

DOES GOVERNMENT DEBT CROWD OUT INVESTMENT? A BAYESIAN DSGE APPROACH

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ABSTRACT. We estimate the crowding out effects of government debt for the U.S. economy using a New Keynesian model that takes into account government consumption and investment, transfers, and distortionary taxation on consumption and on labor and capital income. The estimation finds that whether private investment is crowded *in* or *out* in the short term depends on the fiscal shock that triggers debt accumulation: higher debt can crowd in investment despite a higher real interest rate for a reduction in capital tax rates or an increase in productive government investment. Distortionary financing to retire debt is an important factor contributing to declines in investment. Contrary to the conventional view of crowding out, no systematic relationship among debt, the real interest rate, and private investment exists. This result offers an explanation as to why empirical studies that have focused on the reduced-form relationship between interest rates and debt are often inconclusive. Counterfactual exercises show that the degree of crowding out depends on the monetary authority's responses to inflation and output fluctuations. Also, the tax cuts in 2001 and 2002 had mild expansionary effects, but monetary policy played a more substantial role than fiscal policy in preventing the economy from sliding into a deeper recession.

Keywords: Fiscal Policy; Crowding Out; Distortionary Debt Financing; Fiscal and Monetary Policy Interactions; Bayesian Estimation

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1. INTRODUCTION

The past decade in the United States has been a period of tremendous fiscal activity: expenditures on the war on terrorism, two major tax cuts in 2001 and 2003, two fiscal stimulus packages in 2008 and 2009, and the financial rescue programs. This fiscal activity has occurred against a backdrop of demographic trends that suggest accelerated future spending increases in medical programs and Social Security. The Congressional Budget Office (2009) projects that federal debt in 2080 will reach 283 percent and 716 percent of GDP under the extended current-law and an alternative fiscal scenario, suggesting an unsustainable path for U.S. fiscal policy.¹ The active use of fiscal policy has pushed the discussion of government debt once again to the forefront of macroeconomic research.

Following World War II, many economists were concerned about the impact of government debt [see, for example, Domar (1944), Leland (1944), Lerner (1945), Wallich (1946) and the references therein]. Since then, a conventional view has emerged, suggesting that government borrowing is expansionary in the short run but contractionary in the long run [see Bernheim (1989) and Elmendorf and Mankiw (1999) for a detailed discussion]. Based on Keynesian economics, the theory argues that when prices and/or wages are sticky, higher debt caused by deficit-financed tax cuts or spending increases adds to aggregate demand, leading income and output to increase. The deficits, however, reduce public saving. Since private saving and capital inflows may not increase enough to fully offset government borrowing, interest rates can rise over time. Consequently, investment is crowded out, and capital and output eventually decline, negating the short run expansionary benefits.

Building on this theoretical view, countless empirical studies have estimated the reduced-form relationship between government debt (or deficits) and interest rates at various horizons to search for signs of crowding out. A positive estimated relationship between a measure of debt and the real interest rate is viewed as evidence of crowding out. Survey papers generally conclude a lack of consensus among the findings in the literature [Elmendorf and Mankiw (1999), Gale and Orszag (2002), and Engen and Hubbard (2005)].² By investigating the crowding out effect in a general equilibrium framework, we find that government debt can crowd out investment, but the relationship between debt and real interest rates depends on what fiscal instrument causes an increase in debt. The result explains why empirical studies focusing on the relationship between interest rates and debt are often inconclusive.

We construct a DSGE model with a detailed fiscal policy specification. The model builds upon New Keynesian models which have been shown to fit the data well [as shown for example by Del Negro, Schorfheide, Smets, and Wouters (2004) and Smets and Wouters (2007)].

¹The alternative fiscal scenario incorporates some policy changes that are widely expected to occur and that policymakers have regularly made in the past.

²For a survey of the earlier studies, see Barth, Iden, and Russek (1984) and appendix A in *The Economic Outlook*, February [Congressional Budget Office (1984)]. A recent paper by Laubach (2009) finds a positive and significant relationship between debt or deficits and interest rates when long-horizon forward rates and projected federal deficits are used. Engen and Hubbard (2005) also obtain similar results using the same measures for the two variables. However, they find that when the dependent variable is the change in the forward rate rather than the level, the positive coefficient is insignificant.

Our model differs from these standard models mainly in its fiscal policy specification.³ Because the focus of this paper is on government debt, we allow for rich dynamics induced by the interactions between policy variables and debt. Following Leeper, Plante, and Traum (forthcoming), most fiscal instruments can respond to government indebtedness. In addition, income tax rates can adjust automatically to the state of the economy, as does the income tax policy in practice. The common assumption of non-productive government spending is eliminated; we distinguish between non-productive government consumption and productive government investment. Since the extent to which consumers are myopic has received much attention in theoretical debates,⁴ following Gali, Lopez-Salido, and Valles (2007) and Forni, Monteforte, and Sessa (2007) we also include non-savers (also known as liquidity-constrained or rule-of-thumb agents) as well as savers, who are forward-looking and have rational expectations.

The model's features allow for a variety of factors to potentially direct the effect of government debt. A priori, our model does not impose restrictions as to whether government debt crowds *out* or *in* investment and how government debt affects the economy. By estimating most structural and policy parameters, we assess the importance of various factors—myopic behaviors, fiscal interventions, debt financing, and monetary policy—for determining the crowding out effects in the data.

We estimate the model using Bayesian methods as described in An and Schorfheide (2007). The estimation yields values for most structural parameters comparable to those in the literature. In addition, most fiscal instruments are found to respond to debt systematically under rather diffuse priors: when the debt-to-output ratio rises, the government reduces its purchases and transfers and increases income taxes to rein in debt growth. Historical decompositions show that the dynamics of debt and the primary deficit are in line with historical events that contributed to the worsening of the federal budget.

Recent studies based on neoclassical growth models have focused on two important factors for determining the effect of debt accumulation: the types of fiscal innovations that trigger debt expansions, and the types of fiscal adjustments that stabilize debt. Ludvigson (1996) and Leeper and Yang (2008) find that when a debt increase is due to reductions in distortionary income taxes, crowding out need not occur. Leeper, Plante, and Traum (forthcoming) and Uhlig (2009) show that the effects of a deficit-financed fiscal shock over the medium and longer horizons depend on the instrument and patterns of fiscal adjustments used to maintain a sustainable budget.

Our estimation finds that the short-term effect of government debt is determined by the type of fiscal shock that triggers debt accumulation. Higher government debt can crowd *in* investment despite a higher real interest rate if the debt is generated by a reduction in capital tax rates or an increase in productive government investment, because both raise the net return to capital. Freedman, Kumhof, Laxton, Muir, and Mursula (2009) have recently found a similar result in the International Monetary Fund's calibrated Global Integrated

³Leeper and Sims (1994) and Kim (2000) are the earliest papers that estimate DSGE models with nominal rigidities and accounting for monetary and fiscal policy interactions.

⁴The debates focus on whether people perceive government debt as net wealth. If government debt is regarded as a burden on future generations, people can behave myopically as non-savers in our model [see Modigliani (1961), Barro (1974), Blanchard (1985), and Smetters (1999)].

Monetary and Fiscal Policy open-economy model. In addition, we find that distortionary financing to retire debt is an important factor leading to declines in investment and influences the path of investment following deficit-financed fiscal shocks.

We also find that monetary policy, in particular the central bank's responsiveness to output, matters systematically for the path of investment. The more aggressively the central bank responds to output fluctuations following a deficit-financed fiscal intervention, the smaller the increase or the larger the decline in investment, depending on which fiscal instrument triggers the debt expansion. In the case of a positive government investment shock, a sufficiently large response in the nominal interest rate can reverse the crowding-in effect on investment in the short run.

Aside from estimating the average historical effects of debt, we examine the consequences of specific historical episodes. We study the effects of the 1990s tax increases and the deficit-financed tax cuts during the recession in 2001 and 2002. Counterfactual exercises find that when the contractionary capital and labor tax innovations from 1993Q1 to 1997Q2 are turned off, the real value of federal debt in 1997Q2 is 11 percent higher and investment is 2 percent higher than their historical values, suggesting a mild crowding-out effect due to fiscal adjustments to retire debt. As for the effects of the 2001 and 2002 tax cuts, we find that they had mild expansionary effects, but monetary policy during the period played a more substantial role in preventing the economy from sliding into a deeper recession.

2. THE BENCHMARK MODEL

We augment a conventional New Keynesian model with liquidity constrained non-savers and a relatively detailed model of fiscal policy. The specification is similar to those in Christiano, Eichenbaum, and Evans (2005), Smets and Wouters (2007), Gali, Lopez-Salido, and Valles (2007), and Forni, Monteforte, and Sessa (2007). The model incorporates two real rigidities, variable capital utilization and investment adjustment costs, and two nominal rigidities for prices and wages, both adjusting by a Calvo (1983) mechanism with partial indexation to past inflation.⁵

The model economy consists of seven classes of agents: final good producers, who bundle a continuum of intermediate goods into a final product; monopolistic intermediate goods producers; savers, who consume the final good, accumulate capital and government bonds, and supply differentiated labor services; non-savers, who consume the final good and supply differentiated labor services; monopolistic unions, who act on the savers' and non-savers' behalf to set wages; a government; and a monetary authority. The equilibrium system of the model is log-linearized and solved by Sims's (2001) algorithm. Appendix A describes the equilibrium.

2.1. Households. The economy is populated by a continuum of households on the interval $[0, 1]$, of which a fraction μ are non-savers. These households do not have access to financial or capital markets and consume all of their disposable income each period. As a result, they act

⁵Habit formation, commonly included in DSGE models, is dropped from the specification. As non-saver households react to most of the fiscal shocks differently from savers, the presence of non-savers serve a similar function as habit for smoothing aggregate consumption.

myopically; any expectations about future policy have no effect on their economic decisions. The other $(1 - \mu)$ fraction of households are forward-looking with access to complete asset and capital markets. The superscript S indicates a variable associated with savers and N with non-savers.

All households in the model, whether savers or non-savers, are monopolistic suppliers of differentiated labor inputs. We assume that they work sufficient hours to meet the market demand for the chosen monopolistic wage rates. The wage decisions are delegated to unions, to be discussed below.

2.1.1. *Savers.* The household $j \in [0, 1 - \mu]$ maximizes its utility, given by

$$E_0 \sum_{t=0}^{\infty} \beta^t u_t^b \left[\frac{c_t^S(j)^{1-\gamma} - 1}{1-\gamma} - \frac{L_t^S(j)^{1+\kappa}}{1+\kappa} \right], \quad (1)$$

where $\beta \in (0, 1)$ is the discount factor, $\gamma \geq 0$ is the household's risk aversion, and $\kappa \geq 0$ is the inverse of the Frisch labor elasticity. The economy has a continuum of differentiated labor inputs indexed by $l \in [0, 1]$. Following Schmitt-Grohe and Uribe (2007), we assume that each household supplies all differentiated labor inputs to eliminate labor income discrepancies from individual households supplying differentiated labor services. The total hours supplied by household j satisfies the constraint $L_t^S(j) = \int_0^1 l_t^S(j, l) dl$, where $l_t^S(j, l)$ is the amount of labor input l supplied by saver j .

The general preference shock u_t^b is assumed to follow the AR(1) process

$$\ln(u_t^b) = \rho_b \ln(u_{t-1}^b) + \sigma_b \epsilon_t^b, \quad \epsilon_t^b \sim N(0, 1), \quad (2)$$

where $0 < \rho_b < 1$.

The flow budget constraint in units of consumption goods for saver j is given by

$$\begin{aligned} (1 - \tau_t^L) \int_0^1 \frac{W_t(l)}{P_t} l_t^S(j, l) dl + (1 - \tau_t^K) \frac{R_t^K v_t(j) k_{t-1}^S(j)}{P_t} + \frac{R_{t-1} b_{t-1}^S(j)}{\pi_t} + z_t(j) + d_t^S(j) \\ = c_t^S(j) + \frac{i_t^S(j)}{1 + \tau_t^C} + b_t^S(j), \end{aligned} \quad (3)$$

where τ_t^L , τ_t^K , and τ_t^C are tax rates on labor income, capital income, and consumption, and $z_t(j)$ is lump-sum government transfers. $W_t(l)$ is the nominal wage rate for labor input l , and P_t is the general consumer price; $\int_0^1 \frac{W_t(l)}{P_t} l_t^S(j, l) dl$ is the total real labor income for household j . At time t , household j purchases $b_t^S(j)$ units of government debt, which pays $\frac{R_t b_t^S(j)}{\pi_{t+1}}$ units of consumption goods at $t+1$, where $\pi_{t+1} \equiv \frac{P_{t+1}}{P_t}$ is the gross inflation rate for the consumer price index. $d_t^S(j)$ is dividends received from profits of the monopolistic firms, and $i_t^S(j)$ is saver j 's gross investment. Note that introducing consumption taxes causes a wedge between the producer price index, \bar{P}_t , and the consumer index, given by $P_t = (1 + \tau_t^c) \bar{P}_t$. Following Forni, Monteforte, and Sessa (2007), we assume that no indirect taxes are paid on purchases of investment goods, so that the price index of investment goods is the wholesale price \bar{P}_t .⁶

⁶Dividing the wholesale price index by the consumer price index leaves the tax wedge, which shows up in the investment cost of $i_t^S(j)$ in units of consumption goods $\frac{i_t^S(j)}{1 + \tau_t^c}$.

The model has variable utilization for private capital k_{t-1}^S . A higher utilization rate is associated with a higher depreciation rate of capital, $\delta[v_t(j)]$. Following Schmitt-Grohe and Uribe (2008), $\delta[v_t(j)]$ is given by

$$\delta[v_t(j)] = \delta_0 + \delta_1(v_t(j) - 1) + \frac{\delta_2}{2}(v_t(j) - 1). \quad (4)$$

We calibrate δ_1 so that $v = 1$ in the steady state. We define a new parameter $\psi \in [0, 1)$ such that $\frac{\delta''[1]}{\delta'[1]} = \frac{\delta_2}{\delta_1} \equiv \frac{\psi}{1-\psi}$. Notice that as $\psi \rightarrow 1$, the utilization cost becomes infinite, and the model behaves as if there was no variable capital utilization (since the cost of changing capacity is too high). R_t^K is the nominal rental rate for effective capital $v_t(j)k_{t-1}^S(j)$.

The law of motion for private capital is given by

$$k_t^S(j) = (1 - \delta[v_t(j)])k_{t-1}^S(j) + \left[1 - s\left(\frac{u_t^i i_t^S(j)}{i_{t-1}^S(j)}\right)\right] \times i_t^S(j). \quad (5)$$

Following Smets and Wouters (2003) and Christiano, Eichenbaum, and Evans (2005), when household j varies its investment level from the previous period's, an adjustment cost of $s\left(\frac{u_t^i i_t^S(j)}{i_{t-1}^S(j)}\right) \times i_t^S(j)$ is incurred. By assumption, the function $s(\cdot)$ has the following properties in the steady state: $s(1) = s'(1) = 0$, and $s''(1) \equiv s > 0$. In addition, the adjustment cost is subject to an investment-specific efficiency shock u_t^i , similar to Greenwood, Hercowitz, and Krusell (1997), which follows the AR(1) process

$$\ln(u_t^i) = \rho_i \ln(u_{t-1}^i) + \sigma_i \epsilon_t^i, \quad \epsilon_t^i \sim N(0, 1) \quad (6)$$

2.1.2. *Non-savers.* Non-savers are assumed to have the same preferences as savers. Consistent with the modeling convention, we assume that non-savers consume all their disposable income each period. The budget constraint in units of consumption goods for the non-saver $j \in (1 - \mu, 1]$ is

$$c_t^N(j) = (1 - \tau_t^L) \int_0^1 \frac{W_t(l)}{P_t} l_t^N(j, l) dl + z_t(j). \quad (7)$$

As earlier, $z_t(j)$ is lump-sum government transfers, and the total labor inputs supplied by non-saver j are $L_t^N(j) = \int_0^1 l_t^N(j, l) dl$.

2.2. **Wage Setting and Labor Aggregation.** To introduce wage rigidities, we assume monopolistic unions set the wages for the differentiated labor services, following Colciago (2007) and Forni, Monteforte, and Sessa (2007).⁷ Households supply differentiated labor inputs to a continuum of unions, indexed by l . We assume that households are distributed uniformly across unions, implying that the aggregate demand for a specific labor input is spread uniformly across all households ($l_t^S(j, l) = l_t^N(j, l) \equiv l_t(l)$). Therefore, total hours worked for savers and non-savers are equal: $L_t^S(j) = L_t^N(j) = \int_0^1 l_t(l) dl \equiv L_t$.

⁷This departs from the common setup for sticky wages, where each household owns one unique labor input and is the wage setter for that input, as in Erceg, Henderson, and Levin (2000). In our model, non-savers cannot share the risk associated with labor income fluctuations. If non-savers have different labor inputs, differences in labor income would make the status of a non-saver intractable.

We assume that a perfectly competitive labor packer purchases the differentiated labor inputs and assembles them to produce a composite labor service L_t (sold to intermediate goods producing firms) by the technology due to Dixit and Stiglitz (1977),

$$L_t = \left[\int_0^1 l_t(l)^{\frac{1}{1+\eta_t^w}} dl \right]^{1+\eta_t^w}, \quad (8)$$

where η_t^w denotes a time-varying markup to wages. We assume that η_t^w follows the exogenous AR(1) process

$$\ln(\eta_t^w) = \rho_w \ln(\eta_{t-1}^w) + \sigma_w \epsilon_t^w, \quad \epsilon_t^w \sim N(0, 1), \quad (9)$$

and ϵ_t^w is a wage markup shock.

The demand function for a competitive labor packer can be derived from solving the profit maximization problem subject to (8), which yields

$$l_t(l) = L_t^d \left(\frac{W_t(l)}{W_t} \right)^{-\frac{1+\eta_t^w}{\eta_t^w}}, \quad (10)$$

where L_t^d is the demand for composite labor services, W_t is the aggregate wage, and $\frac{1+\eta_t^w}{\eta_t^w}$ measures the elasticity of substitution between labor inputs. The aggregate labor demand can be computed by integrating (10) over all differentiated labor inputs:

$$\int_0^1 l_t(l) dl = L_t = L_t^d \int_0^1 \left(\frac{W_t(l)}{W_t} \right)^{-\frac{1+\eta_t^w}{\eta_t^w}} dl. \quad (11)$$

The aggregate wage, derived from the zero-profit condition of a labor packer, is

$$W_t = \left[\int_0^1 W_t(l)^{\frac{1}{\eta_t^w}} dl \right]^{\eta_t^w}. \quad (12)$$

In each period, a union receives a signal to reset its nominal wage with probability $(1 - \omega_w)$. Those who cannot reoptimize index their wages to past inflation according to the rule

$$W_t(l) = W_{t-1}(l) \pi_{t-1}^{\chi^w}, \quad (13)$$

$\chi^w \in [0, 1]$ introduces a backward looking component in the inflation process; that is, the wage is indexed by χ^w percent of past inflation. Unions that receive the signal choose the nominal wage rate $W_t(l)$ to maximize an aggregation of both types of households' lifetime utility, given by

$$E_t \sum_{i=0}^{\infty} (\beta \omega_w)^i \left\{ u_{t+i}^b \left[(1 - \mu) \frac{(c_{t+i}^S)^{1-\gamma} - 1}{1 - \gamma} + \mu \frac{(c_{t+i}^N)^{1-\gamma} - 1}{1 - \gamma} - \frac{L_{t+i}^{1+\kappa}}{1 + \kappa} \right] \right\}, \quad (14)$$

subject to four constraints: the aggregate budget constraints for savers and non-savers (the aggregation forms of (3) and (7)), and the labor demand equations (10) and (11).

Let $\widetilde{W}_t(l)$ be the optimal wage chosen by the unions. We focus on the symmetric equilibrium, where $\widetilde{W}_t(l) = \widetilde{W}_t$. Then, \widetilde{W}_t must satisfy

$$\begin{aligned} E_t \sum_{i=0}^{\infty} (\beta\omega_w)^i (1 - \tau_{t+i}^L) [(1 - \mu)\lambda_{t+i}^S + \mu\lambda_{t+i}^N] L_{t+i}^d \left(\frac{\widetilde{W}_t}{W_{t+i}} \right)^{-\eta_t^w} \frac{\widetilde{W}_t}{P_{t+i}} \prod_{s=1}^i \left(\frac{1}{\pi_{t+s-1}^{\chi^w}} \right)^{\eta_t^w} \\ = E_t \sum_{i=0}^{\infty} (\beta\omega_w)^i u_{t+i}^b \frac{\eta_t^w}{\eta_t^w - 1} \left[L_{t+i}^d \left(\frac{\widetilde{W}_t}{W_{t+i}} \right)^{-\eta_t^w} \right]^{1+\kappa} \prod_{s=1}^i \left(\frac{1}{\pi_{t+s-1}^{\chi^w}} \right)^{\eta_t^w (1+\kappa)}, \end{aligned} \quad (15)$$

where λ_t^S and λ_t^N are the marginal utilities of the two types of households' consumption:

$$\lambda_t^S = u_t^b (c_t^S)^{-\gamma}, \quad \lambda_t^N = u_t^b (c_t^N)^{-\gamma} \quad (16)$$

Finally, the nominal aggregate wage evolves according to

$$W_t = \left[(1 - \omega_w) \widetilde{W}_t^{\frac{-1}{\eta_t^w}} + \omega_w \left((\pi_t^w)^{\chi^w} \right)^{\frac{-1}{\eta_t^w}} W_{t-1}^{\frac{-1}{\eta_t^w}} \right]^{-\eta_t^w}, \quad (17)$$

where $\pi_t^w \equiv \frac{W_t}{W_{t-1}}$ is the gross wage inflation rate.

2.3. Firms and Price Setting. The production sector consists of intermediate and final goods producing firms. A perfectly competitive final good producer uses a continuum of intermediate goods $y_t(i)$, where $i \in [0, 1]$, to produce the final good, Y_t , according to the same constant-return-to-scale technology used by the labor packers,

$$\left[\int_0^1 y_t(i)^{\frac{1}{1+\eta_t^p}} di \right]^{1+\eta_t^p} \geq Y_t. \quad (18)$$

where η_t^p denotes a time-varying markup to the intermediate goods' prices. η_t^p is assumed to follow the AR(1) process

$$\ln(\eta_t^p) = \rho_p \ln(\eta_{t-1}^p) + \sigma_p \epsilon_t^p, \quad \epsilon_t^p \sim N(0, 1), \quad (19)$$

where ϵ_t^p is the goods price markup shock.

We denote the price of the intermediate good i as $\bar{p}_t(i)$ and the price of final good Y_t as \bar{P}_t . The final good producing firm chooses Y_t and $y_t(i)$ to maximize profits subject to the technology (18). Note that the final price that the firm maximizes is exclusive of consumption taxes. The demand for $y_t(i)$ is given by

$$y_t(i) = Y_t \left(\frac{\bar{p}_t(i)}{\bar{P}_t} \right)^{-\frac{1+\eta_t^p}{\eta_t^p}}, \quad (20)$$

where $\frac{1+\eta_t^p}{\eta_t^p}$ is the elasticity of substitution between intermediate goods.

Intermediate goods producers, indexed by i , are monopolistic competitors in their product market and take production factor prices as given. We assume that each firm must produce enough to meet the demand for its good given the price that the firm i charges for its product. Firm i produces by a Cobb-Douglas technology

$$y_t(i) = u_t^a (v_t k_{t-1}(i))^\alpha (l_t(i))^{1-\alpha} (K_{t-1}^G)^{\alpha^G}, \quad (21)$$

where $\alpha \in [0, 1]$, and $\alpha^G \geq 0$ is the elasticity of output with respect to government capital K_{t-1}^G . u_t^a denotes a covariance stationary technology shock, which evolves according to

$$\ln(u_t^a) = \rho_a \ln(u_{t-1}^a) + \sigma_a \epsilon_t^a, \quad \epsilon_t^a \sim N(0, 1). \quad (22)$$

Firm i 's cost minimization problem yields an expression for its nominal marginal cost, which is the same across all intermediate firms:

$$MC_t = (1 - \alpha)^{\alpha-1} \alpha^{-\alpha} W_t^{1-\alpha} (R_t^k)^\alpha (u_t^a)^{-1} (K_{t-1}^G)^{-\alpha^G}. \quad (23)$$

Analogous to labor unions, a monopolistic intermediate firm has a probability of $(1 - \omega_p)$ to reset its optimal price. Firms that cannot reset optimally index their prices to past inflation according to the rule

$$\bar{p}_t(i) = \bar{p}_{t-1}(i) \bar{\pi}_{t-1}^{\chi^p}, \quad (24)$$

Firms who can reset their price choose $\bar{p}_t(i)$ to maximize the expected sum of discounted future real profits:

$$\max_{\bar{p}_t(i)} E_t \sum_{j=0}^{\infty} (\omega_p \beta)^j \frac{\lambda_{t+j}^S}{\lambda_t^S} Y_{t+j} \left[\left(\frac{\bar{p}_t(i)}{\bar{P}_t} \right) \prod_{k=1}^j \left(\frac{\bar{\pi}_{t+k-1}^{\chi^p}}{\bar{\pi}_{t+k}} \right) \right]^{-\frac{1+\eta_t^p}{\eta_t^p}} \left\{ \left(\frac{\bar{p}_t(i)}{\bar{P}_t} \right) \prod_{k=1}^j \frac{\bar{\pi}_{t+k-1}^{\chi^p}}{\bar{\pi}_{t+k}} - \frac{MC_{t+j}}{\bar{P}_{t+j}} \right\}. \quad (25)$$

In a symmetric equilibrium, where $\bar{p}_t(i) = \bar{p}_t$, the producer price index \bar{P}_t evolves according to

$$\bar{P}_t = \left[(1 - \omega_p) \bar{p}_t^{\frac{-1}{\eta_t^p}} + \omega_p \left(\bar{\pi}_t^{\chi^p} \right)^{\frac{-1}{\eta_t^p}} \bar{P}_{t-1}^{\frac{-1}{\eta_t^p}} \right]^{-\eta_t^p}. \quad (26)$$

2.4. Aggregation. We denote the aggregate quantity of a variable x_t by its capital letter X_t . Aggregate consumption is given by

$$C_t = \int_0^1 c_t(j) dj = (1 - \mu) c_t^S + \mu c_t^N. \quad (27)$$

Lump-sum transfers are assumed to be identical across households, implying

$$Z_t = \int_0^1 z_t(j) dj = z_t \quad (28)$$

Since only savers have access to the asset and capital markets, aggregate bonds, private capital, investment, and dividends are as follows:

$$B_t = \int_0^1 b_t(j) dj = (1 - \mu) b_t^S, \quad (29)$$

$$K_t = \int_0^1 k_t(j) dj = (1 - \mu) k_t^S, \quad (30)$$

$$I_t = \int_0^1 i_t(j) dj = (1 - \mu) i_t^S, \quad (31)$$

and

$$D_t = \int_0^1 d_t(j) dj = (1 - \mu) d_t^S. \quad (32)$$

Finally, the goods market clearing condition is

$$Y_t = C_t + I_t + G_t^C + G_t^I, \quad (33)$$

where G_t^C and G_t^I are government consumption and investment respectively.

2.5. Monetary Policy. The monetary authority follows a Taylor-type rule, in which the nominal interest rate R_t responds to its lagged value, the current inflation rate, and current output. We denote a variable in percentage deviations from the steady state by a hat. Specifically, the interest rate is set according to

$$\hat{R}_t = \rho_r \hat{R}_{t-1} + (1 - \rho_r) \left[\phi_\pi \hat{\pi}_t + \phi_y \hat{Y}_t \right] + \sigma^m \epsilon_t^m, \quad \epsilon_t^m \sim N(0, 1). \quad (34)$$

2.6. Fiscal Policy. Each period the government collects tax revenues and issues one-period nominal bonds to finance its interest payments and expenditures, which include government consumption, government investment, and transfer payments to the households. The flow budget constraint in units of consumption goods is

$$B_t + \tau_t^K \frac{R_t^K}{P_t} v_t K_{t-1} + \tau_t^L \frac{W_t}{P_t} L_t + \frac{\tau_t^C}{1 + \tau_t^C} C_t = \frac{R_{t-1} B_{t-1}}{\pi_t} + G_t^C + G_t^I + Z_t. \quad (35)$$

We assume that government investment can be productive. The law of motion for government capital is given by

$$K_t^G = (1 - \delta^G) K_{t-1}^G + G_t^I. \quad (36)$$

We assume that fiscal variables respond to the state of the economy according to the following rules:

$$\hat{\tau}_t^K = \rho_K \hat{\tau}_{t-1}^K + (1 - \rho_K) \left(\varphi_K \hat{Y}_t + \gamma_K \hat{s}_{t-1}^b \right) + \sigma_K \epsilon_t^K + \phi_{KL} \sigma_L \epsilon_t^L, \quad (37)$$

$$\hat{\tau}_t^L = \rho_L \hat{\tau}_{t-1}^L + (1 - \rho_L) \left(\varphi_L \hat{Y}_t + \gamma_L \hat{s}_{t-1}^b \right) + \sigma_L \epsilon_t^L + \phi_{KL} \sigma_K \epsilon_t^K, \quad (38)$$

$$\hat{G}_t^C = \rho_{GC} \hat{G}_{t-1}^C - (1 - \rho_{GC}) \gamma_{GC} \hat{s}_{t-1}^b + \sigma_{GC} \epsilon_t^{GC}, \quad (39)$$

$$\hat{G}_t^I = \rho_{GI} \hat{G}_{t-1}^I - (1 - \rho_{GI}) \gamma_{GI} \hat{s}_{t-1}^b + \sigma_{GI} \epsilon_t^{GI}, \quad (40)$$

$$\hat{Z}_t = \rho_Z \hat{Z}_{t-1} - (1 - \rho_Z) \gamma_Z \hat{s}_{t-1}^b + \sigma_Z \epsilon_t^Z, \quad (41)$$

$$\hat{\tau}_t^C = \rho_C \hat{\tau}_{t-1}^C + \sigma_C \epsilon_t^C, \quad (42)$$

where $s_{t-1}^b \equiv \frac{B_{t-1}}{Y_{t-1}}$, and $\epsilon_t^s \sim i.i.d. N(0, 1)$ for $s = \{K, L, GC, GI, C, Z\}$.

When the debt-to-output ratio rises above its steady state level, the government can adjust income taxes, government consumption and investment, or transfers to stabilize debt growth. Among the general equilibrium studies with government debt, the vast majority allow for a limited set of fiscal instruments to ensure fiscal solvency. For example, Erceg, Guerrieri, and Gust (2005), Coenen and Straub (2005), and Ratto, Roeger, and in't Veld (2006) only allow lump-sum taxes to respond to debt. Kumhof and Laxton (2008) have several instruments respond but leave out capital taxes. Forni, Monteforte, and Sessa (2007), Lopez-Salido and Rabanal (2008), Iwata (2009), and Zubairy (2009) allow for taxes to respond to debt but not government spending. Leeper, Plante, and Traum (forthcoming) find that in the U.S. postwar data, labor and capital taxes, government spending, and transfers all play a role in controlling debt growth. Thus, we allow for all these instruments to respond to debt. The

only fiscal instrument that is not allowed to adjust to debt in our model is the consumption tax rate. In the data, U.S. consumption taxes represent federal taxes on production and imports, which consist of excise taxes and custom duties. A majority of the excise taxes are deposited in special trust funds instead of the general fund for budget purposes.⁸

To capture the role of income taxes as automatic stabilizers, capital and labor taxes are allowed to respond to output contemporaneously ($\varphi_K, \varphi_L \geq 0$). We do not allow transfers to respond to contemporaneous output as experimentation with simulated data revealed that such a parameter could not be identified. Finally, since changes in income tax codes often involve changes in labor and capital taxes, we allow an unexpected exogenous movement in one tax rate to affect the other rate, as captured by ϕ_{KL} in (37) and (38).

3. ESTIMATION

The model is estimated with U.S. quarterly data ranging from 1983Q1 to 2008Q1 using Bayesian inference methods. The choice of the sample period is driven by several stability considerations: (1) the period roughly corresponds to the “Great Moderation” era recognized by the literature [Smets and Wouters (2007)]; (2) monetary policy is thought to be characterized by a Taylor rule [Taylor (1993)] over this period; and (3) on average monetary policy is thought to have been active (in the sense of Leeper (1991)) and fiscal policy passive.⁹

We estimate the model using 12 observables, including real aggregate consumption, investment, labor, wages, the nominal interest rate, the gross inflation rate, and fiscal variables—capital, labor, and consumption tax revenues, real government consumption and investment, and transfers.¹⁰ Although the literature typically uses fiscal variables of all governments, our fiscal variables are for the federal government only. State and local governments generally have balanced-budget rules of various forms. This suggests that fiscal financing decisions are likely to differ across federal and state and local governments, and we only consider modeling the former. Appendix B provides a detailed description of the data. Following Smets and Wouters (2003), we detrend the logarithm of each time series with its own linear trend, except for the nominal interest rate, which is detrended by the trend in inflation.

⁸In the post-1983 era, excise taxes were only occasionally used explicitly to reduce deficits. Under the Omnibus Budget Revenue Reconciliation Act (OBRRRA) of 1990, half of the increase in the gasoline excise tax was dedicated to the General Fund for deficit reduction, starting from December 1990. However, the OBRRRA of 1993 reversed this action and required that the gasoline excise taxes be deposited entirely in the Highway Trust Fund beginning in October 1995 [Talley (2000)].

⁹When a longer sample is used, regime-switching between active/passive monetary and fiscal policies (in the sense of Leeper (1991)) is a more pronounced issue. Davig and Leeper (2006) find evidence for regime-switching in the postwar U.S. data. Since the monetary and fiscal policy rules we estimate are assumed to have constant coefficients for inflation and debt, we select a sample period where on average monetary policy is active and fiscal policy is passive.

¹⁰By not including debt, the invertibility test in Fernandez-Villaverde, Rubio-Ramirez, Sargent, and Watson (2007) fails. However, posterior mode estimation based on simulated data shows that our observables can recover true parameters well, especially fiscal parameters. If we include debt as an observable, then one fiscal variable must be dropped to avoid singularity. This makes us unable to identify the standard deviation of the dropped fiscal variable, which further prevents us from conducting historical decompositions later.

The estimation begins with a set of prior distributions for the parameters to be estimated. We assume that the parameters are a priori independent, so that the joint distribution of all the parameters, $p(\theta)$, is simply the product of the marginal distributions. We restrict the parameter space to the subspace in which the model has a unique rational expectations equilibrium. We denote this subspace as Θ_D and let $\mathcal{I}\{\theta \in \Theta_D\}$ be an indicator function that is one if θ is in the determinacy region and zero otherwise. Thus, we define our joint prior distribution as

$$\tilde{p}(\theta) = \frac{1}{c} p(\theta) \mathcal{I}\{\theta \in \Theta_D\}, \quad \text{where } c = \int_{\theta \in \Theta_D} p(\theta) d\theta.$$

The equilibrium system of the model is written in a state-space form, where observables are linked with other variables in the model. For a given set of structural parameters, we compute the value for the log posterior function, which combines the likelihood of the data, $\mathcal{L}(y|\theta)$, with the probability values of the parameters given the prior distributions. The posterior is proportional to

$$p(Y|\theta) \propto \mathcal{L}(y|\theta) \tilde{p}(\theta).$$

The minimization routine `csminwel` by Christopher Sims is used to search for the set of structural parameters that minimize the negative log posterior function. To check if multiple modes exist, we initiate the search for the posterior mode from 50 initial values. The results suggest that multiple modes are not a major concern.¹¹ Next, we construct the posterior distribution using the random walk Metropolis-Hastings algorithm. Finally, diagnostic tests are performed to ensure the convergence of the MCMC chain.¹²

3.1. Prior Distributions. We impose dogmatic priors over several parameters that are hard to identify from the data. The discount factor, β , is set to 0.99, which implies an annual steady state real interest rate of 4 percent. The capital income share of total output, α , is set to 0.36, implying a labor income share of 0.64.¹³ The quarterly depreciation rate for private capital, δ_0 , is set to 0.025 so that the annual depreciation rate is 10 percent. We set $\delta^G = 0.02$, comparable to the calibrated value in DSGE models with productive investment [Baxter and King (1993) and Kamps (2004)]. Steady state markups are assumed to be approximately 13 percent in the product and labor markets, implying the elasticity of substitution in the goods and labor market (η^p, η^w) is 8. This is consistent with evidence that the average price markup of U.S. firms is around 10-15 percent [Basu and Fernald (1995)]. Since there appears to be no consensus in the literature for the average markup in the U.S.

¹¹Forty searches converged to the same values, seven searches were cases where the numerical optimization procedure failed to converge, and the remaining three converged to values with much lower likelihood numbers.

¹²Because the MH algorithm is initialized with the estimated mode and Hessian, we check the gradient and the conditioning number of the Hessian at the mode and plot slices of the likelihood around the mode. We sample one million draws from the posterior distribution and discard the first 20,000 draws. The sample is thinned by every 20 draws. A step size of 0.3 yields an acceptance ratio of 0.307 for the estimation of the benchmark model. Diagnostic tests for convergence include drawing trace plots, verifying if the chain is well mixed, and performing Geweke's ((2005), pp. 149-150) Separated Partial Means test. Results are contained in a separate Estimation Appendix, available upon request.

¹³We set $\alpha = 0.36$, as in Kydland and Prescott (1982). This value is in line with the average share of compensation and two thirds of proprietors' income to GDP from 1983 to 2008, which is roughly 0.62. Another commonly calibrated number is 0.7, which is based on national income accounting.

labor market, we pick the same value for η^w by symmetry. The steady state inflation rate, π , is assumed to be 1.

The elasticity of output to government capital, α^G , cannot be identified without information about the capital stocks. The empirical literature has a wide range of values for α^G , ranging from a small negative number [Evans and Karras (1994)], zero [Kamps (2004)], to near 0.4 [Pereira and de Frutos (1999)].¹⁴ In a conventional neoclassical growth model with lump-sum financing, $\alpha^G = 0.1$ can deliver a long-run multiplier of 4 for a permanent increase in government investment [Baxter and King (1993)]. A priori, we believe that a multiplier much larger than 4 is empirically unlikely. For the baseline estimation, we calibrate $\alpha^G = 0.05$. Sensitivity analysis explores two alternative cases where $\alpha^G = 0$ and $\alpha^G = 0.1$. We find that the data cannot distinguish between the three values for α^G (see table 4), as the log marginal data densities in the three cases are virtually identical.

The rest of the calibrated parameters are steady-state fiscal variables computed from the means of our data sample: the federal government consumption to output share is 0.070, the federal government investment to output share is 0.004, the federal debt to annualized output share is 0.386, the average marginal federal labor tax rate is 0.209, the capital tax rate is 0.196, and finally, the consumption tax rate is 0.015. When computing these shares, we use an output measure that is consistent with our model specification, namely the sum of consumption, investment, and total government purchases.

The first three columns in table 1 list the prior distributions for all estimated parameters. For the parameters that also appear in Smets and Wouters (2007), our priors are either the same as or more diffuse than theirs. The domains cover a range of parameter values estimated by previous studies.

A parameter less encountered in the literature is the share of non-savers, μ . Forni, Monteforte, and Sessa (2007) and Iwata (2009) center the prior at 0.5 but obtain an estimate around 0.35. Lopez-Salido and Rabanal's (2006) estimate using U.S. data over a similar sample period is between 0.10 to 0.39. Based on this information, we choose a beta prior with a mean of 0.3 and standard deviation equal to 0.1.

The priors for the fiscal parameters were chosen to be fairly diffuse and cover a reasonably large range of the parameter space. To stabilize debt as a share of output, government spending and transfers should respond negatively to a debt increase, while taxes should respond positively. We assume normal distributions for the fiscal instruments' responses to debt (the γ 's) with a mean of 0.15 and standard deviation of 0.1. While these priors place a larger probability mass in the regions of expected signs, a small probability is allowed for the opposite signs.¹⁵ Our guidance to determine the prior range for the γ 's is based on two considerations. First, when the γ 's are too high, an overshooting occurs resulting in oscillation patterns that are not observed in the data. Second, when the γ 's are too low, under active monetary policy (in the sense of Leeper (1991)), there does not exist an equilibrium. As capital and labor taxes are progressive in the tax code, we impose the sign restrictions that φ_K and φ_L are positive and follow a gamma distribution. Since we incorporate Social Security taxes in our labor tax revenues, the labor tax rate elasticity is expected to be a value

¹⁴See Leeper, Walker, and Yang (2009) for more discussion on this literature.

¹⁵Note that the priors for each of the γ 's have a positive mean, since the expected signs are reflected in the policy rules.

below the capital tax rate elasticity (since Social Security contributions have a cap and are regressive). The parameter measuring the co-movement between capital and labor tax rates (σ_{KL}) is assumed to have a normal distribution with a mean of 0.2 and a standard deviation of 0.1. The domain covers the range of past estimates for this parameter [see Leeper, Plante, and Traum (forthcoming) and Yang (2005)].

A priori, our model does not impose many restrictions as to whether government debt crowds out or in investment. Table 3 quantifies the extent of crowding out based on 30,000 draws from the prior (and posterior) distributions. It records the percentage of draws that lead to crowding out of investment on impact of various fiscal shocks. Except for government consumption and transfer increases, the priors can deliver positive or negative investment responses following expansionary fiscal policy shocks. The table also reports the 5th and 95th cumulative present-value investment multipliers generated from the prior draws following various fiscal shocks.¹⁶ With the exception of a government investment increase or consumption tax decrease, the priors allow the 90 percent interval of investment multipliers to cover both signs. Even though the present-value investment multipliers for government investment are positive and for consumption taxes are negative, on impact the priors do not restrict the sign of the investment response. Thus, in these cases (as well as the others) the model allows for the medium- and long-run dynamics to vary qualitatively from the short-run dynamics. We explore the economics of both short-run and longer-run responses to expansionary fiscal shocks that lead to debt growth in section 4.

3.2. Posterior Estimates. The last four columns in table 1 provide the mode, mean, and 5 and 95 percentiles from the posterior distributions. Figures 1 and 2 plot priors against posterior distributions. The plots suggest that the data contain information for identifying most parameters. The inverse Frisch elasticity, κ , appears to be weakly identified.¹⁷ The somewhat weak identification of φ_K and φ_L are probably due to the fact that tax revenues, not tax rates, are used as observables. Model comparison results between the benchmark model and an alternative specification where $\varphi_K = \varphi_L = 0$ indicate that the data cannot distinguish between the two specifications [see table 4].

Overall, the estimates for the parameters that also appear in other New Keynesian models are comparable to those estimated with postwar U.S. data. Table 2 summarizes priors and posterior estimates of the common parameters in Smets and Wouters (2007) and Guerron and Rubio-Ramirez (2009), which also use U.S. data. Our estimate of risk aversion γ is much bigger than the values estimated or calibrated in previous studies.¹⁸ The mean estimate of κ implies that the Frisch labor elasticity is 0.48, a value within the range of the findings of micro studies [see Browning, Hansen, and Heckman (1999)]. The mean estimate for the Calvo

¹⁶ Investment multipliers are defined as the present-value sum of investment changes in levels divided by the present-value sum of changes in a fiscal variable. Depending on the fiscal shock that triggers debt growth, the denominator can be changes in capital, labor, or consumption tax revenues, government consumption or investment, or transfers. The sums are over 1000 quarters, and present values are discounted by the model-implied interest rate path.

¹⁷An examination of the singular value decomposition of the Fisher information matrix of the likelihood suggests that κ is the weakest identified parameter in the model.

¹⁸The literature has a wide range of estimates for this parameter. See Guvenen (2006) for the literature survey on the estimates of the intertemporal elasticity of substitution for consumption—the inverse of risk aversion.

parameter for price adjustments, ω_p , is 0.82. This implies that pricing decisions last five and a half quarters on average, a duration slightly larger than micro study estimates [see Klenow and Malin (2009) and the references therein]. The mean estimate for the Calvo parameter for wage adjustments, ω_w , is 0.69, implying that wage contracts are revised roughly every three quarters.

The mean long-run response of the nominal interest rate to inflation is consistent with recent estimates. The mean response to output is similar to Taylor’s (1993) estimate. We also find evidence of a substantial degree of interest rate smoothing, consistent with the literature on estimated interest rate rules. The rest of this section discusses parameters less encountered in the literature and how well the model fits the data.

3.2.1. Fraction of non-savers. The mean estimate for the fraction of non-savers μ is 0.18, and 5th and 95th percentiles are [0.10, 0.27]. The relatively low fraction of non-savers suggests the importance of forward-looking behaviors in explaining the aggregate effects of fiscal policy. Although myopic behaviors have been important in explaining fiscal policy effects in the literature since Mankiw (2000) and Gali, Lopez-Salido, and Valles (2007), our mean estimate is much smaller than the commonly calibrated value of 0.5, based on the single-equation estimation of a consumption function [Campbell and Mankiw (1989) and Gali, Lopez-Salido, and Valles (2007)]. Previous studies have incorporated non-savers into models so that aggregate consumption can increase following a positive government spending shock. Given the mean estimates for the benchmark model, our model requires a fraction of 0.45 in order to deliver a positive short-term consumption response to an increase in government consumption, which falls outside of the 90-percent interval. Our results are consistent with vector autoregression (VAR) estimates.¹⁹ VARs with either federal government consumption alone or the sum of federal government consumption and investment find that for our sample period (1983Q1-2008Q1), an increase in government spending does not have a positive effect on consumption, whether consumption is defined as the sum of non-durables and services or total personal consumption expenditures.²⁰

Technically, the presence of non-savers helps smooth aggregate consumption because non-savers often have qualitatively different consumption responses from savers to shocks, despite that non-savers’ consumption is more volatile than savers’ because non-savers have no means to save. Thus, when we assume habit formation for consumption in the model (the results not shown), the estimate for μ is even smaller, the posterior mode is around 0.1. Given the sensitivity of the estimate for μ to model specifications, further research is needed to understand the role of non-savers in explaining aggregate effects of fiscal policy.

3.2.2. Fiscal rules. Most fiscal instruments have the expected signs for their responses to government debt as a share of output, despite the fact that the priors allow for the opposite signs. The mean estimate for government investment’s response is negative, but the

¹⁹The VARs are ordered with government spending first, followed by GDP, consumption, and investment. Identification is achieved using a Cholesky decomposition. When consumption excludes durables, investment is defined as the sum of gross private domestic investment and durables.

²⁰The evidence of the positive consumption response following a government spending shock found in the literature [e.g. Gali, Lopez-Salido, and Valles (2007) and Bouakez and Rebei (2007)] is based on a longer postwar U.S. sample, and consumption excludes durables.

90-percent interval encompasses zero (as does the 90-percent interval for the response of transfers to debt), indicating that government investments (and transfers) were not used systematically for controlling debt growth.

As in Leeper, Plante, and Traum (forthcoming), we find that the federal government relies on raising income taxes and reducing government consumption to stabilize debt. Differing from their results, labor income taxes in our estimation play a slightly more important role than capital taxes for fiscal adjustments.

3.3. Model Fit. Figure 3 plots the autocorrelations and cross-correlations for the observables (solid line) and the 90 percent posterior intervals for the theoretical moments from the model (dashed lines). Many correlations fall within the posterior intervals, suggesting that the model is able to mimic several cross-correlations in the data within a one year horizon. Most cross-correlations involving fiscal policy variables fall within the posterior intervals, with the exception of some cross-correlations with consumption and labor tax revenues. Also, the correlations between transfers and consumption are estimated to be a little high and between capital tax revenues and investment to be a little low. Correlations with hours worked appear to be the worst matched.

3.4. Debt Dynamics. Historical decompositions in figure 4 show the model implied dynamics of real debt and the real primary deficit (defined as the sum of government consumption, investment, and transfers less total tax revenues).²¹ The top row shows the breakdown of all shocks organized by monetary, fiscal (aggregating tax, government spending, and transfer shocks), and structural (aggregating all non-policy shocks) shocks; the bottom two panels further decompose among the six fiscal shocks. The thick solid lines are the model-implied data series, and the units on the y-axis are percentage deviations from the steady state path. The bottom two panels plot the decomposition for the six fiscal shocks. They suggest that the dominant driving forces (in the order from the darkest to lightest shade) are government consumption, capital tax, labor tax, and transfer shocks.

Overall, fiscal shocks are the most important sources for movements in real debt. The series imply that the fiscal position gradually worsened throughout the 1980s. The increases in federal government consumption and investment (rising from about 8 percent of GDP in 1979 to 10 percent in 1986) and reductions in individual and corporate income tax rates (enacted in the Economic Recovery Tax Act of 1981 and the Tax Reform Act of 1986) are the main factors contributing to this surge. Debt started to decline around 1994 until 2000. The improvement was mainly due to an increase in individual income tax rates on the relatively high income brackets (enacted in Omnibus Budget Reconciliation Act of 1993) and a decrease in federal spending (falling from 9 percent in 1990 to about 6 percent in the late 1990s). Interestingly, the model implied deficit series experiences a small spike in 1991, moving from above the trend to below the trend in the first quarter of 1991 before continuing to further increase above the trend until approximately 1993. This corresponds

²¹We use the posterior mean estimates and the Kalman smoother to obtain values of the innovations for each shock. The discrepancies between the model implied values and the shock contributions are due to initial conditions [see Alvarez-Lois, Harrison, Piscitelli, and Scott (2008) for more details on the construction of the decomposition].

with the Omnibus Budget Reconciliation Act of 1990's enactment to increase the highest income tax rates, which became effective January 1, 1991.

In addition to fiscal shocks, monetary policy shocks also play an important role in real debt movements. The top row of figure 4 shows that monetary policy shocks tended to offset the fiscal shocks' impact on debt or the primary deficit. During the boom in the 1990s, monetary policy became relatively tight starting in late 1994. A positive interest rate shock drove up the real value of debt by lowering the price level and increasing interest rate payments. Similarly but in the opposite direction, when the federal funds rate was gradually lowered during the economic downturn in early 2000s, monetary policy contributed to lowering the real value of debt.

4. THE CROWDING OUT EFFECT OF GOVERNMENT DEBT

As we have shown, fiscal and monetary shocks are the main driving forces for the real value of U.S. government debt in the post-1983 sample. In this section, we investigate the economics underlying the links between investment and government debt, focusing on the debt changes driven by fiscal and monetary policy shocks.

To understand how investment is determined in the model, we first examine the model implied Tobin's q [Tobin (1969)]. We define $q_t \equiv \frac{\xi_t(1+\tau_t^C)}{\lambda_t^S}$, where ξ_t and λ_t^S are the Lagrangian multipliers for the budget constraints (3) and (5) in the savers' utility optimization problem. q_t has the interpretation of the shadow price of increasing capital at the end of t by one unit.²² Investment tends to rise when the deviation of q_t from its steady state value is positive. The log-linearized expression of Tobin's q from its steady state (denoted by variables in hats) is

$$\hat{q}_t = \frac{\tau^C}{1 + \tau^C} \hat{\tau}_t^C - (\hat{R}_t - E_t \hat{\pi}_{t+1}) + \beta(1 + \tau^C)(1 - \tau^K)r^K E_t \hat{r}_{t+1}^K - [\tau^K r^K \beta (1 + \tau^C)] E_t \hat{\tau}_{t+1}^K + \beta(1 - \delta) E_t \hat{q}_{t+1} - \frac{\beta \tau^C (1 - \delta)}{(1 + \tau^C)} E_t \hat{\tau}_{t+1}^C, \quad (43)$$

where $r_t^K \equiv \frac{R_t^K}{P_t}$ is the real rate of return for private capital.

Consistent with the conventional view, the negative coefficient on the real interest rate ($\hat{R}_t - E_t \hat{\pi}_{t+1}$) indicates that a higher real rate discourages investment. Equation (43) also points out that investment decisions are influenced by several other factors. A higher expected real return on capital makes agents want to invest more, while a higher expected capital tax rate does the opposite. In the model, the consumption tax shock serves as a relative price shock between consumption and investment, because consumption taxes are only levied on consumption goods. An increase in the consumption tax signals a fall in the price of investment goods relative to the consumption goods. In contrast, expectations of future cheaper investment goods, through an expected increase in the future consumption tax rate, delay investment decisions. Finally, the higher expected shadow price indicates

²²One unit of investment goods can be exchanged for $\frac{1}{1+\tau_t^C}$ units of consumption goods, and the Tobin's q is expressed relative to the shadow price of increasing consumption goods that has the same value of one unit of investment goods.

that capital is more valuable in the future, so it encourages current investment. Next, we examine how fiscal and monetary shocks affect investment decisions.

4.1. Fiscal Policy and Crowding Out. When a fiscal shock hits the economy, it has a direct effect on the evolution of variables from the shock itself and a secondary effect through future debt financing. Delayed financing causes government debt to accumulate, which brings forth future policy adjustments that can affect both the current economy (through policy expectations) and the future economy (through the implementation of policy adjustments). We first look at the relationship between debt and investment implied by the overall effect of a fiscal policy shock. Later we contrast the results with the net effect from debt financing.

Figures 5 and 6 show one standard deviation impulse responses to all policy shocks. The solid lines are the responses under the posterior mean estimates. The dotted-dashed lines give the 5th and 95th percentiles based on the posterior distributions. The y-axis measures percentage deviations from the steady state, and the x-axis denotes the number of years after a shock. We return to the dashed lines later, and the last column in figure 6 (for a monetary policy shock) is discussed in section 4.2.

While all the expansionary fiscal shocks cause government debt to grow, investment can rise or fall, depending on the type of shock. When government investment is increased or the capital tax rate is decreased, higher debt is associated with higher investment, as shown by the solid lines in the second and third columns of figure 5. When government investment is productive, increases to government investment imply a higher stock of future government capital, which raises the marginal product of capital. Similarly, a reduction in the capital tax rate directly increases the after-tax rate of return for investment. Because the tax shock is persistent, this lowers expectations of future capital tax rates. Under either circumstance, investment rises because of the higher expected net return on capital. In the conventional view (as discussed in Elmendorf and Mankiw (1999)), the crowding out effect results from decreases in national saving, which shifts the supply curve in the loanable funds market to the left and drives up the real interest rate. A higher real rate in turn crowds out investment. Following an increase in government investment or a decrease in the capital tax rate, the dominant movement is a right shift of the demand curve in the loanable funds market (the investment schedule). The real interest rate rises initially to clear the loanable funds market, yet the higher expected return to capital or lower expected capital tax rate causes investment to rise, as suggested by equation (43).

When labor or consumption tax rates decrease (the first and second columns of figure 6), the probability intervals allow for investment to be crowded in or out in the short run. A negative labor tax shock has the direct effect to increase labor demand, which drives up the marginal product of capital, and hence makes agents want to invest more. However, the debt-financed labor tax cut induces policy adjustments, which involve higher capital and labor tax rates and lower government spending. Under most combinations of fiscal adjustments drawn from the posterior distributions, investment falls. For the reduction in the consumption tax rate, the direct effect is a reduction in investment as investment goods become relatively more expensive than consumption goods. However, the more aggressively the monetary authority responds to inflation, the more the real interest rate declines, making savers more willing to invest.

Among the six fiscal shocks, the only two shocks that produce debt effects largely consistent with the conventional view are government consumption and transfers shocks. The first column of figure 5 shows that following an increase in government consumption, the real interest rate rises and investment falls. When the government absorbs a larger share of goods, it leaves the private sector with fewer goods to invest. As goods become more valuable, the real interest rate rises to clear the goods market. A similar pattern is also observed with the transfer shock (the third column of 6). Rising transfers increase aggregate consumption because non-savers consume more due to higher disposable income. Higher demand for goods drives up the real interest rate, discouraging investment. Although the real interest rate rises most of the times for either shock, it can be negative initially. Since higher demand leads to higher prices and inflation expectations, the real interest rate (the nominal rate less inflation expectations) can fall initially if prices are less sluggish to adjust.

The above discussion shows that debt growth need not lead to rising real interest rates and falling investment. The relationships among these variables depend on the source of the fiscal innovation that bring forth the growth in government debt.

4.1.1. *Crowding-out effects of debt financing.* One important channel in which government debt can affect the economy is through policy adjustments necessary to stabilize debt growth. We turn to the effect of debt financing on investment. In particular, we focus on distorting financing mechanisms because they are the more relevant instruments for debt financing in practice.

To sort out the effects of distorting financing due to debt accumulation, we construct a hypothetical economy that is identical to the benchmark economy except for the manner in which government debt is financed. In the hypothetical economy, the government follows a balanced budget rule, and $\gamma_{GC} = \gamma_{GI} = \gamma_K = \gamma_L = \gamma_Z = 0$. We introduce a new lump-sum tax X_t on savers, which only shows up in the savers' budget constraints, and evolves to satisfy

$$X_t = G_t^C + G_t^I + Z_t - \tau_t^K \frac{R_t^K}{P_t} v_t K_{t-1} - \tau_t^L \frac{W_t}{P_t} L_t - \frac{\tau_t^C}{1 + \tau_t^C} C_t \quad (44)$$

As savers possess rational expectations and have access to asset markets, the lump-sum tax is non-distorting and does not affect savers' marginal decisions. In this economy, the dynamics of aggregate variables are not affected by debt accumulation and debt financing.

Returning to figures 5 and 6, we now examine the dashed line responses, which are the differences between the mean estimates of the benchmark and hypothetical economies, or the responses due to distortionary financing of debt. The investment responses are mostly negative, with the exception of the government investment shock which has almost no response. At the same time, the movements in the real interest rate are negligible. The result indicates that the crowding out effect of government debt is more pronounced under distortionary fiscal financing.

Since the combination of distorting financing policies imposed here is those obtained from estimation, our results reflect the effects of debt financing under the fiscal adjustments observed in the post-1983 sample. It is, however, worth noting that among the five fiscal instruments allowed to respond to debt growth, not every instrument has a negative effect on investment. Raising capital and labor tax rates and reducing government investment

have negative impacts on investment, but cutting government consumption or transfers do not. This implies that the government should avoid the former set of policies to minimize the crowding-out effect from debt financing.

4.2. Monetary Policy and Crowding Out. The historical decompositions in section 3.4 show that monetary policy shocks are also important for real debt movements. In addition, the literature has noted that monetary policy can influence the degree of crowding out [Buiter and Tobin (1980) and Gali, Lopez-Salido, and Valles (2007)]. The last column of figure 6 reports the impulse responses to a debt surge driven by a tightening in monetary policy (an increase in the nominal interest rate). A higher nominal interest rate leads the price level to fall and hence the real interest to rise. This induces savers to substitute away from capital and into government bonds. The real value of government debt rises because the higher nominal rate increases interest payments to service debt. Since the debt growth is followed by the rising real rate and declining investment, it is consistent with the conventional view on the crowding out effect of government debt.

To further investigate how monetary policy can influence the degree of crowding out, we compare the responses to various fiscal shocks under different response magnitudes of the nominal interest rate to inflation and output: $\phi_\pi = 1.05, 1.7,$ and 2.5 ; $\phi_Y = 0, 0.11,$ and 0.3 . All other parameters are kept at their posterior mean estimates. Figures 7 and 8 depict the responses following one standard deviation exogenous changes in each fiscal instrument (as in figures 5 and 6). The y-axis is in percentage deviations from the steady state. The x-axis denotes the numbers of years after the shock.

4.2.1. Response magnitudes to inflation. Varying how aggressively the monetary authority reacts to inflation can have qualitative and quantitative effects on the responses of variables following expansionary fiscal shocks. The monetary authority's attitude in maintaining price stability influences inflation expectations and the real rate, which can change the short-run response of investment under some values of ϕ_π .

Following an increase in government consumption or transfers, the price level rises due to increased demand. The weaker the monetary authority's reaction to inflation (the lower value of ϕ_π), the larger the decrease in the real interest rate, and hence the smaller the crowding out effect of government debt, as shown by the first and last columns of figure 7. The crowding out effect for an increase in government consumption or transfers is smallest when $\phi_\pi = 1.05$. Following the labor tax cut, the price level falls initially because of increased production but soon turns positive from higher consumption. When the monetary authority is less aggressive in maintaining price stability, the real interest rate can turn negative, and government debt can crowd in investment under $\phi_\pi = 1.05$ for the first year, compared to the crowding-out result under $\phi_\pi = 1.7, 2.5$.

In contrast, the positive investment response is the smallest (or can turn negative) under government investment or capital tax shocks when $\phi_\pi = 1.05$. Both shocks initially reduce the price level due to increased levels of production. When the monetary authority acts less aggressively to control the falling price level, the real interest rate rises more, resulting in a smaller positive investment response. In the case of a government investment increase, under $\phi_\pi = 1.05$, government debt crowds out investment for the first two years, before it turns positive. As the price level falls more under the smaller value of ϕ_π , the real marginal

cost of production is also higher, leading profits to fall. Declining profits reduce the demand for capital, and hence, investment can be below its steady state level in the short run (as shown by the dashed lines).

For the consumption tax shock, investment can also be crowded in or out in the short run depending on the value of ϕ_π . As mentioned earlier, a lower consumption tax rate makes investment goods relatively more expensive than consumption goods, leading investment to decline. However, higher values for ϕ_π lead to larger declines in the real interest rate following a consumption tax shock, making savers more willing to invest. As shown by dashed-dotted line in the second to the last column in figure 8, when $\phi_\pi = 2.5$, government debt can crowd in investment in the short run under a reduction in the consumption tax rate.

4.2.2. Response magnitudes to output. Although we do not observe a systematic relationship between the monetary authority's response to inflation and investment, a systematic relationship exists between the monetary authority's response to output and investment. Figure 8 shows that a larger value of ϕ_Y is associated with a smaller investment response (either a less positive or more negative response). Higher ϕ_Y values imply that the central bank raises the nominal interest more in response to an output expansion due to a deficit-financed fiscal intervention. A higher nominal interest rate implies a higher real rate (either a more positive or less negative change), which induces agents to demand more government bonds and less capital. Hence, investment rises less (or falls more). For the case of a government investment increase or consumption tax decrease, on impact private investment can be crowded in or out depending on the values of ϕ_Y .

The fiscal shocks that we consider all have initial expansionary effects on output. Figure 8 also shows that the more aggressively the monetary authority responds to output, the less expansionary the fiscal shocks are. Our results highlight the importance of accounting for monetary policy when assessing fiscal policy effects, especially during recessions when deficit-financed fiscal interventions and more accommodative monetary policy actions are often practiced.²³

5. REDUCED-FORM ESTIMATES

Although our results support the conventional view that government debt can crowd out investment, such a causal relationship is difficult to infer without controlling for which policy innovation triggers a debt expansion. Thus, the prevailing empirical approach to search for evidence of the crowding out effect by focusing on the relationship between government debt or deficits and real interest rates is inappropriate, subject to serious identification problems.

²³Our analysis is conditional on an active monetary policy and passive fiscal policy regime, in the sense of Leeper (1991). Davig and Leeper (2009) estimate Markov-switching rules of monetary and fiscal policy for the U.S. economy. They find that government consumption can generate a much larger private consumption response under a passive monetary and active fiscal regime than under an active monetary and passive fiscal regime.

To demonstrate this, we simulated 500 data series using the mean estimates of the posterior distribution,²⁴ and estimated the reduced-form equations

$$\begin{aligned}\hat{r}_t &= \beta_0 + \beta_1 \hat{s}_t^b + \epsilon_t \\ \hat{r}_t^{10} &= \beta_0 + \beta_1 \hat{s}_t^b + \epsilon_t\end{aligned}$$

for each data series. \hat{s}_t^b is the model-implied debt-to-GDP ratio, and \hat{r}_t is the model-implied one period real interest rate. Since the literature often focuses on the relationship between debt and interest rates with a longer horizon, we also construct \hat{r}_t^{10} , the model-implied ten year real rate, which is generated by imposing the pure expectations-hypothesis of the term structure.

Table 5 displays the mean and 90 percentile estimates of β_1 from the regressions. The reduced-form estimates from the model can be positive, negative, or equal to zero. The relationship depends strongly on the relative magnitudes of the simulated disturbances. When only government consumption shocks are simulated (and all other disturbances are set to zero), there is a small, positive relationship between the current real interest rate and debt-to-GDP ratio, consistent with the impulse responses in figure 5. In contrast, when only labor tax shocks are simulated, the reduced-form relationship is more likely to be estimated as negative or zero. This result offers an explanation as to why empirical studies that focus on the reduced-form relationship between interest rates and debt are often inconclusive. Since the real interest rate movements depend on the source of policy shocks that result in debt growth, and different shocks can have different implications on interest rates, the estimated sign depends on the relative magnitudes of innovations and thus, the sample period estimated.

Aside from producing a wide-range of reduced-form estimates on the coefficient of debt to interest rates, the model, once feeding the estimated sequence of historical innovations (calculated using the Kalman smoother), can also reproduce magnitudes of β_1 consistent with the literature. Table 6 gives the reduced-form estimates using the mean parameters of the posterior distribution, as well as the 90 percentile intervals of reduced-form estimates from the estimated posterior distribution of the parameters. A one percentage increase in the debt-to-GDP ratio from its benchmark (steady state) value is estimated to increase the 10 year real interest rate by 2.7 basis points. Previous studies [Engen and Hubbard (2005), Gale and Orszag (2004)] find that a one percentage point increase in the government debt to GDP ratio leads to an approximately one to six basis points increase in the real interest rate. For instance, the estimate of Engen and Hubbard (2005), a 4.7 basis point increase, falls within the range of estimates from the posterior distribution. Furthermore, 61% of the regression estimates were insignificant at the 10% level, consistent with the findings of Engen and Hubbard (2005).

Given the complicated interactions among various fiscal interventions, monetary policy, debt, interest rates, and investment, it is not surprising that the reduced-form approach cannot identify the crowding out effect of government debt. This suggests that one should be cautious in interpreting reduced-form relationships between the real interest rate and debt as evidence of crowding-out.

²⁴For each case, we simulated a series 1000 periods long and burned the first 900 periods, leaving a sample size comparable to our sample length for estimation of the model.

6. COUNTERFACTUAL APPLICATIONS

Upon isolating fiscal innovations in the data, we pursue two counterfactual exercises to examine the effects of two tax interventions; one was to rein in debt growth (the tax increases in the 1990s), and the other was to stimulate the economy (the tax cuts in the early 2000s).

6.1. The Impact of Tax Increases in the 1990s. We ask how the economy would have evolved if there had been no fiscal policy innovations from 1993Q1 to 1997Q2, a period of contractionary fiscal policy (roughly between the enactment of Omnibus Budget Reconciliation Act of 1993 and the Taxpayer Relief Act of 1997). Figure 9 plots five paths of key macroeconomic variables in the model: solid lines are conditional on the estimated sequence of all shocks; dashed lines are conditional on the estimated sequence of all shocks except capital and labor tax disturbances; dotted lines are conditional on the estimated sequence of all shocks except expenditure shocks (government consumption, government investment, and transfer shocks); the dotted-dashed lines are conditional on the estimated sequence of all shocks except fiscal policy shocks; and the stars are conditional on the estimated sequence of all shocks except the monetary policy shock.

The real value of federal government debt would have continued to grow if exogenous tax changes had not occurred. The capital and labor tax increases enacted over the period led debt to be 11 percent lower than it otherwise would have been by the second quarter of 1997. To a lesser extent, innovations to government consumption and investment, consumption taxes, and transfers also contributed to debt retirement; debt would have been 6 percent higher without changes to these fiscal instruments. The contractionary tax actions had a negative effect on private investment: investment would have been about 7 percent higher without the tax increases. This provides evidence that fiscal adjustments, which are necessary to maintain budget sustainability, can have nontrivial negative effects on the economy. If the government had delayed actions to control the debt growth, the consequences to retire debt would have been more severe as the magnitude of the tax increases necessary to offset the debt growth would have been larger.

In contrast, when all fiscal policy shocks during this period are turned off, investment would have been 0.5 percent lower than its observed path in the second quarter of 1997. Note that when government expenditures alone are reduced for fiscal adjustments, they have a positive effect on investment (but a negative effect on output). This effect offsets the negative investment response from the higher tax rates. The effects of debt retirement for individual historical episodes depend on the specific combination of fiscal adjustments.

The figure also shows the effects of monetary policy disturbances over the period. During this episode, the monetary authority raised the nominal interest rate to combat inflationary pressures. Without these positive monetary policy shocks, output would have been higher and government debt lower (as interest payments would have been lower without the increased interest rates). It appears that the monetary and fiscal authorities did not coordinate their policies to reduce the level of debt, as the fiscal authority acted to reduce the deficit and the monetary authority's actions worked to sustain it.

6.2. The Impact of Tax Cuts in 2001 and 2002. Next, we ask how the economy would have evolved if capital and labor tax or monetary policy innovations were turned off from

2001Q3 to 2002Q4 (after the enactment the Economic Growth and Tax Relief Reconciliation Act of 2001). Since both monetary and fiscal policies were adopted to counteract the recession in 2001, we examine the relative effectiveness of countercyclical fiscal and monetary policies for this particular recession. Figure 10 contains three paths of key macroeconomic variables in the model: solid lines are conditional on the estimated sequence of all shocks; dashed lines are conditional on the estimated sequence of all shocks except capital and labor tax disturbances, and the dotted-dashed lines are conditional on the estimated sequence of all shocks except the monetary policy shock.

The real value of federal government debt would have continued its trend of decline from the late 1990s if discretionary tax changes had not occurred. The tax cuts made the real value of federal debt 7 percent higher than it otherwise would have been by the end of 2002. On the other hand, the lower interest rates due to discretionary monetary policy helped reduce interest payments to service debt and hence the total amount of debt. The lower nominal interest rate reduced the real value of debt by 3 percent by 2002Q4.

The tax cuts in 2001 and 2002 had mild expansionary effects: in 2002Q4, consumption, output, and investment would have been 0.5, 0.8, and 2.2 percent higher than if the tax cuts were not enacted. Monetary policy, however, appeared to be more effective in counteracting the recession. In particular, consumption and output were 0.95 and 1.2 percent higher than they would have been without discretionary monetary policy actions. This result suggests that while deficit-financed tax cuts can stimulate the economy in the short run, the effects are relatively small. Monetary policy appeared to play a more substantial role in preventing the economy from sliding into a bigger recession in 2001.

7. ROBUSTNESS ANALYSIS

In this section we investigate the robustness of the effects of expansionary fiscal policy on investment under a number of alternative model specifications. The results of these robustness checks are summarized in table 7. To get a sense of how the investment response varies quantitatively across model specifications, we report impact and cumulative present value multipliers [calculated as in footnote 16] for each case.

7.1. Varying α^G . The elasticity of output to government capital, α^G , cannot be identified from our observables. For the baseline estimation, we calibrate $\alpha^G = 0.05$. To determine how sensitive our estimates and inferences are to this parameter, we estimate the model for two alternative cases where $\alpha^G = 0.001$ and $\alpha^G = 0.1$. We find that the data cannot distinguish between the three values for α^G (see table 4), as the log marginal data densities in the three cases are virtually identical. The second and third columns of table 7 show the investment multipliers when $\alpha^G = 0.001$ and $\alpha^G = 0.1$. Varying α^G only affects the multipliers following a government investment shock. When α^G is very small, a government investment shock resembles a non-productive government consumption shock. The more productive government investment is, (i.e. the larger α^G is), the higher the cumulative present value multiplier is, as the returns to investment rapidly increase.

7.2. No Automatic Stabilizers. Since the estimation for the contemporaneous response of income tax rates to output is largely influenced by our priors (see figure 1), we check if

our results are very sensitive to the estimates of automatic stabilizer coefficients, φ_K and φ_L . We estimate a version of the model where these parameters are calibrated to zero. The fourth column of table 7 shows that this only substantially affects the multipliers following a government investment shock. Following a government investment shock, output rises as productivity increases. Automatic stabilizers cause capital and labor taxes to increase as well, dampening the overall effects.

7.3. Standard Calibration of Consumption and Labor Supply Elasticities. Our benchmark estimates of the intertemporal elasticity of substitution ($1/\gamma$) and the Frisch elasticity of labor supply ($1/\kappa$) differ from the standard values used in the RBC literature. We also re-estimate the model when these parameters are calibrated to more typical values ($\gamma = \kappa = 1$). Once again, overall this modification has small quantitative effects (see column 5 of table 7). It raises the present-value government investment multiplier and causes investment to increase on impact following a consumption tax shock.

8. CONCLUDING REMARKS

We estimate the crowding out effect of U.S. government debt using a structural DSGE approach. Two contributions to the literature follow. First, our model has a rather detailed fiscal specification, which can account for the dynamics between fiscal and monetary policy interactions and induced by debt and fiscal financing. Most fiscal instruments are found to respond to debt systematically: when the debt-to-output ratio rises, the government reduces its purchases and transfers and increases income taxes to rein in debt growth. Further, by allowing for myopic and forward-looking behaviors in the model, our estimate confirms that forward-looking behaviors are important for the effects of U.S. fiscal policy.

Second, whether the crowding out effect of government debt holds depends on the source of policy innovation that brings forth debt growth. In addition, distorting fiscal financing and monetary policy are found to be important for gauging the extent of crowding out of investment. We find that increases in future capital and labor taxes in order to offset debt accumulation have a negative impact on investment. Also, the responses of real interest rates and investment to debt growth can be influenced by how aggressive the central bank is in stabilizing inflation and output. Contrary to the conventional view, our estimation shows no systematic relationship between government debt and real interest rates.

Our estimation focuses on the post-1983 U.S. sample. Leeper, Plante, and Traum (forthcoming) find evidence of instability in the estimates of fiscal policy parameters across various sample periods. Davig and Leeper (2009) estimate Markov-switching rules for monetary and fiscal policy from 1949Q1 to 2008Q4 and find multiple regime changes among active/passive monetary/fiscal policies. Future studies investigating the crowding out effect of government debt or the interactions between monetary and fiscal policies must confront these instability issues and account for the possibility of passive monetary policy and active fiscal policy in earlier samples.

APPENDIX A. THE EQUILIBRIUM SYSTEM OF THE BENCHMARK MODEL

The equilibrium system in the log-linearized form consists of the following equations:

- Real interest rates $\left(\hat{R}_t - E_t \hat{\pi}_{t+1}\right)$

$$\frac{1}{\gamma} \left(\hat{R}_t - E_t \hat{\pi}_{t+1}\right) + \hat{C}_t^S - \frac{1}{\gamma} \hat{u}_t^b + \frac{1}{\gamma} E_t \hat{u}_{t+1}^b = E_t \hat{C}_{t+1}^S$$

- Tobin's q, see equation (43).

- Investment

$$s(1 + \beta) \hat{I}_t - \hat{q}_t + s \hat{u}_t^i - \beta s E_t \hat{I}_{t+1} - \beta s E_t \hat{u}_{t+1}^i = s \hat{I}_{t-1}$$

- Capital utilization

$$\hat{q}_t + \frac{\psi}{1 - \psi} \hat{v}_t = \hat{r}_t^K - \frac{\tau^K}{1 - \tau^K} \hat{\tau}_t^K + \frac{\tau^C}{1 + \tau^C} \hat{\tau}_t^C$$

- Law of motion for private capital

$$\hat{K}_t - \delta \hat{I}_t + r^K (1 - \tau^K) (1 + \tau^C) \hat{v}_t = (1 - \delta) \hat{K}_{t-1}$$

- Phillips curve

$$\begin{aligned} \hat{\pi}_t - \alpha \frac{(1 - \beta \omega_p)(1 - \omega_p)}{\omega_p(1 + \beta \chi^p)} \hat{r}_t^K - (1 - \alpha) \frac{(1 - \beta \omega_p)(1 - \omega_p)}{\omega_p(1 + \beta \chi^p)} \hat{w}_t + \frac{(1 - \beta \omega_p)(1 - \omega_p)}{\omega_p(1 + \beta \chi^p)} \hat{u}_t^a - \hat{u}_t^p \\ - \frac{\tau^C(1 - \beta \omega_p)(1 - \omega_p)}{(1 + \tau^C)\omega_p(1 + \beta \chi^p)} \hat{\tau}_t^C - \frac{\beta}{1 + \beta \chi^p} E_t \hat{\pi}_{t+1} = \frac{\chi^p}{1 + \beta \chi^p} \hat{\pi}_{t-1} - \alpha^G \frac{(1 - \beta \omega_p)(1 - \omega_p)}{\omega_p(1 + \beta \chi^p)} \hat{K}_{t-1}^G, \end{aligned}$$

where $w_t \equiv \frac{W_t}{P_t}$ is the real wage rate.

- Wage

$$\begin{aligned} [1 + \zeta(1 - \beta \omega_w)] \hat{w}_t + \left(\frac{1 + \beta \chi^w}{1 + \beta}\right) \hat{\pi}_t - [\kappa \zeta(1 - \beta \omega_w)] \hat{L}_t - \frac{\zeta(1 - \beta \omega_w)(1 - \mu) \lambda^S \gamma}{[(1 - \mu) \lambda^S + \mu \lambda^N]} \hat{C}_t^S \\ - \frac{\zeta(1 - \beta \omega_w) \mu \lambda^N \gamma}{[(1 - \mu) \lambda^S + \mu \lambda^N]} \hat{C}_t^N - \frac{\zeta(1 - \beta \omega_w) \tau^L}{1 - \tau^L} \hat{\tau}_t^L - \hat{u}_t^w - \frac{\beta}{1 + \beta} E_t \hat{w}_{t+1} - \frac{\beta}{1 + \beta} E_t \hat{\pi}_{t+1} \\ = \left(\frac{1}{1 + \beta}\right) \hat{w}_{t-1} + \frac{\chi^w}{1 + \beta} \hat{\pi}_{t-1} \end{aligned}$$

where $\zeta \equiv \frac{1 - \omega_w}{\omega_w(1 + \beta)(1 + \eta^w \kappa)}$.

- Production factors

$$\hat{K}_{t-1} + \hat{v}_t = \hat{L}_t + \hat{w}_t - \hat{r}_t^K$$

- Production function

$$\hat{Y}_t = \hat{u}_t^a + \alpha \hat{v}_t + \alpha \hat{K}_{t-1} + (1 - \alpha) \hat{L}_t + \alpha^G \hat{K}_{t-1}^G$$

- Non-saver households' consumption rule

$$C^N \hat{C}_t^N = (1 - \tau^L) wL \left(\hat{w}_t + \hat{L}_t\right) - \tau^L wL \hat{\tau}_t^L + Z \hat{Z}_t$$

- Aggregate consumption

$$C \hat{C}_t = (1 - \mu) C^S \hat{C}_t^S + \mu C^N \hat{C}_t^N$$

- Producer and consumer price indices

$$\hat{\pi}_t = \hat{\pi}_t + \frac{\tau^C}{1 + \tau^C} (\hat{\tau}_t^C - \hat{\tau}_{t-1}^C)$$

- Aggregate resource constraint

$$Y\hat{Y}_t = C\hat{C}_t + I\hat{I}_t + G^I\hat{G}_t^I + G^C\hat{G}_t^C$$

- Government budget constraint

$$\begin{aligned} & B\hat{B}_t + \tau^K r^K K (\hat{\tau}_t^K + \hat{r}_t^K + \hat{v}_t + \hat{K}_{t-1}) + \tau^L wL (\hat{\tau}_t^L + \hat{w}_t + \hat{L}) + \frac{\tau^C C}{1 + \tau^C} \hat{C}_t + \frac{\tau^C C}{(1 + \tau^C)^2} \hat{\tau}_t^C \\ = & \frac{B}{\beta} (\hat{R}_{t-1} + \hat{B}_{t-1} - \hat{\pi}_t) + G^I\hat{G}_t^I + G^C\hat{G}_t^C + Z\hat{Z}_t \end{aligned}$$

- Monetary and fiscal policy rules are listed in (34).and (37)-(42).

APPENDIX B. DATA DESCRIPTION

Unless otherwise noted, the following 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 1.1.2 line 3), PRI is proprietors' income (table 1.1.2 line 3), and CI is capital income. Capital income is defined as rental income (table 1.1.2 line 12), corporate profits (table 1.1.2 line 13), interest income (table 1.1.2 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).

Government Expenditure. Government expenditure, G^C , is defined as government consumption expenditure (table 3.2 line 20) and government net purchases of non-produced assets (table 3.2 line 43), minus government consumption of fixed capital (table 3.2 line 44).

Government Investment. Government investment, G^I , is defined as government gross investment (table 3.2 line 41).

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).

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 U.S. Department of Labor).

Emp:: Civilian Employment: Sixteen Years & Over, measured in thousands, Seasonally Adjusted. (from U.S. Department of Labor, Bureau of Labor Statistics, CE16OV). Turned into an index where 1992:3 = 100.

Hours worked are then defined as

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

Wage Rate. The wage rate is defined as Nonfarm Business, All Persons, Hourly Compensation Duration : index, 1992 = 100, Seasonally Adjusted (from U.S. Department of Labor).

Inflation. The gross inflation rate is defined using the GDP deflator for personal consumption expenditures (line 2 in Table 1.1.4).

Interest Rate. The nominal interest rate is defined as the average of daily figures of the Federal Funds Rate (from the Board of Governors of the Federal Reserve System).

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 Pop, constructed so that 1992:3 = 1,

Pop:: Civilian noninstitutional population, ages 16 years and over, Seasonally Adjusted. Number in thousands (from U.S. Bureau of Labor Statistics), LNS10000000,

and x = consumption, investment, hours worked, government spending, government investment, capital tax revenues, consumption tax revenues, labor tax revenues, and transfers. The real wage rate is defined in the same way, except that it is not divided by the total population.

Parameters	Prior			Posterior			
	func.	mean	std.	mode	mean	5 %	95%
preference and technology							
γ , risk aversion	G	1.5	0.3	2.7	2.7	2.2	3.3
κ , inverse Frisch labor elast.	G	2	0.5	2	2.1	1.4	3
μ , fraction of non-Ricar. households	B	0.3	0.1	0.18	0.18	0.099	0.27
frictions							
ω_w , wage stickiness	B	0.5	0.1	0.76	0.69	0.59	0.79
ω_p , price stickiness	B	0.5	0.1	0.87	0.82	0.75	0.88
ψ , capital utilization	B	0.6	0.15	0.32	0.38	0.22	0.55
s , investment adj. cost	N	6	1.5	7.5	7.4	5.2	9.6
χ^w , wage partial indexation	B	0.5	0.15	0.36	0.39	0.19	0.62
χ^p , price partial indexation	B	0.5	0.15	0.25	0.31	0.13	0.54
fiscal policy							
γ_{GC} , govt consumption resp to debt	N	0.15	0.1	0.23	0.17	0.0051	0.33
γ_{GI} , govt investment resp to debt	N	0.15	0.1	-0.019	0.0033	-0.11	0.14
γ_K , capital tax resp to debt	N	0.15	0.1	0.16	0.17	0.028	0.32
γ_L , labor tax resp to debt	N	0.15	0.1	0.20	0.16	0.021	0.3
γ_Z , transfers resp to debt	N	0.15	0.1	0.087	0.074	-0.02	0.18
φ_K , capital resp. to output	G	0.75	0.35	0.63	0.78	0.3	1.4
φ_L , labor resp. to output	G	0.40	0.15	0.34	0.43	0.15	0.83
monetary policy							
ϕ_π , interest rate resp. to inflation	N	1.5	0.25	1.7	1.9	1.6	2.3
ϕ_y , interest rate resp. to output	N	0.125	0.10	0.11	0.095	0.048	0.15
ρ_r , lagged interest rate resp.	B	0.5	0.2	0.86	0.86	0.83	0.89
serial correl. in disturbances							
ρ_a , technology	B	0.5	0.2	0.89	0.89	0.84	0.95
ρ_b , preference	B	0.5	0.2	0.94	0.94	0.9	0.97
ρ_i , investment	B	0.5	0.2	0.54	0.55	0.41	0.68
ρ_w , wage markup	B	0.5	0.2	0.39	0.3	0.15	0.47
ρ_p , price markup	B	0.5	0.2	0.27	0.34	0.11	0.59
ρ_{GC} , government consumption	B	0.5	0.2	0.95	0.96	0.93	0.98
ρ_{GI} , government investment	B	0.5	0.2	0.74	0.76	0.64	0.86
ρ_K , capital tax	B	0.5	0.2	0.89	0.89	0.84	0.95
ρ_L , labor tax	B	0.5	0.2	0.92	0.94	0.89	0.98
ρ_C , consumption tax	B	0.5	0.2	0.91	0.90	0.84	0.95
ρ_Z , transfer	B	0.5	0.2	0.82	0.79	0.7	0.88
std. of shocks							
σ_a , technology	IG	0.1	2	0.64	0.64	0.56	0.74
σ_b , preference	IG	0.1	2	2.3	2.4	1.9	3.1
σ_m , monetary policy	IG	0.1	2	0.14	0.14	0.13	0.16
σ_i , investment	IG	0.1	2	4.2	4.3	3.6	5.2
σ_w , wage markup	IG	0.1	2	0.23	0.27	0.22	0.33
σ_p , price markup	IG	0.1	2	0.18	0.19	0.16	0.23
σ_{GC} , government consumption	IG	1	∞	2.7	2.8	2.5	3.1
σ_{GI} , government investment	IG	1	∞	3.9	4	3.5	4.5
σ_K , capital tax	IG	1	∞	4.2	4.2	3.8	4.7
σ_L , labor tax	IG	1	∞	2.2	2.3	2	2.5
σ_C , consumption tax	IG	1	∞	3.1	3.3	2.9	3.7
σ_Z , transfers	IG	1	∞	2.6	2.6	2.3	3
σ_{KL} , co-movement btw K and L taxes	N	0.2	0.1	0.21	0.23	0.17	0.29

TABLE 1. Prior and Posterior Distributions for the Estimated Parameters.

	Smets and Wouters		Fernandez-Villaverde et al		Our estimates	
sample period	1966:1-2004:4		1959:1-2007:1		1983:1-2008:1	
γ , risk aversion	1.38	$N(1.5, 0.37)$	1	calibrated	2.70	$G(1.5, 0.3)$
κ , inverse Frisch elast.	1.83	$N(2, 0.75)$	1.17	$N(1, 0.25)$	2.1	$G(2, 0.5)$
f , investment adj. cost	5.74	$N(4, 1.5)$	9.74	$N(4, 1.5)$	7.4	$N(6, 1.5)$
ψ , capital utilization	0.54	$B(0.5, 0.15)$	0.001	calibrated	0.38	$B(0.6, 0.15)$
ω_w , wage stickiness	0.70	$B(0.5, 0.1)$	0.68	$B(0.5, 0.1)$	0.69	$B(0.5, 0.1)$
ω_p , price stickiness	0.66	$B(0.5, 0.1)$	0.82	$B(0.5, 0.1)$	0.82	$B(0.5, 0.1)$
χ^w , wage indexation	0.58	$B(0.5, 0.15)$	0.62	$B(0.5, 0.1)$	0.39	$B(0.5, 0.15)$
χ^p , price indexation	0.24	$B(0.5, 0.15)$	0.63	$B(0.5, 0.15)$	0.31	$B(0.5, 0.15)$
ϕ_π , interest to inflation	2.04	$N(1.5, 0.25)$	1.29	$N(1.5, 0.125)$	1.9	$N(1.5, 0.25)$
ϕ_y , interest to output	0.08	$N(0.12, 0.05)$	0.19	$N(0.12, 0.05)$	0.095	$N(0.125, 0.1)$
ρ_m , Taylor persistence	0.81	$B(0.75, 0.1)$	0.77	$B(0.75, 0.1)$	0.86	$B(0.5, 0.2)$

TABLE 2. Comparisons of priors and posterior estimates for common parameters. Smets and Wouters' (2007) and our estimates are posterior means while Fernandez-Villaverde's et al (2009) are posterior medians.

	Shocks	$G^C \uparrow$	$G^I \uparrow$	$\tau^K \downarrow$	$\tau^L \downarrow$	$\tau^C \downarrow$	$Z \uparrow$
Impact	Prior	100%	44%	3%	70%	60%	100%
	Posterior	100%	0%	0%	83%	30%	100%
PV	Prior	(-1.05, 0.042)	(2.38, 4.28)	(-1.56, 0.66)	(-0.9, 0.33)	(-0.53, -0.1)	(-0.98, 0.072)
	Posterior	(-1.52, -0.29)	(0.53, 0.99)	(-0.6, -0.16)	(-2.24, 3.21)	(-1.15, -0.01)	(-0.96, -0.12)

TABLE 3. Prior-posterior analysis. The top two rows are percentage of prior/posterior draws that lead to crowding out of investment following various fiscal shocks on impact. The bottom two rows are 90 percent intervals of cumulative present value multipliers for prior/posterior draws following various fiscal shocks. Results are based on 30,000 draws from the prior and posterior distributions.

Key Parameters	Model				
	benchmark ($\alpha_g = 0.05$)	$\alpha_g = 0.001$	$\alpha_g = 0.1$	$\varphi_K = \varphi_L = 0$	only transfers adjust to B
preference and technology					
γ , risk aversion	2.7 (2.2, 3.3)	2.7 (2.2, 3.3)	2.7 (2.2, 3.3)	2.7 (2.2, 3.3)	2.7 (2.2, 3.3)
κ , inverse Frisch labor elast.	2.1 (1.4, 3)	2.1 (1.3, 3)	2.1 (1.4, 3)	2.1 (1.3, 3)	2.1 (1.4, 3)
μ , fraction of non-Ricar. households	0.18 (0.099, 0.27)	0.18 (0.1, 0.28)	0.18 (0.1, 0.28)	0.18 (0.1, 0.28)	0.2 (0.11, 0.3)
frictions					
ω_w , wage stickiness	0.69 (0.59, 0.79)	0.69 (0.59, 0.79)	0.7 (0.59, 0.79)	0.7 (0.59, 0.79)	0.69 (0.59, 0.79)
ω_p , price stickiness	0.82 (0.75, 0.88)	0.81 (0.74, 0.88)	0.82 (0.75, 0.88)	0.82 (0.74, 0.88)	0.82 (0.74, 0.87)
ψ , capital utilization	0.38 (0.22, 0.55)	0.38 (0.23, 0.55)	0.37 (0.22, 0.54)	0.38 (0.22, 0.55)	0.39 (0.24, 0.55)
f , investment adj. cost	7.4 (5.2, 9.6)	7.3 (5.2, 9.5)	7.4 (5.2, 9.6)	7.3 (5.2, 9.6)	7.4 (5.2, 9.6)
χ^w , wage partial indexation	0.39 (0.19, 0.62)	0.39 (0.19, 0.62)	0.38 (0.18, 0.61)	0.38 (0.18, 0.62)	0.38 (0.19, 0.62)
χ^p , price partial indexation	0.31 (0.13, 0.54)	0.32 (0.13, 0.55)	0.3 (0.13, 0.54)	0.3 (0.13, 0.53)	0.29 (0.13, 0.53)
fiscal policy					
γ_{GC} , govt consumption resp to debt	0.17 (0.0051, 0.33)	0.16 (0.0045, 0.32)	0.16 (0.0074, 0.32)	0.16 (0.0034, 0.32)	-
γ_{GI} , govt investment resp to debt	0.0033 (-0.11, 0.14)	-0.0031 (-0.12, 0.13)	0.0075 (-0.11, 0.16)	0.0006 (-0.11, 0.14)	-
γ_K , capital tax resp to debt	0.17 (0.028, 0.32)	0.17 (0.03, 0.32)	0.17 (0.027, 0.32)	0.16 (0.017, 0.31)	-
γ_L , labor tax resp to debt	0.16 (0.021, 0.3)	0.16 (0.023, 0.3)	0.15 (0.022, 0.3)	0.15 (0.02, 0.3)	-
γ_Z , transfers resp to debt	0.074 (-0.02, 0.18)	0.075 (-0.02, 0.18)	0.07 (-0.02, 0.18)	0.069 (-0.02, 0.18)	0.2 (0.15, 0.38)
φ_K , capital resp. to output	0.78 (0.3, 1.4)	0.78 (0.3, 1.4)	0.73 (0.3, 1.4)	-	0.71 (0.29, 1.4)
φ_L , labor resp. to output	0.43 (0.15, 0.83)	0.43 (0.15, 0.83)	0.4 (0.15, 0.82)	-	0.38 (0.14, 0.81)
monetary policy					
ϕ_π , interest rate resp. to inflation	1.9 (1.6, 2.3)	1.9 (1.6, 2.3)	1.9 (1.6, 2.2)	1.9 (1.6, 2.3)	1.9 (1.6, 2.3)
ϕ_y , interest rate resp. to output	0.095 (0.048, 0.15)	0.093 (0.047, 0.15)	0.095 (0.051, 0.15)	0.094 (0.05, 0.15)	0.093 (0.048, 0.15)
ρ_r , lagged interest rate resp.	0.86 (0.83, 0.89)	0.86 (0.83, 0.89)	0.86 (0.83, 0.89)	0.86 (0.83, 0.89)	0.86 (0.83, 0.89)
model comparison					
log marginal data density	-63.45	-63.65	-63.30	-64.17	-66.44
Bayes Factor rel. to benchmark	1	exp[0.2]	exp[-0.15]	exp[0.72]	exp[2.99]

TABLE 4. Sensitivity Analysis. The table reports posterior means and 90% credible intervals (in parenthesis) for various models. In addition, log-marginal data densities calculated using Geweke's (1999) modified harmonic mean estimator are reported along with Bayes factors relative to the benchmark model. The log-marginal data densities are calculated using a truncation parameter of 0.5.

dependent variable	all innovations	gov. consumption shocks	labor tax shocks
\hat{r}_t	-0.0005 (-0.015, 0.0117)	0.0008 (-0.0002, 0.0021)	0.0 (-0.0003, 0.0002)
\hat{r}_t^{10}	-0.0201 (-0.2097, 0.1108)	0.0182 (-0.0043, 0.0406)	-0.0058 (-0.0087, -0.0026)

TABLE 5. Reduced-form regression results from simulated data series using the mean posterior parameter estimates. Estimates are for β_1 from the reduced-form regression $x_t = \beta_0 + \beta_1 \hat{s}_t^b + \epsilon_t$ where the dependent variable is either the one period real interest rate \hat{r}_t or the ten year real interest rate \hat{r}_t^{10} . The table reports the mean and 90% interval (in parenthesis) from 500 simulated data series.

	Dependent variable	
	\hat{r}_t	\hat{r}_t^{10}
$\hat{\beta}_1$	0.0132 (0.0113, 0.0151)	0.0269 (-0.0045, 0.0614)

TABLE 6. Reduced-form regression results from the estimated sequence of the historical innovations. Estimates are for β_1 from the reduced-form regression $x_t = \beta_0 + \beta_1 \hat{s}_t^b + \epsilon_t$ where the dependent variable is either the one period real interest rate \hat{r}_t or the ten year real interest rate \hat{r}_t^{10} . The table reports the mean and 90% interval (in parenthesis) from the posterior distribution of parameter estimates.

		Investment Multipliers				
		Benchmark $\alpha_G = 0.05$	Varying α_G $\alpha_G = 0.001$ $\alpha_G = 0.1$		No Output Responses	$\gamma = 1,$ $\kappa = 1$
$G^C \uparrow$	PV	-0.69	-0.68	-0.68	-0.67	-0.52
	impact	-0.066	-0.066	-0.066	-0.064	-0.053
$G^I \uparrow$	PV	0.84	-0.34	6.58	3.48	2.6
	impact	-0.011	-0.029	0.084	0.032	0.024
$\tau^K \downarrow$	PV	-0.42	-0.43	-0.42	-0.44	-0.45
	impact	-0.073	-0.074	-0.074	-0.077	-0.055
$\tau^L \downarrow$	PV	0.45	0.43	0.44	0.44	0.29
	impact	0.0097	0.0096	0.0091	0.0091	0.007
$\tau^C \downarrow$	PV	0.33	0.32	0.33	0.33	0.42
	impact	-0.02	-0.02	-0.02	-0.02	0.015
$Z \uparrow$	PV	-0.42	-0.42	-0.42	-0.42	-0.32
	impact	-0.017	-0.017	-0.016	-0.017	-0.014

TABLE 7. Robustness checks for the short and long run effects of expansionary fiscal policy on investment. The rows display impact and cumulative present value (PV) multipliers for investment following various shocks. Present value multiplier calculations are described in footnote 16.

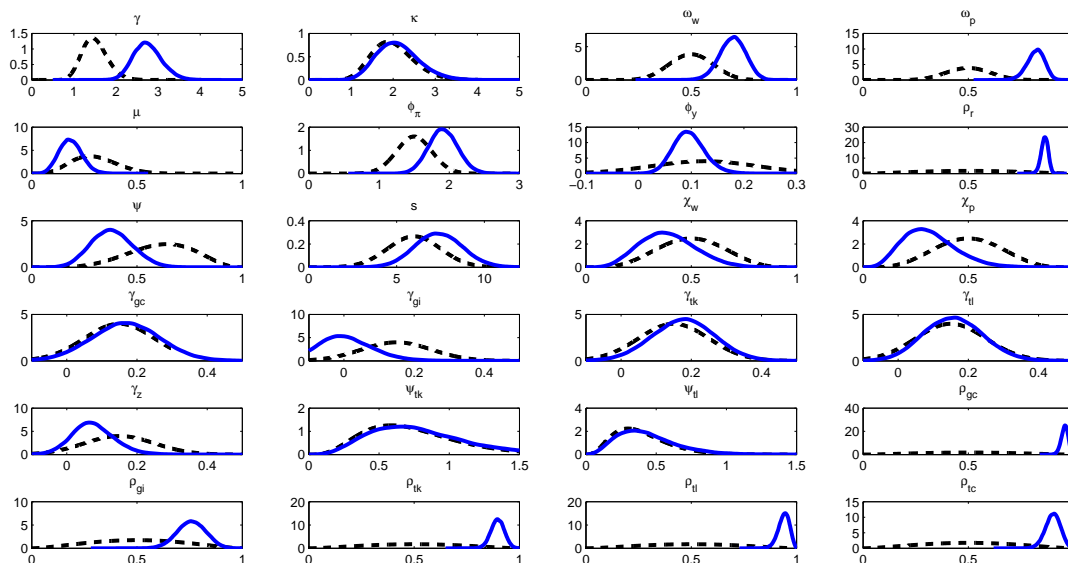


FIGURE 1. Prior (dashed lines) vs. posterior (solid lines) distributions.

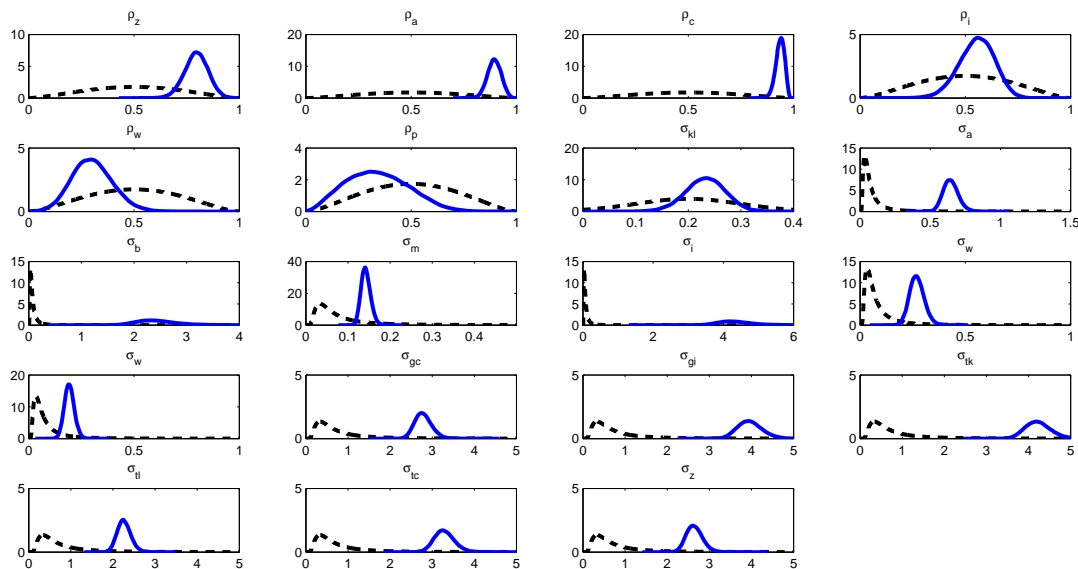
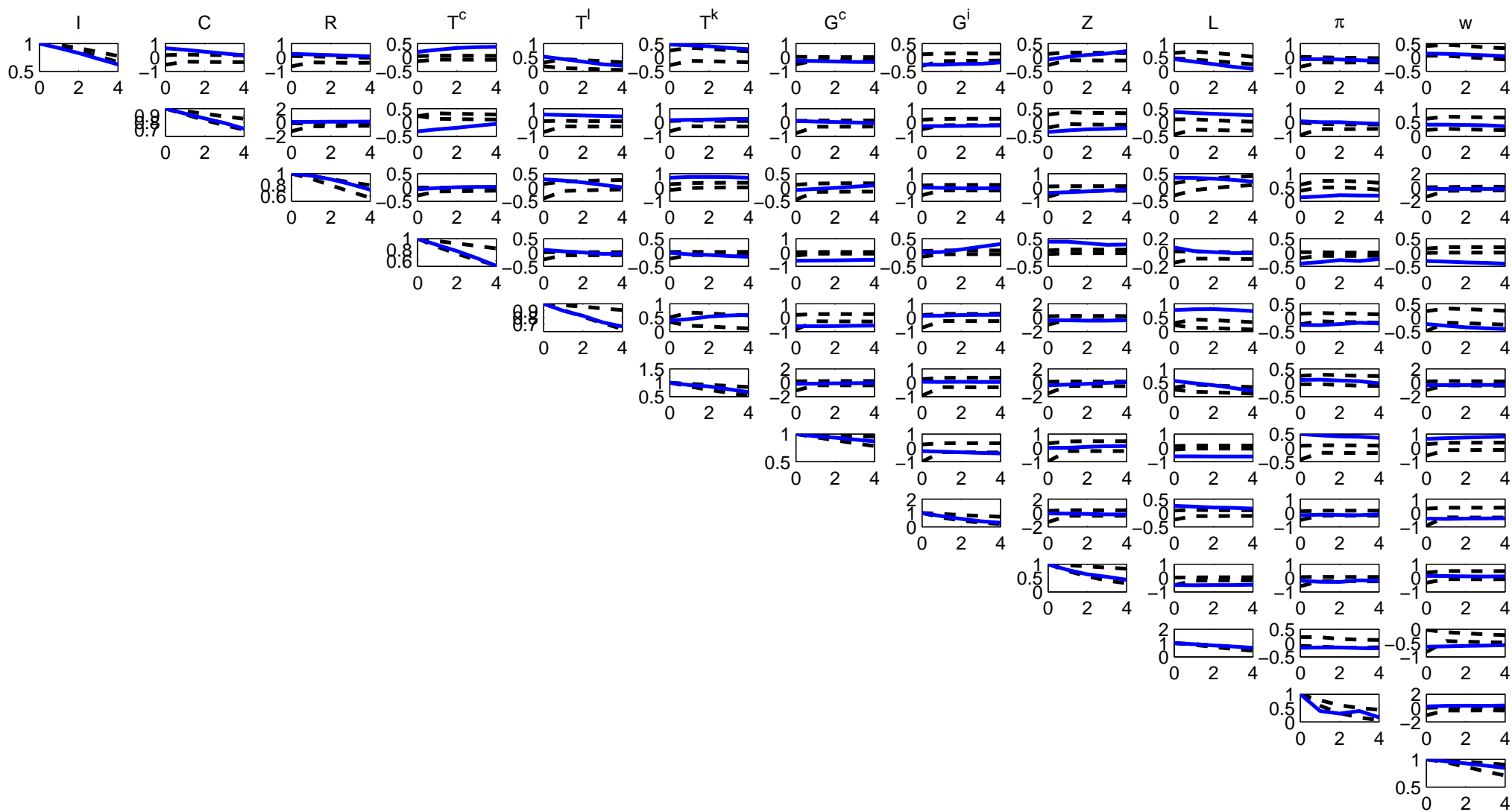


FIGURE 2. Prior (dashed lines) vs. posterior (solid lines) distributions.

FIGURE 3. Autocorrelations and cross-correlations for the data (solid lines) and the model (dashed lines—90 percent posterior intervals). T^c , T^l , and T^k are consumption, labor, and capital tax revenues. The x-axis is in quarters.



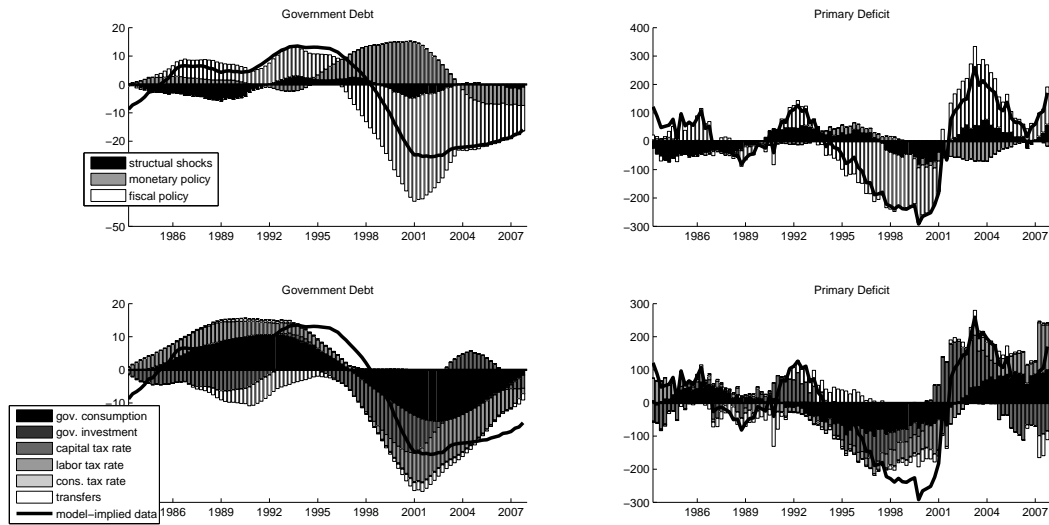


FIGURE 4. Historical variance decomposition for model-implied federal debt and primary deficits. Top row: breakdown by fiscal, monetary, and all other shocks; bottom row: breakdown among fiscal shocks—the main four shocks are government consumption, capital tax, labor tax, and transfers shocks, in the order of the darkest to lightest shade. Units for the y-axis are percentage deviation from the steady state path.

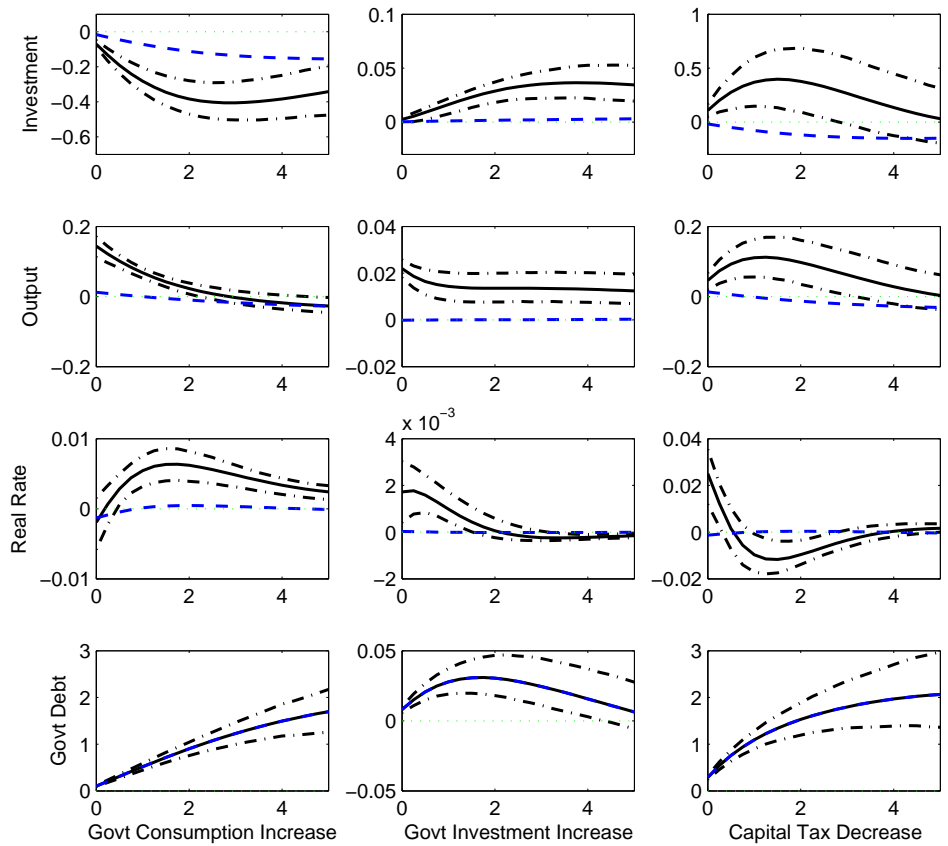


FIGURE 5. Impulse responses for fiscal shocks of one standard deviation. Solid lines: estimated mean responses; dotted-dashed lines: 90 percent pointwise probability intervals; dashed lines: responses due to distorting fiscal financing. X-axis is in years.

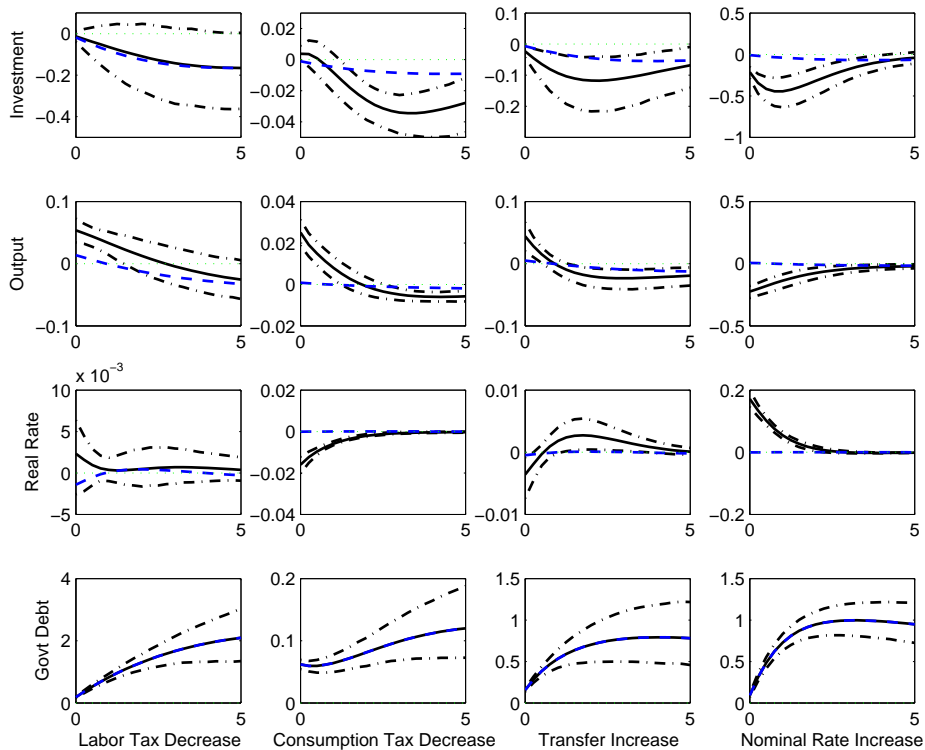


FIGURE 6. Impulse responses for fiscal shocks of one standard deviation. Solid lines: estimated mean responses; dotted-dashed lines: 90 percent pointwise probability intervals; dashed lines: responses due to distorting fiscal financing. X-axis is in years.

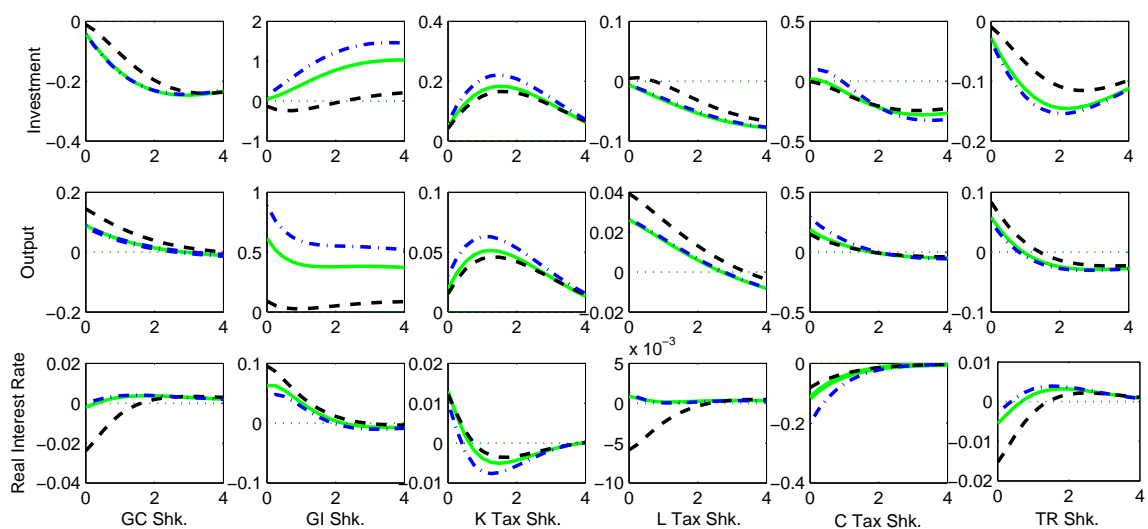


FIGURE 7. Impulse responses under various response magnitudes to inflation. Dashed lines: $\phi_\pi = 1.05$; solid lines: $\phi_\pi = 1.70$; dotted dashed lines: $\phi_\pi = 2.5$. The y-axis is in percentage deviations from the steady state. The x-axis measures years.

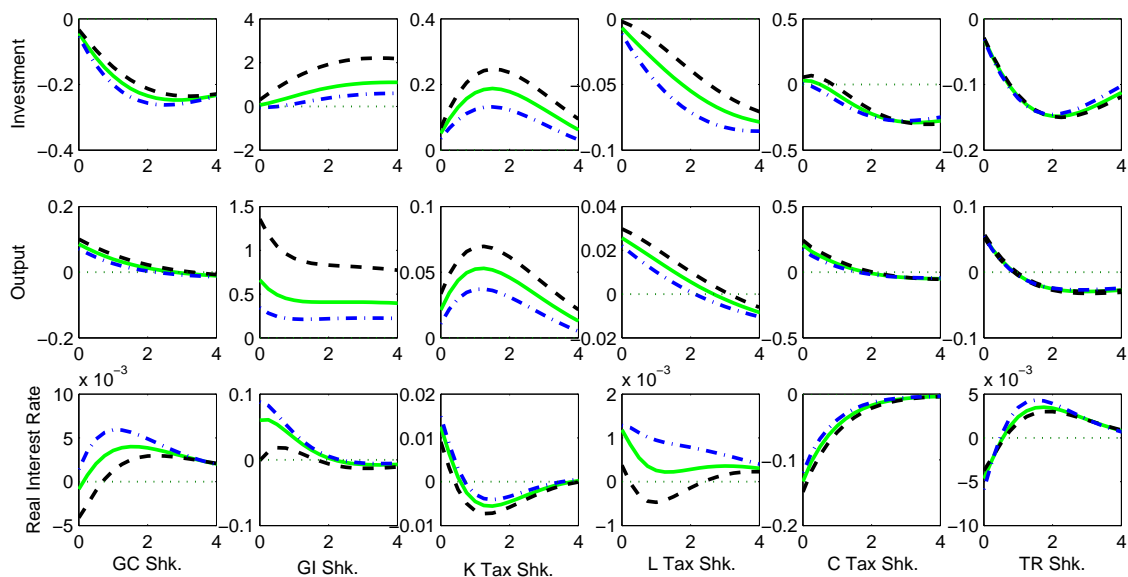


FIGURE 8. Impulse responses under various response magnitudes to output. Dotted-dashed lines: $\phi_Y = 0$; solid lines: $\phi_Y = 0.11$; dashed lines: $\phi_Y = 0.3$. The y-axis is in percentage deviations from the steady state. The x-axis measures years.

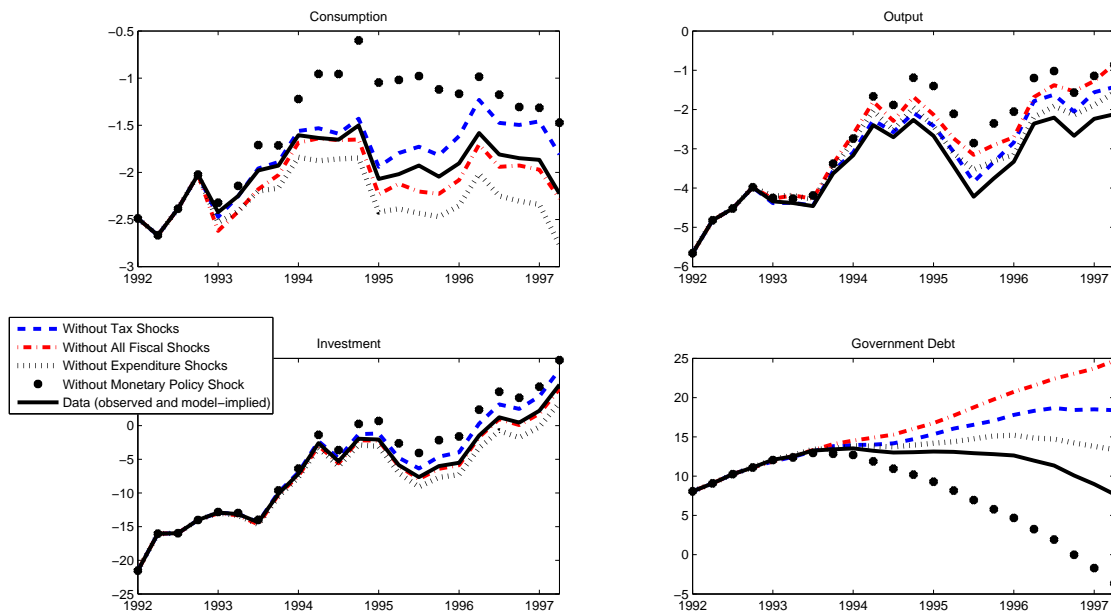


FIGURE 9. Counterfactual exercise: tax increases in the 1990s. Solid lines: conditional on the estimated sequence of all shocks; dashed lines: capital and labor tax shocks turned off; dotted lines: fiscal expenditure shocks turned off; dotted-dashed lines: all fiscal policy shocks turned off; and stars: monetary policy shock turned off.

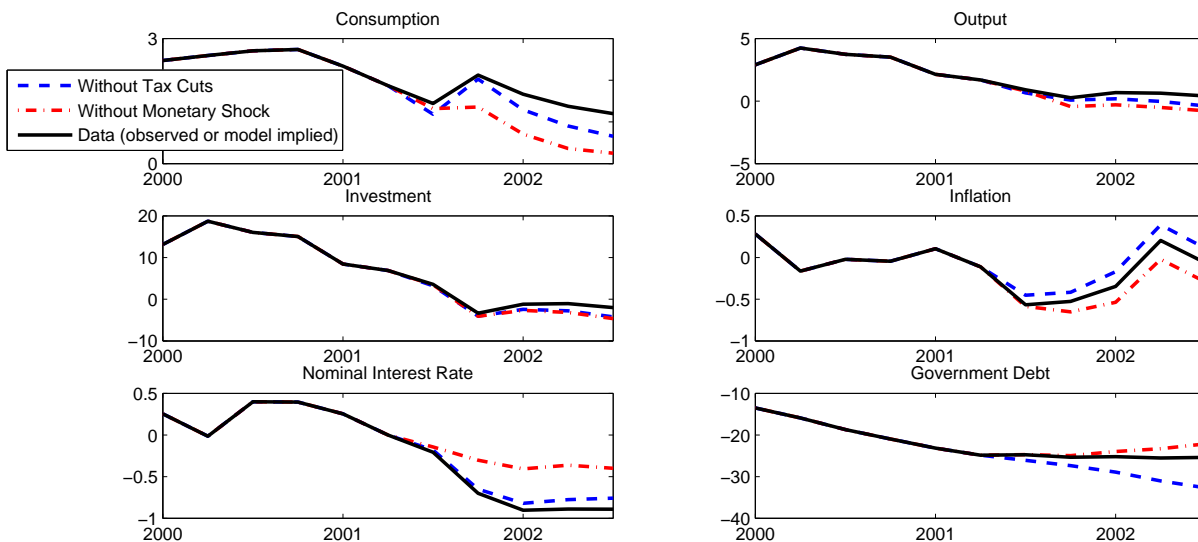


FIGURE 10. Counterfactual exercise: tax cut in 2001 and 2002. Solid lines: conditional on the estimated sequence of all shocks; dashed lines: capital and labor tax shocks turned off; and dotted-dashed lines: monetary policy shock turned off.

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