses parameters from the best-fitting model where all fiscal instruments adjust to debt. No automatic response (dashed line); estimated responses (solid line); twice the estimated responses (dotted line); three times the estimated responses (dotted-dashed line). The x-axis measures quarters.

highlights that *short-run* countercyclical fiscal behavior can make the *long-run* multiplier for government spending dramatically different.

6. Concluding remarks

Even a casual observer of the fiscal policy process acknowledges that it is immensely complex. The estimates from the model with the best fit to data make this point precise: shocks that raise government debt outstanding trigger dynamic reactions in government spending, capital and labor taxes, and transfer payments that can take many decades to play out fully. The practice of examining the macroeconomic consequences of fiscal changes without also studying the resulting debt dynamics and subsequent fiscal adjustments is sharply at odds with time-series data.

Three central messages emerge from the estimates:

1. The data prefer rich fiscal policy specifications.
2. Assumptions about which fiscal instruments may adjust to stabilize debt are very important for the ultimate impacts of changes in fiscal policy.
3. Because debt-financed fiscal changes trigger very long-lived dynamics, even in completely conventional models, short-run impacts can differ sharply from long-run effects, even being of different signs.

Because inferences about policy effects depend strongly on the underlying fiscal rules, the findings underscore the importance of modeling and understanding fiscal financing dynamics.

Although the dynamic interactions among policy variables in the estimated models are complex, understanding these complexities is just the first step in understanding how fiscal policy affects the economy. Introducing non-neutral transfer payments (Blanchard, 1985; Weil, 1987; Gali et al., 2007), a distinction between productive and unproductive government spending (Aschauer, 1989; Baxter and King, 1993), monetary policy behavior (Leeper and Sims, 1994; Kim, 2000), regime-switching policy (Davig and Leeper, 2006, 2009), models capable of handling trends in fiscal variables, and the possibility of fiscal foresight (Leeper et al., 2009), is a short list of further complications worthy of modeling attention. Multipliers and effects of fiscal policy changes could substantially differ by introducing these additional complications, and understanding these issues seems crucial for fiscal policy analysis.

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**Appendix A. Derivations of model equations**

This appendix lists the equilibrium conditions, steady state, and log-linearized system used for the estimation.

**A.1. Equilibrium conditions**

Define  $q_t = \frac{u_t}{\lambda_t}$ .

$$\frac{u_t^b(C_t - hC_{t-1})^{-\gamma}}{1 + \tau_t^c} = E_t \frac{\beta R_t u_{t+1}^b (C_{t+1} - hC_t)^{-\gamma}}{1 + \tau_{t+1}^c} \tag{A.1}$$

$$u_t^l L_t^{1+\kappa} (1 + \tau_t^c) = (C_t - hC_{t-1})^{-\gamma} (1 - \tau_t^l) (1 - \alpha) Y_t \tag{A.2}$$

$$q_t = \beta E_t \frac{u_{t+1}^b (C_{t+1} - hC_t)^{-\gamma} (1 - \tau_{t+1}^c)}{u_t^b (C_t - hC_{t-1})^{-\gamma} (1 + \tau_{t+1}^c)} \times \left\{ (1 - \tau_{t+1}^k) \frac{\alpha Y_{t+1}}{K_t} + q_{t+1} [1 - \delta(v_{t+1})] \right\} \tag{A.3}$$

$$\frac{\alpha Y_t (1 - \tau_t^k)}{v_t K_{t-1}} = q_t [\delta_1 + \delta_2 (v_t - 1)] \tag{A.4}$$

$$1 = q_t \left\{ [1 - s_t(\cdot)] - s_t'(\cdot) \frac{u_t^i I_t}{I_{t-1}} \right\} + \beta E_t \left\{ \frac{\lambda_{t+1}}{\lambda_t} q_{t+1} s_{t+1}'(\cdot) \left( \frac{u_{t+1}^i I_{t+1}}{I_t} \right)^2 \right\} \tag{A.5}$$

$$Y_t = C_t + G_t + I_t \tag{A.6}$$

$$K_t = [1 - \delta(v_t)] K_{t-1} + \left[ 1 - s \left( \frac{u_t^i I_t}{I_{t-1}} \right) \right] I_t \tag{A.7}$$

$$B_t + T_t^k + T_t^l + T_t^c = R_{t-1} B_{t-1} + G_t + Z_t \tag{A.8}$$

$$T_t^k = \tau_t^k \alpha Y_t \tag{A.9}$$

$$T_t^l = \tau_t^l (1 - \alpha) Y_t \tag{A.10}$$

$$T_t^c = \tau_t^c C_t \tag{A.11}$$

$$Y_t = u_t^a (v_t K_{t-1})^\alpha (L_t)^{1-\alpha} \tag{A.12}$$

Eqs. (A.1)–(A.12) along with the fiscal policy rules, Eqs. (11)–(15) in the text, and the shock processes defined in the text, Eqs. (1), (2), (5) and (8), define a competitive equilibrium.

**A.2. Steady state**

$$q = 1, \quad v = 1$$

$$R = \frac{1}{\beta}$$

$$R^k = \frac{\frac{1}{\beta} - (1 - \delta_0)}{1 - \tau^k}$$

$$\delta_1 = R^k (1 - \tau^k)$$

$$I = \delta_0 K.$$

$Y, K, C,$  and  $L$  can be solved from the following set of equations:

$$Y(1 - s_g) = C + \delta_0 K$$

$$Y = K^\alpha L^{1-\alpha}$$

$$R^k = \frac{\alpha Y}{K}$$

$$(1 + \tau^c) L^{1+\kappa} = (C - hC)^{-\gamma} (1 - \tau^l) (1 - \alpha) Y$$

where  $s_g = G/Y \in (0, 1)$ . Finally,  $Z$  can be solved for from the government budget constraint:

$$Z = \tau^k \alpha Y + \tau^l (1 - \alpha) Y + \tau^c C - Y \left( s_g + \frac{1 - \beta}{\beta} s_b \right)$$

where  $s_b = B/Y \in (0, 1)$ .

**A.3. Log-linearized system**

$$\hat{u}_t^b - \frac{\gamma(1+h)}{1-h} \hat{C}_t + \frac{\gamma h}{1-h} \hat{C}_{t-1} - \frac{\tau^c}{1+\tau^c} \hat{\tau}_t^c = \hat{R}_t - \frac{\tau^c}{1+\tau^c} E_t \hat{\tau}_{t+1}^c + E_t u_{t+1}^b - \frac{\gamma}{1-h} E_t \hat{C}_{t+1} \tag{A.13}$$

$$\hat{u}_t^l + (1 + \kappa) \hat{L}_t + \frac{\tau^c}{1 + \tau^c} \hat{\tau}_t^c = \hat{Y}_t - \frac{\tau^l}{1 - \tau^l} \hat{\tau}_t^l - \frac{\gamma}{1 - h} \hat{C}_t + \frac{\gamma h}{1 - h} \hat{C}_{t-1} \tag{A.14}$$

$$\hat{q}_t = E_t \hat{u}_{t+1}^b - \frac{\gamma}{1-h} E_t \hat{C}_{t+1} + \frac{\gamma(1+h)}{1-h} \hat{C}_t - \frac{\tau^c}{1+\tau^c} E_t \hat{\tau}_{t+1}^c - \hat{u}_t^b - \frac{\gamma h}{1-h} \hat{C}_{t-1} + \frac{\tau^c}{1+\tau^c} \hat{\tau}_t^c + \beta(1 - \tau^k) \alpha \frac{Y}{K} E_t \hat{Y}_{t+1} - \beta(1 - \tau^k) \alpha \frac{Y}{K} \hat{K}_t - \beta \tau^k \alpha \frac{Y}{K} E_t \hat{\tau}_{t+1}^k - \beta \delta_1 E_t \hat{v}_{t+1} + \beta(1 - \delta_0) E_t \hat{q}_{t+1} \tag{A.15}$$

$$\hat{Y}_t - \frac{\tau^k}{1 - \tau^k} \hat{\tau}_t^k - \hat{K}_{t-1} = \hat{q}_t + \left( 1 + \frac{\delta_2}{\delta_1} \right) \hat{v}_t \tag{A.16}$$

$$\frac{1}{s''(1)} \hat{q}_t - (1 + \beta) \hat{l}_t + \hat{l}_{t-1} + \beta E_t \hat{l}_{t+1} - \hat{u}_t^i + \beta E_t \hat{u}_{t+1}^i = 0 \tag{A.17}$$



$$Y\hat{Y}_t = C\hat{C}_t + G\hat{G}_t + \hat{I}_t \quad (\text{A.18})$$

$$\hat{K}_t = (1 - \delta_0)\hat{K}_{t-1} + \delta_1\hat{v}_t + \delta_0\hat{l}_t \quad (\text{A.19})$$

$$\begin{aligned} B\hat{B}_t + \tau^k\alpha Y(\hat{\tau}_t^k + \hat{Y}_t) + \tau^l(1 - \alpha)Y(\hat{\tau}_t^l + \hat{Y}_t) + \tau^c C(\hat{\tau}_t^c + \hat{C}_t) \\ = \frac{B}{\beta}\hat{R}_{t-1} + \frac{B}{\beta}\hat{B}_{t-1} + G\hat{G}_t + Z\hat{Z}_t \end{aligned} \quad (\text{A.20})$$

$$\hat{Y}_t = \hat{u}_t^a + \alpha\hat{v}_t + \alpha\hat{K}_{t-1} + (1 - \alpha)\hat{L}_t. \quad (\text{A.21})$$

These equations, along with the exogenous processes given by Eqs. (1), (2), (5), (8) and (11)–(15) in the text, comprise the set of equations used to solve the model using Sims's (2001) algorithm.

## Appendix B. Data construction

Unless otherwise noted, all data are from the Bureau of Economic Analysis' NIPA. All data in levels are nominal values. Nominal data are converted to real values by dividing by the GDP deflator for personal consumption expenditures (line 2 in Table 1.1.4).

**Consumption.** Consumption,  $C$ , is defined as personal consumption expenditure on nondurable goods (Table 1.1.5 line 4) and on services (Table 1.1.5 line 5).

**Investment.** Investment,  $I$ , is defined as personal consumption expenditure on durable goods (Table 1.1.5 line 3) and gross private domestic investment (Table 1.1.5 line 6).

**Consumption tax revenues.** The consumption tax revenues,  $T^c$ , include excise taxes and customs duties (lines 5 and 6 in NIPA Table 3.2).

**Consumption tax rates.** The average consumption tax rate is defined as

$$\tau^c = \frac{T^c}{C - T^c - T_s^c}$$

where  $T_s^c$  is state and local sales taxes (Table 3.3 line 12).

**Capital and labor tax rates.** Following Jones (2002), first the average personal income tax rate is computed:

$$\tau^p = \frac{IT}{W + PRI/2 + CI}$$

where  $IT$  is personal current tax revenues (Table 3.2 line 3),  $W$  is wage and salary accruals (Table 1.12 line 3),  $PRI$  is proprietors' income (Table 1.12 line 3), and  $CI$  is capital income. Capital income is defined as rental income (Table 1.12 line 12), corporate profits (Table 1.12 line 13), interest income (Table 1.12 line 18), and  $PRI/2$ .

The average labor income tax rate is computed as

$$\tau^l = \frac{\tau^p(W + PRI/2) + CSI}{EC + PRI/2}$$

where  $CSI$  is contributions for government social insurance (Table 3.2 line 11) and  $EC$  is compensation of employees (Table 1.12 line 2). The average capital income tax rate is calculated as

$$\tau^k = \frac{\tau^p CI + CT}{CI + PT}$$

where  $CT$  is taxes on corporate income (Table 3.2 line 7) and  $PT$  is property taxes (Table 3.3 line 8).

**Capital and labor tax revenues.** The capital and labor tax revenues are constructed by multiplying the average tax rate and tax base.

**Government expenditure.** Government expenditure,  $G$ , is defined as government consumption expenditure (Table 3.2 line 20), government gross investment (Table 3.2 line 41), and government net purchases of non-produced assets (Table 3.2 line 43), minus government consumption of fixed capital (Table 3.2 line 44).

**Transfers.** Transfers,  $TR$ , are defined as net current transfers, net capital transfers, and subsidies (Table 3.2 line 31), minus the

tax residual. Net current transfers are defined as current transfer payments (Table 3.2 line 21) minus current transfer receipts (Table 3.2 line 15). Net capital transfers are defined as capital transfer payments (Table 3.2 line 42) minus capital transfer receipts (Table 3.2 line 38). The tax residual is defined as current tax receipts (Table 3.2 line 2), contributions for government social insurance (Table 3.2 line 11), income receipts on assets (Table 3.2 line 12), and the current surplus of government enterprises (Table 3.2 line 18), minus total tax revenue,  $T$  (consumption, labor, and capital tax revenues).

**Government debt.** Government debt,  $B$ , is defined as

$$B_t = NB - \text{Seigniorage} + B_{t-1}$$

where Seigniorage is defined as  $M_t - M_{t-1}$ ,  $M$  is the St. Louis Fed's adjusted monetary base,<sup>19</sup> and  $NB$  is net borrowing. Net borrowing is computed using the NIPA deficits concept, specifically as  $G + INT + TR - T$ , where  $INT$  is interest payments (Table 3.2 line 28).<sup>20</sup>

**Hours worked.** Hours worked is constructed from the following variables:

**H** Nonfarm business, all persons, average weekly hours duration: index, 1992 = 100, seasonally adjusted. (From US Department of Labor, PRS85006023.)

**Emp** Civilian employment: 16 years and over, measured in thousands, seasonally adjusted. (From US Department of Labor, Bureau of Labor Statistics, CE16OV.) Turned into an index where 1992:3 = 100.

Hours worked are then defined as

$$N = \frac{H * \text{Emp}}{100}$$

## Definitions of observable variables

The observable variable  $X$  is defined by making the following transformation to variable  $x$ :

$$X = \ln\left(\frac{x}{\text{Popindex}}\right) * 100$$

where

**Popindex** index of Population, constructed so that 1992:3 = 1.

**Pop** Civilian noninstitutional population, ages 16 years and over, seasonally adjusted. Number in thousands (from US Bureau of Labor Statistics), LNS10000000.

and  $x$  = consumption, investment, hours worked, government spending, labor tax revenues, capital tax revenues, consumption tax revenues, government debt, and transfers.

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<sup>19</sup> Quarterly rates are computed as averages of monthly rates.

<sup>20</sup> We calculate our data series starting from 1947, so that the starting value of our debt series will not be too sensitive to the initialization of the debt series. To initialize our debt series, we use the 1947Q1 value of the Cox and Hirschhorn (1983) market value of debt. The Cox–Hirschhorn debt series is not used in general since the series is not consistent with NIPA's net borrowing definition. However, the correlation between the debt series in this paper and the Cox–Hirschhorn debt series, which is maintained and updated at the Federal Reserve Bank of Dallas, is approximately 0.998.

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