WHEN DOES GOVERNMENT DEBT CROWD OUT INVESTMENT?

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Abstract. We examine when government debt crowds out investment for the U.S. economy using an estimated New Keynesian model with detailed fiscal specifications and accounting for monetary and fiscal policy interactions. Whether investment is crowded *in* or *out* in the short term depends on policy shocks triggering debt expansions: Higher debt can crowd in investment for cutting capital tax rates or increasing government investment. Contrary to the conventional view, no systematic relationships between real interest rates and investment exist, explaining why reduced-form regressions are inconclusive about crowding-out. At longer horizons, distortionary financing is important for the negative investment response to debt.

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

JEL Codes: C11; E63; H63

1. Introduction

The past decade in the United States has been a period of tremendous fiscal activity: expenditures on the war on terrorism, a series of income tax cuts, and fiscal stimulus and financial rescue programs. These activities have occurred against a backdrop of demographic trends that suggest accelerated spending increases in medical programs and Social Security. The Congressional Budget Office (2012) projects that federal debt in

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2043 will exceed 250 percent of GDP and rise rapidly afterwards under the alternative fiscal scenario, suggesting an unsustainable path for U.S. fiscal policy.[1] Will this government debt accumulation lead to declines in (i.e. crowd out) private investment? This paper quantifies the extent of crowding out in a dynamic stochastic general equilibrium (DSGE) model for the U.S. economy.

Two key factors drive the investment response to rising government debt: the source of policy changes that give rise to debt growth and distortionary debt financing. In the short run, the effect of government debt is mainly determined by the type of fiscal or monetary policy shock that triggers a debt expansion. Higher government debt can crowd *in* investment if the debt is generated by a reduction in capital tax rates or by an increase in productive government investment, because both raise the net return to capital. Over a longer horizon, distortionary financing plays an important role in the negative investment response following a debt expansion.

After World War II, many economists were concerned about the impact of government debt [e.g., Domar (1944), Leland (1944), 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.[2] Keynesian theory argues that when prices and wages are sticky, higher debt that is caused by deficit-financed tax cuts or spending increases adds to aggregate demand, leading income and output to increase. However, the deficits reduce public saving. If private saving and capital inflows do not increase enough to fully offset government borrowing, interest rates rise over time. Consequently, investment is crowded out, and capital and output eventually decline, negating the short-run expansionary benefits.

[1]Between the two fiscal scenarios projected, that is the extended baseline and the alternative scenario, the latter incorporates some policy changes that regularly have been made in the past and are widely expected to occur, and hence is more realistic.
[2]See Bernheim (1989) and Elmendorf and Mankiw (1999) for a detailed discussion.

Building on this conventional view, many empirical studies have estimated the reduced-form relationship between government debt (or deficits) and interest rates. A positive relationship between the two variables is viewed as evidence of crowding out. Literature surveys generally conclude a lack of consensus among the findings.[3] One of our core results is that a systematic reduced-form relationship between debt and real interest rates does not exist, even if government debt can reduce investment.

After isolating historical innovations, we evaluate the effects of two fiscal interventions: the tax increases in 1990s and the deficit-financed tax cuts during the recession in early 2000s. Counterfactual exercises find that the income tax increases from 1993Q1 to 1997Q2 were effective in controlling debt growth but had a negative effect on investment. Both countercyclical monetary and fiscal policies in 2001 and 2002 were expansionary. The interest rate cuts played a larger role in counteracting the recession by the second quarter of 2002, while tax cuts became more effective afterwards.

Methodologically, this paper is related to several DSGE analyses studying fiscal policy effects. A few gaps in fiscal specifications remain in this literature. One strand of papers estimates real business cycle models and thus is unable to capture monetary and fiscal policy interactions [e.g., Leeper et al. (2010)]. Another strand addresses policy interactions but does not account for distortionary financing [Leeper and Sims (1994) and Kim (2000)]. Several recent papers incorporate fiscal policy into New Keynesian models. Most of them omit government debt or only permit a limited set of instruments to respond to debt [Coenen and Straub (2005), López-Salido and Rabanal (2006), Ratto et al. (2009), Forni et al. (2009), Cogan et al. (2010), and Zubairy (forthcoming)].

[3]See Barth et al. (1984), Barth et al. (1991), Elmendorf and Mankiw (1999), Gale and Orszag (2003), Gale and Orszag (2004), and Engen and Hubbard (2005). 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), however, find that when the dependent variable is the change in the forward rate rather than the level, the positive coefficient is insignificant.

To address these omissions, we add fiscal details to a standard New Keynesian model [e.g., Del Negro et al. (2007) and Smets and Wouters (2007)]. Most fiscal instruments can respond to government debt. Instead of assuming all government spending is wasteful, productive government investment is distinguished from government consumption. We find that most fiscal instruments respond to debt systematically under rather diffuse priors. When the debt-to-output ratio rises, the government mainly relies on reducing its purchases and increasing income taxes to stabilize debt. Also, since the extent to which consumers are myopic has received much attention in the debate of fiscal policy effects, we include non-savers (also known as liquidity-constrained or rule-of-thumb agents), following Galí et al. (2007) and Forni et al. (2009). The estimated low share of non-savers suggests the importance of forward-looking behaviors in fiscal policy effects.

2. The Estimated Model

We estimate a New Keynesian model that includes a stochastic growth path, as in Del Negro et al. (2007) and Fernandez-Villaverde et al. (2010). The model includes forward-looking savers with access to complete asset and capital markets, and non-savers, who do not have access to financial or capital markets and consume all of their disposable income each period. Because non-savers have a higher marginal propensity to consume than savers, their presence allows stronger short-run demand effects following expansionary fiscal policy than in models with only savers. Non-savers break Ricardian equivalence, as lump-sum transfers are distortionary. Other features included are standard in New Keynesian models. The equilibrium system of the model (available in the online appendix) is log-linearized and solved by Sims's (2001) algorithm. Unless otherwise noted, all exogenous disturbances follow AR(1) processes.

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

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

where η_t^p denotes an exogenous time-varying markup to the intermediate goods' prices.

We denote the price of the intermediate goods i as $\bar{p}_t(i)$ and the price of final goods Y_t as $\bar{P}_t$. The final goods producing firm chooses Y_t and $y_t(i)$ to maximize profits subject to the technology (1). The demand for $y_t(i)$ is given by

$$y_t(i) = Y_t \left(\frac{\bar{p}_t(i)}{\bar{P}_t}\right)^{-\frac{1+\eta_t^p}{\eta_t^p}}, \tag{2}$$

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

Intermediate goods producers are monopolistic competitors in their product market. Firm i produces using the technology

$$y_t(i) = (v_t k_{t-1}(i))^{\alpha}(A_t l_t(i))^{1-\alpha}\left(\frac{K_{t-1}^G}{\int_0^1 y_t(i)di + A_t\Omega}\right)^{\frac{\alpha^G}{1-\alpha^G}} - A_t\Omega, \tag{3}$$

where $\alpha \in [0,1]$ and $\Omega > 0$ represents fixed costs to production that grow at the rate of technological progress. Public capital K_{t-1}^G provides a positive externality to production, but the service flow depends on the ratio of public capital to the average of intermediate output, reflecting public congestion as in Drautzburg and Uhlig (2011). A_t denotes a permanent shock to technology. The logarithm of its growth rate, $u_t^a = \ln A_t - \ln A_{t-1}$, follows the stationary AR(1) process

$$u_t^a = (1-\rho_a)\gamma + \rho_a u_{t-1}^a + \sigma^a \epsilon_t^a, \;\; \epsilon_t^a \sim N(0,1). \tag{4}$$

A monopolistic intermediate firm has a probability $(1-\omega_p)$ each period to reset its price. Firms that cannot reset optimally index their prices to past inflation according to the rule

$$\bar{p}_t(i) = \bar{p}_{t-1}(i)\bar{\pi}_{t-1}^{\chi^p}\bar{\pi}^{1-\chi^p}. \tag{5}$$

Firms that can reset optimally choose their price $\bar{p}_t(i)$ to maximize the expected sum of discounted future real profits. In a symmetric equilibrium, where $\overline{p}_t(i) = \overline{p}_t$, the producer price index $\bar{P}_t$ evolves according to

$$\bar{P}_t = \left[(1-\omega_p)\overline{p}_t^{\frac{-1}{\eta_t^p}} + \omega_p(\bar{\pi}_{t-1}^{\chi^p}\bar{\pi}^{1-\chi^p}\bar{P}_{t-1})^{\frac{-1}{\eta_t^p}}\right]^{-\eta_t^p}. \tag{6}$$

2.2. **Households.** The economy is populated by a continuum of households on the interval $[0,1]$, of which a fraction μ are non-savers and a fraction $(1-\mu)$ are savers. The superscript S indicates a variable associated with savers and N with non-savers.

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

$$E_0 \sum_{t=0}^{\infty} \beta^t u_t^b \left[\ln\left(c_t^S(j) - \theta c_{t-1}^S\right) - \frac{L_t^S(j)^{1+\kappa}}{1+\kappa}\right], \tag{7}$$

where $\beta \in (0,1)$ is the discount factor, $\theta \in [0,1)$ is the external habit parameter, c_{t-1}^S is lagged per capita consumption of savers, and $\kappa \geq 0$ is the labor preference parameter. u_t^b is a shock to general preferences. The economy has a continuum of differentiated labor inputs indexed by $l \in [0,1]$. We assume that each household supplies all differentiated labor inputs to eliminate labor income discrepancies from individual households supplying differentiated labor services, as in Schmitt-Grohé and Uribe (2004). The total hours supplied by household j satisfy the constraint $L_t^S(j) = \int_0^1 l_t^S(j,l)dl$, where $l_t^S(j,l)$ is labor input l supplied by saver j. Hours are demand-driven. Each household j works sufficient hours to meet the market demand for the chosen monopolistic wage rates. The wage decisions are delegated to unions, which are discussed below.

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

$$(1-\tau_t^L)\int_0^1 \frac{W_t(l)}{P_t} l_t^S(j,l)dl + (1-\tau_t^K)\frac{R_t^K v_t(j) k_{t-1}(j)}{P_t} + \frac{R_{t-1}b_{t-1}(j)}{\pi_t} + z_t(j) + d_t(j)$$
$$= (1+\tau_t^C)c_t^S(j) + i_t(j) + b_t(j), \tag{8}$$

where τ_t^L, τ_t^K, and τ_t^C are tax rates on labor income, capital income, and consumption, and $z_t(j)$ represents lump-sum government transfers. $W_t(l)$ is the nominal wage rate for labor input l, and P_t is the general price level. At time t, household j purchases $b_t(j)$ units of government debt, which pays $R_t b_t(j)/\pi_{t+1}$ units of consumption goods at $t+1$, where $\pi_{t+1} \equiv P_{t+1}/P_t$ is the gross inflation rate. $d_t(j)$ is dividends received from profits of the monopolistic firms, and $i_t(j)$ is saver j's gross investment.

Savers control both the size of the capital stock k_{t-1} and its utilization rate v_t. A higher utilization rate is associated with a higher depreciation rate of capital:

$$\delta[v_t(j)] = \delta_0 + \delta_1(v_t(j)-1) + \frac{\delta_2}{2}(v_t(j)-1)^2, \tag{9}$$

as in Schmitt-Grohé and Uribe (2012). We calibrate δ_1 so that $v=1$ in the steady state. We define a parameter $\psi \in [0,1)$ such that $\frac{\delta''[1]}{\delta'[1]} = \frac{\delta_2}{\delta_1} \equiv \frac{\psi}{1-\psi}$.

The law of motion for private capital is given by

$$k_t(j) = (1-\delta[v_t(j)])k_{t-1}(j) + u_t^i\left[1 - s\left(\frac{i_t(j)}{i_{t-1}(j)}\right)\right] \times i_t(j), \tag{10}$$

where $s\left(\frac{i_t(j)}{i_{t-1}(j)}\right) \times i_t(j)$ is investment adjustment costs, as in Smets and Wouters (2003) and Christiano et al. (2005). By assumption, $s(1) = s'(1) = 0$, and $s''(1) \equiv s > 0$. Also, the adjustment costs are subject to an investment-specific efficiency shock u_t^i.

2.2.2. *Non-savers.* Non-savers have the same preferences as savers and receive the same lump-sum transfers. The budget constraint for the non-saver $j \in (1-\mu, 1]$ is

$$(1+\tau_t^C)c_t^N(j) = (1-\tau_t^L)\int_0^1 \frac{W_t(l)}{P_t} l_t^N(j,l)dl + z_t(j). \tag{11}$$

2.3. **Wage Setting and Labor Aggregation.** To introduce wage rigidities, we assume that monopolistic unions set the wages for the differentiated labor services, following Forni et al. (2009) and Colciago (2011). Households supply differentiated labor inputs to a continuum of unions, indexed by l. Households are distributed uniformly across the unions, implying that the aggregate demand for a specific labor input is spread uniformly across all households. Therefore, in equilibrium the total hours worked for savers and non-savers are equal: $L_t^S(j) = L_t^N(j) = \int_0^1 l_t(l)\, dl \equiv L_t$.

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),

$$L_t = \left[\int_0^1 l_t(l)^{\frac{1}{1+\eta_t^w}}\, dl \right]^{1+\eta_t^w}, \tag{12}$$

where η_t^w denotes a time-varying exogenous markup to wages.

The demand function for a competitive labor packer, derived from solving their profit maximization problem subject to (12), is

$$l_t(l) = L_t^d \left(\frac{W_t(l)}{W_t} \right)^{-\frac{1+\eta_t^w}{\eta_t^w}}, \tag{13}$$

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.

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

$$W_t(l) = W_{t-1}(l) \left(\pi_{t-1} e^{u_{t-1}^a}\right)^{\chi^w} \left(\pi e^{\gamma}\right)^{1-\chi^w}, \tag{14}$$

where $\chi^w \in [0,1]$. Unions that receive the signal choose the optimal nominal wage rate $\tilde{W}_t(l)$ to maximize the lifetime utility of all households:

$$E_t \sum_{i=0}^{\infty} (\beta\omega_w)^i \left\{ u^b_{t+i} \left[(1-\mu) \ln\left(c^S_t(j) - c^S_{t-1}\right) + \mu \ln\left(c^N_t(j) - c^N_{t-1}\right) - \frac{L_t(j)^{1+\kappa}}{1+\kappa} \right] \right\}, \quad (15)$$

subject to four constraints: the aggregate budget constraints for savers and non-savers and the individual and aggregate labor demand functions. Since savers' and non-savers' hours are equal in equilibrium, we drop their superscripts. In a symmetric equilibrium, where $\tilde{W}_t(l) = \tilde{W}_t$, the nominal aggregate wage evolves according to

$$W_t = \left[(1-\omega_w) \widetilde{W}_t^{\frac{-1}{\eta^w_t}} + \omega_w \left((\pi_{t-1} e^{u^a_{t-1}})^{\chi^w} (\pi e^{\gamma})^{1-\chi^w} W_{t-1} \right)^{\frac{-1}{\eta^w_t}} \right]^{-\eta^w_t}. \quad (16)$$

2.4. **Monetary Policy.** The monetary authority follows a Taylor-type rule, in which the nominal interest rate R_t responds to its lagged value, current output, and the current consumer inflation rate, $\pi^c_t \equiv \pi_t \frac{1+\tau^C_t}{1+\tau^C_{t-1}}$. We denote a variable in percentage deviations from the steady state by a caret, as in $\hat{R}_t$. Specifically, the interest rate is set by

$$\hat{R}_t = \rho_r \hat{R}_{t-1} + (1-\rho_r) \left[\phi_\pi \hat{\pi}^c_t + \phi_y \hat{Y}_t \right] + \sigma^m \epsilon^m_t, \quad \epsilon^m_t \sim N(0,1). \quad (17)$$

2.5. **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 G^C_t, government investment G^I_t, and transfers to the households. The flow budget constraint in units of consumption goods is

$$B_t + \tau^K_t \frac{R^K_t}{P_t} \upsilon_t K_{t-1} + \tau^L_t \frac{W_t}{P_t} L_t + \tau^C_t C_t = \frac{R_{t-1} B_{t-1}}{\pi_t} + G^C_t + G^I_t + Z_t. \quad (18)$$

Government investment turns into public capital by the process

$$K^G_t = \left(1 - \delta^G\right) K^G_{t-1} + G^I_t. \quad (19)$$

In practice, fiscal policy making is often motivated by changes in the government's budget position or macroeconomic conditions. Our fiscal rules are specified as follows:

$$\hat{\tau}^K_t = \rho_K \hat{\tau}^K_{t-1} + (1-\rho_K) \left(\varphi_K \widehat{Y}_t + \gamma_K \hat{s}^b_{t-1} \right) + \sigma_K \epsilon^K_t + \phi_{KL} \sigma_L \epsilon^L_t, \quad (20)$$

$$\hat{\tau}_t^L = \rho_L \hat{\tau}_{t-1}^L + (1-\rho_L)\left(\varphi_L \widehat{Y}_t + \gamma_L \hat{s}_{t-1}^b\right) + \sigma_L \epsilon_t^L + \phi_{KL}\sigma_K \epsilon_t^K, \tag{21}$$

$$\hat{G}_t^C = \rho_{GC}\hat{G}_{t-1}^C - (1-\rho_{GC})\gamma_{GC}\hat{s}_{t-1}^b + \sigma_{GC}\epsilon_t^{GC}, \tag{22}$$

$$\hat{G}_t^I = \rho_{GI}\hat{G}_{t-1}^I - (1-\rho_{GI})\gamma_{GI}\hat{s}_{t-1}^b + \sigma_{GI}\epsilon_t^{GI}, \tag{23}$$

$$\hat{Z}_t = \rho_Z \hat{Z}_{t-1} - (1-\rho_Z)\gamma_Z \hat{s}_{t-1}^b + \sigma_Z \epsilon_t^Z, \tag{24}$$

$$\hat{\tau}_t^C = \rho_C \hat{\tau}_{t-1}^C + \sigma_C \epsilon_t^C, \tag{25}$$

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 capital and labor income taxes, government consumption and investment, and/or transfers to stabilize debt growth. To capture the role of income taxes as automatic stabilizers, capital and labor taxes are allowed to respond to output contemporaneously ($\varphi_K, \varphi_L \geq 0$).[4] Because changes in income tax codes often involve changes in labor and capital taxes simultaneously, we also allow an unexpected exogenous movement in one tax rate to affect the other rate, as captured by ϕ_{KL} in (20) and (21).[5]

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

$$C_t = \int_0^1 c_t(j)dj = (1-\mu)c_t^S + \mu c_t^N. \tag{26}$$

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

$$Z_t = \int_0^1 z_t(j)dj = z_t. \tag{27}$$

[4]Tax rates in the model correspond to average effective rates. In the U.S., automatic stabilizers are mainly embedded in a progressive income tax system. In a boom, higher income moves some households to higher tax brackets, subject to higher statutory marginal rates. Hence, average effective rates are automatically higher without changing the tax code.

[5]We do not allow consumption taxes to respond to debt. In the data, consumption taxes consist of federal excise taxes and custom duties, which have an average share of GDP less than one percent. Also, we do not allow transfers to include an automatic stabilizer response. Although some transfer components such as food stamps and unemployment insurance are countercyclical, they are only a small share—about 5 percent on average—of the federal transfers data in our sample.

Because only savers have access to the asset and capital markets, aggregate bonds, private capital, investment, and dividends are

$$B_t = \int_0^{1-\mu} b_t(j)dj = (1-\mu)b_t, \quad K_t = \int_0^{1-\mu} k_t(j)dj = (1-\mu)k_t, \tag{28}$$

$$I_t = \int_0^{1-\mu} i_t(j)dj = (1-\mu)i_t, \quad D_t = \int_0^{1-\mu} d_t(j)dj = (1-\mu)d_t. \tag{29}$$

Finally, the goods market clearing condition is

$$Y_t = C_t + I_t + G_t^C + G_t^I. \tag{30}$$

3. Estimation

We estimate the model with U.S. quarterly data from 1983Q1 to 2008Q1 using Bayesian inference methods (see An and Schorfheide (2007) for a survey). The sample period choice is driven by two stability considerations: (1) monetary policy is characterized by a Taylor rule [Taylor (1993)], and (2) monetary policy is thought to be active and fiscal policy passive over this period (in the sense of Leeper (1991)).[6]

The estimation uses 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.[7] Details of the data construction, the linkage to observables, and the estimation methods are available in the online appendix.

[6]When a longer sample is used, regime-switching between monetary and fiscal policies is more pronounced [Davig and Leeper (2006)]. Because our policy rules have constant coefficients for inflation and debt, we select a period where monetary policy is active and fiscal policy is passive. For an investigation of policy interactions in pre-1983 samples, see Traum and Yang (2011).

[7]Although the literature typically uses fiscal variables of all governments, our fiscal variables are for the federal government only. Because state and local governments generally have balanced-budget rules of various forms, fiscal financing decisions are likely to differ across federal and state and local governments.

3.1. **Prior Distribution.** We calibrate several parameters that are difficult to identify from the data. The discount factor β is set to 0.99, implying an annual steady-state real interest rate of 4 percent. The capital income share of total output α is 0.36, implying a labor income share of 0.64. The 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)]. η^p and η^w are set to 0.14 to have the steady-state markups in the product and labor markets be 14 percent, consistent with evidence that the average price markup of U.S. firms is 10-15 percent [Basu and Fernald (1995)]. Since there appears to be no consensus for the average markup in the labor market, we pick the same value for η^w by symmetry. The steady-state inflation rate, π, is assumed to be 1.[8]

The output elasticity to public capital, α^G, cannot be identified without information on the capital stocks. The empirical literature has a wide range of values for α^G, from a small negative number [Evans and Karras (1994)], to zero [Kamps (2004)], to near 0.4 [Pereira and de Frutos (1999)]. For the baseline estimation, we make a conservative assumption on the productiveness of public capital and set $\alpha^G = 0.05$.[9]

The rest of the calibrated parameters are steady-state fiscal variables computed from the sample means. 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 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 consistent with the model specification, namely, the sum of consumption, investment, and total government purchases.

[8]The average inflation in the sample period is not one. Since our analysis focuses on deviation dynamics from the steady state, assuming the steady-state inflation rate to be 1 greatly simplifies the algebra in deriving the equilibrium system, as in Smets and Wouters (2003) and Del Negro et al. (2007).
[9]Sensitivity analysis in the online appendix explores $\alpha^G = 0$ and $\alpha^G = 0.1$. We find that the data cannot distinguish among the three α^G's, as the log marginal data densities are virtually identical.

Columns 2 to 5 in Table 1 list the prior distributions. Our priors for common New Keynesian parameters are similar to those in Smets and Wouters (2007). One parameter less encountered is the share of non-savers, μ. Forni et al. (2009) and Iwata (2009) center the prior at 0.5 but obtain an estimate around 0.35. López-Salido and Rabanal's (2006) estimate using U.S. data over a similar sample period is between 0.10 to 0.39. Thus, we choose a beta prior with a mean of 0.3 and standard deviation of 0.1.

The priors for the fiscal parameters are chosen to be fairly diffuse. To stabilize debt, government spending and transfers (taxes) should respond negatively (positively) to a debt increase. We assume normal distributions for the fiscal instruments' responses to debt 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, some probability is allowed for the opposite signs. The prior ranges are guided by two considerations. First, when fiscal adjustment responses to debt are too high, overshooting occurs, resulting in oscillation patterns not observed in the data. Second, when adjustment responses are too low, under active monetary policy, there does not exist an equilibrium.

As capital and labor taxes are progressive, we restrict φ_K and φ_L to be positive. Since Social Security taxes are incorporated in our labor tax revenues, the labor tax rate elasticity is expected to be a value 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 Yang (2005) and Leeper et al. (2010)].

The online appendix conducts prior predictive analysis about whether various deficit-financed fiscal shocks crowd out or in investment. The results are compared to the same exercise from the posterior. The comparison shows substantial differences between prior and posterior multipliers. However, the priors do imply some restrictions on short-run multipliers, particularly for government consumption, transfers, and capital taxes.

3.2. **Posterior Estimates.** The last two columns of Table 1 provide the mean and 90th percentiles from the posterior distributions.[10] Overall the data are informative about the parameters estimated, as the 90-percent intervals are different from those implied by the priors, with the main exception of the technology growth rate γ. Our estimates for the common parameters in New Keynesian models are comparable to others estimated with postwar U.S. data [Smets and Wouters (2007), Del Negro et al. (2007), and Fernandez-Villaverde et al. (2010)], as shown in the online appendix.

The mean estimate for the non-savers's fraction μ is 0.1. This low fraction suggests the importance of forward-looking behavior in the aggregate effects of fiscal policy. Although myopic behavior has been seen as important in understanding fiscal policy effects since Mankiw (2000), our estimate is much smaller than the commonly calibrated value of 0.5, based on single-equation estimation of a consumption function [Campbell and Mankiw (1989) and Galí et al. (2007)]. Previous studies model non-savers so that aggregate consumption can increase following a positive government spending shock. Given our mean estimates for the benchmark model, a fraction of 0.29 is required to deliver a positive short-term consumption response to an increase in government consumption, which falls outside the 90-percent interval [0.06, 0.16]. Our results are nonetheless consistent with vector autoregression (VAR) estimates of the same sample period. VARs with either federal government consumption alone or the sum of federal government consumption and investment find that, for 1983Q1 to 2008Q1, an increase in government spending does not have a positive effect on consumption.[11]

[10]The online appendix contains results of various diagnostic analysis, including plot slices of the likelihood around the mode, trace plots, comparison plots of priors against posterior distributions.

[11]The VAR is ordered with government spending first, followed by GDP, consumption, and investment. Identification is achieved using Cholesky decomposition. The evidence of the positive consumption

The 90-percent intervals of all fiscal instruments—except for transfers—have the expected signs for their responses to debt. We find that the federal government mainly relies on reducing government consumption and raising income taxes to stabilize debt, as in Leeper et al. (2010). The similar 90-percent intervals between prior and posterior estimations for the government investment response to debt (γ_{GI}) suggest that this parameter is less well identified.

3.3. **Historical Decomposition.** To illustrate what drove the debt dynamics historically, Figure 1 presents the historical decomposition of the model-implied dynamics of real primary deficits (defined as the sum of government consumption, investment, and transfers less total tax revenues).[12] The breakdowns of shocks are organized by monetary, fiscal (aggregating tax, government spending, and transfers), and structural (aggregating all non-policy) shocks. The thick solid lines are the model-implied series, and the units on the y-axis are percentage deviations from the steady-state path.

The figure shows that fiscal and structural shocks are important in driving primary deficits. The fiscal position worsened in early 1990s (continuing from the 1980s). To reduce deficits, the first Bush and Clinton administrations signed into law the Omnibus Budget Reconciliation Acts of 1990 and of 1993, respectively, to increase the statutory tax rates on high income earners. Consequently, primary deficits fell below the steady-state trend path in the second half of 1990s. The trend was reversed in early 2000s mainly due to the recession, a series of tax cuts, and increased defense spending, as captured by the dominance of structural and fiscal shocks shown in Figure 1.

response following a government spending shock found in the literature [e.g. Galí et al. (2007) and Bouakez and Rebei (2007)] is based on a longer postwar U.S. sample. VARs based on shorter, more recent samples [Perotti (2005) and Bilbiie et al. (2008)] find a muted consumption response.

[12] We use the posterior mean estimates and the Kalman smoother to obtain values of the innovations for each shock. The decomposition prior to 1990s is not shown because initial conditions are more dominant in debt dynamics than shocks. See Alvarez-Lois et al. (2008) for more details on the construction of the decomposition.

Aside from fiscal shocks, monetary policy also affected deficit dynamics particularly in the post-2000 period. The low interest rate environment following the 2001 recession stimulated economy activity and expanded the tax base. Thus, monetary policy worked to reduce primary deficits relative to a scenario without interest rate cuts.

4. Crowding Out by Government Debt

To answer the question posed by the title of the paper, this section investigates the economics underlying the links among government debt, the real interest rate, and investment. We focus on the debt changes driven by policy shocks.

4.1. **Tobin's Q.** The model implied Tobin's q [Tobin (1969)] summarizes the factors affecting investment decisions. Define $q_t \equiv \frac{\xi_t\left(1+\tau_t^C\right)}{\lambda_t^S}$, where λ_t^S and ξ_t are the Lagrangian multipliers for the constraints (8) and (10) 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. The log-linearized expression of Tobin's q from its steady state is

$$\hat{q}_t = -\left(\hat{R}_t - E_t\hat{\pi}_{t+1}\right) + \beta e^{-\gamma}(1-\tau^K)r^K E_t\hat{r}^K_{t+1} - \beta e^{-\gamma}r^K\tau^K E_t\hat{\tau}^K_{t+1} + \beta e^{-\gamma}(1-\delta_0)E_t\hat{q}_{t+1}, \tag{31}$$

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. Other components in (31), however, imply that more than the real interest rate can matter. A higher expected real return to capital makes agents want to invest more, but a higher expected capital tax rate does the opposite. By iterating on this equation, we see that investment depends not only on the current values of relevant variables, but on their entire expected future paths. Tobin's q reveals that policy shocks leading to debt accumulation but increasing capital's return or lowering the capital tax rate may crowd in investment, despite a higher real interest rate.

4.2. **Effects of Fiscal and Monetary Policy Shocks.** When a fiscal shock hits the economy, it has a direct effect from the shock itself and an indirect effect through financing. A deficit financed policy change 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). Figures 2 and 3 show the impulse responses to all policy shocks that lead to a maximum 1-percent increase in debt from the steady state. Solid lines are the responses under the posterior mean estimates. Dotted-dashed lines give the 5th and 95th percentiles based on the posterior distributions. Dashed lines are the effects of distortionary debt financing, to be explained later.

Although all the expansionary fiscal shocks cause government debt to grow, investment can rise or fall, depending on the type of shock. When government investment increases or the capital tax rate decreases, higher debt is associated with higher investment at least in the short run (the solid lines and confidence intervals of Figure 2). An increase in productive government investment implies more future public capital, which raises the marginal product of private capital (higher $E_t\hat{R}^K_{t+1}$ in (31)). A reduction in the capital tax rate increases the after-tax rate of return to investment. Because the tax shock is persistent, this lowers expectations of future capital tax rates. Contradicting to the conventional view, if a debt expansion is due to an increase in government investment or a decrease in the capital tax rate, investment rises within the first three years, despite a higher interest rate (in the case of government investment increases).

When the labor tax rate decreases (Figure 3), the probability intervals indicate that investment can be crowded in or out in the short run. A negative labor tax shock increases labor demand, driving up the marginal product of capital and making agents want to invest more. However, the deficit-financed labor tax cut induces future fiscal adjustments involving higher income tax rates and lower government spending. For most combinations of parameters drawn from the posterior distributions, a decrease in the labor tax rate crowds in investment in the short run, but fiscal adjustments discourage investment later as in the case of a capital tax rate cut. A negative consumption tax shock increases the prices of investment goods relative to consumption goods. The initial slightly positive response of investment is driven by the monetary authority's response to falling consumer's price, which leads the real interest rate to decline and gives a positive investment incentive. Despite a substantial fall in the real interest rate, investment is mostly crowded out for a negative consumption tax shock.

Among the six fiscal shocks, only government consumption and transfers produce debt effects largely consistent with the conventional view. The first column of Figure 2 shows that following a government consumption increase, the real interest rate rises for most periods and investment falls. More goods absorption by the government leaves the private sector with fewer goods to invest. As goods become more valuable, the real interest rate rises to clear the market. A positive transfer shock (the third column of Figure 3) also increases good demand because non-savers consume more due to higher disposable income. The deficit-financed transfer increase, however, generates expectations of higher future income taxes, discouraging current investment.

The last column of Figure 3 reports the impulse responses to a debt surge driven by an exogenous 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 rate 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. Because the debt growth is accompanied by a rising real rate and declining investment, it is in line with the conventional view on crowding out. Although crowding-out is often characterized as a fiscal phenomenon, we find that monetary policy can also influence the degree of crowding out as noted in the literature [e.g., Brunner and Meltzer (1972) and Buiter and Tobin (1980)].

4.3. **Distortionary Debt Financing.** Since the total debt effects just analyzed include the fiscal adjustment effects, we further isolate the effects of debt financing. To do this, a hypothetical economy is constructed such that it 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 so $\gamma_{GC} = \gamma_{GI} = \gamma_K = \gamma_L = \gamma_Z = 0$. We introduce a new lump-sum tax X_t on savers only, which evolves to satisfy the revised government budget constraint

$$X_t = G_t^C + G_t^I + Z_t - \tau_t^K \frac{R_t^K}{P_t} v_t K_{t-1} - \tau_t^L \frac{W_t}{P_t} L_t - \tau_t^C C_t. \tag{32}$$

Because savers possess rational expectations and have access to asset markets, the lump-sum tax is non-distorting and does not affect savers' marginal decisions.

Returning to Figures 2 and 3, we now examine the dashed line responses—the differences between the responses of the benchmark and the hypothetical economy computed using the posterior mean parameter values, or the responses due solely to distortionary debt financing. The investment responses are mostly negative, with the exception of the government investment shock. This indicates that the crowding-out effect, if it occurs, is more pronounced under distortionary fiscal financing. The slight positive investment response with the government investment shock is mainly because tax rates are lower in response to falling government debt in later years due to the persistent positive output effects. Meanwhile, the differences between the responses of the real interest rate in the two economies are negligible, demonstrating that the differences in investment are not due to interest rate effects.

The overall negative investment responses of debt financing (as shown in Figures 2 and 3) are driven by the fiscal adjustment effects from all instruments as estimated from data. It is worth noting that among the five instruments allowed to respond to debt, not every instrument has a negative effect on investment. Raising capital or labor tax rates and reducing government investment have a negative impact on investment, but cutting government consumption or transfers does not. Thus, the debt financing effect depends crucially on the policy combination to retire debt. We return to this point later in the counterfactual analysis of Section 6.

4.4. **Delayed Debt Financing.** Our fiscal specification assumes that fiscal adjustments occur with one-quarter delay, and the estimates of fiscal adjustment parameters are the average, long-term responses of various instruments. Fiscal adjustments in practice can be much delayed. To see whether crowding-out effects are influenced by the timing of debt financing, Figure 4 compares the mean impulse responses with one-quarter delay (solid lines) to those with five-year delay (dashed lines) for the three shocks to which debt accumulations generate the crowding out effect. Specifically, the dashed lines are produced by replacing $\hat{s}^b_{t-1}$ in (20)-(24) with $\hat{s}^b_{t-20}$.

Relative to one-quarter delay in debt-financing, government debt rises much more with five-year delay for the same size of a shock. With five-year delayed financing, crowding out is smaller in the short and medium runs, but it comes at a price of more severe crowding out in the longer run. Delayed financing means higher debt services and hence higher debt accumulation. As a result, more fiscal adjustments are required later, worsening and prolonging the crowding out effect. As shown by the second and third rows of Figure 4, capital and labor tax rates rise substantially five years after the shock, and the increase in the tax rates eventually become larger than the tax rate responses with one-quarter delay.[13]

5. Reduced-Form Estimates

The previous section finds that a relationship among government debt, investment, and real interest rates is difficult to infer without controlling for which policy shock triggers a debt expansion. Thus, the prevailing empirical approach to searching for evidence of crowding out by focusing on the reduced-form relationship between government debt or deficits and real interest rates is subject to serious identification problems.[14]

To illustrate this, we simulate 500 data series using the mean estimates of the posterior distribution,[15] and estimate for each series the reduced-form OLS equations

$$\hat{r}_t = \beta_0 + \beta_1 \hat{s}_t^b + \epsilon_t, \quad \hat{r}_t^{10} = \beta_0 + \beta_1 \hat{s}_t^b + \epsilon_t. \tag{33}$$

$\hat{s}_t^b$ and $\hat{r}_t$ are the model-implied debt-to-output ratio and one-quarter real interest rate. Because 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, generated by imposing the pure expectations hypothesis of the term structure. In addition to conditioning on all shocks, regressions are also performed on simulated data conditional on each shock in the model. Table 2 summarizes the estimation results.

Conditional on all the shocks, the reduced-form regressions produce a large range of estimates as anticipated, whether $\hat{r}_t$ or $\hat{r}_t^{10}$ is the dependent variable. The results based on individual shocks show that the regressions also cannot obtain the expected

[13]The small movements in the tax rates during the first five years are due to automatic stabilizers, which move along with output. In addition to raising income tax rates, government consumption and transfers also respond to debt changes, which are not plotted here.

[14]For recent surveys of results from the literature on reduced-form relationship between debt-real interest rates and deficits-real interest rates, see footnote 3.

[15]For each case, we simulate a series 1000 periods long and burn the first 900 periods, leaving a sample length comparable to our data series.

signs of β_1 for most shocks, even when only one shock is present in the data. For example, Figure 3 suggests that the real rate falls significantly for the first five quarters when government debt increases are driven by the consumption tax shock. Yet, our estimated β_1's are mostly positive (see the rows under ϵ_t^C). Returning to Figure 3, we see that the real rate turns slightly positive starting from quarter six, while government debt remains positive for a prolonged period, implying a positive correlation in later horizons. The simple specification of reduced-form regressions cannot control for this *dynamic* response of the real rate even in data driven by one shock.[16]

To control for endogeneity issues, Laubach (2009) proposes to regress the five-year ahead expectation of the ten year real interest rate on the five-year projection of debt. We conduct a similar exercise, estimating the reduced-form OLS equation

$$E_t \hat{r}_{t+20}^{10} = \beta_0 + \beta_1 E_t \hat{s}_{t+20}^b + \epsilon_t. \tag{34}$$

The median estimate of β_1 is 0.03 and a 90-percent interval of $[-0.04, 0.10]$. Thus, relative to the specifications of (33), the reduced-form estimates with projected variables do appear more likely to find a positive response.

Aside from a particular parameter combination producing a wide range of reduced-form estimates on the coefficient of debt to interest rates, we also perform regressions based on data generated from estimated historical innovations.[17] The posterior distribution of β_1 encompass those estimated values reported in the literature. Previous studies [Gale and Orszag (2004), Engen and Hubbard (2005), and Laubach (2009)] find that a one-percentage point increase in the government debt to GDP ratio leads to an

[16]To confirm our reasoning, we use the simulated data generated by a one-period consumption tax shock (as the data used to plot the impulse responses) and perform the regression on debt (instead of the debt-to-GDP ratio) without a constant. Despite the pronounced negative relationship between the real rate and government debt for the first five quarters, the estimated β_1 is still positive. Next, we set the small positive real rate responses after quarter five to zero. Then, the estimate turns negative as expected.

[17]$\hat{r}_t$, $\hat{r}_t^{10}$, and $\hat{s}_t^b$ were constructed using the estimated sequence of historical innovations (calculated using the Kalman smoother).

increase of approximately 3-6 basis points in the real interest rate. Using the model-implied ten-year rate, the 90-percent interval of β_1 is $[-0.20, 0.08]$, implying an upper bound of 8 basis points. Using the five-year expected variables in the regression, the 90-percent interval of β_1 is narrowed to $[-0.05, 0.03]$, but still encompasses zero.

6. Counterfactual Applications

DSGE estimation provides a framework to assess the effects of historical policy interventions. Having isolated the policy shocks from the data, we pursue two counterfactual exercises. The first policy intervention was intended to rein in debt growth in the 1990s, and the second was aimed to stimulate the economy in the early 2000s.

6.1. **The Tax Increases in the 1990s.** We ask how the economy would have evolved if there had been no policy innovations from 1993Q1 to 1997Q2, a period of contractionary fiscal policy (roughly between the enactment of the Omnibus Budget Reconciliation Act of 1993 and the Taxpayer Relief Act of 1997). Figure 5 plots four paths of key macroeconomic variables: 1) Solid lines are conditional on the estimated sequences of all shocks; 2) dashed lines are on all the estimated sequences except capital and labor tax shocks; 3) dotted lines are on all the estimated sequences except spending shocks (government consumption, government investment, and transfer shocks); and 4) dots are on all the estimated sequences except the monetary policy shock. All the paths are in percent deviation from the steady state.

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 7 percent lower than it otherwise would have been by 1997Q2. To a lesser extent, innovations to government consumption and investment, consumption taxes, and transfers also contributed to debt reduction; debt would have been 2 percent higher without changes to these fiscal instruments. The contractionary tax actions had a negative effect on investment: Investment would have been about 1.2 percent higher without the tax increases relative to the observed path. This provides evidence that fiscal adjustments, necessary to maintain budget sustainability, can have negative macroeconomic effects.

In contrast, when spending shocks are turned off (dotted lines), investment would have been 1 percent lower than its observed path in 1997Q2. Note that when government spending alone is reduced for fiscal adjustments, it has a positive effect on investment (but a negative effect on output), mainly due to less government consumption. The comparison of various instruments to retire debt shows that the effects of debt retirement depend on the specific composition of fiscal adjustments.

Figure 5 also shows the isolated effects of monetary policy disturbances. During this episode, the monetary authority raised the nominal interest rate to combat inflation. Without these actions, output and inflation would have been higher and government debt lower (because interest payments would have been lower without the increased interest rates). Over this period, the fiscal authority acted to reduce the deficit, while the monetary authority's actions worked to sustain it. In addition, the monetary authority acted to reduce inflation while the fiscal authority's actions, particularly the tax increases, contributed to inflationary pressures.

6.2. **The Tax Cuts in 2001 and 2002.** Next, we ask how the economy would have evolved without policy interventions from 2001Q3 to 2002Q4 (after the enactment of the Economic Growth and Tax Relief Reconciliation Act of 2001). Because monetary and fiscal policies were both adopted to counteract the recession in 2001, we examine the relative effectiveness of the countercyclical measures. Figure 6 contains three paths: Solid lines are conditional on the estimated sequence of all shocks; dashed lines are on all the estimated sequences except capital and labor tax shocks; and dotted-dashed lines are on all the estimated sequences except the monetary policy shock.

The real value of federal debt would have continued its trend of decline from the late 1990s if discretionary tax changes had not occurred. The tax cuts made federal debt 8 percent higher than it otherwise would have been by 2002Q4. 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.

Both the tax cuts and interest rate reductions were expansionary in 2001 and 2002. Monetary policy was more effective during the first half of 2002. In 2002Q2, output would have been 0.65 percent lower than the observed path without the monetary interventions, compared to 0.23 percent lower without the tax intervention. The tax cuts became more effective in counteracting the recession in the second half of 2002. In 2002Q4, output would have been 0.8 percent lower than the observed path if the tax cuts were not enacted, compared to 0.6 percent lower if the nominal interest rates were not reduced. Also, the effects of monetary and fiscal actions on inflation worked in the opposite directions. The monetary authority's actions added to inflation, whereas the tax cuts reduced inflation in 2001 and 2002. Lowering the nominal interest rate to fight the recession reduced the demand for government bonds and increased investment and consumption, which increased inflationary pressures. In contrast, both tax cuts enhanced the net return of production factors and increased the aggregate supply of goods, thus reducing inflation.

7. Conclusion

This paper studies the crowding out effect by U.S. government debt using a structural DSGE approach. Two contributions to the literature follow. First, we estimate a New Keynesian model with a detailed fiscal specification, which can account for the dynamics between fiscal and monetary policy interactions and fiscal adjustments induced by debt accumulation. Most fiscal instruments are found to respond to debt systematically: When the debt-to-output ratio rises, the federal government mainly reduces its consumption and increases income taxes to rein in debt growth. The relatively low estimate for the fraction of non-savers suggests the importance of forward-looking behaviors in explaining the aggregate effects of fiscal policy.

Second, our estimation implies that there is no systematic reduced-form relationship between government debt and real interest rates, which helps explain why empirical studies focusing on this relationship are often inconclusive. Whether government debt crowds out private investment depends on the type of policy innovation that brings forth debt growth. Distortionary fiscal financing also is important for gauging the magnitude of the investment and real interest rate responses following a debt expansion. In particular, future increases capital and labor taxes necessary to offset debt accumulation have a negative impact on investment.

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Table 1. **Prior and Posterior Distributions for Estimated Parameters.**

Parameters	**Prior**				**Posterior**	
	func.	mean	std.	90% int.	mean	90% int.
Preference and technology						
100γ, steady state growth	N	0.5	0.03	[0.45, 0.55]	0.5	[0.45, 0.55]
κ, inverse Frisch labor elast.	G	2	0.5	[1.3, 2.9]	2.41	[1.65, 3.30]
θ, habit	B	0.5	0.2	[0.17, 0.83]	0.70	[0.63, 0.77]
μ, fraction of non-Ricar. households	B	0.3	0.1	[0.14, 0.48]	0.10	[0.06, 0.16]
Frictions						
ω_w, wage stickiness	B	0.5	0.1	[0.34, 0.66]	0.28	[0.18, 0.43]
ω_p, price stickiness	B	0.5	0.1	[0.34, 0.66]	0.70	[0.64, 0.77]
ψ, capital utilization	B	0.6	0.15	[0.35, 0.85]	0.75	[0.66, 0.84]
s, investment adj. cost	N	6	1.5	[3.5, 8.5]	5.78	[3.65, 8.11]
χ^w, wage partial indexation	B	0.5	0.15	[0.25, 0.75]	0.30	[0.20, 0.41]
χ^p, price partial indexation	B	0.5	0.15	[0.25, 0.75]	0.28	[0.13, 0.49]
Fiscal policy						
γ_{GC}, govt consumption resp to debt	N	0.15	0.1	[-0.01, 0.3]	0.28	[0.15, 0.42]
γ_{GI}, govt investment resp to debt	N	0.15	0.1	[-0.01, 0.3]	0.16	[0.01, 0.30]
γ_K, capital tax resp to debt	N	0.15	0.1	[-0.01, 0.3]	0.20	[0.07, 0.33]
γ_L, labor tax resp to debt	N	0.15	0.1	[-0.01, 0.3]	0.10	[0.02, 0.20]
γ_Z, transfers resp to debt	N	0.15	0.1	[-0.01, 0.3]	0.02	[−0.09, 0.17]
φ_K, capital resp. to output	G	0.75	0.35	[0.28, 1.4]	0.51	[0.19, 0.93]
φ_L, labor resp. to output	G	0.40	0.15	[0.14, 0.76]	0.73	[0.24, 1.37]
Monetary policy						
ϕ_π, interest rate resp. to inflation	N	1.5	0.25	[1.1, 1.8]	2.39	[2.12, 2.68]
ϕ_y, interest rate resp. to output	N	0.125	0.05	[0.04, 0.21]	0.04	[0.004, 0.07]
ρ_r, lagged interest rate resp.	B	0.5	0.2	[0.17, 0.83]	0.85	[0.82, 0.88]
Serial correl. in disturbances						
ρ_a, technology	B	0.5	0.2	[0.17, 0.83]	0.24	[0.12, 0.35]
ρ_b, preference	B	0.5	0.2	[0.17, 0.83]	0.91	[0.85, 0.95]
ρ_i, investment	B	0.5	0.2	[0.17, 0.83]	0.90	[0.84, 0.95]
ρ_w, wage markup	B	0.5	0.2	[0.17, 0.83]	0.92	[0.82, 0.97]
ρ_p, price markup	B	0.5	0.2	[0.17, 0.83]	0.95	[0.91, 0.98]
ρ_{GC}, government consumption	B	0.5	0.2	[0.17, 0.83]	0.97	[0.94, 0.99]
ρ_{GI}, government investment	B	0.5	0.2	[0.17, 0.83]	0.94	[0.89, 0.98]
ρ_K, capital tax	B	0.5	0.2	[0.17, 0.83]	0.87	[0.81, 0.92]
ρ_L, labor tax	B	0.5	0.2	[0.17, 0.83]	0.91	[0.83, 0.97]
ρ_C, consumption tax	B	0.5	0.2	[0.17, 0.83]	0.98	[0.97, 0.995]
ρ_Z, transfer	B	0.5	0.2	[0.17, 0.83]	0.91	[0.83, 0.98]
Std. of shocks						
σ_a, technology	IG	0.1	2	[0.02, 0.28]	0.98	[0.86, 1.12]
σ_b, preference	IG	0.1	2	[0.02, 0.28]	2.26	[1.67, 3.18]
σ_m, monetary policy	IG	0.1	2	[0.02, 0.28]	0.14	[0.12, 0.16]
σ_i, investment	IG	0.1	2	[0.02, 0.28]	0.39	[0.32, 0.47]
σ_w, wage markup	IG	0.1	2	[0.02, 0.28]	0.26	[0.19, 0.37]
σ_p, price markup	IG	0.1	2	[0.02, 0.28]	0.14	[0.10, 0.18]
σ_{GC}, government consumption	IG	1	∞	[0.21, 2.8]	1.89	[1.68, 2.12]
σ_{GI}, government investment	IG	1	∞	[0.21, 2.8]	4.23	[3.77, 4.75]
σ_K, capital tax	IG	1	∞	[0.21, 2.8]	4.49	[3.99, 5.07]
σ_L, labor tax	IG	1	∞	[0.21, 2.8]	1.76	[1.57, 1.99]
σ_C, consumption tax	IG	1	∞	[0.21, 2.8]	3.25	[2.89, 3.65]
σ_Z, transfers	IG	1	∞	[0.21, 2.8]	2.40	[2.13, 2.69]
σ_{KL}, co-movement btw K and L taxes	N	0.2	0.1	[0.036, 0.36]	0.24	[0.19, 0.29]

TABLE 2. **Reduced-form Regressions with Simulated Data**

Shocks	$\hat{r}_t$	$\hat{r}_t^{10}$
All	0.001	-0.020
	(-0.015, 0.014)	(-0.18, 0.15)
ϵ_t^a	0.006	-0.13
	(-0.001, 0.018)	(-0.37, 0.11)
ϵ_t^b	-0.004	-0.11
	(-0.022, 0.010)	(-0.51, 0.18)
ϵ_t^i	0.085	0.004
	(-0.16, 0.31)	(-0.018, 0.020)
ϵ_t^p	0.002	-0.002
	(-0.038, 0.027)	(-0.007, 0.001)
ϵ_t^w	0.028	0.002
	(-0.034, 0.096)	(-0.002, 0.009)
ϵ_t^m	0.006	-0.020
	(-0.008, 0.022)	(-0.043, 0.002)
ϵ_t^{GC}	0.000	0.001
	(-0.002, 0.001)	(-0.019, 0.014)
ϵ_t^{GI}	0.003	0.050
	(-0.001, 0.010)	(-0.012, 0.143)
ϵ_t^K	-0.024	0.000
	(-0.033, -0.008)	(-0.001, 0.001)
ϵ_t^L	-0.001	-0.027
	(-0.002, -0.001)	(-0.042, -0.004)
ϵ_t^C	0.002	0.004
	(-0.001, 0.012)	(-0.005, 0.012)
ϵ_t^Z	-0.001	-0.014
	(-0.001, 0.000)	(-0.024, 0.000)

Notes: Estimates are for β_1 from the OLS regression $x_t = \beta_0 + \beta_1 \hat{s}_t^b + \epsilon_t$, where x_t 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 from the posterior mean.

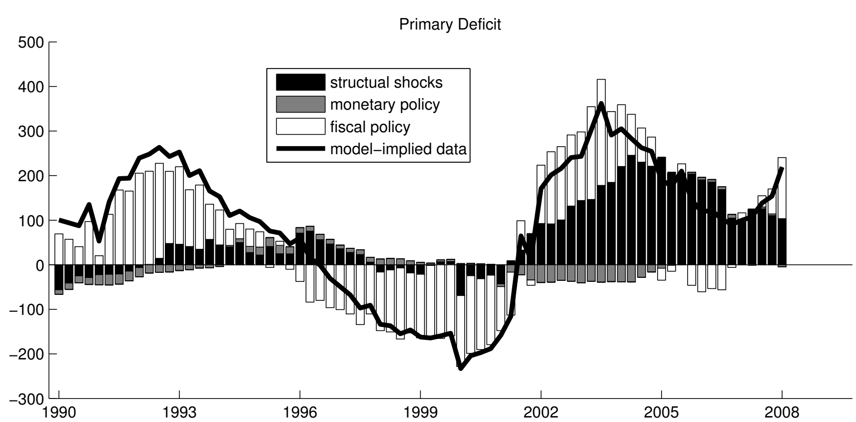

FIGURE 1. **Historical variance decomposition for model-implied primary deficits.** Structural shocks are the aggregate of all non-policy shocks. Units for the y-axis are percentage deviation from the steady-state path.

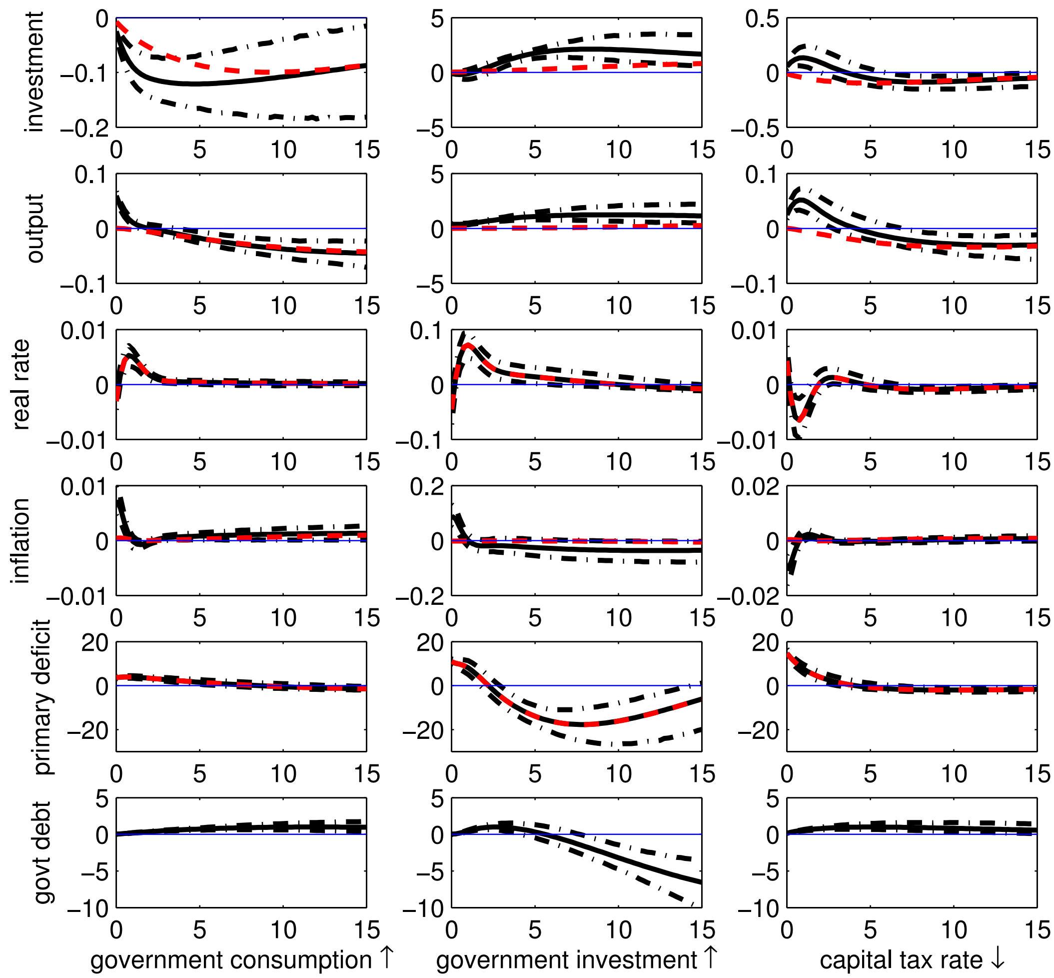

FIGURE 2. **Impulse responses for policy shocks I.** Solid lines—mean responses; dotted-dashed lines—90-percent pointwise probability intervals; dashed lines—responses due to distortionary fiscal financing. The y-axis measures percentage deviation from the steady state. The x-axis is in years after a shock.

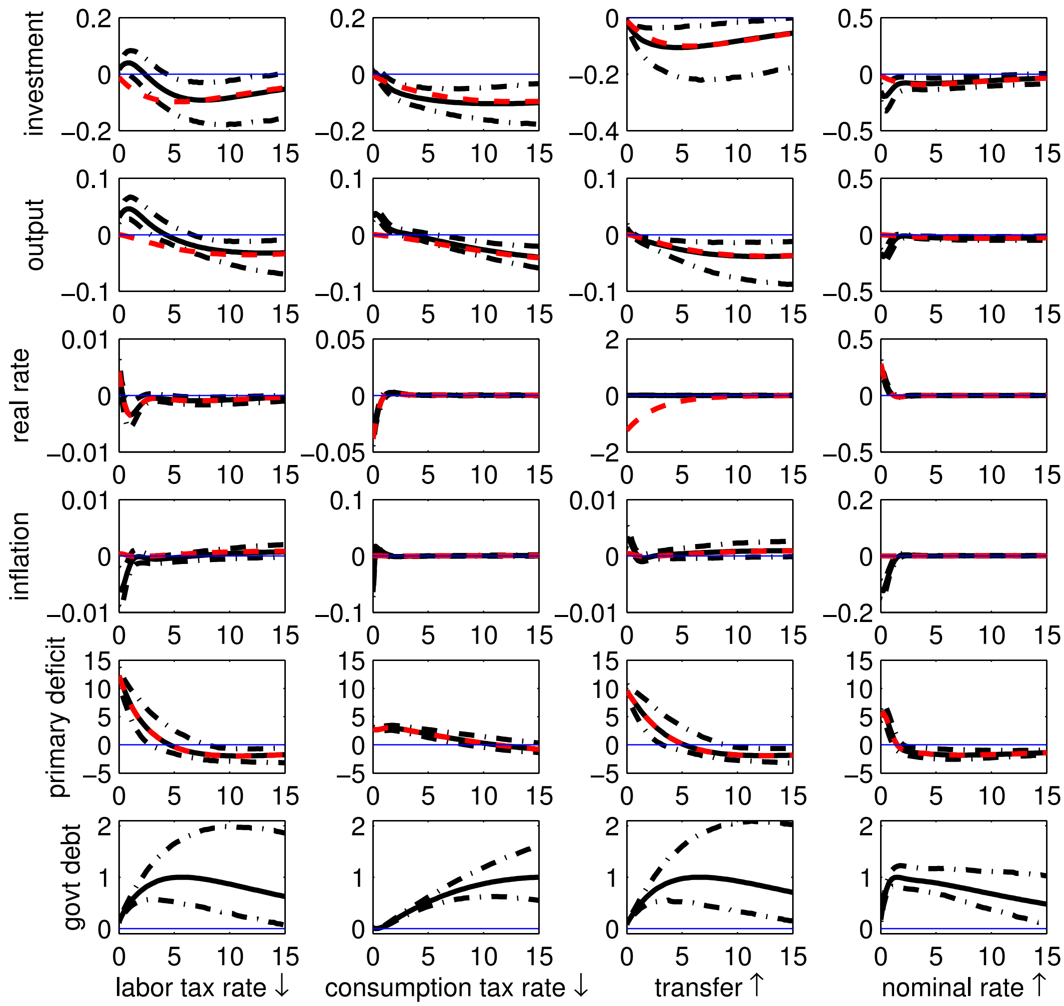

FIGURE 3. **Impulse responses for policy shocks II.** Solid lines—mean responses; dotted-dashed lines—90-percent pointwise probability intervals; dashed lines—responses due to distortionary fiscal financing. The y-axis measures percentage deviation from the steady state. The x-axis is in years after a shock.

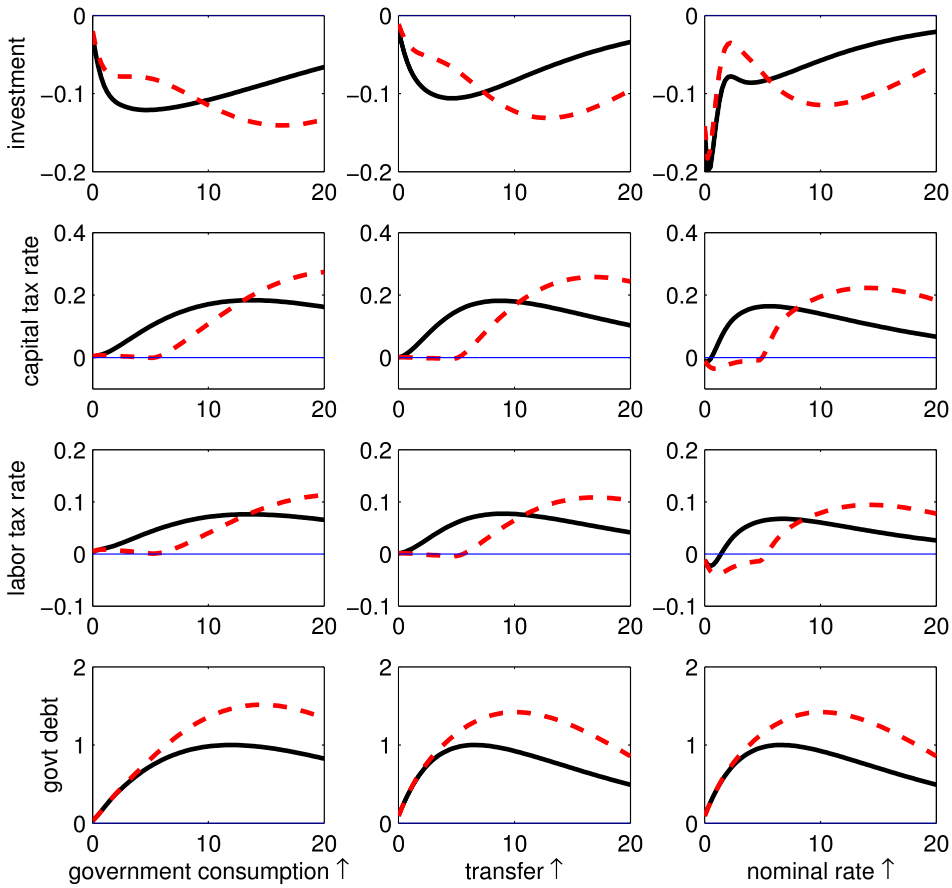

FIGURE 4. **Impulse responses with delayed financing.** Solid lines—mean responses with one-quarter delay; dashed lines—mean responses with five-year delay. The y-axis measures percentage deviation from the steady state. The x-axis is in years after a shock.

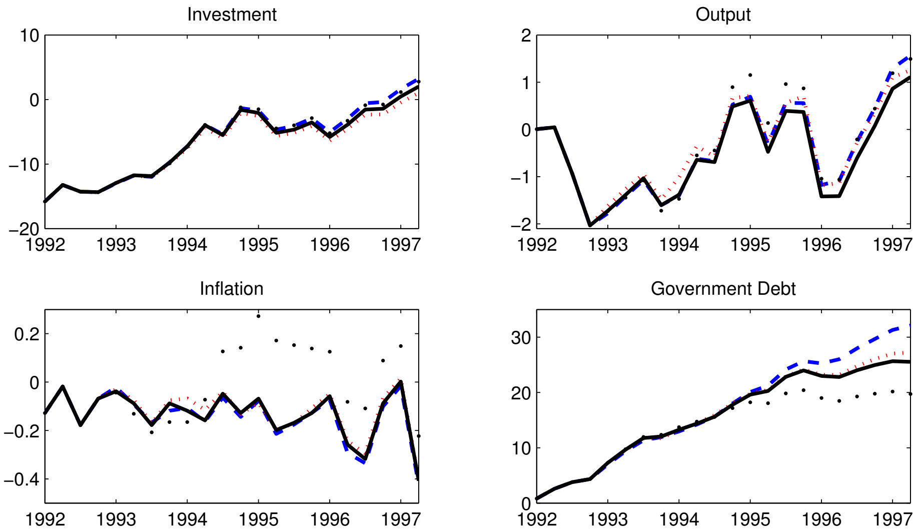

FIGURE 5. **Counterfactual exercise: tax increases in the 1990s.** Solid lines—data (observed or model-implied) conditional on all the estimated shocks; dashed lines—capital and labor tax shocks turned off; dotted lines—spending shocks turned off; dots—monetary policy shock turned off. The y-axis measures percentage deviation from the steady state.

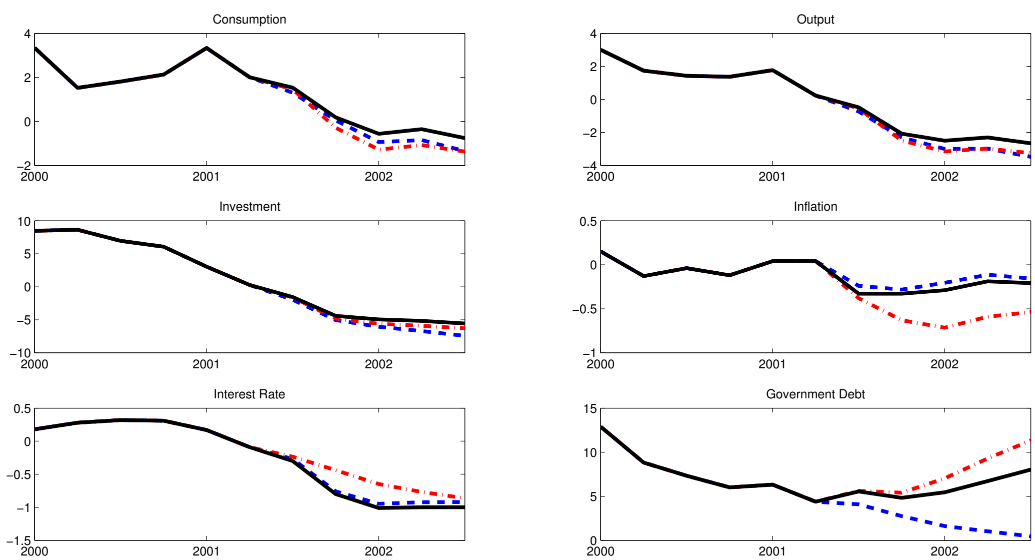

FIGURE 6. **Counterfactual exercise: tax cuts in 2001 and 2002.** Solid lines—data (observed or model-implied) conditional on all the estimated shocks; dashed lines—capital and labor tax shocks turned off; dotted-dashed lines—monetary policy shock turned off. The y-axis measures percentage deviation from the steady state.

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