Is Government Spending Predetermined? A Test of Identification for Fiscal Policy Shocks.

Anna Kormilitsina

June 2, 2016

Abstract

Strategies to identify fiscal policies and their effects often use an idea that fiscal instruments cannot respond to realizations of macroeconomic uncertainties within one quarter. I evaluate the validity of this assumption in a standard estimated DSGE model, where informational subperiods are introduced to ensure fiscal policy choices are made before the current state of economy realizes. At the same time, fiscal instruments are allowed to partially respond to macroeconomic shocks, and these responses are estimated using the Bayesian method. The resulting estimates indicate that within one quarter, government spending is adjusted in response to the neutral technology shock, and the tax rate responds to realizations of the preference shock. Moreover, the model capturing contemporaneous responses of fiscal instruments to shocks provides a better fit to the data than the model where fiscal variables are completely predetermined. These results suggest that treating fiscal instruments as predetermined is misleading. Instead of identifying fiscal shocks, such a strategy identifies a combination of the shocks and other macroeconomic uncertainties. I demonstrate that the positive consumption response to the government spending shock in a Cholesky identified structural VAR model reflects the response to the technology shock, while the consumption response is negative in the estimated model.

Keywords:government spending shocks, DSGE model estimation, timing, informational subperiods

JEL codes: E32, C11, E62

[0]Department of Economics, Southern Methodist University, e-mail: annak@smu.edu

1 Introduction

In spite of an increased number of studies evaluating the role of government on the economy, the effects of fiscal policies are still not well understood. Empirical research disagrees about important issues, such as the size of the government spending multipliers, and the sign of the consumption response to increased government spending. This disagreement seems to be influenced by the use of different methodologies to identify fiscal policy shocks. One popular strategy was proposed by Blanchard and Perotti (2002), who measure the effect of fiscal policies in a structural VAR (SVAR) framework. Blanchard and Perotti (2002) order fiscal instruments first, and use Cholesky decomposition of variance matrix of reduced form residuals to extract the exogenous shock component. Studies that follow this approach generally find that consumption positively responds to increased government spending (Fatas and Mihov (2001a), Fatas and Mihov (2001b), Galí, Lopez-Salido, and Vallés (2007), Bouakez and Rebei (2007).)

Alternative approaches to identify fiscal policy shocks tend to come to a different conclusion. One popular strategy, for example, utilizes the narrative approach of Ramey and Shapiro (1998). Ramey (2011) relies on the narrative approach to argue that consumption response to government spending is negative. Burnside, Eichenbaum, and Fisher (2004) also find that consumption mildly decreases after the shock. Mountford and Uhlig (2009) identify government spending shocks in an SVAR model using sign restrictions. The response of consumption in their study is negative, although mostly not significantly different from zero. Finally, Fisher and Peters (2010) look into stock returns to identify government spending shocks. Although they report a positive effect of government spending on consumption, it does not start to increase until after 5 quarters after the shock, while the initial response is still negative.

The positive consumption response is problematic, because it cannot be explained by a standard general equilibrium model. Indeed, an increase in wasteful government spending creates a negative wealth effect in the economy, which causes consumption of rational agents to decrease. To address the inconsistency between the predictions of theoretical and Cholesky identified SVAR models, multiple modifications to a standard model were introduced. These modified models were developed to justify the positive effect on consumption after the government spending shock.[1] Rather than attempting to justify the positive response of consumption in a theoretical model, I critically evaluate the identification strategy in Cholesky identified SVAR models. A crucial assumption behind this identification scheme is that government spending cannot respond immediately to any other sources of uncertainty in the economy. According to this assumption, an unexpected change in government spending can only be caused by the government spending shock. Blanchard and Perotti (2002) justify this approach by pointing out that "Direct evidence on the conduct of fiscal policy suggests that it takes policymakers and legislatures more than a quarter to learn about a GDP shock, decide what fiscal measures, if any, to take in response, pass these measures through the legislature, and actually implement them."[2] However, concerns have been raised that government expenditures may still reflect the current state of the economy. For example, Ramey (2011) emphasizes that government consumption expenditures are by definition services produced by government, which are valued at the cost of production. It is reasonable to assume that current economic conditions can influence these costs, and therefore a change in the state of the economy can cause government expenditures to adjust at the same time.[3]

The aim of this paper is to evaluate, to what extent, if at all, government spending responds to realizations of macroeconomic shocks in the same quarter. With this purpose, I start by adopting a standard DSGE model extended with informational subperiods. I assume that fiscal instruments, such as government spending and the tax rate, are determined based on information about the current value of output. However, the state of the economy is not revealed yet when the fiscal policy choices are made. This timing structure allows to ensure that the model is consistent with the main assumption in Blanchard and Perotti (2002), and at the same time, it represents fiscal policy decision making in a more sensible way than it is usually done in the literature.[4]

[1] See, for example, Galí, Lopez-Salido, and Vallés (2007), Bouakez and Rebei (2007), Linnemann and Schabert (2006), Monacelli and Perotti (2008), Zubairy (2014), among others.

[2] See Blanchard and Perotti (2002), page 1334.

[3] A negative shock, such as prolonged subfreezing temperatures that cause a shut down of schools and post offices, may have a negative effect on the cost of services provided by government employees, and therefore, on government consumption.

[4] A common strategy to induce consistency between the Cholesky identification and the theoretical

In order to empirically evaluate the hypothesis that fiscal policy instruments are predetermined relative to the current state of the economy, I modify the model with informational subperiods to allow a pass through of information about the state of the economy to fiscal policymakers. With this purpose, I explicitly assume that fiscal variables can partially respond to the current state of the economy. These responses can be obtained together with other structural model parameters by standard Bayesian or classical estimation methods, and their estimates allow to judge whether fiscal instruments are influenced by macroeconomic fundamental within the same period of time.

I find a strong evidence that government spending responds to current realizations of the neutral technology shock: an improvement in neutral technology causes government spending to increase in the same quarter. More specifically, a one percent improvement in the neutral technology, which is found to increase aggregate output by approximately 0.43 percent, is also associated with an increase in government spending anywhere from 0.1 to 0.5 percent. The tax rate is also found to be negatively related with the current realizations of the discount rate shock. I do not find sufficient evidence of the pass through from other shocks to the fiscal instruments.

These results suggest that the assumption of predetermined fiscal policy instruments is not supported by the data. In other words, government spending and the tax rate cannot be treated as predetermined in Cholesky identified SVAR models. An important implication of this result is that impulse responses obtained in Cholesky identified SVAR models must be biased, as these models do not identify the fiscal policy shocks correctly. I evaluate the bias in impulse responses to the government spending shock, and conclude that a rise in consumption after the government spending shock observed in Cholesky identified SVARs is the result of a shock identification error. While the model implied response of consumption to an increase in government spending is negative, the response

model is either to assume that government spending is exogenous in the model, or that government spending instrument is determined as a ratio to the previous period's output, or technology trend (See Kormilitsina and Zubairy (2016), Schmitt-Grohé and Uribe (2012)). The first approach still is not consistent with the Cholesky identified SVAR strategy, because government spending in an SVAR model is not completely exogenous: it responds to the state of the economy with a lag. The second approach disregards the forward looking behavior of the fiscal authority.

of consumption in the Cholesky identified SVAR model[5] is positive. This result remains robust for alternative specifications of the government spending process.

The finding of this paper is in line with that in Ramey (2011), who also argues that the positive response of consumption to an increase in government spending reflects the bias of identification due to erroneous timing of the shocks. Ramey claims that the bias arises due to the fact that fiscal shocks are not completely unexpected. If government spending policy is preannounced several quarters before a change in government spending is actually implemented, then the economy responds to the government spending shock upon announcement. Because consumption decreases upon the announcement of the positive government spending shock, then it starts to recover by the time when the policy is implemented. Therefore, the standard SVAR model erroneously captures the positive response of consumption, while the actual short run response is consistent with the prediction of the standard general equilibrium model. Similar to Ramey (2011), the bias in consumption response in this paper is also motivated by erroneous timing of the government spending shock. However, the nature of the bias is different. I show that the Cholesky identified SVAR model captures the combination of the government spending and technology shock rather than the government spending shock per se, and as a result, the positive consumption response reflects the response of the economy to the positive technology shock, when consumption response to the government spending is actually negative.

The consumption bias in the SVAR model arises from missing the fact the government spending is endogenous, because it is not completely predetermined. This idea is similar to the one expressed in Féve, Matheron, and Sahuc (2013), who emphasize that taking into account endogeneity of government policy is important to correctly evaluate macroeconomic effects of fiscal policies in quantitative models. These authors show that omitting the countercyclical response in the government spending rule results in a downward bias of consumption response in an estimated DSGE model. Differently from that paper, I show that failure to account for endogeneity of government spending results in an upward bias of the consumption response in an SVAR model.

[5]Estimated on artificial data implied by the model

This paper proceeds as follows. In Section 2, I present empirical evidence about the effect of government spending shock. Section 3 explains the modeling strategy that allows to quantitatively evaluate the assumption for identification of government spending shocks. I present the model in Section 4, and discuss the estimation strategy and results in Section 5. Finally, Section 7 concludes.

2 Empirical effects of government spending shocks.

The effects of fiscal policies can be determined by estimating a vector autoregressive model with L lags:

$$Y_t = B_1 Y_{t-1} + B_2 Y_{t-2} .... + B_L Y_{t-L} + u_t,$$

where B_i, $i = 1, ..., 4$ are square matrices of coefficients with the size of 6, and u_t is the mean-zero, $i.i.d$ the vector of reduced form innovations, with covariance matrix Σ_u. I include 6 variables in vector Y_t in the following order: government spending, the tax rate, consumption, investment, inflation, and the interest rate. A detailed definition of each variable is provided in Appendix 8.1. Consumption, investment, and government spending are present as their logarithms times 100, inflation, and the interest rate are expressed as annualized percentages.

Following Blanchard and Perotti (2002), identification of fiscal policy shocks makes use of the idea that government spending cannot respond to structural innovations within the same quarter. More formally, identification can be achieved by Cholesky decomposition of the variance matrix of the reduced form residuals: $\Sigma = AA'$, where matrix A is the square lower triangular matrix. This assumes that the reduced form and structural innovations are linearly related as follows:

$$u_t = Ae_t,$$

where e_t is the mean-zero, non-correlated vector of structural innovations with the diagonal covariance matrix Σ_ϵ.

I estimate the SVAR model with $L = 4$ lags to evaluate the response of consumption to a change in government spending. The graph on the left of Figure 1 shows the impulse response of consumption to a government spending shock of the size of one standard deviation. The vertical axis shows the percent deviation from trend, and quarters appear on the horizontal axis. The solid line represents the estimated response, and the grey bands show 90 percent confidence intervals.[6] The figure shows that consumption increases after a rise in government spending by approximately 0.13 percent on impact, the response is hump-shaped, and reaches approximately 0.2 percent at a peak between the fourth and tenth quarters. The consumption response is significantly different from zero in the first year after the shock.

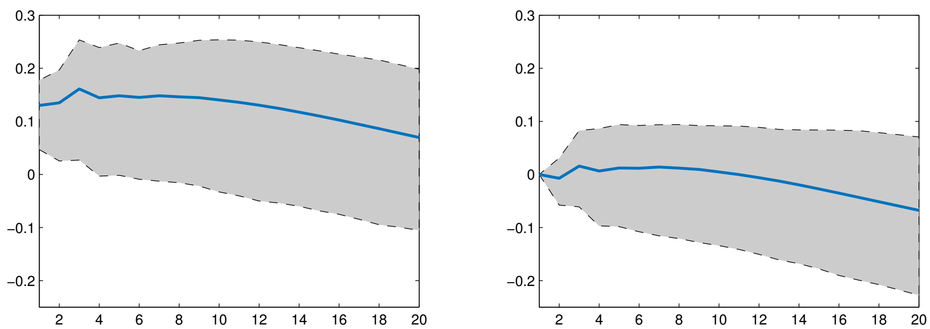

Figure 1: Empirical consumption response to a government spending shock.

Notes: The figure on the left shows the response in case when government spending and the tax rate are ordered first, the figure on the right shows the response in case when consumption and investment are ordered prior to government spending and the tax rate. The horizontal axis shows quarters, and the vertical axis shows the response in percentage deviation from trend. Grey are measures the confidence bands, obtained as the 5^{th} and 95^{th} quantiles of impulse response distributions generated by bootstrapping model residuals and reestimating the model 100 times.

The positive consumption response is conditional on the assumption that government spending cannot be influenced by macroeconomic uncertainties unrelated to fiscal policy in the same period. The simplest way to evaluate the importance of this assumption is to change the order of variables in the VAR by placing consumption before the government spending variable. Cholesky factorization in this case no longer implies that fiscal variables are predetermined: government spending can now be influenced by innovations

[6]Confidence intervals are calculated by bootstrapping reduced form residuals.

to consumption and investment, which may reflect, among others, technology and preference shocks. The second graph in Figure 1 shows the impulse response of consumption to the government spending shock under an alternative identification, where the order of variables in the SVAR model is the following: consumption, investment, government spending, tax rate, inflation, and the interest rate. The figure shows that consumption response is no longer positive. Moreover, consumption decreases slightly in the first two quarters, although the response is not significantly different from zero at any quarter after the shock.[7] It is interesting to note that consumption response in the second graph of Figure 1 is very similar to the one obtained by Mountford and Uhlig (2009), who rely on an alternative methodology for identification, which does not assume that government spending is predetermined. Therefore, assuming that predetermined government spending seems important for producing the positive response of consumption to the shock in government spending. In the next Section, I critically evaluate this assumption in an estimated DSGE model with informational subperiods.

3 Modeling Informational Subperiods.

The standard approach in DSGE modeling is to assumes that all shocks have realizations in the beginning of a period, so that economic agents know these realizations when making their decisions. The equilibrium in such a model is defined by a sequence of model variables that satisfy a system of expectational equations. This system consists of first order and market clearing conditions, and can be summarized in the form $Ef(Y', X', Y, X) = 0$, where E is the expectations operator conditional on the current state of the economy, X and Y are the vector of state and control variables, while prime superscript denotes future period realizations.[8]

This theoretical model can only be consistent with the Cholesky shock identification of the SVAR model when the government spending process is exogenous, or when gov-

[7] Due to the fact that it is ordered prior to the government spending, consumption does not adjust on impact to the innovation in government spending under Cholesky identification.

[8] In this formulation, the vector of state variables consists of endogenous predetermined and exogenous variables.

ernment spending is only allowed to adjust when previous periods' states change. If the policy rule is specified where government spending respond to the current output gap, or current values other endogenous variables, then the DSGE model is not consistent with the Cholesky identification.

However, this inconsistency can be avoided if informational subperiods, or timing restrictions are introduces in the model. Following Kormilitsina (2013), each period can be formally divided into two subperiods. In subperiod 1, government spending shock is realized, and the amount of government spending must be announced. In period 2, the technology and other shocks become known, and after that all endogenous choices are made by economic agents.

The equilibrium in the model with informational subperiods is determined by the same sequence of variables and equations as in the model without the timing constraints. The only difference is that the expectations operator must reflect the difference in information sets of the government and other economic agents. Therefore, the equilibrium system in the model with timing restrictions can be written as

$$\mathcal{E} f(Y', X', Y, X) = 0,$$

where $\mathcal{E}$ is the expectations operator that takes into account informational restrictions within a period, and the control and state vectors can be partitioned as follows:

$$X = [x;\ \theta], \tag{1}$$

$$Y = [y;\ z], \tag{2}$$

where vector x consists of endogenous predetermined variables, and exogenous variables with realizations in the beginning of the first subperiod.[9] Vector θ contains n_θ exogenous stochastic variables with realizations in the beginning of the second subperiod. Vector y contains full information control variables, the decisions for which are made in the

[9] This includes the government spending and tax rate policy shocks.

second subperiod, when realizations of all shocks are known. Finally, vector z represents partial control variables, such as the government spending and the tax rate, which are determined in the first subperiod, when only the realization of the government spending shock is known. Figure 2 visualizes the timing of events in the model.

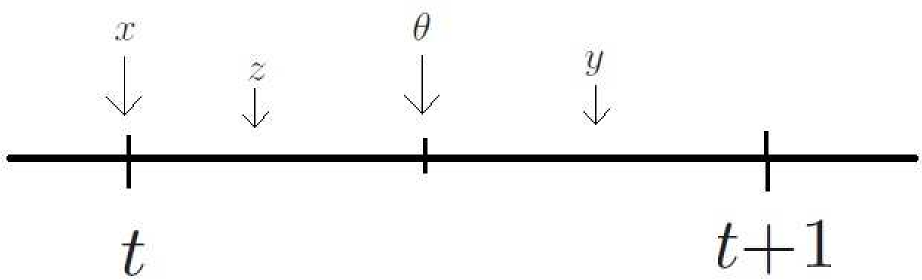

Figure 2: Timing of events within a period

Without the loss of generality, equations in $f(\cdot)$ can be arranged as follows

$$f = [f^0;\, f^1;\, f^\theta]. \tag{3}$$

The set of equations f^0 consists of equations that determine the choice of partially endogenous variables, G_t and τ_t. Equations in f^1 describe the optimal choices of fully endogenous variables in vector y, and the dynamics of the state variables in vector x. The set of equations in f^θ describes the evolution of the exogenous shocks in θ. I asume that the shock dynamics can be represented as a multivariate $AR(1)$ process as follows:

$$\theta' = P\theta + \sigma\epsilon'_\theta, \tag{4}$$

where P is a diagonal $n_\theta \times n_\theta$ matrix of autoregressive coefficients, and ϵ'_θ is an vector of shocks from a multivariate normal distribution with mean 0, and a diagonal variance matrix Σ.[10]

As shown in Kormilitsina (2013), the first-order linear solution to the model with

[10]Matrix P may be different from diagonal as well.

informational subperiods can be presented in matrix form as

$$\begin{bmatrix} y \\ z \end{bmatrix} = \begin{bmatrix} \bar{g}_x & g_\theta & g_{\theta_{-1}} \\ \bar{j}_x & 0_{n_z \times n_\theta} & j_{\theta_{-1}} \end{bmatrix} \begin{bmatrix} x \\ \theta \\ \theta_{-1} \end{bmatrix}, \tag{5}$$

and

$$\begin{bmatrix} x \\ \theta \end{bmatrix}' = \begin{bmatrix} \bar{h}_x & h_\theta & h_{\theta_{-1}} \\ 0_{n_\theta \times n_\theta} & P & 0_{n_\theta \times n_\theta} \end{bmatrix} \begin{bmatrix} x \\ \theta \\ \theta_{-1} \end{bmatrix} + \epsilon'. \tag{6}$$

Notice first that $\bar{g}_x$, $\bar{j}_x$, and $\bar{h}_x$ are matrices with n_y, n_z, n_x rows, and n_x columns that represent the marginal response of variables in Y to changes in x, everything else held constant. These responses are equivalent to the corresponding responses in the standard model without informational subperiods, which are denoted with a bar symbol. Also, because current realizations of shocks in θ are not in the information set of policy variables in vector z, the response of z to θ is a zero-valued matrix $0_{n_z \times n_\theta}$, while matrix $j_{\theta_{-1}}$ represents the response of z to previous period's realizations of shocks in θ. It can be shown that the elements of $j_{\theta_{-1}}$ capture the projection for θ given θ_{-1}, and the response of z to the projected state θ. Therefore,

$$j_{\theta_{-1}} = \bar{j}_\theta P, \tag{7}$$

where matrix $\bar{j}_\theta$ is the partial response of z variables to θ in the full information version of the model. Once $j_{\theta_{-1}}$ is known, matrices $g_{\theta_{-1}}$, and $h_{\theta_{-1}}$ can be recovered from the linear transformation:

$$\Delta(f^1)_{[x',y]} \begin{bmatrix} h_{\theta_{-1}} \\ g_{\theta_{-1}} \end{bmatrix} = -f^1_z j_{\theta_{-1}}, \tag{8}$$

in which

$$\Delta(f^1)_{[x',y]} = [f^1_{Y'} G_x + f^1_{x'},\ f^1_y] \tag{9}$$

is the jacobian of the system of equations f^1 with respect to vector $[x',\ y]$, and $f^1_{Y'}$, $f^1_{x'}$, f^1_y, and f^1_z are derivative matrices of a vector f^1 with respect to vectors Y', x', y and z

correspondingly, evaluated at a steady state, and $G_x = [\bar{g}_x; \bar{j}_x]$ is the matrix of response of endogenous variables to variables in vector x. Finally, given $g_{\theta_{-1}}$, and $h_{\theta_{-1}}$, g_θ and h_θ can be obtained from the following relationships

$$\begin{aligned} g_{\theta_{-1}} + g_\theta P &= \bar{g}_\theta P, \\ h_{\theta_{-1}} + h_\theta P &= \bar{h}_\theta P, \end{aligned} \tag{10}$$

where bars above g and h matrices are again used to denote the corresponding submatrices of the dynamics in the model without informational subperiods.

The model with informational subperiods retains the existence and uniqueness property of the equilibrium in the model without informational constraints. One may notice that the solution of the model with informational subperiods is pinned down by the assumption that variables in z are not responsive to current realizations of shocks in θ. Suppose however, that variables in z can react, at least to some extent, to shocks in θ. In this case, the partial response of z to θ is no longer zero, but can be represented as a $n_z \times n_\theta$ matrix J. Then, the dynamics of the model's endogenous variables can be written as

$$\begin{bmatrix} y \\ z \end{bmatrix} = \begin{bmatrix} g_x & g_\theta & g_{\theta_{-1}} \\ j_x & J & j_{\theta_{-1}} \end{bmatrix} \begin{bmatrix} x \\ \theta \\ \theta_{-1} \end{bmatrix}. \tag{11}$$

The elements of $j_{\theta_{-1}}$ can then be obtained as

$$j_{\theta_{-1}} = (\bar{j}_\theta - J)P,$$

while matrices $g_{\theta_{-1}}$, $h_{\theta_{-1}}$, g_θ, and h_θ can still be recovered from Equation (8), (9) and (11). Matrices h_θ and $h_{\theta_{-1}}$ will generally differ from those implied by the model with completely predetermined variables in vector z, and therefore, the dynamic properties of model variables and their statistics, including the likelihood function, will vary depending on parametrization of J, the partial pass through of shocks in θ to variables in z. The estimate of J can therefore be obtained using conventional estimation methods, along with other structural model parameters. Notice that if J is zero valued, then the model is reduced to the model with informational subperiods. Alternatively, if $J = \bar{j}_\theta$, then the model represents the economy without informational restrictions. The estimation results, such as standard test statistics or posterior distributions, can help evaluate the validity of the hypothesis that fiscal policy variables are predetermined relative to the current state of the economy. The next section provides the details of the Dynamic stochastic general equilibrium (DSGE) model used in estimation and subsequent analysis.

4 DSGE model

The model is a fairly standard DSGE model with nonstationary trends in macroeconomic variables. While a number of modeling strategies exist to allow for the positive response of consumption to the government spending shock, none of them are implemented in this model, because it is not the aim of this study to replicate the positive response of consumption documented in much of the SVAR literature.

4.1 Households

The economy is populated by a continuum of infinitely-lived households. Households consume final goods, supply differentiated labor services to the labor packer, accumulate capital, and rent capital services to firms, pay taxes and receive dividends from ownership in firms.

The life-time expected utility of households is determined as:

$$E_0 \sum_{t=0}^{\infty} \beta^t d_t \left[\phi ln(C_t - bC_{t-1}) + (1-\phi) ln(1-h_t) \right],$$

where E_0 denotes expectations based on period zero information set, β is the discount factor, d_t is the preference shock, C_t is the current level of consumption. Homogenous labor h_t is a Dixit-Stiglitz aggregate of differentiated labor services h_t^j, for $j \in [0, 1]$

supplied by households to a labor packer:

$$h_t = \left(\int_0^1 (h_t^j)^{1-\frac{1}{\eta^w}} dj \right)^{\frac{1}{1-\frac{1}{\eta^w}}}.$$

Here, $\eta^w > 1$ is the elasticity of substitution across different types of labor, and the upper script j helps to distinguish between different types of labor.

The homogenous labor h_t is supplied to firms at a real rate W_t. Households possess monopolistic power over their wages, and have the ability to set the labor specific wage rate; however, they are required to satisfy the demand for labor at this wage rate. Changes in the wage rate are subject to quadratic adjustment costs, determined as

$$\Psi \left(\frac{W_t^j}{W_{t-1}^j} \right) = \frac{\alpha_w}{2} \left(\frac{W_t^j}{W_{t-1}^j} - \mu_{z^*} \pi \right)^2,$$

per (real) dollar of the wage bill. In this formula, $\alpha_w > 0$ is the wage adjustment cost parameter, W_t^j is the individual real wage rate, π is the inflation rate along the balanced growth path, and μ_{z^*} is the rate of growth of the economy (output, consumption, and wages) along the balances growth path.

The households own physical capital, K_t. Capital is accumulated through the process of investing, and the total stock of capital depreciates at a rate δ. Investment adjustments are costly, with the capital loss of $\mathcal{S}(\cdot)$ per unit of investment. The dynamics of capital is therefore:

$$K_{t+1} = (1-\delta)K_t + I_t \left(1 - \mathcal{S} \left(\frac{I_t}{I_{t-1}} \right) \right), \tag{12}$$

The cost of investment $S(\cdot)$ is quadratic:

$$\mathcal{S} \left(\frac{I_t}{I_{t-1}} \right) = \frac{\kappa}{2} \left(\frac{I_t}{I_{t-1}} - \mu_I \right)^2,$$

where $\kappa > 0$, and μ_I is the steady-state growth rate of capital and investment.

Following Fisher (2003), investment goods I_t are obtained from consumption using a stochastic linear technology, according to which at each date t, one unit of consumption can produce Υ_t units of investment, where Υ_t is the investment specific technology. The gross growth rate of Υ_t, $\mu_{\Upsilon,t} \equiv \Upsilon_t/\Upsilon_{t-1}$ is a stochastic process described below.

Households own shares in firms, and receive dividends with the real value Φ_t. They pay capital and labor income tax, at the same rate τ_t, and receive a lump-sum transfer in the amount Tr_t in terms of consumption. Households buy and sell one-period risk-free government bonds at a price $1/R_t$. The budget constraint can be written in real terms as[11]

$$C_t + \Upsilon_t^{-1} I_t + \frac{B_{t+1}}{R_t} = \frac{B_t}{\pi_t} + (1-\tau_t)(R_t^k K_t + W_t h_t) - \int \left(\Psi \left(\frac{W_t^j}{W_{t-1}^j} \right) \right) W_t^j h_t^j dj + \Phi_t + Tr_t,$$

where B_t is the real value of government bonds.

4.2 Firms

A continuum of monopolistically competitive firms of measure 1 produce differentiated intermediate goods. For production, each firm uses capital and labor, K_t and h_t according to the following technology

$$F(K_t, Z_t h_t) \leq (K_t)^\theta (Z_t h_t)^{1-\theta} - Z_t^* \vartheta, \tag{13}$$

where $0 < \theta < 1$, $Z_t^* \vartheta$ represents the fixed costs of operating a firm in each period,[12] Z_t is the stochastic labor-augmenting productivity process, growing at a rate of $\mu_{z,t} \equiv Z_t/Z_{t-1}$.

Each firm $i \in [0,1]$ maximizes the present discounted value of dividend payments, given by

$$E_t \sum_{s=0}^{\infty} Q_{t,t+s} \Phi_{t+s}^i,$$

where $Q_{t,t+s}$ is the firm's discount factor, and period t dividend payments in real terms

[11] To simplify notation, the household specific superscript $j$is omitted when possible.

[12] Z_t^* is the stochastic trend for the economy, which is combination of the investment specific and labor-augmenting technologies.

are

$$\Phi_t^i = \frac{P_t^i}{P_t} Y_t^i - R_t^k K_t^i - W_t h_t^i - \Omega\left(\frac{P_t^i}{P_{t-1}^i}\right),$$

where Y_t^i is the demand for the firm i's output, $\Omega(\cdot)$ is the quadratic cost of price changes, which is proportional to the stochastic trend Z_t^*:

$$\Omega\left(\frac{P_t^i}{P_{t-1}^i}\right) = \frac{\alpha_p Z_t^*}{2}\left(\frac{P_t^i}{P_{t-1}^i} - \pi\right)^2,$$

with $\alpha_p > 0$, denoting the degree of price stickiness. Monopolistically competitive firms are required to satisfy the demand for their output at the posted price.

The final good is the aggregate of differentiated goods produced by monopolistically competitive firms using a Dixit-Stiglitz technology, which implies that the demand for individual good varieties is

$$Y_t^i = \left(\frac{P_t^i}{P_t}\right)^{-\eta_p} Y_t^d,$$

where $\eta_p > 1$ is the elasticity of substitution between individual good varieties, and Y_t^d is the demand for the final good.

Monetary policy is described by a generalized Taylor type rule with the interest rate smoothing and response to inflation and output growth, as follows:

$$ln\left(\frac{R_t}{R}\right) = \alpha_R ln\left(\frac{R_{t-1}}{R}\right) + \alpha_\pi ln\left(\frac{\pi_t}{\pi}\right) + \alpha_Y ln\left(\frac{Y_t}{Y_{t-1}\mu_{z^*}}\right) + \epsilon_t^r, \tag{14}$$

where Y_t is aggregate real output, α_R, α_π, α_Y are Taylor rule parameters, and $\epsilon_t^r \sim i.i.d.(0, \sigma_r^2)$ is the monetary policy shock, with $\sigma_r > 0$.

4.3 Fiscal policy

Government levies taxes, pays lump-sum transfers to households, and develops public projects with real cost of G_t. For simplicity, I assume that government budget is balanced in each period. Contrary to quantitative studies that evaluate the effects of fiscal policies using in a stationary framework (Leeper, Plante, and Traum (2010), Zubairy (2014), Bouakez and Rebei (2007), etc.), it is important to ensure that government spending has the same trend as output, to ensure the existence of the balanced growth path. I proceed by assuming that the instrument of the government spending policy is the share of government spending in output. However, because the information set of the government is restricted in such a way that current output is not observed at the moment when government spending is determined, the spending policy instrument is determined as the expected share of public expenditures:

$$\varsigma_t^g = \mathcal{E}_t^g(G_t/Y_t),$$

where $\mathcal{E}_t^g$ denotes government's expectations at the moment of the decision making. The dynamics of ς_t^g is modeled as an exogenous process, described in Subsection 4.4 below.

Alternative strategies exist to model cointegration of government spending and output in non-stationary models. For example, Féve, Matheron, and Sahuc (2013), and Leeper, Traum, and Walker (2011) assume that government spending evolves around the stochastic trend of the neutral technology process. In a standard model without informational subperiods, this strategy implies that government spending responds endogenously to an increase in Z_t^*, which is in contradiction with the main assumption behind the Cholesky shock identification in SVAR models. For this reason, some authors require that the policy instrument be determined as the ratio of government spending to the previous period's realization of the technology shock (Kormilitsina and Zubairy (2016)). Chahrour, Schmitt-Grohé, and Uribe (2012) also follow this strategy, although they generalize the definition of the government spending instrument, allowing for a smoother trend, although while still imposing cointegration of public expenditures and the technology process. I evaluate the robustness of the results to alternative strategies of modeling cointegration of government spending and output in a robustness exercise in Section 6.

I assume that income tax at the rate τ_t reflects some inertia, and responds to the output gap:

$$ln\left(\frac{\tau_t}{\tau}\right) = \alpha_\tau ln\left(\frac{\tau_{t-1}}{\tau}\right) + \alpha_{\tau,y}\mathcal{E}_t^g ln(\frac{Y_t}{\tilde{Y}_t}) + \epsilon_t^\tau, \tag{15}$$

where $0 < \alpha_\tau < 1$, and $\epsilon_t^\tau \sim N(0, \sigma_\tau^2)$, with $\sigma_\tau > 0$, is the tax shock. $\tilde{Y}_t = Z_t^* y$ is a measure of potential output, where y is the steady state level of detrended output.

4.4 Equilibrium and Stationary Transformations

Because the model exhibits non-stationary trends, the model equations need to be expressed in terms of stationary transformations of variables. The stationary transformations are defined by using lower-case letters, and summarized in Table 1. Consumption, output, the wage rate, and the household borrowing are transformed into their stationary versions by discounting with Z_t^*, while investment, and the level of next period capital are discounted with $\Upsilon_t Z_t^*$. Government spending is transformed by discounting with previous period's trend Z_t^*. This is necessary to ensure that both transformed and non-stationary government spending variables are in the same information set, that does not include current realizations of shocks (except for government spending shock itself). The rental rate of capital is multiplied by Υ_t to obtain a stationary transformation. Finally, the wage and price cost functions are also transformed by discounting with Z_t^*.

Symmetric competitive equilibrium is defined as the sequence of 15 variables,

$$\{c_t,\, y_t,\, i_t,\, w_t,\, h_t,\, k_{t+1},\, b_{t+1}\, \lambda_t,\, \pi_t,\, \varrho_t,\, \tilde{\mu}_t,\, mc_t,\, g_t,\, \tau_t,\, r_t\}_{t=0}^{\infty}$$

that satisfy 15 equilibrium conditions, given k_0, b_0, and any sequence of shock variables

$$\{\mu_{z,t},\, \mu_{\Upsilon_t,},\, d_t,\, \varsigma_t^g,\, \epsilon_t^\tau,\, \epsilon_t^r\}_{t=0}^{\infty}.$$

The dynamics of all shocks except the tax and monetary policy shocks, is modeled as a simple AR(1) process for logarithms:

$$ln(\frac{x_{t+1}}{x}) = \rho_x ln(\frac{x_t}{x}) + \epsilon_t^x,$$

where $x = \mu_z,\, \mu_\Upsilon, d,\, \varsigma^g$. Table 3 provides the full set of equilibrium conditions in terms of stationary variables.

Table 1: Stationary transformation of model variables

Original variable	Stationary variable	Stationary transformation obtained by
Y_t, C_t, B_{t+1}, W_t	y_t, c_t, b_{t+1}, w_t	dividing by Z_t^*
G_t	g_t	dividing by Z_{t-1}^*
K_{t+1}, I_t	k_{t+1}, i_t	dividing by $Z_t^*\Upsilon_t$
R_t^k	r_t^k	multiplying by Υ_t

5 Estimation

I rely on a Bayesian method to estimate the model, where the likelihood function is estimated using the Kalman filter, and combined with prior distributions for model parameters. The data y_t is the 5×1 vector of observable variables defined as follows

$$h_t = \{\, dl(G_t),\, ln(TR_t/Y_t),\, dl(C_t),\, dl(I_t),\, 4dl(P_t),\, R_t \,\},$$

where $dl(X_T) = 100(ln(X_t) - ln(X_{t-1}))$, G_t, C_t, and I_t, Y_t are government spending, consumption, investment expenditures, and GDP, TR_t represents tax revenues, P_t is GDP deflator, and therefore $4dl(P_t)$ measures annualized inflation rate, R_t is the nominal annualized interest rate, measured by the effective (annualized) Federal funds rate, in percentages. All the data in vector y_t appear in quarterly frequency, spanning from 1954:3 to 2010:4.

The observable variables and model variables are related as follows:

$$h_t = \begin{bmatrix} \mu_{z^*} \\ \tau \\ \mu_I \\ \mu_{z^*} \\ \pi \\ R \end{bmatrix} + \begin{bmatrix} \hat{g}_t - \hat{g}_{t-1} + \mu_{z^*,t-1} \\ \hat{\tau}_t \\ \hat{i}_t - \hat{i}_{t-1} + \mu_{I,t} \\ \hat{c}_t - \hat{c}_{t-1} + \mu_{z^*,t} \\ \hat{\pi}_t \\ \hat{R}_t \end{bmatrix} \tag{16}$$

In this observation equation, the stationary transformation of government spending is obtained by discounting with the previous period's trend according to $g_t = G_t/Z_{t-1}^*$, which helps ensure the consistency of the timing restriction for both the stationary and original government spending series. As a result, $\mu_{z^*,t-1}$ appears in the relationship of the observable rate of growth of aggregate government spending with that of the model, rather than $\mu_{z^*,t}$ as in the observation equation for consumption growth, where the stationary transformation is obtained by discounting with the current period's trend: $c_t = C_t/Z_t^*$.

The vector of estimated model parameters contains 32 parameters:

$$\theta = \{\, \tau,\, \mu_{z^*},\, \mu_I,\, \pi,\, R,\, b,\, \alpha_p,\, \alpha_w,\, \kappa,\, \alpha_R,\, \alpha_\pi,\, \alpha_Y,\, \alpha_\tau,\, \alpha_{\tau,y},$$

$$\rho_g,\, \rho_z,\, \rho_\Upsilon,\, \rho_d,\, \sigma_g,\, \sigma_z,\, \sigma_\Upsilon,\, \sigma_d,\, \sigma_r,\, \sigma_\tau,\, J^\tau,\, J^g \,\},$$

where the first five parameters of θ represent steady state values of modes variables, the following parameters measure real and nominal frictions, monetary and tax policy rules, autocorrelations and standard deviations of shocks. Vectors J^τ and J^g have four elements each, and represent the response of the tax rate and the government spending to contemporaneous realizations of the four fundamental shocks.

Parameters presented in Table 2 are calibrated according to conventional wisdom or due to identification issues. The parameter governing the steady state share of capital is set at $\theta = 0.3$. The intertemporal discount factor $\beta = 0.999$. The depreciation rate is fixed at a conventional value $\delta = 0.025$. The actual average ratio of government expenditures in GDP, $s^g = 0.2$, is used to calibrate the steady state share of government expenditures in the model. Finally, the elasticity of substitution for intermediate goods and labor types is calibrated because estimating these parameters is usually problematic. Parameter η_p is set at 6 and $\eta_w = 21$, which imply the steady state price and wage markups of 20 and 5 percent correspondingly.

5.1 Estimation Results

Tables 4 - 6 show mean values of the posterior distributions together with their 5^{th} and 95^{th} quantiles, as well as the prior distributions of estimated parameters. The posterior distribution is obtained from the elements of the MCMC chain, discarding the first 10 percent of $600,000$ elements. Table 4 presents the contemporaneous responses of fiscal variables to the same-period realizations of the four structural shocks. Table 5 presents the structural model parameters, including the parameters of the monetary policy and tax rules. Table 6 focuses on estimates of the shock processes.

The prior distributions of parameters in vectors J^{τ} and J^{g} are all zero-mean normal distributions with standard deviations of 0.1. For the first 5 parameters of Table 5, the priors are centered to approximately match the mean values of the observable variables. The priors for the structural parameters of the model are centered at values conventionally used in the literature. For example, the autoregressive parameters for shock processes all have the mean of 0.7 and standard deviation of 0.1, and the priors for standard deviations of shocks are centered at 0.1 with standard deviations 1, for all shocks except the monetary policy shock, which has the prior distribution centered at 0.01 with the standard deviation of 0.1. Beta-distributions represent priors for parameters with bounded support, such as the tax rate, consumption habits, inertia in monetary and fiscal policy, and autoregressive parameters of shock processes. Gamma or inverse gamma distributions are used for priors of parameters with lower bound in support.

The estimates of J^{τ} and J^{g} in Table 4 reveal that both the tax rate and government spending are sensitive to some sources of uncertainty in the same period. More specifically, the tax rate responds negatively to the preference shock, and government spending responds positively to the neutral technology shock, and negatively to the investment specific shock. An increase in the neutral technology shock of one percent causes government spending to increase by approximately one half of a percent. At the same time, a one percent increase in investment specific technology causes government spending to decrease by 0.22 percent. Finally, an increase in the preference shock of one percent is associated with a reduction in the tax rate by 0.045 percent. These estimates are statistically significant in the sense that they are confirmed by at least 90 percent of the posterior distributions. The contemporaneous responses of public spending and taxes to other shocks are not statistically different from zero, as the 90 percent confidence intervals include zero.

Figure 3 shows the prior and posterior distributions of the partial response of policy variables to current realizations of the four shocks. The figures in the upper row show the responsiveness of the tax rate, and those in the lower row show the distributions of the responsiveness of government spending. The columns represents the monetary policy shock, the neutral and investment specific technology, and the discount factor shocks. The red solid line shows the prior distribution, and the grey shaded area depicts the posterior. The histograms allow to visually verify that the estimated positive effect of the neutral technology shock on government spending is well-identified, as the posterior distributions are different from the priors.

Figures 4 present impulse responses to a 1 percent government spending shock as implied by the estimated model. The horizontal axis shows quarters, and the vertical axis shows responses as deviation from the balanced growth path in percentages for all variables except inflation and the interest rate. The latter responses are expressed in annualized rates, and shown as deviations from the steady state. The figure demonstrates that a one percent positive government spending shock causes government spending to increase by 1.2 percent. Government spending increases by more than 1 percent, because fiscal policy anticipates that an increase in public spending boosts output in the short run, therefore, a one percent increase in the government spending to GDP ratio requires a larger expansion in government spending. In response to the shock, both consumption and investment decrease. A decrease in investment is a result of the standard crowding out effect, when increased public expenditures result in higher real interest rates. Investment decreases by approximately 0.3 percent relative to the balanced growth path on impact, the response is hump shaped, and the trough is reached at -0.4 percent in the second or third quarter. Consumption response is less pronounced, with consumption decreasing by approximately 10 basis points on impact, with the maximum response not exceeding -0.25 percent approximately 7 to 9 quarters after the shock. The negative effect on consumption is consistent with theory, where the drop in consumption is caused by the negative wealth effect from an increase in wasteful government spending.

An important implication of the estimates reported in Table 4 is that fiscal policy variables do partially respond to some shocks in the same period. Therefore, treating fiscal policy variables as exogenous is erroneous, and will result in biased estimates of impulse responses. This is the case for Cholesky identified SVAR models that place fiscal variables first to identify the government spending shock. Rather than identifying the the government spending shock, this strategy identifies a combination of the government spending shock and the technology shocks. As a result, the impulse responses, and variance decomposition obtained from the SVAR model can be substantially biased.

To evaluate the bias in impulse responses, I compare the responses to the government spending shock implied by the estimated model with those implied by the SVAR model estimated on an artificial dataset generated from the estimated model. With this purpose, I generate 1000 datasets of 250 elements each, using the model parameterized by a parameter vector drawn randomly from the posterior distribution. For each dataset, I estimate the SVAR model, where government spending variable is placed first, and Cholesky decomposition of the covariance matrix of reduced form innovations is used to identify the government spending shock. The data in the dataset are model analogue of the data in Equation (16), have the same ordering and are detrended with the quadratic trend. The resulting responses of observable variables to the government spending shock are shown in Figure 5. A general comparison with Figure 4 reveals a substantial difference in impulse responses. In particular, the Cholesky-identified VAR model predicts a rise in consumption after the shock, as shown in Figure 5, while the true response of consumption is negative. Similarly, while investment responds negatively to a rise in government spending in the underlying DSGE model, it increases in the SVAR model. At the same time, the response of government spending to the shock is similar in the two figures, except that the SVAR model's response on impact is slightly larger, with public spending increasing by approximately 1.5 percent after the shock, while the rise in public spending is just approximately 1.3 percent in the underlying DSGE model. This difference is due to a larger estimated of volatility of the government spending shock identified by the SVAR model, which arises because the government spending shock estimated by the SVAR model is actually a mixture of several underlying sources of uncertainty.

To shed more light on why the effect of the government spending shock evaluated using the SVAR model is different from that in the underlying model, it is useful to consider the 6×6 matrix of true responses of model variables to structural shocks, A_0. Matrix A_0 can be uniquely decomposed into a product of a lower triangular matrix Σ and an orthonormal matrix Ω:

$$A_0 = \Sigma\Omega. \tag{17}$$

The conditional variance of observable variables is $A_0A_0' = \Sigma\Omega\Omega'\Sigma' = \Sigma\Sigma'$. Provided the VAR model is a good approximation to the true model dynamics, and the short sample bias is absent, Σ represents the Cholesky decomposition of the variance of the reduced form VAR model's residuals. Cholesky identification implies that the immediate responses to shocks are measured by Σe_t, where e_t is vector of Cholesky identified innovations. Because the first variable in the VAR, government spending, helps identify the government spending shock, the immediate response of observable variables to this shock is represented by the first column of Σ.

Since A_0 represents the model implied immediate responses to the structural shocks, matrix Ω provides a link between the SVAR identified shocks e_t and model implied structural shocks ϵ_t as follows:

$$e_t = \Omega\epsilon_t. \tag{18}$$

Therefore, any row i of Ω provides a linear combination of model implied shocks in ϵ_t that determines the i's shock obtained by the Cholesky identification. For example, Cholesky identified shock to government spending becomes

$$e_t^g = \Omega_{1,1}\epsilon_t^g + \Omega_{1,2}\epsilon_t^\tau + ...\Omega_{1,n}\epsilon_t^r.$$

If the SVAR model identifies the government spending shock correctly, then $\Omega_{1,1} = 1$, and $\Omega_{1,i} = 0$ for $i = 2, .., n$, so the first row of Ω is a unit vector.[13] This is the case when government spending is completely predetermined or exogenous. However, if there is a pass through of the model shocks to government spending in the same period, then the first row of Ω is different from a unit vector. This means that the SVAR identified shock is actually a linear combination of the other structural shocks, and the impulse responses to the SVAR identified shock represent the combined impulse response to all structural shocks. The size of the bias in impulse responses from the SVAR identification depends

[13]Moreover, if the SVAR model identifies all shocks correctly, Ω can be arranged as an identity matrix, if the ordering of shocks in the SVAR model is the same as that in the underlying model.

on the importance of other shocks are in linear combination (18), in comparison with the shocks the model intends to identify.

Table 7 shows the elements of the first two rows of Ω. The first row provides the linear composition of true structural shocks to determine the Cholesky identified government spending shock, e_t^g, while the second row represents the linear combination for e_t^τ. The table reveals that the Cholesky shock e_t^g is determined primarily by the government spending and the neutral technology shocks, ϵ_t^g and ϵ_t^z. Strikingly, the weight assigned to the neutral technology shock is 0.98, which is almost five times larger than that of the government spending policy shock, 0.2. Therefore, the Cholesky identified government spending shock may possess some properties of the technology shock. For example, the positive response of consumption in the SVAR model with Cholesky identification is likely observed because the positive consumption effect of the neutral technology shock compensates the negative effect from increased government spending.[14] The second row of the table represents the composition of the SVAR identified tax policy shock. Interestingly, the tax shock seems to be identified correctly, as the largest weight in the linear combination is placed on the tax policy shock (0.99), while the contribution of the other structural shocks is relatively small, not exceeding 0.1 for any of these shocks.

It is worth noting that the elements of the first two rows of matrix Ω are dictated by the data through the estimation procedure: If the estimates of all elements of J were near zero, then Ω_1 would be close to the unit vector. Figure 6 presents the immediate consumption response to the government spending shock as implied by the Cholesky identification across the elements in J^g. Cholesky identified response in these graphs is obtained as the corresponding element $\Sigma_{1,3}$ of matrix Σ in decomposition (17). Only one parameter is varied at a time, keeping the remaining parameters at their posterior mean values. The figure shows that consumption increases in response to the government spending shock for all considered parameterizations for sensitivity of public spending to the monetary policy, preference or investment specific shocks. At the same time, the positive consumption response crucially depends on the positive estimate for J_z^g. This indicates once again

[14]Figure 9 in Appendix demonstrates that the theoretical impulse responses to the neutral technology shock are indeed very similar to the impulse responses obtained by Cholesky identification.

that the positive response of consumption to the government spending shock observed in the Cholesky identified SVAR model reflects the positive effect of the neutral technology shock on government spending, and does not represent the true negative response to the government spending shock implied by the estimated theoretical model.

Tables 4-6 also present the estimates in alternative versions of the model. The second column named "Part info" assumes the partial information structure without the possibility of contemporaneous pass through of shocks to fiscal variables. This is achieved by setting all parameters in J^g and J^τ to zero. The third column, "Full info", estimates the model without the timing structure. It follows a standard approach where all shocks are assumed to have realizations in the beginning of each period, before any choices are made. In this case, the elements of J^g and J^τ are the corresponding submatrices of the standard log-linear solution. A few observations can be made from comparing the estimation outcomes in Tables 4-6. First, the structural parameters in Tables 5 and 6 are very similar across the models. However, the standard deviation of the government spending shock is larger in the model with timing constraints and where the same period pass through of the macro shocks to fiscal policy is absent. It can be explained by the fact that the conditional volatility of government spending in this model is due to the government spending shock only, while in the other two models it is a mixture of the government spending and other (primarily neutral technology) shocks. Second, The estimates of J^g ad J^τ in the baseline model resemble those of the unconstrained model. This is especially true for the effect of the neutral technology shock on government spending: $J^g_z = 0.55$ in the baseline model and $J^g_z = 0.524$ in the model without informational subperiods. The last two rows of Table 6 present the mean value of log-likelihood distribution, as well as the log of the marginal likelihood values across the models. The log-likelihood in the model without the immediate pass through of the shock to government spending is -1470, which is substantially smaller than that in the models where the pass-through is allowed. Therefore, the model where the contemporaneous effect of the shocks on government spending is absent does not fit the data as well as the other two models. Interestingly, the model without informational subperiods delivers the same log likelihood statistics as the model where the partial response of government spending to shocks is possible, with both values falling in the interval between −1385 and −1386. In terms of the marginal likelihood, however, the model without the informational subperiods outperforms the other two models.

6 Robustness Analysis

Trend in Government Spending

The discrepancy in consumption responses of the SVAR and implied theoretical models could be driven by the modeling assumption about the government spending process.

In a nonstationary model with a balanced growth path, it is necessary in ensure that government spending is cointegrated with output, and therefore, government spending must have the same rate of growth, at least asymptotically, as the rest of the economy. The baseline model in Section 4 implements this by defining the instrument of the spending policy as the share of public spending in GDP, ς. This strategy associates an adjustment in government spending as a government spending shock only if it is accompanied by a change in the share of public spending in output. Otherwise, the event is considered an automatic response to a change in economic conditions and does not indicate an adjustment in the spending policy. While this seems a reasonable strategy that has been implemented in previous research (see Fernández-Villaverde, Guerrón-Quintana, Kuester, and Rubio-Ramírez (2015), Kormilitsina and Zubairy (2016)), alternative ways to model cointegration of government spending and output in nonstationary models are considered in the literature as well. For example, Leeper, Traum, and Walker (2011) introduce the government spending instrument is the ratio of spending to the stochastic growth rate of the economy, G_t/Z_t^*.[15] More generally, Schmitt-Grohé and Uribe (2012) assume that the short-run trend for government spending X_t^G, while being determined by the stochastic trend Z_t, is also an AR(1) process, which makes it less volatile than the stochastic trend of the economy, and at the same time ensures cointegration of government spending and output.

[15]Sometimes, the previous period's realization is used in the denominator to determine the policy instrument, to reflect the assumption that government spending is predetermined relative to the current state.

To evaluate the robustness of my findings to the modeling of the fiscal policy instrument, I consider a modification of this latter approach. More specifically, I define government spending instrument g_t as follows:

$$g_t = G_t/X_t^G, \tag{19}$$

where the stochastic trend in government spending is modeled according to an AR(1) process for logs:

$$X_t^G = (X_{t-1}^G)^{\rho_g^x}(Z_t^*)^{1-\rho_g^x}. \tag{20}$$

Notice that parameter $\rho_g^x \in [0, 1)$, which can be estimated, indicates the relative smoothness of the trend for government spending, compared to the stochastic trend Z_t^*. This formulation is different from the one in Schmitt-Grohé and Uribe (2012) in is that I use Z_t^* rather than its previous period's value in Formula (20). Alternatively, I also assume that X_t^G in Equation (19) is determined based on output Y_t rather Z_t^* than process:

$$X_t^G = (X_{t-1}^G)^{\rho_g^x}(Y_t)^{1-\rho_g^x}. \tag{21}$$

If the estimate for ρ_g^x turns out to be near zero, the process converges to the one in the baseline model, since $X_t^G \equiv Y_t$.

The estimates of J^g and J^τ, along with the additional parameter ρ_g^x are presented in Table 8. Columns (a) and (b) report the estimates for the model where government spending is determined by Equations (20), and (21), respectively. Stars show when the posterior parameter distribution does not include zero between the 5^{th} and 95^{th} quantiles, which indicates that the estimated parameter is significantly different from zero. It is important to note that for the government spending process as in Formula (20), there are only two elements for the matrix of immediate responses J^g. If the value of government spending is determined based on the economy's trend Z_t^*, then fiscal policy will only look to respond to the neutral and investment specific technology shocks that compose Z_t^*, and not the other two shocks.

Table 8 reveals that for both models, the estimate for ρ_g^x is relatively close to 1. Therefore, the trend in government spending is much smoother than the stochastic output trend. This result is consistent with the idea that the specifics of legislation does not allow government spending to adjust very quickly. The estimates of J^{τ} turn out to be very robust to the modification of the government spending shock. The estimates of J^{g} and J^{τ} are quite similar to the ones obtained for the baseline model. One exception, however is the smaller estimate of the immediate response of government spending to the neutral technology shock. In both models, the estimate for J_{z}^{g} is in between of 0.12 and 0.16, which is 3 to 4 times as small as that in the baseline model. However, in both models (a) and (b), the estimates of J_{z}^{g} are still significantly different from zero. Another difference is that the estimate J_{v}^{z} is no longer significantly different from zero, while it is slightly negative in the baseline model.

Anticipation effect of government spending shocks

Ramey (2011) demonstrates that the positive response of consumption to an increase in government spending observed in SVAR models is also the result of false shock identification. Ramey demonstrates that the bias in the consumption response is due to anticipation effect that is not taken into account. An increase in government spending is preceded by the news about the event, which causes the economy to respond momentarily, long before the government spending actually increases. In response to such fiscal policy news, consumption decreases, and then it begins to recover slowly. At the moment when government spending adjusts, consumption continues to adjust up. Therefore, the positive consumption response is just a coincidence. Ramey (2011) demonstrates that taking proper account of anticipation effect in fiscal policy eliminates the positive consumption response to the non-anticipated increase in public spending.

Similar to Ramey (2011), I find that the government spending shock in SVAR models is misspecified. Differently from that study, the positive consumption response represents the response of consumption to the neutral technology shock, rather than the lagged effect of consumption due to news of an upcoming increase in the government spending. Nevertheless, anticipation effect is absent from the model in Section 4. To evaluate the effect of anticipation, I add the anticipated government spending shock as another source of uncertainty in the model. In particular, I assume that adjustments of the government spending instrument ς^g may be due to either anticipated or non-anticipated policy shock:

$$ln\left(\frac{\varsigma^g_{t+1}}{\varsigma^g}\right) = \rho_g ln\left(\frac{\varsigma^g_t}{\varsigma^g}\right) + \epsilon^g_{t+1} + \epsilon^a_{4,t-3}, \tag{22}$$

where $\epsilon^a_{4,t} \sim N(0, \sigma^2_a)$, with $\sigma_a > 0$, is the news in period t of a change in government spending with implementation lag of 4 quarters, and the government spending shock ϵ^g_{t+1} represents the unexpected, or non-anticipated change in government spending.

I estimate two models with anticipation in government spending policy. The first is the baseline model, and the second model is the one with a smooth trend in government spending, where the trend is determined by Equation (21). The resulting estimates J^g and J^t are shown in the last two columns of Table 8, Columns (c) representing the baseline model specification and column (d) representing the model with the smooth trend in government spending. The estimates of J^g and J^t in column (c) are very similar to those presented in Table 4 for the baseline model. The government spending is still very sensitive to the neutral technology shock, and the tax rate still negatively responds to the preference shock, and posterior distributions of both estimates are statistically different from zero. These results are confirmed by estimates in column (d). Differently from the baseline model, the sensitivity parameter $J^g_z = 0.104$ in the model with a smooth trend in spending, which implies that public spending response to neutral technology shocks is less pronounced than that in the baseline model. Still, both models confirm that the immediate effect of shocks on government spending is non-negligible and statistically different from zero.

Table 8 also reports the measures of fit to data across the model alternatives considered. The largest values for log-likelihood function, as well as for the marginal likelihood, are reported in column (b). The model behind the results reported in column (d) is identical to that model, except that it introduces anticipated shocks to government spending, however, it does not provide a better data fit. The same conclusion arises if one compares the marginal likelihood in model (c) with that in the baseline model. Therefore, accounting for anticipation effect in government spending does not seem to improve the model's outcome. Another observation one can make is that models with a smooth trend in government spending, such as the models (a), (b), and (d), deliver improved log-likelihood and marginal likelihood values than their counterparts without the smoothed trend ($\rho_g^x = 0$).

Figure 7 reports the response of consumption to the shock in government spending, according to the model (dashed line) and as estimated in the SVAR model on artificial data, for the four alternative models, (a), (b), (c), and (d). In all the figures, the model implied the response of consumption is negative, while the Cholesky identified SVAR model produces a positive consumption response. The size of the SVAR response is the largest for model (c), which restricts the trend in government spending to be proportional to the level of output. This response is very similar to that of the baseline model, in spite of the fact that this model takes into account anticipation in government spending. Models (a), and (b), provide similar responses. These responses are more muted than those produced in the baseline model, which is explained by the smaller estimate of the public spending responsiveness to neutral technology shock, J_z^g. The consumption response of model (d) is the smallest in magnitude, both the model implied and the one produced by the SVAR model. The discrepancy in the sign of the consumption responses implied by the models and their SVAR counterparts is present in all the four figures.

7 Conclusion

This paper finds that, contrary to the common beliefs, fiscal instruments are not predetermined with respect to the current state of the economy. Therefore, SVAR models that often rely on this assumption do not identify the government spending shock correctly. Instead, what these models identify is a combination of the government spending and technology shocks. As a result, an increase in consumption in response to rising government spending observed in these models reflects the positive effect of technology shocks on consumption, while the estimated model implies the response of consumption to a rise in government spending is negative. To test the hypothesis that fiscal variables are predetermined, I build a DSGE model with informational subperiods, and introduce the possibility of a partial pass through from the current realizations of macroeconomic shocks to the fiscal instruments. I rely on Bayesian estimation to estimate the sensitivity of government spending and the tax rate to current realizations of macroeconomic shocks along with other parameters.

8 Appendix

8.1 Data definitions

Investment is measured as the sum of investment expenditures and expenditures on durable goods, according to The national income and product accounts published by BEA, while consumption is expenditures on services and non-durable goods. Government spending, investment, and consumption are per capita real variables, obtained by dividing the GDP deflator, and labor force statistics from the Current Population Survey published by BLS. The tax rate τ is measured as personal current taxes, taxes on corporate income, and contributions for government social insurance, as the ratio to GDP. The hat above all the variables in Y_t implies they are detrended using a quadratic trend. The data sample begins in the third quarter of 1954 ends in the forth quarter of 2010.

8.2 Tables and Figures

Table 2: Parameter calibration and steady state values

Parameter	Description	Value
θ	Production: capital share	0.3
β	Intertemporal discount factor	0.999
δ	Depreciation rate	0.025
ϱ	Shadow price of capital	1
h	Steady state labor	0.8
s^g	Steady state share of govt. spending in output	0.2
η_p	Prices: elasticity of substitution	6
η_w	Wages: elasticity of substitution	21
d	Preference shock	1

Table 3: Equilibrium System

Price adjustment	$\omega_t = 0.5\alpha_p(\pi_t - \pi)^2$
Output growth	$\mu_{z^*,t} = \mu_{\Upsilon,t}^{\theta/(1-\theta)}\mu_{z,t}$
Investment growth	$\mu_{I,t} = \mu_{\Upsilon,t}\mu_{z^*,t}$
M.U. of consumption	λ_t
Wage markup	$\tilde{\mu}_t$
Capital shadow price	ϱ_t
Price markup	mc_t
Labor choice	$\frac{w_t\lambda_t}{\tilde{\mu}_t} = \frac{1-\sigma}{1-h_t}$
Consumption	$\lambda_t = \frac{\sigma}{c_t - b\frac{c_{t-1}}{\mu_{z^*,t}}} - \frac{b\beta}{\mu_{z^*,t+1}}\frac{\sigma}{c_{t+1} - b\frac{c_t}{\mu_{z^*,t+1}}}$
Capital	$\varrho_t = \beta\frac{\lambda_{t+1}}{\lambda_t\mu_{I,t+1}}[(1-\tau_{t+1})r_{t+1}^K + \varrho_{t+1}(1-\delta)]$
Investment	$1 = \varrho_t\left(1 - S_t - S_t'\frac{i_t}{i_{t-1}}\mu_{I,t}\right) + \beta E_t\frac{\lambda_{t+1}}{\lambda_t}\varrho_{t+1}S_{t+1}'\left(\frac{i_{t+1}}{i_t}\right)^2\mu_{I,t+1}$
Borrowing	$1 = \beta R_t E_t\frac{\lambda_{t+1}}{\lambda_t\mu_{z*,t+1}\pi_{t+1}}$
Wage rate	$\Psi_t'\frac{w_t}{w_{t-1}}\pi_t\mu_{z^*,t} = (1-\eta_w)(1-\tau_t-\Psi_t) + \frac{\eta_w}{\tilde{\mu}_t} + E_t\beta\frac{\lambda_{t+1}}{\lambda_t}\Psi_{t+1}'(\frac{w_{t+1}}{w_t})^2\mu_{z^*,t+1}\pi_{t+1}\frac{h_{t+1}}{h_t}$
Capital factor	$r_t^k = mc_t\theta(\frac{k_t}{h_t\mu_{I,t}})^{\theta-1}$
Labor factor	$w_t = mc_t(1-\theta)(\frac{k_t}{h_t\mu_{I,t}})^{\theta}$
Pricing	$\pi_t\omega'(\pi_t) = (1-\eta_p+\eta_p mc_t)y_t + E_t\beta\frac{\lambda_{t+1}}{\mu_{z^*,t+1}\lambda_t}\pi_{t+1}\omega'(\pi_{t+1})$
Market clearing	$(\frac{k_t}{\mu_{I,t}})^{\theta}h_t^{1-\theta} - \vartheta - \omega_t = c_t + \frac{g_t}{\mu_{z^*,t}} + i_t + \Psi_t w_t h_t$
Output	$y_t = (\frac{k_t}{\mu_{I,t}})^{\theta}h_t^{1-\theta} - \vartheta_t - \omega_t$
Capital dynamics	$k_{t+1} = (1-\delta)\frac{k_t}{\mu_{I,t}} + i_t(1-\mathcal{S}_t)$
Monetary policy	$ln(\frac{R_t}{R}) = \alpha_R ln(\frac{R_{t-1}}{R}) + \alpha_\pi ln(\frac{\pi_t}{\pi}) + \alpha_y ln(\frac{y_t\mu_{z_t^*}}{y_{t-1}\mu_{z^*}}) + ln(\frac{\mu_{r,t}}{\mu^r})$
Spending instrument	$\varsigma_t^g = g_t/y_t/\mu_{z^*,t-1}$
Tax policy	$ln(\frac{\tau_t}{\tau}) = \alpha_\tau ln(\frac{\tau_{t-1}}{\tau}) + \alpha_y^\tau ln(\frac{y_t}{y}) + ln(\frac{\upsilon_t^\tau}{\upsilon^\tau})$

Table 4: Parameter estimates, part I

Response	Prior	Baseline (5%, 95%)	Part info	Full Info
J^t_r	N(0.0/ 0.1)	0.004 (-0.279/ 0.286)	0	-0.005
J^t_z	N(0.0/ 0.1)	0.102 (-0.082/ 0.281)	0	-0.002
J^t_υ	N(0.0/ 0.1)	-0.222 (-0.477/ 0.033)	0	-0.0055
J^t_d	N(0.0/ 0.1)	-0.051 (-0.096/ -0.015)	0	1.3×10^{-5}
J^g_r	N(0.0/ 0.1)	-0.271 (-0.531/ -0.008)	0	-1.1012
J^g_z	N(0.0/ 0.1)	0.544 (0.457/ 0.629)	0	0.524
J^g_υ	N(0.0/ 0.1)	-0.233 (-0.408/ -0.064)	0	-0.768
J^g_d	N(0.0/ 0.1)	0.008 (-0.004/ 0.021)	0	0.0028

Notes. The table presents the estimates of contemporaneous response of fiscal variables to current state shocks. Prior distributions, as well as the mean, 5^{th} and 95^{th} quantiles of the posterior distribution are shown. The prior distribution for all parameters is normal with zero mean and the standard deviation of 0.1. "Baseline" represents the baseline model where parameters partial responses J^τ and J^g are estimated. "Part info" is the models where contemporaneous response of government spending to shocks is not allowed. "Full info" represents the model without timing restrictions. In this case, the elements of matrix J are the corresponding elements of the linear model solution. Estimates are obtained from the last 90 percent of $600,000$ elements of a Markov chain generated using the Metropolis Hastings algorithm.

Table 5: Parameter estimates, part II

Parameter	Prior	Posterior	Part info	Full info
		$(5\%, 95\%)$	$(5\%, 95\%)$	$(5\%, 95\%)$
τ	B(0.2/ 0.1)	0.180	0.181	0.181
		(0.170/ 0.188)	(0.172/ 0.189)	(0.172/ 0.189)
μ_{z^*}	G(0.4/ 0.1)	0.319	0.327	0.330
		(0.215/ 0.429)	(0.226/ 0.439)	(0.225/ 0.443)
μ_υ	G(0.2/ 0.1)	0.193	0.200	0.192
		(0.122/ 0.276)	(0.125/ 0.285)	(0.122/ 0.274)
π	G(3/ 1)	6.326	7.145	7.051
		(5.076/ 7.700)	(5.643/ 8.764)	(5.722/ 8.661)
R	G(2/ 1)	6.438	7.317	7.906
		(4.496/ 8.563)	(5.113/ 9.560)	(5.784/ 10.284)
b^c	B(0.7/ 0.1)	0.644	0.568	0.600
		(0.578/ 0.713)	(0.488/ 0.647)	(0.520/ 0.678)
α_p	G(20/ 5)	28.016	29.867	29.436
		(18.835/ 40.017)	(21.098/ 39.803)	(20.589/ 39.312)
α_w	G(100/20)	126.859	150.470	139.387
		(91.474/167.280)	(112.146/193.934)	(103.500/179.750)
α_R	B(0.7/ 0.1)	0.795	0.792	0.805
		(0.755/ 0.832)	(0.754/ 0.828)	(0.767/ 0.841)
α_π	G(0.5/ 0.2)	0.515	0.503	0.514
		(0.454/ 0.580)	(0.448/ 0.563)	(0.455/ 0.578)
α_Y	G(0.1/ 0.1)	0.135	0.139	0.153
		(0.100/ 0.172)	(0.105/ 0.175)	(0.116/ 0.193)
κ	G(1/ 0.5)	0.287	0.268	0.311
		(0.201/ 0.408)	(0.195/ 0.358)	(0.220/ 0.429)
α_τ	B(0.7/ 0.1)	0.940	0.936	0.937
		(0.915/ 0.963)	(0.912/ 0.959)	(0.913/ 0.961)
$\alpha_{\tau,y}$	I(0.01/ 0.1)	0.004	0.005	0.005
		(0.002/ 0.009)	(0.002/ 0.010)	(0.002/ 0.011)

Notes. Table shows prior distributions and Bayesian estimates of parameters across different models. Notation in the second columns is as follows: B = beta, G = gamma, I = inverse gamma distributions. Estimates are presented as mean values and standard deviations across the last 90 percent of $600,000$ elements of a Markov chain generated using the Metropolis Hastings algorithm.

Table 6: Parameter estimates, part III

Parameter	Prior	Posterior mean	Part info	Full info
		$(5\%, 95\%)$	$(5\%, 95\%)$	$(5\%, 95\%)$
ρ_g	B(0.7/ 0.1)	0.980	0.963	0.979
		(0.970/ 0.988)	(0.949/ 0.976)	(0.969/ 0.988)
ρ_z	B(0.7/ 0.1)	0.472	0.362	0.471
		(0.363/ 0.577)	(0.254/ 0.471)	(0.361/ 0.575)
ρ_υ	B(0.7/ 0.1)	0.813	0.797	0.849
		(0.755/ 0.866)	(0.737/ 0.850)	(0.801/ 0.892)
ρ_d	B(0.7/ 0.1)	0.987	0.991	0.992
		(0.978/ 0.993)	(0.984/ 0.995)	(0.985/ 0.995)
σ_g	I(0.1/ 1)	0.011	0.016	0.011
		(0.010/ 0.013)	(0.015/ 0.017)	(0.010/ 0.012)
σ_z	I(0.1/ 1)	0.013	0.014	0.013
		(0.012/ 0.015)	(0.013/ 0.016)	(0.011/ 0.014)
σ_υ	I(0.1/ 1)	0.006	0.007	0.006
		(0.005/ 0.008)	(0.005/ 0.008)	(0.005/ 0.007)
σ_d	I(0.1/ 1)	0.096	0.122	0.134
		(0.059/ 0.144)	(0.066/ 0.195)	(0.074/ 0.208)
σ_r	I(0.01/ 0.1)	0.003	0.003	0.003
		(0.002/ 0.003)	(0.002/ 0.003)	(0.002/ 0.003)
σ_τ	I(0.1/ 1)	0.026	0.026	0.026
		(0.024/ 0.028)	(0.024/ 0.028)	(0.024/ 0.028)
$logL$		-1387.245	-1469.685	-1385.104
ML		-1519.7	-1564.7	-1486.3

Notes. See Notes to Table 5.

Table 7: Relationship between Cholesky-identified and structural shocks

	ϵ^g	ϵ^τ	ϵ^Υ	ϵ^d	ϵ^z	ϵ^R
Baseline model						
e^g	0.20	-0.016	-0.021	0.0015	0.98	-0.009
e^τ	-0.089	0.99	-0.049	-0.024	0.033	0.004
Model (b)						
e^g	0.88	-0.005	0.032	0.0043	0.48	-0.015
e^τ	-0.048	0.99	-0.063371	-0.045	0.10	0.003

Notes. This table shows the representation of the Cholesky identified SVAR model implied shocks to government spending and the tax rate as a linear combination of the structural model shocks. linear combinations in the baseline model, and the last two rows represent model (b), as defined in notes to Table 8.

Table 8: Estimates of J, alternative models

Parameter	(a)	(b)	(c)	(d)
ρ_g^x	0.988	0.926	-	0.962
	(0.015)	(0.029)	(0.000)	(0.027)
J_r^t	0.015	0.018	0.041	0.014
J_z^t	0.069	0.085	0.084	0.063
J_υ^t	-0.212	-0.209	-0.346	-0.224
J_d^t	-0.078*	-0.083*	-0.050*	-0.083*
J_r^g	-	-0.078	-0.285	-0.058
J_z^g	0.120*	0.157*	0.498*	0.104*
J_υ^g	0.099	0.050	-0.182	0.072
J_d^g	-	0.005	0.006	0.001
$logL$	-1358	-1351	-1388	-1357
ML	-1450	-1443	-1537	-1455

Notes. Column (a): X_t^G is determined by Equation (20); Column (b): X_t^G is determined by Equation (21); Column (c): baseline model with anticipated shocks to government spending; Column (d): X_t^G is determined by Equation (21) and assumes anticipated shocks to government spending. Star indicates that the confidence interval based on the 5^{th} and 95^{th} quantiles of the posterior distribution does not include zero.

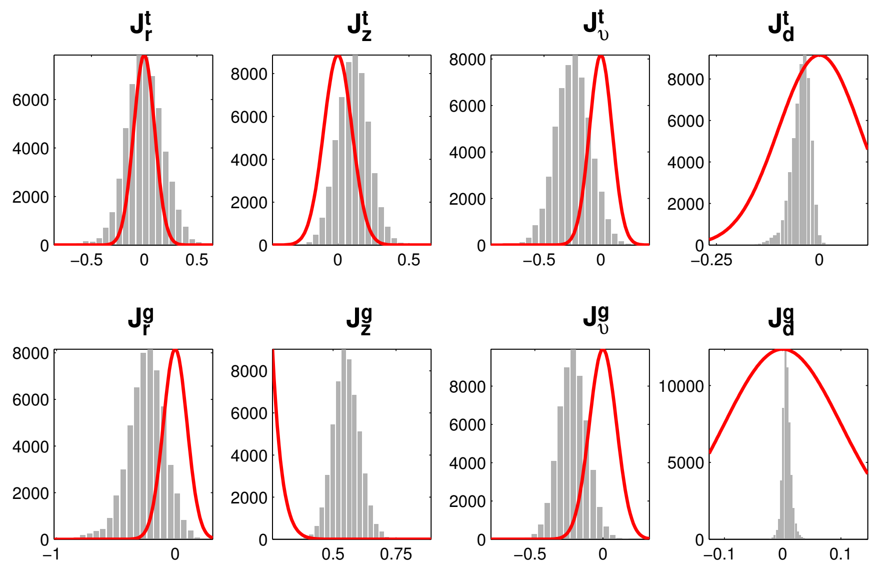

Figure 3: Government spending and the tax rate: Responsiveness to shocks

Notes: Posterior distributions are obtained from MCMC chains of 600,000 elements, where the first 10 percent of elements are discarded.

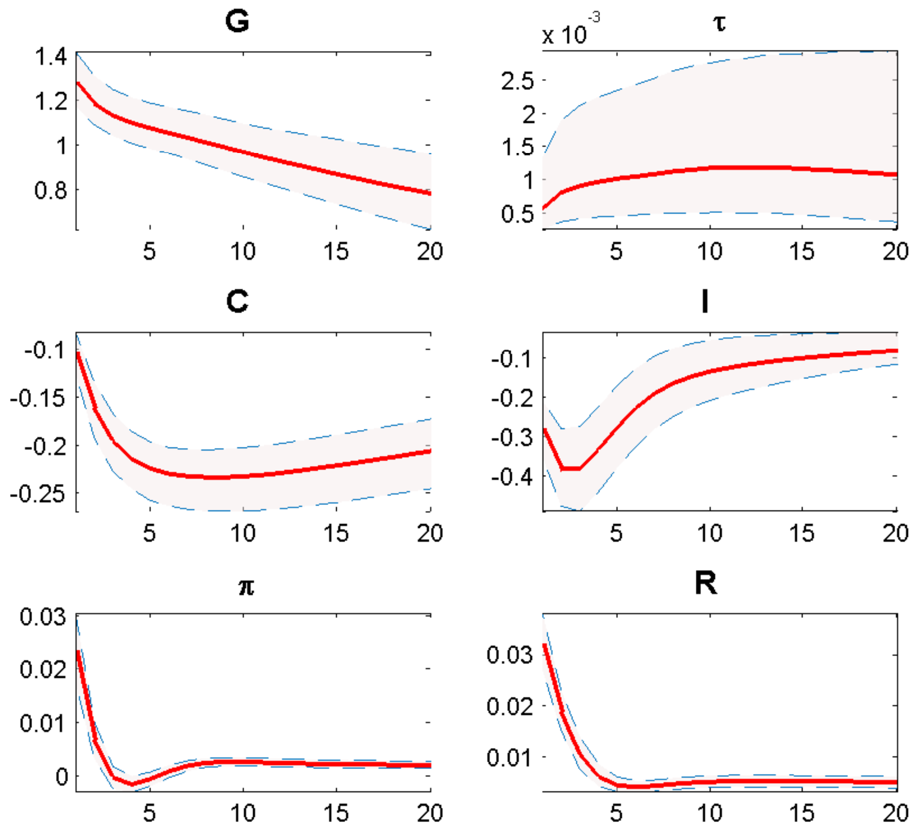

Figure 4: Model-implied impulse responses to a government spending shock

Notes: The figure shows impulse responses to 1 percent government spending shock implied by the estimated model. Quarters are along the horizontal an percentage deviation from the balanced growth path along the vertical axis, in percentages.

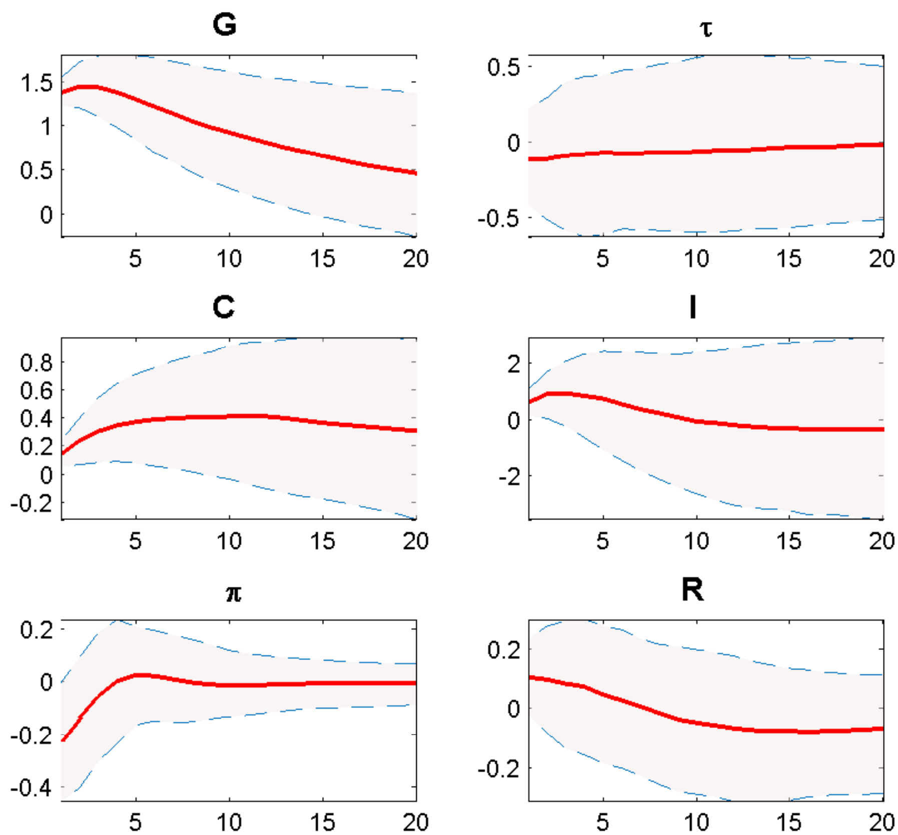

Figure 5: Cholesky-identified impulse responses to a government spending shock

Notes: The figure shows impulse responses to a government spending shock of one standard deviation size as estimated on artificial dataset generated from the theoretical model. The impulse responses are obtained from the estimated SVAR model with Cholesky identification, where government spending variable is ordered first. Quarters are along the horizontal an percentage deviation from the balanced growth path along the vertical axis, in percentages.

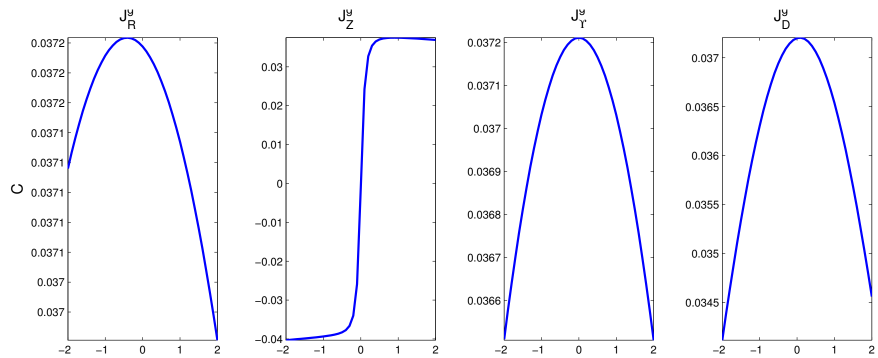

Figure 6: Cholesky-identified immediate response of consumption and investment to a government spending shock

Notes:

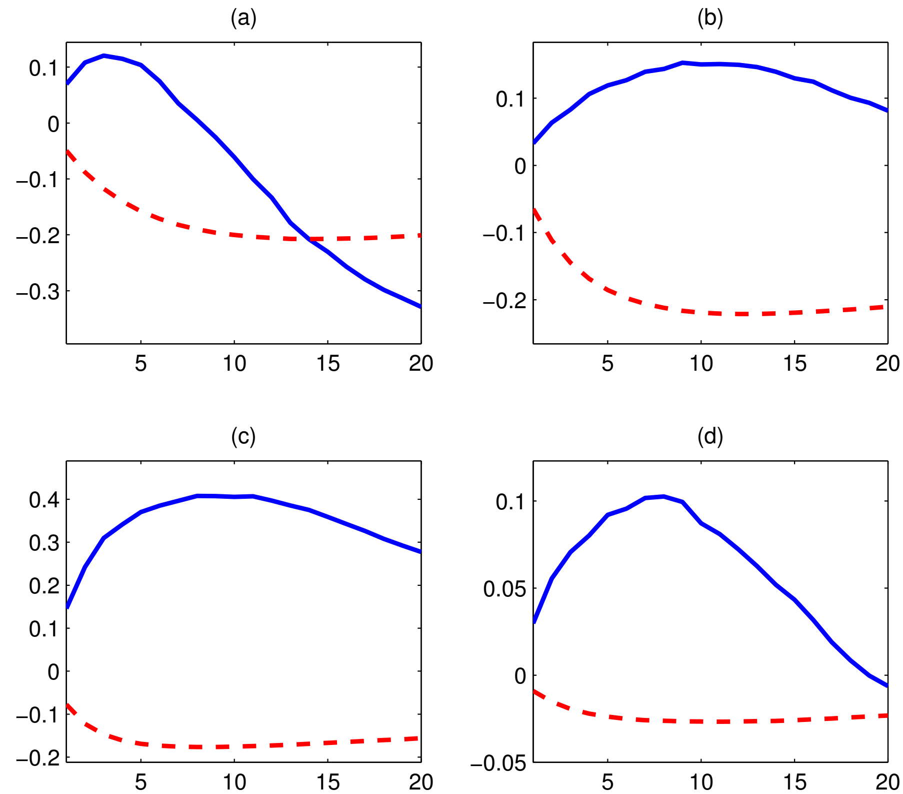

Figure 7: Cholesky-identified and model implied response of consumption to a government spending shock

Notes:Solid blue line represents Cholesky-identified response of consumption, dashed red line represents the model implied response of consumption to the government spending shock. Figure (a) assumes X_t^G is determined by Equation (20); Figure (b) assumes X_t^G is determined by Equation (21); Figure (c) represents the baseline model with anticipated shocks to government spending; Figure (d) assumes X_t^G is determined by Equation (21) and assumes anticipated shocks to government spending. Quarters are along the horizontal axis, and percentage deviation from trend is along the vertical axis.

References

Blanchard, O., and R. Perotti (2002): "An Empirical Characterization Of The Dynamic Effects Of Changes In Government Spending And Taxes On Output," *The Quarterly Journal of Economics*, 117(4), 1329–1368.

Bouakez, H., and N. Rebei (2007): "Why does Private Consumption Rise After a Government Spending Shock?," *Canadian Journal of Economics*, 40(3), 954–979.

Burnside, C., M. Eichenbaum, and J. D. M. Fisher (2004): "Fiscal shocks and their consequences," *Journal of Economic Theory*, 115(1), 89–117.

Chahrour, R., S. Schmitt-Grohé, and M. Uribe (2012): "A Model-Based Evaluation of the Debate on the Size of the Tax Multiplier," *American Economic Journal: Economic Policy*, 4(2), 28–45.

Fatas, A., and I. Mihov (2001a): "The Effects of Fiscal Policy on Consumption and Employment: Theory and Evidence," CEPR Discussion Papers 2760, C.E.P.R. Discussion Papers.

——— (2001b): "The Effects of Fiscal Policy on Consumption and Employment: Theory and Evidence," CEPR Discussion Papers 2760, C.E.P.R. Discussion Papers.

Fernández-Villaverde, J., P. Guerrón-Quintana, K. Kuester, and J. Rubio-Ramírez (2015): "Fiscal Volatility Shocks and Economic Activity," *American Economic Review*, 105(11), 3352–84.

Féve, P., J. Matheron, and J.-G. Sahuc (2013): "A Pitfall with Estimated DSGE-Based Government Spending Multipliers," *American Economic Journal: Macroeconomics*, 5(4), 141–78.

Fisher, J. (2003): "Technology Shocks Matter," FRB of Chicago w.p #2002-14, December.

Fisher, J., and R. Peters (2010): "Using Stock Returns to Identify Government Spending Shocks," *Economic Journal*, 120(544), 414–436.

Galí, J., J. D. Lopez-Salido, and J. Vallés (2007): "Understanding the Effects of Government Spending on Consumption," *Journal of the European Economic Association*, 5(1), 227–270.

Kormilitsina, A. (2013): "Solving Rational Expectations Models with Informational Subperiods: A Perturbation Approach," *Computational Economics*, 41(4), 525–555.

Kormilitsina, A., and S. Zubairy (2016): "Propagation Mechanisms for Government Spending Shocks: A Bayesian Comparison," working paper.

Leeper, E. M., M. Plante, and N. Traum (2010): "Dynamics of Fiscal Financing in the United States," *Journal of Econometrics*, 156(2), 304–321.

Leeper, E. M., N. Traum, and T. B. Walker (2011): "Clearing Up the Fiscal Multiplier Morass," NBER Working Paper 17444.

Linnemann, L., and A. Schabert (2006): "Productive Government Expenditure In Monetary Business Cycle Models," *Scottish Journal of Political Economy*, 53(1), 28–46.

Monacelli, T., and R. Perotti (2008): "Fiscal Policy, Wealth Effects, and Markups," NBER Working Papers 14584, National Bureau of Economic Research, Inc.

Mountford, A., and H. Uhlig (2009): "What are the Effects of Fiscal Policy Shocks?," *Journal of Applied Econometrics*, 24(6), 960–992.

Ramey, V. A. (2011): "Identifying Government Spending Shocks: It's all in the Timing," *The Quarterly Journal of Economics*, 126(1), 1–50.

Ramey, V. A., and M. D. Shapiro (1998): "Costly capital reallocation and the effects of government spending," *Carnegie-Rochester Conference Series on Public Policy*, 48(1), 145–194.

Schmitt-Grohé, S., and M. Uribe (2012): "What's News in Business Cycles," *Econometrica*, 80(6), 2733–2764.

Zubairy, S. (2014): "On Fiscal Multipliers: Estimates From A Medium Scale Dsge Model," *International Economic Review*, 55, 169–195.

9 Technical Appendix

9.1 Equilibrium conditions

The model can be presented in terms of stationary transformations described in Table 1. Denote the trend in output and investment $Z_t^* = Z_t \Upsilon_t^{\theta/(1-\theta)}$ and $Z_t^I = Z_t^* \Upsilon_t$, then their growth rates are, respectively,

$$\mu_{z^*,t} = \mu_{\Upsilon,t}^{\theta/(1-\theta)} \mu_{z,t}$$

$$\mu_{I,t} = \mu_{\Upsilon,t} \mu_{z^*,t}$$

The wage cost function can be written in stationary terms as

$$\Psi_t = 0.5\alpha_w (\frac{w_t \pi_t \mu_{z^*,t}}{w_{t-1}} - \mu_{z^*} \pi)^2,$$

The investment cost function is

$$S_t = S\left(\frac{i_t}{i_{t-1}} \mu_{I,t}\right) = 0.5\kappa \left(\frac{i_t}{i_{t-1}} \mu_{I,t} - \mu_I\right)^2.$$

Household's problem. Intra-temporal utility:

$$u_t(c_t - b\frac{c_{t-1}}{\mu_{z^*,t}}, h_t) = d_t[\sigma log(c_t - b\frac{c_{t-1}}{\mu_{z^*,t}}) + (1-\sigma) log(1-h_t)]$$

Suppose $\beta^t \lambda_t$, $\beta^t \varrho_t$, and $\beta^t \frac{\lambda_t w_t}{\tilde{\mu}_t}$ are the lagrange multipliers on the budget constraints, capital accumulation, and labor supply equation. Then, household's problem Lagrangian can be written as:

$$\mathcal{L}_t = E_t \sum_{s=t}^{\infty} \beta^{s-t} \left\{ u_s(c_s - b\frac{c_{s-1}}{\mu_{z^*,s}}, h_s) + d_s \sigma ln(Z_s^*) + \right.$$

$$\lambda_s \left[(1-\tau_s) \frac{r_s^k k_s}{\mu_{I,s}} + \int \left(1 - \tau_s - \Psi\left(\frac{w_s^j}{w_{s-1}^j} \mu_{z^*,s} \pi_s \right) \right) w_s^j \left(\frac{w_s^j}{w_s} \right)^{-\eta^w} h_s^d dj + \right.$$

$$\phi_s + \frac{b_s}{\mu_{z^*,s}\pi_s} + tr_s - c_s - i_s - \frac{b_{s+1}}{R_s}\Bigg] +$$

$$\lambda_s \varrho_s \left[-k_{s+1} + (1-\delta)\frac{k_s}{\mu_{I,s}} + i_s(1 - S(\frac{i_s}{i_{s-1}}\mu_{I,s})) \right] +$$

$$\int \frac{\lambda_s w_s}{\tilde{\mu}_s^j}(h_s^j - \left(\frac{w_s^j}{w_s}\right)^{-\eta^w} h_s^d)dj \Bigg\}$$

First order conditions with respect to h_t (in a symmetric equilibrium) are

$$\frac{w_t \lambda_t}{\tilde{\mu}_t} = \frac{1-\sigma}{1-h_t},$$

consumption c_t:

$$\lambda_t = \frac{\sigma}{c_t - b\frac{c_{t-1}}{\mu_{z^*,t}}} - \frac{b\beta}{\mu_{z^*,t+1}} \frac{\sigma}{c_{t+1} - b\frac{c_t}{\mu_{z^*,t+1}}},$$

capital k_{t+1}:

$$\varrho_t = \beta \frac{\lambda_{t+1}}{\lambda_t \mu_{I,t+1}} [(1-\tau_{t+1})r_{t+1}^K + \varrho_{t+1}(1-\delta)],$$

Investment i_t:

$$1 = \varrho_t \left(1 - \frac{\kappa}{2} \left(\frac{i_{t+1}}{i_t}\mu_{I,t+1} - \mu_I \right)^2 - \kappa(\frac{i_t}{i_{t-1}}\mu_{I,t} - \mu_I)\frac{i_t}{i_{t-1}}\mu_{I,t} \right) +$$

$$\beta E_t \frac{\lambda_{t+1}}{\lambda_t} \varrho_{t+1} \kappa(\frac{i_{t+1}}{i_t}\mu_{I,t+1} - \mu_I) \left(\frac{i_{t+1}}{i_t}\right)^2 \mu_{I,t+1},$$

Borrowing b_{t+1}:

$$1 = \beta R_t E_t \frac{\lambda_{t+1}}{\lambda_t \mu_{z^*,t+1}\pi_{t+1}},$$

Wage rate w_t:

$$\psi'(\frac{w_t}{w_{t-1}}\mu_{z^*,t}\pi_t)\frac{w_t}{w_{t-1}}\pi_t \mu_{z^*,t} h_t = (1-\eta_w)(1-\tau_t - \psi(\frac{w_t}{w_{t-1}}\mu_{z^*,t}\pi_t))h_t + \frac{\eta_w}{\tilde{\mu}_t}h_t +$$

$$E_t \beta \frac{\lambda_{t+1}}{\lambda_t} \psi'(\frac{w_{t+1}}{w_t}\mu_{z^*,t+1}\pi_{t+1})(\frac{w_{t+1}}{w_t})^2 \mu_{z^*,t+1}\pi_{t+1}h_{t+1},$$

Firm's problem.

Firm's production function in a stationary form:

$$f(\frac{k_t}{\mu_{I,t}}, h_t) = (\frac{k_t}{\mu_{I,t}})^\theta h_t^{1-\theta} - \vartheta_t,$$

Firm's demand

$$y_t^i = (\rho_t^i)^{-\eta_p} y_t^d,$$

where $\rho_t^i = \frac{P_t^i}{P_t}$ is the relative price of good i, and y_t^d is the demand for aggregate output. The stationary transformation of the price adjustment cost function is

$$\omega_t = 0.5\alpha_p(\pi_t - \pi)^2.$$

Firm's problem Lagrangian:

$$\mathcal{L}_t^F = E_t \sum_{s=t}^{\infty} Q_{t,t+s} \left\{ \left((\rho_s^i)^{1-\eta_p} y_s^d - R_s^K \frac{k_s}{\mu_{I,s}} - w_s h_s^i - 0.5\alpha_p(\frac{\rho_s^i}{\rho_{s-1}^i}\pi_s - \pi)^2 \right) + \right.$$

$$\left. mc_s \left((\frac{k_s}{\mu_{I,s}})^\theta h_s^{1-\theta} - \vartheta - (\rho_s^i)^{-\eta_p} y_s^d \right), \right\}$$

where the firm's discount factor is such that for any t, and $s > t$, $Q_{t,t} = 1$, $Q_{t,t+s} = \prod_{i=1}^s Q_{t+i-1,t+i}$, and

$$Q_{t,t+1} = \beta \frac{\lambda_{t+1}}{\lambda_t \mu_{z^*,t+1}}.$$

First-order conditions with respect to capital factor:

$$r_t^k = mc_t \theta (\frac{k_t}{h_t \mu_{I,t}})^{\theta-1},$$

labor factor:

$$w_t = mc_t(1-\theta)(\frac{k_t}{h_t \mu_{I,t}})^\theta,$$

price level:

$$\pi_t\omega'(\pi_t) = (1-\eta_p+\eta_p mc_t)(c_t+\frac{g_t}{\mu_{z^*,t}}+i_t+\Psi_t w_t h_t)+E_t\beta\frac{\lambda_{t+1}}{\lambda_t\mu_{z^*,t+1}}\pi_{t+1}\omega'(\pi_{t+1}).$$

Market clearing conditions:

$$(\frac{k_t}{\mu_{I,t}})^\theta h_t^{1-\theta}-\vartheta-\omega_t = c_t+\frac{g_t}{\mu_{z^*,t}}+i_t+\Psi_t w_t h_t$$

Output

$$y_t = (\frac{k_t}{\mu_{I,t}})^\theta h_t^{1-\theta}-\vartheta_t-\omega_t.$$

Capital dynamics:

$$k_{t+1} = (1-\delta)\frac{k_t}{\mu_{I,t}}+i_t\left(1-\mathcal{S}\left(\frac{i_{t+1}}{i_t}\mu_{I,t+1}\right)\right).$$

Monetary policy:

$$ln(\frac{R_t}{R}) = \alpha_R ln(\frac{R_{t-1}}{R})+\alpha_\pi ln(\frac{\pi_t}{\pi})+\alpha_y ln(\frac{y_t\mu_{z_t^*}}{y_{t-1}\mu_{z^*}})+ln(\frac{\mu_{r,t}}{\mu^r}).$$

Fiscal Policy instruments

$$\varsigma_t^g = \frac{g_t}{y_t\mu_{z^*,t}},$$

$$ln(\frac{\tau_t}{\tau}) = \alpha_\tau ln(\frac{\tau_{t-1}}{\tau})+\alpha_y^\tau ln(\frac{y_t}{y})+ln(\frac{\upsilon_t^\tau}{\upsilon^\tau}).$$

Table 9: Parameter calibration and steady state values

Stationary variable	Calibration
growth of Υ_t	$\mu_\Upsilon = \mu_I / \mu_{z^*}$
growth of Z_t	$\mu_z = \mu_{z^*} / \mu_\Upsilon^{\theta/(1-\theta)}$
Nominal interest rate	$R = \pi \mu_{z^*} / \beta$
Capital rental rate	$r^k = (\frac{\mu_I}{\beta} - \varrho(1-\delta))/(1-\tau)$
Wage markup	$\tilde{\mu} = \eta_w / (\eta_w - 1)/(1-\tau)$
Marginal cost	$mc = 1 - 1/\eta_p$
Capital	$k = h\mu_I (\frac{r^k}{mc\theta})^{1/(\theta-1)}$
Investment	$i = (1 - \frac{1-\delta}{\mu_I})k$
Wage rate	$w = mc(1-\theta)(\frac{k}{h\mu_I})^\theta$
Output	$y = hmc(\frac{k}{h\mu_I})^\theta$
Production fixed cost	$\vartheta = (1-mc)(\frac{k}{\mu_I})^\theta h^{1-\theta}$
Government spending	$g = s^g y \mu_{z^*}$
Consumption	$c = y - i - \frac{g}{\mu_{z^*}}$
M.U. of consumption	$\lambda = \frac{d}{c} \frac{(1-\beta\frac{b}{\mu_{z^*}})}{(1-\frac{b}{\mu_{z^*}})} / (1 + \frac{(1-h)w}{\tilde{\mu} c} \frac{(1-\beta\frac{b}{\mu_{z^*}})}{(1-\frac{b}{\mu_{z^*}})})$
Utility parameter	$\sigma = 1 - (1-h)\frac{\lambda w}{d\tilde{\mu}}$
Gov. spending instrument	$\varsigma^g = g/(y\mu_{z^*})$

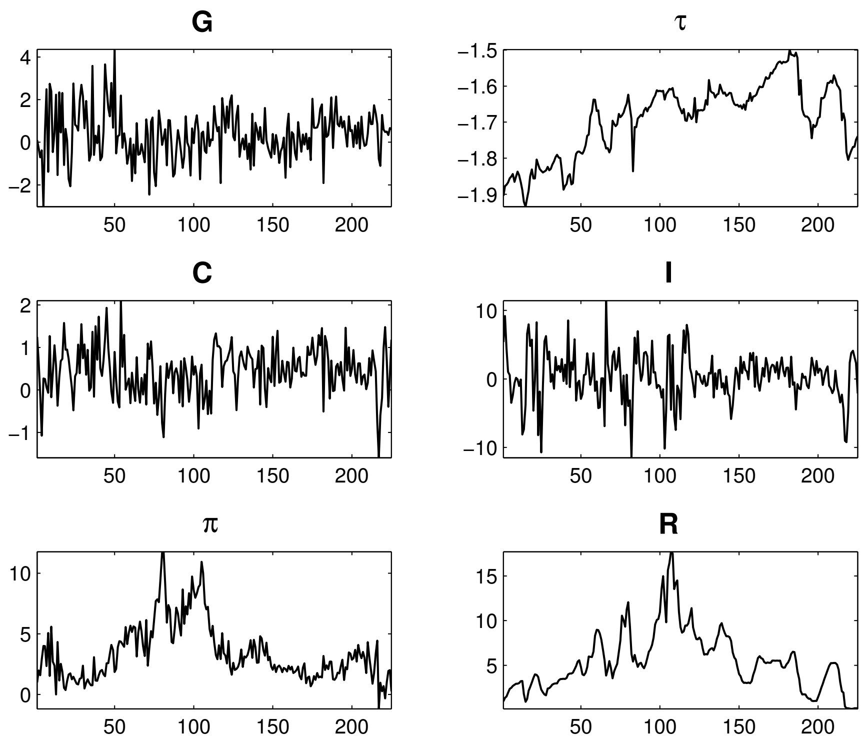

Figure 8: Observable data series

Notes: Government spending, consumption and investment are presented as logarithms of first differences of time series, multiplied by 100, the tax rate is the logarithm of tax revenues ratio to GDP, inflation and the interest rate are measured in percentages at annualized rates.

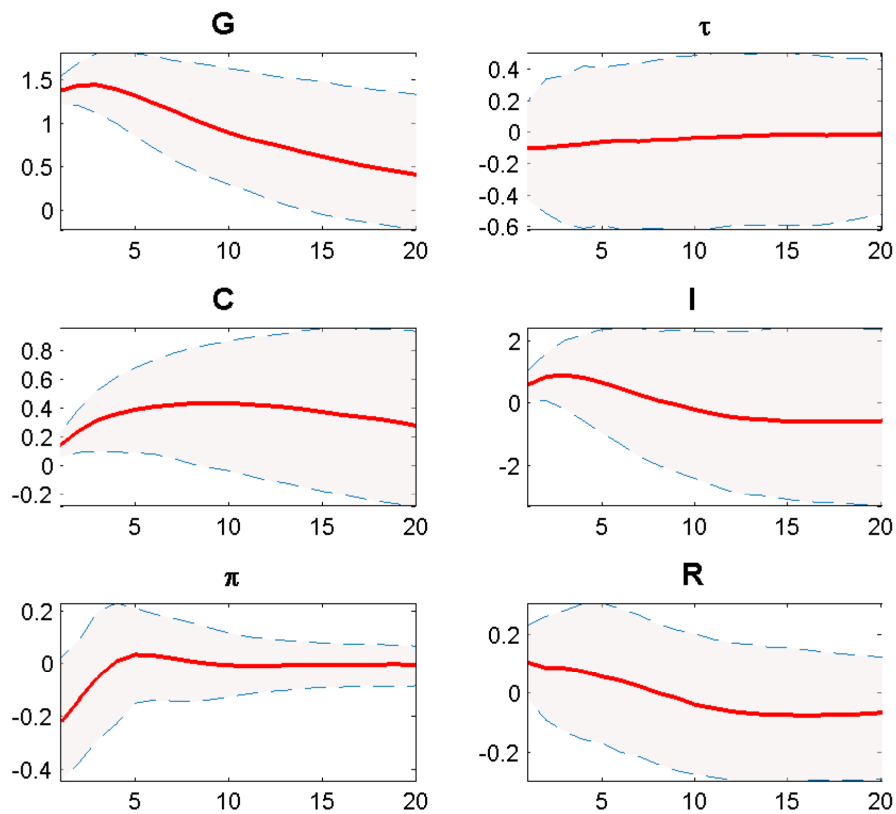

Figure 9: Impulse Responses to a positive neutral technology shock of one standard deviation

Notes: The figure shows impulse responses to a neutral technology shock of one standard deviation size. Quarters are along the horizontal an percentage deviation from the balanced growth path along the vertical axis, in percentages.

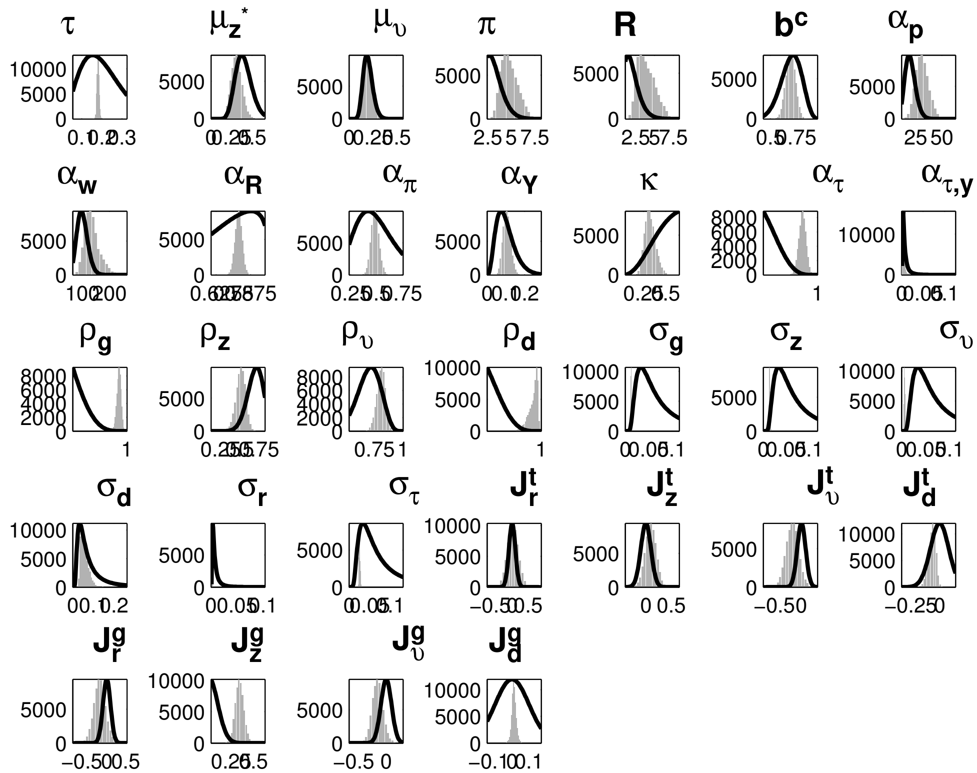

Figure 10: Posterior Distributions of estimated parameters

Notes: Posterior distributions are obtained from MCMC chains of 600,000 elements, where the first 10 percent of elements are discarded.