Explaining the Effects of Government Spending Shocks *

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Abstract

The objective of this paper is to identify and explain effects of a government spending shock. After accounting for large military events, in response to a structural unanticipated government spending shock, output, consumption, wages all rise, whereas investment falls on impact. I estimate a medium scale DSGE model augmented with deep habits and show that it successfully explains these effects. Of all the rigidities in the model, deep habits in public and private consumption and wage rigidities play an important role in accounting for the persistent hump-shaped responses to a government spending shock. In addition, I show that in order to match the response of wages and consumption to government spending shocks, deep habits significantly improve the fit of the model compared to a model with superficial habits.

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1 Introduction

Recently in public debates, there is renewed interest in the role of fiscal instruments in stabilizing an economy and about the dynamic effects of discretionary fiscal policy. I am interested in the latter question and the objective of this paper is to identify and explain the effects of government spending shocks in an estimated model.

While many studies have focused on using dynamic stochastic general equilibrium (DSGE) models to analyze consequences of monetary policy and have had great success, I would like to study the effects of fiscal policy in a similar framework. Since most pre-existing models are not suitable for studying fiscal shocks, understanding the effects of an unexpected increase in government purchases is additionally of particular interest for assessing empirical validity of competing macroeconomic models.

In the case of fiscal policy, identification of shocks is complicated due to the fact that there are usually lags between the announcement of a change in spending or taxes, and the actual implementation once the legislation passes through Congress. Blanchard and Perotti (2002) show that government spending does not react to other contemporaneous macroeconomic variables automatically and so government spending shocks can be identified by a recursive ordering with government spending ordered first in a vector autoregression (VAR).[1] In an alternative approach, Ramey and Shapiro (1998) identified spending shocks by events that signal large military buildups in US history. Ramey (2008) shows that these dates of military buildup Granger-cause the identified structural shocks. Since these events can be thought of as anticipated increases in government defense spending, I have put together both identification schemes to construct structural spending shocks which are independent of any information in the identified military buildup episodes. I find that in response to an unexpected rise in government spending, output, consumption, wages and hours worked, all go up, whereas investment declines on impact.

As shown in Baxter and King (1993), most commonly used business cycle models with lump-sum taxes might not be appropriate to study the effects of spending shocks, because in these models when government spending rises, households face higher taxes and due to the negative wealth effect, they inevitably lower their consumption and increase hours worked. This increase in labor supply also causes real wages to fall. Thus, these models are unable to generate the positive response of consumption and wages to a government spending shock.

Some recent studies have recognized this shortcoming of the existing models and have had varying degree of success in qualitatively matching the response of a few variables of interest. Linnemann (2006) gets a positive response for consumption by considering a utility function that is non-separable in leisure and consumption.[2] However, this does not change the negative response of wages to an unexpected rise in public spending. Another approach consists of considering nominal

[1] This is the same approach followed by Fatas and Mihov (2001), Gali, Lopez-Salido, and Valles (2007) and Perotti (2007).

[2] Bilbiie (2006) shows that if one relies on non-separable preferences for consumption to increase in a simple RBC model, it must be the case that consumption is an inferior good, and also positive co-movement between consumption and hours is possible only if either consumption or leisure is inferior.

rigidities in a new-Keynesian model with monopolistic competition. For instance Linnemann and Schabert (2003), show that in a model with sticky prices, in response to a rise in aggregate demand, firms raise labor demand, which puts upward pressure on wages. However, even in the case where labor demand rises sufficiently to overcome the rise in labor supply, and we see wages going up, it does not necessarily lead to a positive response of consumption. Gali, Lopez-Salido, and Valles (2007) introduce a model that does a fairly good job at matching the qualitative responses of wages and consumption. In addition to sticky prices, they model non-competitive behavior in labor markets and a fraction of the economy consisting of rule of thumb consumers who can not borrow and save, and consume their entire current income each period. If close to half of all consumers in the economy are assumed to be credit constrained, they get a positive response of consumption to a government spending shock. However, the empirical relevance of this explanation has been questioned by Coenen and Straub (2005) who estimate this model with credit constrained consumers for the Euro area. They find the estimated share of rule-of-thumb consumer being relatively low, and unable to generate a positive response of consumption to a government spending shock.[3]

An alternative approach that can successfully predict the positive responses of wages and consumption in response to a government spending shock is introduced in Ravn, Schmitt-Grohe, and Uribe (2006). They develop a model of deep habits in an economy with imperfectly competitive product markets. Deep habits imply that households form habits over narrowly defined categories of consumption goods, such as cars, clothing etc. This feature gives rise to a demand function with a price-elastic component that depends on aggregate consumption demand, and a perfectly price-inelastic component. An increase in aggregate demand in the form of government purchases increases the share of the price-elastic component, and so this rise in price elasticity induces the firms to reduce the markup of price over marginal cost.[4] Thus labor demand goes up and if the labor demand exceeds labor supply, wages go up in response to a government spending shock. This higher real wage causes individuals to substitute away from leisure towards consumption, so consumption also rises as a result. I incorporate this mechanism, which has not been explored to a great extent in the context of models explaining the US economy, in my theoretical model.[5]

In contrast to most of the aforementioned studies and others which typically involve only qualitatively matching the impact responses of a few particular variables to a public spending shock, I am undertaking a more complete analysis where firstly instead of calibrating the parameters of the model, I estimate them using evidence from the US data, and secondly I also account for responses

[3]Forni, Monteforte, and Sessa (2009) also estimate a DSGE model with rule of thumb consumers for Euro data, but model taxes and composition of government spending differently, and get a positive response of consumption. Lopez-Salido and Rabanal (2006) carry out a similar estimation exercise for US data, but they also include non-separable preferences in their framework. Their major finding is that allowing for this complementarity between consumption and hours worked leads to a small estimated fraction of rule of thumb consumers, but these two features can work together to give a positive response of consumption.

[4]Rotemberg and Woodford (1992) also model countercyclical markups in order to generate a rise in real wage along with output in response to demand shocks. They model imperfect competition with colluding firms, and when faced with a higher demand, to prevent a breakdown in the collusion, the agreement involves smaller markups.

[5]Recently, Ravn, Schmitt-Grohe, and Uribe (2007) have used deep habits in an open economy model and shown that it helps to explain the responses of consumption and exchange rate to a domestic public spending shock.

of a broader variety of key macroeconomic variables.[6] I am considering a medium scale DSGE model with several nominal and real rigidities that capture the high degree of persistence characterizing macroeconomic time series, developed in Christiano, Eichenbaum, and Evans (2005), and the specific departure is the introduction of deep habits, as a transmission mechanism for government spending shocks.

The model is estimated using a Laplace type estimator suggested by Chernozhukov and Hong (2003), which are defined similarly to Bayesian estimators, but instead of the parametric likelihood function, one can use a general statistical criterion function. In this paper, I am using the distance between the impulse response function implied by the empirical model and the ones generated by theoretical model. The estimation results suggest that the model does a great job at quantitatively accounting for the estimated responses of the US economy to a public spending shock. Of all the features, deep habits in public and private consumption, and wage rigidities play an important role in accounting for the persistent, hump-shaped responses of most of the variables.

The rest of the paper is organized as follows: Section 2 describes the empirical evidence regarding the effects of government spending shocks. Section 3 describes the theoretical model with deep habits. Section 4 provides the description of the estimation procedure used. Section 5 presents the estimation results and dynamics of the estimated model and finally, Section 6 concludes.

2 Empirical Evidence

This section describes how the government spending shocks are identified, and shows the responses of the various macroeconomic variables to this shock.

2.1 Identification

In this section I analyze the effects of government spending shocks. There are two approaches that have primarily been used in the literature to identify these shocks, and have seemingly different predictions. Ramey and Shapiro (1998) use information from historical accounts and identified the government spending shocks as dates where large increases in defense spending were anticipated. The military date variable, D_t, takes value of 1 in the following quarters: 1950:3, 1965:1 and 1980:1, which correspond with the start of the Korean War, the Vietnam war and the Carter-Reagen buildup respectively. Recently September 11th, 2001 has also been added to the list.

Blanchard and Perotti (2002) identify a government spending shock by using institutional information to show that government spending is predetermined relative to other macroeconomic

[6] Burnside, Eichenbaum, and Fisher (2004) is similar in spirit as they quantitatively match impulse response functions of several macro variables to a government spending shock, and show that the addition of habit formation and investment adjustment costs improves the performance of a standard RBC model. However, the fundamental difference between their work and mine is the identification scheme used to identify government spending shock. They rely on narrative evidence on episodes of military buildup presented in Ramey and Shapiro (1998), whereas as mentioned earlier I construct structural government spending shocks which are unanticipated innovation in government spending, independent of the Ramey-Shapiro episodes. Burnside, Eichenbaum, and Fisher (2004) also consider distortionary taxes in their model, whereas in this paper I am only considering lump-sum taxes, however considering distortionary taxation is an extension worth pursuing in future work.

variables and does not respond contemporaneously to output, consumption etc. in quarterly data. This identification scheme is implemented by ordering government spending first in a VAR and using a Choleski decomposition.

With government spending shocks, implementation lags is a major concern since there may be delay between the announcement and the actual implementation of a government spending change. Ramey (2008) shows that the structurally identified government spending shocks are Granger caused by the lags of the Ramey-Shapiro dummy, as evidence that the structurally identified shocks are in fact not entirely unanticipated.

In this paper, in order to capture unanticipated government spending shocks, I combine the two approaches. For this purpose I use the new narrative evidence presented in Ramey (2008), that is much richer than the Ramey-Shapiro military dates, as it includes additional events when the newspapers started forecasting significant changes in government spending, is no longer a binary dummy variable, and for the dates identified, it equals the present discounted value of the anticipated change in government spending. Since I am interested in unanticipated changes in government spending, I run the following reduced form VAR,

$$Y_t = \alpha_0 + \alpha_1 t + A(L)Y_{t-1} + B(L)\epsilon_t^R + u_t \tag{1}$$

where α_0 is a constant, α_1 is the coefficient of the time trend, Y_t is a vector of the variables of interest, ϵ_t^R is the new Ramey variable and u_t is the reduced form shock. The unanticipated government spending shock is then identified by government spending being ordered first in Y_t and then using Choleski decomposition. Note, that in contrast to the approach of Blanchard and Perotti (2002), due to the addition of the Ramey variables and its lags on the right hand side of the equation, the structurally identified shock in this case is orthogonal to the episodes identified in the narrative approach, and thus captures unanticipated changes in government spending [7]. In this specification $A(L)$ and $B(L)$ are polynomials of degree 4.[8] The data spans 1954:3-2006:4, where the starting date is based on availability of federal funds rate data. Y_t is a vector of the following endogenous variables:

$$Y_t = [g_t \quad y_t \quad h_t \quad c_t \quad i_t \quad w_t \quad \pi_t \quad R_t]'$$

where g_t is logarithm of real per capita government spending, y_t is logarithm of real per capita GDP, h_t is logarithm of per capita hours worked, c_t is logarithm of real per capita consumption expenditure on nondurables and services, i_t is the logarithm of real per capita gross domestic investment and consumption expenditures on durables, w_t is logarithm of real wages in the non-farm business sector, π_t is GDP deflator inflation and R_t is the federal funds rate.[9]

[7] This was first suggested to me by Martin Uribe. Since then Jordi Gali has made the same point in his NBER discussion of Ramey (2008).

[8] Akaike and Schwartz criterion support lags lengths of 2 and 1 respectively. The empirical results shown here are robust to these lag lengths.

[9] All the data sources are provided in the Appendix.

2.2 Empirical Findings

The impulse responses of the macro variables in Y_t to the government spending shock are shown in Figure 1. The shock is a one standard error shock to government spending, and the impulse responses are shown with 95 % confidence bands constructed by Monte Carlo simulations. The response function are shown for a horizon of 20 quarters.

Notice that the government spending shock is extremely persistent. Output rises significantly in response to a positive government spending shock. Hours also rise to a significant degree with a slight delay. Investment falls initially and rises after 4 quarters, but the response is insignificant for all horizons following the impact response. The two variables of interest and controversy in the fiscal literature, consumption and wages, both rise in response to this shock. Most of the variables have a hump-shaped response which is extremely persistent and peaks between 10-12 quarters after the shock hits the economy. The findings here are consistent with the ones of Blanchard and Perotti (2002) and Fatas and Mihov (2001) as far as the responses of GDP, hours, wages, consumption and investment are concerned, even though the identification scheme is slightly different. This seems to suggest that the anticipation effects captured by the Ramey variable in our VAR are not very significant.[10]

Inflation and nominal interest rate fall in response to the government spending shock, even though the confidence bands are large and the responses are insignificant at most horizons. Most studies do not consider the response of inflation and nominal interest rate, but Fatas and Mihov (2001) show GDP deflator falling and real T-bill rate rising in response to a government spending shock. Perotti (2002) studies the effects of government spending shocks in OECD countries, and finds that inflation and the 10 year nominal interest rate in the US either have insignificant or negative responses. Mountford and Uhlig (2002) use sign restrictions for identification, and also find both GDP deflator and nominal interest rates falling in response to a government expenditure shock.

3 Model

I am considering a model economy that has been studied in Altig, Christiano, Eichenbaum, and Linde (2005) and Schmitt-Grohe and Uribe (2005), which is rich in elements that are shown to match the empirical response of the economy to monetary and technology shocks. This model consists of several nominal frictions like sticky prices and sticky wages and real rigidities, namely investment adjustment costs, variable capacity utilization and imperfect competition in factor and product markets. In this paper, since the response of macroeconomic variables to a government spending shock is of particular interest, I introduce deep habits, for which the motivation was given in the introduction.

[10] The appendix shows the IRFs in both the cases of including and excluding ϵ_t^R, the Ramey variable, in Equation(1). It is clear that there are no significant differences between the two IRFs.

3.1 Households

The economy is populated by a continuum of identical households of measure one indexed by $j \in [0,1]$. Each household $j \in [0,1]$ maximizes lifetime utility function,

$$E_0 \sum_{t=0}^{\infty} \beta^t U(x_t^{c,j}, h_t^j), \tag{2}$$

The preferences are over consumption and leisure, and take the following form,

$$U(x_t^c, h_t) = \frac{[(x_t^c)^a (1-h_t)^{1-a}]^{1-\sigma} - 1}{1-\sigma}$$

where $\sigma \geq 0$ is the coefficient of relative risk aversion, or the inverse of the intertemporal elasticity of substitution. The parameter, σ controls the effect of leisure on the marginal utility of consumption.[11] If $\sigma > 1$, it implies $U_{ch} > 0$, i.e. leisure and consumption are gross substitutes and an increase in hours worked increases marginal utility of consumption. This also means that wages will have a positive effect on consumption growth, so that when real wage rate rises, leisure will decline and consumption will rise. On the other hand, $\sigma < 1$ implies $U_{ch} < 0$, raising hours worked decreases marginal utility of consumption.

The variable x_t^c is a composite of habit adjusted consumption of a continuum of differentiated goods indexed by $i \in [0,1]$.

$$x_t^{c,j} = \left[\int_0^1 (c_{it}^j - b^c s_{it-1}^C)^{1-\frac{1}{\eta}} di \right]^{1/(1-\frac{1}{\eta})} \tag{3}$$

where s_{it-1} denotes the stock of habit in consuming good i in period t. The parameter $b^c \in [0,1)$ measures the degree of external habit formation, and when b^c is zero, the households do not exhibit deep habit formation. The stock of external habit is assumed to depend on a weighted average of consumption in all past periods. Habits are assumed to evolve over time according to the law of motion,

$$s_{it}^C = \rho^c s_{it-1}^C + (1-\rho^c) c_{it} \tag{4}$$

The parameter $\rho^c \in [0,1)$ measures the speed of adjustment of the stock of external habit to variations in the cross-sectional average level of consumption of variety i. When ρ^c takes the value zero, habit is measured by past consumption. As will become apparent later, this slow decay in habit allows for persistence in the markup decline.

For any given level of consumption of $x_t^{c,j}$, purchases of each individual variety of goods $i \in [0,1]$ in period t must solve the dual problem of minimizing total expenditure, $\int_0^1 P_{it} c_{it} di$, subject to the aggregation constraint (3), where P_{it} denotes the nominal price of a good of variety i at time t.

[11] If $\sigma = 1$, it implies a separable, logarithmic utility function of the form, $a \log x_t^c + (1-a) \log(1-h_t)$. Note $U_{ch} = 0$ in this case, and so the marginal utility of consumption is independent of the choice of labor.

The optimal level of c_{it}^j for $i \in [0,1]$ is then given by

$$c_{it}^j = \left(\frac{P_{it}}{P_t}\right)^{-\eta} x_t^{c,j} + b^c s_{it-1}^C, \tag{5}$$

where P_t is a nominal price index defined as

$$P_t \equiv \left[\int_0^1 P_{it}^{1-\eta} di\right]^{\frac{1}{1-\eta}}.$$

Note that consumption of each variety is decreasing in its relative price, P_{it}/P_t and increasing in level of habit adjusted consumption $x_t^{c,j}$. Notice that the demand function in equation (5) has a price-elastic component that depends on aggregate consumption demand, and the second term is perfectly price-inelastic. An increase in aggregate demand increases the share of the price-elastic component, and thus an increase in the elasticity of demand, inducing a decline in the mark-ups. In addition to this, firms also take into account that today's price decisions will affect future demand, as is apparent due to s_{it-1} term, and so when the present value of future per unit profit are expected to be high, firms have an incentive to invest in the customer base today. Thus, this gives them an additional incentive to appeal to a broader customer base by reducing markups in the current period.

Each household provides a differentiated labor service and faces a demand for labor given by $\left(W_t^j/W_t\right)^{-\tilde{\eta}} h_t^d$. Here W_t^j denotes the nominal wage charged by household j at time t, W_t is an index of nominal wages prevailing in the economy, and h_t^d is a measure of aggregate labor demand by firms. At this given wage, the household j is assumed to supply enough labor, h_t^j, to satisfy demand,

$$h_t^j = \left(\frac{w_t^j}{w_t}\right)^{-\tilde{\eta}} h_t^d, \tag{6}$$

where $w_t^j \equiv W_t^j/P_t$ and $w_t \equiv W_t/P_t$.

The household is assumed to own physical capital, k_t, which accumulates according to the following law of motion,

$$k_{t+1}^j = (1-\delta)k_t^j + i_t^j \left[1 - \mathcal{S}\left(\frac{i_t^j}{i_{t-1}^j}\right)\right], \tag{7}$$

where i_t^j denotes investment by household j and δ is a parameter denoting the rate of depreciation of physical capital. The function $\mathcal{S}$ introduces investment adjustment costs and has the following functional form, $\mathcal{S}\left(\frac{i_t}{i_{t-1}}\right) = \frac{\kappa}{2}\left(\frac{i_t}{i_{t-1}} - 1\right)^2$, and therefore in the steady state it satisfies $\mathcal{S} = \mathcal{S}' = 0$ and $\mathcal{S}'' > 0$. These assumptions imply the absence of adjustment costs up to first-order in the vicinity of the deterministic steady state.

Owners of physical capital can control the intensity at which this factor is utilized. Formally, let u_t measure capacity utilization in period t. It is assumed that using the stock of capital with intensity u_t entails a cost of $a(u_t)k_t$ units of the composite final good.[12] Households rent the capital stock to firms at the real rental rate r_t^k per unit of capital. Total income stemming from the rental of capital is given by $r_t^k u_t k_t$.

Households are assumed to have access to a complete set of nominal state-contingent assets. Specifically, each period $t \geq 0$, consumers can purchase any desired state-contingent nominal payment A_{t+1}^h in period $t+1$ at the dollar cost $E_t r_{t,t+1} A_{t+1}^h$. The variable $r_{t,t+1}$ denotes a stochastic nominal discount factor between periods t and $t+1$. Households pay real lump-sum taxes in the amount τ_t per period.

The household's period-by-period budget constraint is then given by:

$$E_t r_{t,t+1} a_{t+1}^h + x_t^{c,j} + \omega_t^j + i_t^j + a(u_t)k_t^j + \tau_t = \frac{a_t^h}{\pi_t} + r_t^k u_t k_t^j + w_t^j \left(\frac{w_t^j}{w_t}\right)^{-\tilde{\eta}} h_t^d + \phi_t, \tag{8}$$

where $\omega_t = b^c \int_0^1 P_{it} s_{it-1}^C / P_t di$. The variable a_t^h/π_t denotes the real payoff in period t of nominal state-contingent assets purchased in period $t-1$. The variable ϕ_t denotes dividends received from the ownership of firms and $\pi_t \equiv P_t/P_{t-1}$ denotes the gross rate of consumer-price inflation.

The wage-setting decision of the household is subject to a Calvo-type lottery where a household can not reset optimal wages in a fraction $\tilde{\alpha} \in [0,1)$ of labor markets. In these markets, the wage rate is indexed to last period's inflation, so $w_t^j = w_{t-1}^j(\pi_{t-1})^{\tilde{\chi}}$, where $\tilde{\chi}$ is measuring the degree of wage indexation.

3.2 Government

Each period $t \geq 0$, nominal government spending is given by $P_t g_t$. Real government expenditures, denoted by g_t are assumed to be exogenous, stochastic and follow the following univariate first-order autoregressive process.

$$\ln\,(g_t/\bar{g}) = \tilde{\rho}_g\, \ln(g_{t-1}/\bar{g}) + \epsilon_t^g \tag{9}$$

where ϵ_t^g is a government spending shock.

Like households, the government is also assumed to form habits over its consumption of individual varieties of goods. This can be thought of as the government favoring transactions with vendors that supplied public goods in the past. Or alternatively, we can think of households deriving utility from public goods that is separable from private consumption and leisure, and they exhibit good-by-good habit formation for public goods also. The government allocates spending over individual varieties of goods, g_{it}, so as to maximize the quantity of composite good produced with the differentiated varieties of goods according to the relation,

$$x_t^g = \left[\int_0^1 (g_{it} - b^g s_{it-1}^G)^{1-1/\eta} di\right]^{1/(1-1/\eta)}$$

[12]The costs of higher capacity utilization are given as follows, $a(u) = \gamma_1(u-1) + \frac{\gamma_2}{2}(u-1)^2$. In steady state, u is set to be equal to 1, and so $a(u) = 0$. During the estimation, $a''(1)/a'(1) = \gamma_2/\gamma_1$ is estimated.

The variable s_{it}^G denotes the government's stock of habit in good i and is assumed to evolve as follows,

$$s_{it}^G = \rho^g s_{it-1}^G + (1-\rho^g) g_{it} \tag{10}$$

The government's problem consists in choosing g_{it}, $i \in [0,1]$, so as to maximize x_t^g subject to the budget constraint $\int_0^1 P_{it} g_{it} di \leq P_t g_t$, taking as given the initial condition $g_{it} = g_t$, for $t = -1$ and all i. The resulting demand function for each differentiated good $i \in [0,1]$ by the public sector is,

$$g_{it} = \left(\frac{P_{it}}{P_t}\right)^{-\eta} x_t^g + b^g s_{it-1}^G \tag{11}$$

Government spending expenditures are assumed to be financed by lump-sum taxes. Note that since Ricardian equivalence holds in this model, the path of debt becomes irrelevant if we assume initial government debt to be zero.

The monetary authority is assumed to use a Taylor rule of the following form, where there is interest rate smoothing and nominal interest rate responds to deviations of inflation and output from steady state levels.

$$\ln\left(\frac{R_t}{R}\right) = \alpha_R \ln\left(\frac{R_{t-1}}{R}\right) + (1-\alpha_R)\left[\alpha_\pi \ln\left(\frac{\pi_t}{\pi}\right) + \alpha_y \ln\left(\frac{y_t}{y}\right)\right] \tag{12}$$

3.3 Firms

Each variety of final goods is produced by a single firm in a monopolistically competitive environment. Each firm $i \in [0,1]$ produces output using capital services, k_{it}, and labor services, h_{it} as factor inputs . The production technology is given by

$$F(k_{it}, h_{it}) - \psi$$

where the function F is assumed to be homogenous of degree one, concave, and strictly increasing in both arguments and has the following functional form,

$$F(k,h) = k^\theta h^{1-\theta}$$

The parameter $\psi > 0$ introduces fixed costs of operating a firm in each period, and are modeled to ensure a realistic profit-to-output ratio in steady state.

The firm is assumed to satisfy demand at the posted price. Formally,

$$F(k_{it}, h_{it}) - \psi \geq c_{it} + i_{it} + g_{it} = a_{it} \tag{13}$$

The objective of the firm is to choose contingent plans for P_{it}, h_{it}, k_{it} and m_{it}^f so as to maximize the present discounted value of dividend payments, given by

$$E_t \sum_{s=0}^{\infty} r_{t,t+s} P_{t+s} \phi_{it+s}$$

where,

$$\phi_{it} = \frac{P_{it}}{P_t} a_{it} - r_t^k k_{it} - w_t h_{it} - \frac{\alpha}{2}\left(\frac{P_{it}}{P_{it-1}} - \tilde{\pi}_t\right)^2$$

subject to (11), (5), and the demand function for investment faced by firm i. Note that sluggish price adjustment is introduced following Rotemberg (1982), by assuming that the firms face a quadratic price adjustment cost for the good it produces. This is because the introduction of deep habits makes the pricing problem dynamic and accounting for additional dynamics arising from Calvo-Yun type price stickiness makes aggregation non-trivial.

3.4 Market Clearing

The market clearing conditions in the final goods market yields the following resource constraint,

$$F(u_t k_t, h_t^d) - \psi = c_t + g_t + i_t + a(u_t)k_t + \frac{\alpha}{2}(\pi_t - \tilde{\pi}_t)^2$$

where the last term is the resource cost of price adjustment. The market clearing condition in the labor market is given by,

$$h_t = \tilde{s}_t h_t^d$$

where $\tilde{s}_t$, a measure of wage dispersion, evolves over time according to,

$$\tilde{s}_t = (1-\tilde{\alpha})\left(\frac{\tilde{w}_t}{w_t}\right)^{-\tilde{\eta}} + \tilde{\alpha}\left(\frac{w_{t-1}}{w_t}\right)^{-\tilde{\eta}}\left(\frac{\pi_t}{(\pi_{t-1})^{\tilde{\chi}}}\right)^{\tilde{\eta}} \tilde{s}_{t-1}$$

In the capital market the following market clearing condition holds,

$$\int_0^1 k_{it} di = u_t k_t.$$

Note also that,

$$\tilde{\pi}_t = \chi \pi_{t-1} + (1-\chi)\pi$$

where π is steady state inflation, and χ is the degree of indexation to past inflation.

4 Estimation Strategy

In this section, the estimation methodology is discussed. The model parameters are divided into two groups. The first group consists of parameters that are calibrated and are given in Table 1. These include the discount factor β, set at $1.03^{-1/4}$, which implies a steady-state annualized real interest rate of 3 percent. The depreciation rate, δ, is set at 0.025, which implies an annual rate of depreciation on capital equal to 10 percent. θ is set at 0.38, which corresponds to a steady state share of capital income roughly equal to 38%. Also, the steady state labor is set at 0.5 and the share of government spending in aggregate output is taken at 0.18, which matches the average share of government spending in GDP over the sample period considered in this paper.

The labor elasticity of substitution, $\tilde{\eta}$ is set at 21, and goods elasticity of substitution, η is set at 5.3. These parameters are calibrated but the steady state value of markups is eventually pinned down by the estimated degree of price and wage rigidities and deep habits. The autoregressive parameter, $\tilde{\rho}_g$, in the government spending process is calibrated to be 0.985. The Appendix shows that an AR(1) process for government spending with this value of $\tilde{\rho}_g$ is not statistically significantly different from the VAR representation of the government spending process.

The set of parameters being estimated are: $\{b^c, \rho^c, \alpha, \tilde{\alpha}, \kappa, \alpha_R, \alpha_\pi, \alpha_Y, b^g, \rho^g, \gamma_2/\gamma_1, \sigma, \tilde{\chi}, \chi\}$. I allow for varying degree of deep habit formation in private consumption and public consumption, denoted by b^c and b^g respectively. Similarly, the speed of adjustment of habit formation is different for public and private consumption, given by ρ^c and ρ^g.

To estimate the parameters of interest, I apply the Laplace type estimator (LTE) suggested by Chernozhukov and Hong (2003), which are defined similarly to Bayesian estimators, but use general statistical criterion function instead of the parametric likelihood function. Chernuzhukov and Hong show that these estimators are as efficient as the classical extremum estimators, while being computationally more attractive. The estimates are the mean values of a Markov chain sequence of draws from the quasi-posterior distribution of θ, generated by the tailored Metropolis Hastings algorithm. For the proposal distribution in the algorithm, the initial value of parameters are optimized values generated by running cmaes-dsge.m,[13]and the variance is given by the inverse Hessian matrix computed numerically.

The LTE of the vector θ, minimizes the quasi posterior risk function,

$$\theta = arg \inf_{\xi \in \Theta} [Q_n(\xi)]$$

where the quasi posterior function is defined as,

$$Q_n(\xi) = \int_{\theta \in \Theta} \rho_n(\theta - \xi) p_n(\theta) d\theta$$

Here $\rho_n(.)$ is the appropriate penalty function associated with an incorrect choice of parameter, and p_n is the quasi-posterior distribution, defined using the Laplace transformation of the distance

[13]This refers to the Covariance Matrix Adaption Evolutionary Strategy (CMA-ES) optimization routine adapted for use with DSGE models by Martin Andreasen (in Andreasen (2008)), who was kind enough to provide the MATLAB code.

function L_n and the prior probability of the parameter θ.[14]

$$p_n(\theta) = \frac{e^{L_n(\theta)}\pi(\theta)}{\int e^{L_n(\theta)}\pi(\theta)d\theta}$$

The distance function $L_n(\theta)$ is the weighted sum of squares of the difference between the impulse responses generated by the empirical VAR model, $I\hat{R}F$, and the ones generated by the theoretical model, $IRF(\theta)$.

$$L_n(\theta) = -(IRF(\theta) - I\hat{R}F_n)'V^{-1}(IRF(\theta) - I\hat{R}F_n)$$

Here V is a diagonal weighting matrix with the sample variances of the impulse responses along the diagonal.[15]

5 Estimation Results

In this section, the parameter estimates are presented and the role of various rigidities in the model is explored to a greater extent.

5.1 Parameter Estimates

Table 2 presents the estimation results for the model above, in the column labeled Baseline.[16]

The deep habit parameters are estimated to be 0.80 and 0.55 for habit formation in private consumption and public consumption respectively. The estimation for deep habit formation in household consumption is close to estimates of habits the level of composite good in the existing literature. However the parameter for deep habit formation for public consumption is a bit lower. The parameters ρ^c and ρ^g measure the speed of adjustment of the stock of external habit to variation in cross-sectional levels of consumption of a given variety. The estimated values of both these parameters is significantly high, indicating that high persistence in markups is needed to match the empirical responses, since wages and consumption do not have a big impact response to the demand shock but peak after 10 or so quarters. The estimated value of deep habit formation imply the steady state value of markup of price over marginal costs being 26.9%, which is within the range of empirical evidence presented in Rotemberg and Woodford (1999).

The coefficient of relative risk aversion is estimated to be 5.15. This suggests that consumption and leisure are substitutes, and the implied intertemporal elasticity of substitution is 0.19. Even though the empirical evidence is not so clear for this parameter, this estimated value seems to be in line with existing empirical studies.[17]

[14] In this paper I use uninformed priors, where parameters are just restricted to be within the permissible domain, e.g. the deep habit parameters are restricted to be within the unit interval, [0,1].

[15] I am matching impulse responses for 20 periods but a more efficient number of lag length can be determined using the statistical criterion suggested in Hall, Inoue, Nason, and Rossi (2007).

[16] The reported estimates are the mean values and standard deviation of the Markov chain sequence of draws, generated by the Metropolis Hastings algorithm with an acceptance rate of 42%.

[17] For instance, Barsky, Kimball, Juster, and Shapiro (1997) use microdata to estimate the intertemporal elasticity

The estimated wage stickiness parameter is equal to 0.88. Note, however that typically utility is defined as a function of a single differentiated type of labor. However in this paper utility is defined as a function of an aggregate of different types of labor, similar to Schmitt-Grohe and Uribe (2005). As shown in Schmitt-Grohe and Uribe (2006), in this variant of wage stickiness the parameter needs to be higher than the corresponding wage stickiness parameter in the set-up in Altig, Christiano, Eichenbaum, and Linde (2005) to obtain the same wage Phillips curve.[18] The wage indexation parameter, $\tilde{\chi}$ is estimated to be 0.61, implying a significant degree of indexation of wages to inflation. The price stickiness parameter is estimated to be close to 16. Recall, that price stickiness is modeled as a quadratic price adjustment cost. The mapping between the Phillips curve implied by this deep habits model with a price adjustment costs to the one arising in the Calvo-Yun price stickiness model, suggests that the average duration of price contracts is close to three quarters. There is a significant degree of estimated indexation to past inflation at 0.41.

The estimated investment adjustment costs parameter is much smaller than the estimates in other studies and does not seem to play a significant role. The parameter κ being small means that $1/\kappa$, the elasticity of investment with respect to a one percent temporary increase in the current price of installed capital, is high.

The estimated variable capacity utilization parameter, γ_2/γ_1, tends towards zero. Therefore, the parameter is restricted to be 0.001. This low value of the parameter indicates that it is relatively less costly for firms to vary the utilization of capital.

The estimated parameters in the monetary policy Taylor rule suggest moderate nominal interest rate smoothing as $\alpha_R = 0.74$. The coefficient on inflation is estimated to be 1.18 which satisfies the Taylor principle, but is smaller than the estimate in Clarida, Gali, and Gertler (2000) which is closer to 1.5. Also the estimated result suggest a small response to output, and $\alpha_Y = 0.013$. Notice that the theoretical responses of inflation and nominal interest rate, even though highly persistent, lie within the confidence bands.

5.2 Understanding Dynamics of the Estimated Model

Figure 2 shows the impulse response of the model to a one standard deviation shock to government spending, represented by the starred lines. Note that the estimated model does a reasonably good job at matching the empirical responses. All of the model responses lie within the two-standard deviation confidence intervals from the data. The model is successful in quantitatively matching the persistent and hump-shaped responses of wages and consumption, whereas most standard neoclassical model lack the transmission mechanism to generate positive responses for these two variables. In this section, the role of the various rigidities is examined in detail.

Note in this model I have abstracted from distortionary taxes and the government only relies on lump-sum taxes. The government spending shock therefore leads to a negative wealth effect

of substitution of 0.18, and Hall (1988) employs macrodata and concludes that intertemporal elasticity is most likely less than 0.2.

[18]The mapping shown in Schmitt-Grohe and Uribe (2006) between the two variants of wage stickiness however does not exactly apply here since preferences used here are different

since households face higher taxes. This induces them to increase hours worked, so labor supply goes up, and reduce consumption. These are the effects seen in standard RBC models.

In this model, due to the addition of deep habits, recall from equation (11), that the demand faced by firm i from the public sector in period t is of the form,

$$g_{it} = \left(\frac{P_{it}}{P_t}\right)^{-\eta} (g_t - b^g s^G_{t-1}) + b^g s^G_{it-1}$$

and there is a similar demand function for private consumption. The demand function has a price-elastic component that depends on aggregate consumption demand, and the second term is perfectly price-inelastic. An increase in aggregate demand increases the share of the price-elastic component, and thus an increase in the elasticity of demand, inducing a decline in the mark-ups. In addition to this, firms also take into account that today's price decisions will affect future demand, and so when the present value of future per unit profit are expected to be high, firms have an incentive to invest in the customer base today. Thus, they induce higher current sales via a decline in the current markup. If producers have market power and are able to set price above the marginal cost, then one of the firm's optimality condition look as follows, $F_2(u_t k_t, h^d_t) = \mu_t w_t$. Here μ_t is the ratio of price to marginal cost, and with imperfect competition, variations in the markup shift the labor demand and therefore, wages increase with output as a result of an increase in demand.[19] This higher real wage cause individuals to substitute away from leisure to consumption, and this substitution effect is large enough to offset the negative wealth effect so that overall consumption rises in response to a government spending shock. In the next section, the comparison of the baseline model with a model with superficial habits further sheds light on the importance of deep habits as a transmission mechanism in replicating the effects of a government spending shock

If there is a positive shock to government spending, there are two basic effects: firstly, there is an increase in output supply brought about by the negative wealth effect on labor supply. Secondly, there is an increase in aggregate demand due to a crowding in of consumption. Both these effects raise output, but their relative size determines what happens to prices. There is a drop in inflation in the model which means that aggregate supply exceeds aggregate demand.

In order to understand the role of wage stickiness in the baseline model, I estimate the model with flexible wages, i.e. set $\tilde{\alpha} = 0$, whereas all other rigidities are still present. Figure 3 shows the estimated model with flexible wages, and Table 2 shows the corresponding parameter estimates. The model is able to replicate most empirical responses with the glaring exception of consumption. The response of consumption is still positive, though of much smaller magnitude in this case.[20] Wage stickiness gives rise to a wedge between the disutility of labor and average wage prevailing in the economy.[21] In the absence of this wedge or average markup that unions impose on the labor

[19]This countercyclicality of the price markup has been empirically documented by Rotemberg and Woodford (1999) and Gali, Gertler, and Lopez-Salido (2007) among others. Monacelli and Perotti (2008), in fact, also show this fall in the markup in response to a government spending shock in a SVAR.

[20]The positive, yet small magnitude response for consumption in a model with deep habits is similar to one shown in Ravn, Schmitt-Grohe, and Uribe (2006).

[21]Note that the first order condition in the household problem with respect to labor is $\frac{-U_h(x^c_t, h_t)}{\lambda_t} = \frac{w_t}{\tilde{\mu}_t}$, where $\tilde{\mu}_t$

market, wages still rise due to deep habits when faced with a demand shock, but the disutility of labor is not as high as before, and thus it leads to a smaller degree of substitution from leisure to consumption, relative to the baseline case. Since the model tries to match the output and hours response, in the absence of wage rigidities, the response of wages is also much larger than the baseline case. The importance of the role played wage rigidities is also explored further in the next section where a model with superficial habits is considered.

Notice that the empirical results show investment falling on impact and rising to be point-wise positive after 4 quarters. The baseline model is able to match the initial drop in investment, but not the rise after 5 quarters or so, even though the theoretical response from the baseline model is within the confidence bands. This initial drop in investment in response to a government spending shock is primarily due to the crowding out effect of government spending as there is a tradeoff between the response of consumption versus investment.

In order to examine the role of capacity utilization, notice that the point estimate for γ_2/γ_1 tends close to zero, and we restrict it to be 0.001. This means that after a government spending shock, since demand goes up, capacity utilization goes up, leading to a fall in the rate of return of investment which generates the decline in investment. This is because output rises in response to the spending shock, where both capital and labor are inputs in the production function, and since hours worked rise and investment falls, effective capital, $u_t k_t$ also rises in response to the shock. A rise in capacity utilization after the shock hits the economy also shifts the marginal product of labor so that labor demand shifts up too. This adds another mechanism for the labor demand to shift sufficiently for us to see a rise in wage in response to the demand shock. To determine if the model relies too much on variable capacity utilization, the dynamic response of capital utilization in the estimated model is reported along with the corresponding empirical evidence in Figure 4. The empirical response is constructed by adding capacity utilization in the VAR[22], under the assumption that government spending does not contemporaneously respond to capacity utilization. Empirical evidence suggests that capacity utilization falls on impact and is positive after 2 quarters. Apart from the slight discrepancy in the two initial periods, the response of the estimated baseline model lies within the confidence bands.

Figure 5 shows the impulse response functions for an estimated model without variable capacity utilization. In this case, investment still drops on impact but rises to be positive within 4 quarters. However, in order to match the rise in capital, hours rise much more than in the baseline case, and also because of the tradeoff between the consumption and investment response, the magnitude of the rise in consumption is smaller than in the baseline case. Looking at the parameter estimates in Table 2, notice the difference in Taylor rule coefficients where a more aggressive inflation and output response translates into a flat response of real interest rate.

Lastly, Figure 6 shows the impulse response functions of a model estimated with flexible prices and it is apparent that the model does as good a job as the baseline model to fit the empirical

is the wedge.

[22]Data for capacity utilization used is the Federal Reserve Board's time series, which measures the intensity with which all factors of production are used the industrial production sector

responses. Linnemann and Schabert (2003) have emphasized the importance of price stickiness in order to see labor demand going up in response to a demand shock, and show that it is possible to see wages rise on impact depending on the monetary policy regime as characterized by the estimated coefficients in the Taylor rule. However, since the model has deep habits as a feature, it plays the role of generating sufficiently large countercyclical markups to lead to a rise in real wage in response to the spending shock, and price stickiness is no longer needed in the model. Comparing the estimates for the model with flexible prices to the baseline case, the only major difference is the speed of adjustment of the public spending habit stock, which is needed to generate persistent responses.

5.3 Comparing deep habits with superficial habits

In this section, the baseline model with deep habits is compared to a model with habit formation at the level of composite good, or alternatively referred to as superficial habits. Deep habits and superficial habits give rise to the same Euler equation. However, the differences arise in the demand side of the problem. To distinguish between the two, the model was also estimated with superficial habits, so that there is habit formation at the level of the aggregate consumption basket instead of on a good-by-good basis. More precisely, the utility function is now,

$$U(c_t - bc_{t-1}, h_t)$$

where b is the superficial habit formation parameter. The results are shown in Figure 7, and the estimates for the model with superficial habits are shown in Table 2.

While most responses once again lie within the confidence bands, the greatest discrepancy lies within the responses of wages and somewhat for consumption. Real wages fall in response to a government spending shock, and overall have a very weak response. Consumption, however, goes up but the magnitude is smaller than in the case of deep habits. Looking at the parameter estimates in Table 2, note that the estimated value of superficial habit formation, b is 0.275, which is significantly positive, but lower than existing estimates in the literature which are close to 0.6. Like the baseline model, however, there is an insignificant investment adjustment cost and a significant degree of wage stickiness. The degree of price stickiness, in this case though is lower than the baseline model with deep habits.

In this model, wages fall in response to a government spending shock due to the negative wealth effect as described earlier, since labor supply exceeds labor demand and in the absence of deep habits, price stickiness alone does not generate sufficiently large price markup mechanism to counter this effect. The consumption response, on the other hand is interesting, and surprisingly, positive. The key mechanism for that is the presence of wage stickiness. Consider Figure 8, which in the left panel shows the impulse response functions for the estimated model with superficial habits and the right panel shows the ones where all parameter values are kept at their estimated values but the wage stickiness parameter is set to 0. Although most responses no longer display a hump shaped behavior, the response of consumption is significantly different and no longer positive. Wages are a major component of marginal cost and thus wage rigidities dampen changes in wages and thus prices, thinking in terms of the price Phillips curve. In the absence of wage stickiness, there is not as significant a fall in inflation and therefore as shown in Figure 8, there is also no longer such a significant rise in output. Given the estimated values in the Taylor monetary rule, the absence of wage stickiness means a muted fall in the implied real interest rate and no longer a case for intertemporal substitution of consumption today to consumption tomorrow.

While the negative wealth effect causes households to reduce consumption, since the aggregate wage markup is countercyclical, recalling from the discussion earlier, for a given wage rate this causes individuals to substitute away from leisure to consumption. This becomes clearer by looking at the first order conditions of the household,

$$\frac{-U_h(c_t, h_t)}{U_c(c_t, h_t)} = \frac{w_t}{\tilde{\mu_t}}$$

where $\tilde{\mu_t}$ is the wedge between real wage and the marginal rate of substitution between consumption and leisure. Overall the substitution effect is larger than the wealth effect, resulting in a rise in consumption seen when wage stickiness is a feature of the model. The role of wage stickiness in response to a government spending shock has not been explored to a great deal, but the countercyclicality of the wage markup has been documented empirically, e.g. Gali, Gertler, and Lopez-Salido (2007).[23].

6 Conclusion

The objective of this paper is to identify and explain effects of a government spending shock. After accounting for events that signal large changes in military spending, in response to a structural government spending shock, I show that output, consumption, wages all rise in response, whereas investment, inflation and nominal interest rate fall on impact. A medium scale DSGE model augmented with deep habits successfully explains these effects. Of all the rigidities in the model, deep habits in public and private consumption and wage stickiness play an important role in matching the significantly positive and persistent responses of consumption and wages to a government spending shock. In addition, the paper compares the model with deep habits to the one with superficial habits and shows that deep habits significantly improve the fit of the model.

The model in this paper has the government relying on lump-sum taxes. One obvious extension is to consider a more realistic fiscal setup with distortionary labor and capital income taxes, where it might also be interesting to explore how in the context of a similar model, the economy responds to discretionary fiscal policy, in the form of not just spending shocks but also tax shocks.

[23] This countercyclicality of the wage markup has additionally been used to explain other puzzles, e.g. DiCecio (2009)

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Parameter	Calibrated value
Share of govt. spending in GDP, G/Y	0.18
Depreciation rate, δ	0.025
Discount factor, β	$1.03^{-1/4}$
Steady state inflation	$1.042^{1/4}$
Steady state capacity utilization	1
Steady state labor	0.5
Wage elasticity of demand for specific labor variety, $\tilde{\eta}$	21
Price elasticity of demand for specific good variety, η	5.3
Capital share, θ	0.38
Serial correlation of log of government spending, $\tilde{\rho}_g$	0.985

Table 1: Calibrated Parameters

Parameter	Description	Baseline Model	No Wage Stickiness	No Variable Utilization	No Price Stickiness	Superficial Habits
b^c	Deep habit in private cons.	0.805 (0.012)	0.881 (0.009)	0.918 (0.002)	0.588 (0.011)	-
ρ^c	Speed of adj. of private habit stock	0.887 (0.008)	0.977 (0.003)	0.979 (0.001)	0.958 (0.004)	-
α	Price stickiness parameter	15.992 (0.139)	23.071 (0.030)	18.622 (0.051)	-	11.665 (0.949)
$\tilde{\alpha}$	Wage stickiness parameter	0.868 (0.008)	-	0.891 (0.001)	0.897 (0.003)	0.742 (0.005)
κ	Investment adjustment cost	0.063 (0.006)	0.206 (0.023)	0.049 (0.002)	0.041 (0.004)	0.055 (0.0133)
α_R	Interest rate smoothing parameter	0.739 (0.026)	0.830 (0.018)	0.853 (0.001)	0.749 (0.011)	0.846 (0.017)
α_π	Inflation coefficient in Taylor rule	1.181 (0.040)	1.033 (0.021)	2.346 (0.002)	1.086 (0.020)	2.038 (0.025)
α_Y	Output coefficient in Taylor rule	0.013 (0.002)	0.007 (0.001)	0.153 (0.002)	0.010 (0.001)	0.055 (0.006)
b^g	Deep habit in public cons.	0.555 (0.020)	0.555 (0.017)	0.422 (0.002)	0.406 (0.006)	-
ρ^g	Speed of adj. of public habit stock	0.331 (0.019)	0.989 (0.001)	0.989 (0.001)	0.989 (0.001)	-
$\frac{\gamma_2}{\gamma_1}$	Capacity utilization parameter	0.001*	0.008 (0.006)	-	0.001*	0.243 (0.012)
σ	Intertemporal elasticity of substitution	5.155 (0.135)	1.563 (0.024)	5.048 (0.029)	6.049 (0.072)	1.898 (0.388)
$\tilde{\chi}$	Degree of wage indexation	0.617 (0.033)	-	0.656 (0.004)	0.734 (0.013)	0.063 (0.005)
χ	Degree of price indexation	0.415 (0.046)	0.021 (0.012)	0.9946 (0.001)	-	0.007 (0.005)
b	Superficial habit persistence parameter	-	-	-	-	0.275 (0.009)

Table 2: Parameter estimates. The estimates reported are the mean values of the Markov chains, the values in brackets indicate the standard errors and * means the value is constrained.

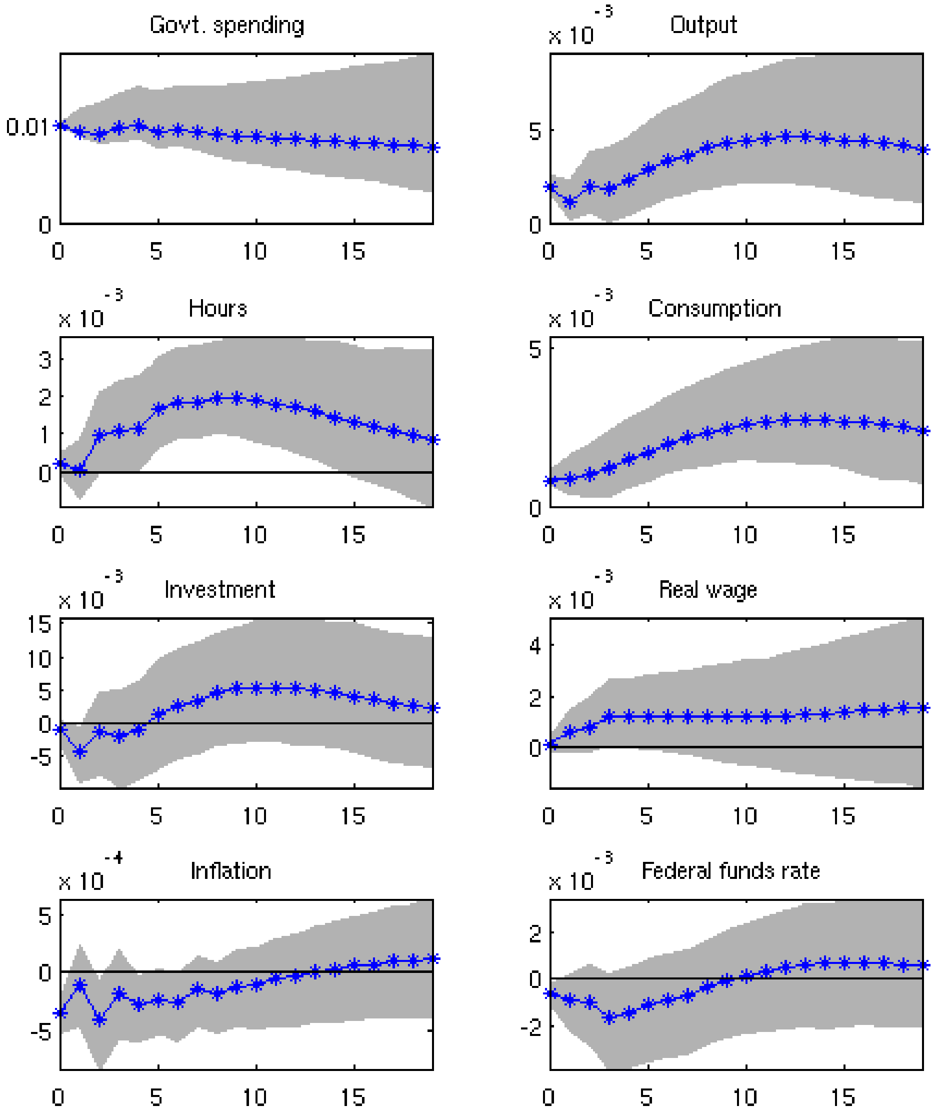

Figure 1: Impulse response function to a one standard deviation government spending shock as identified in the SVAR. The shaded gray regions are the 95 % confidence bands constructed by Monte Carlo simulations.

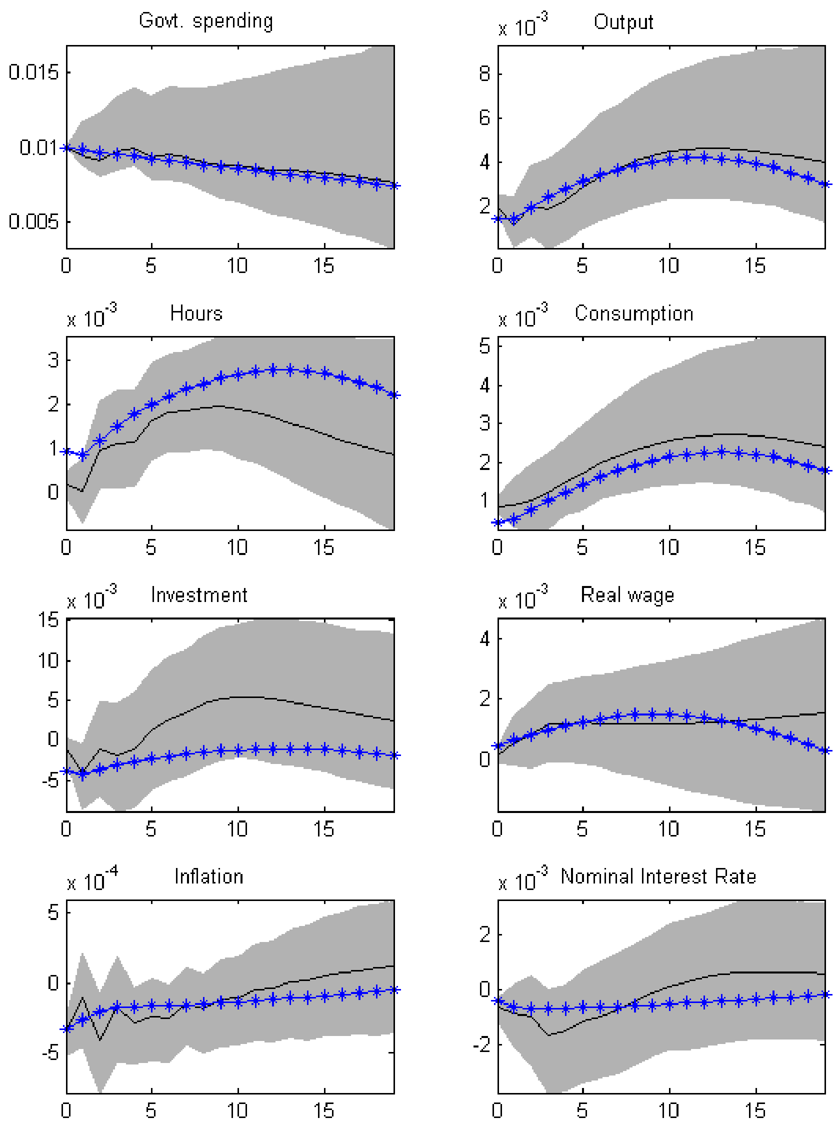

Figure 2: Impulse responses of the baseline model. Solid lines are the empirical responses and starred lines are the responses for the estimated model.

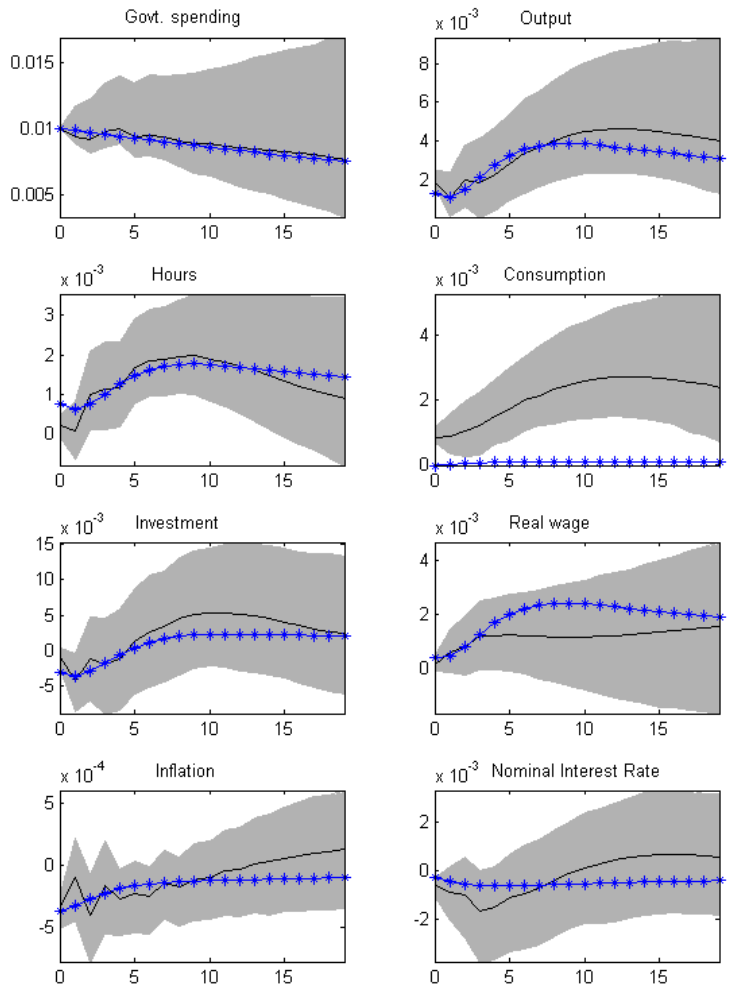

Figure 3: Impulse responses of the model estimated with flexible wages. Solid lines are the empirical responses and starred lines are the responses for the estimated model.

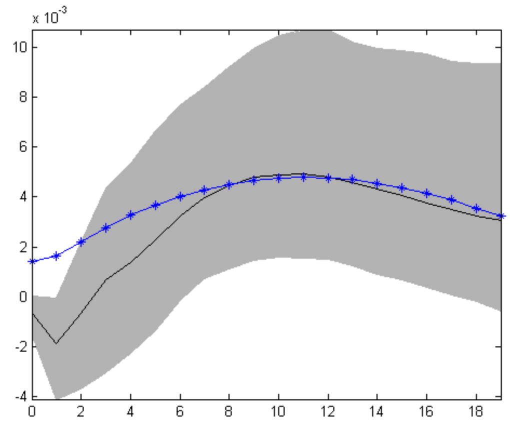

Figure 4: The response of capacity utilization in the estimated baseline model. Solid line is the empirical response and starred line is the responses of capacity utilization in the baseline estimated model

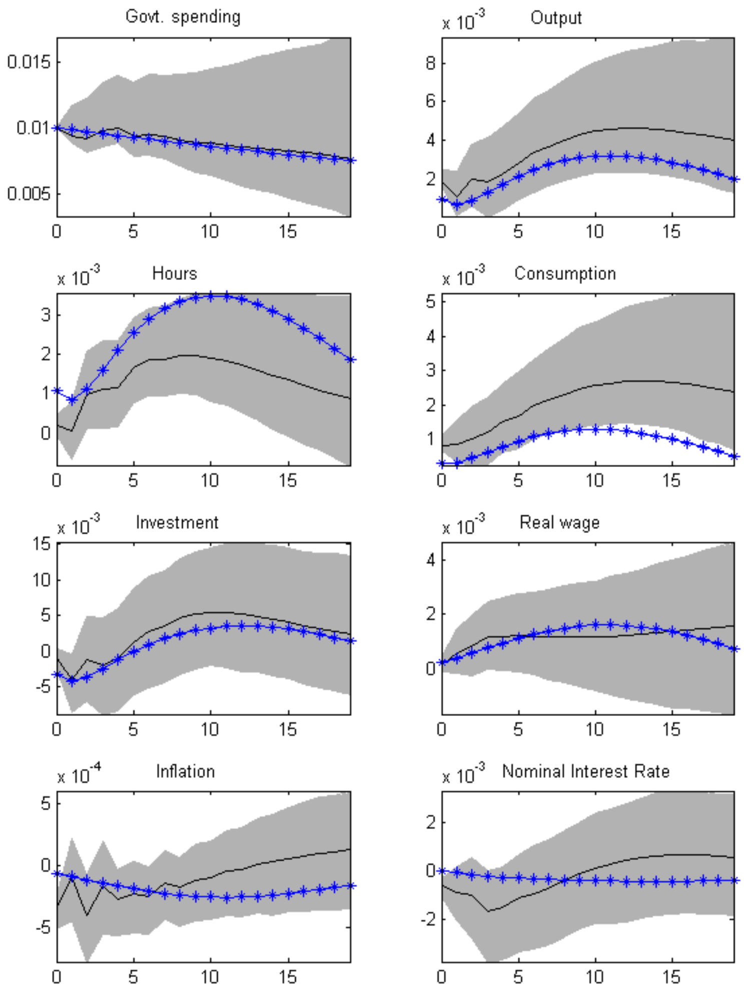

Figure 5: Impulse responses of the model estimated with no variable capacity utilization. Solid lines are the empirical responses and starred lines are the responses for the estimated model.

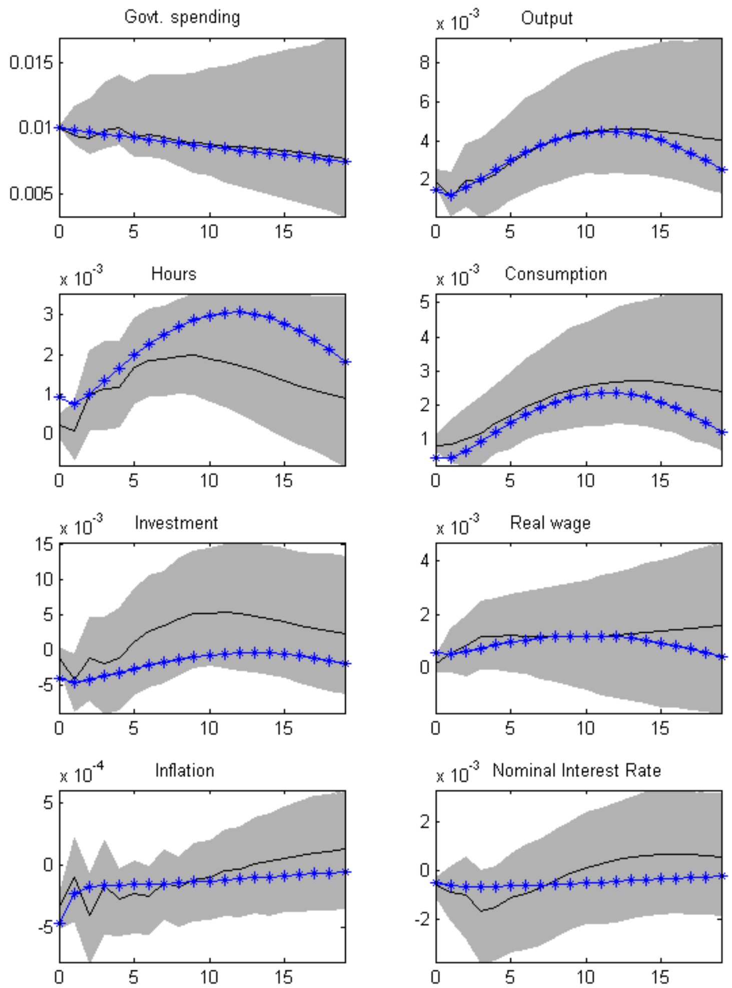

Figure 6: Impulse responses of the model estimated with flexible prices. Solid lines are the empirical responses and starred lines are the responses for the estimated model.

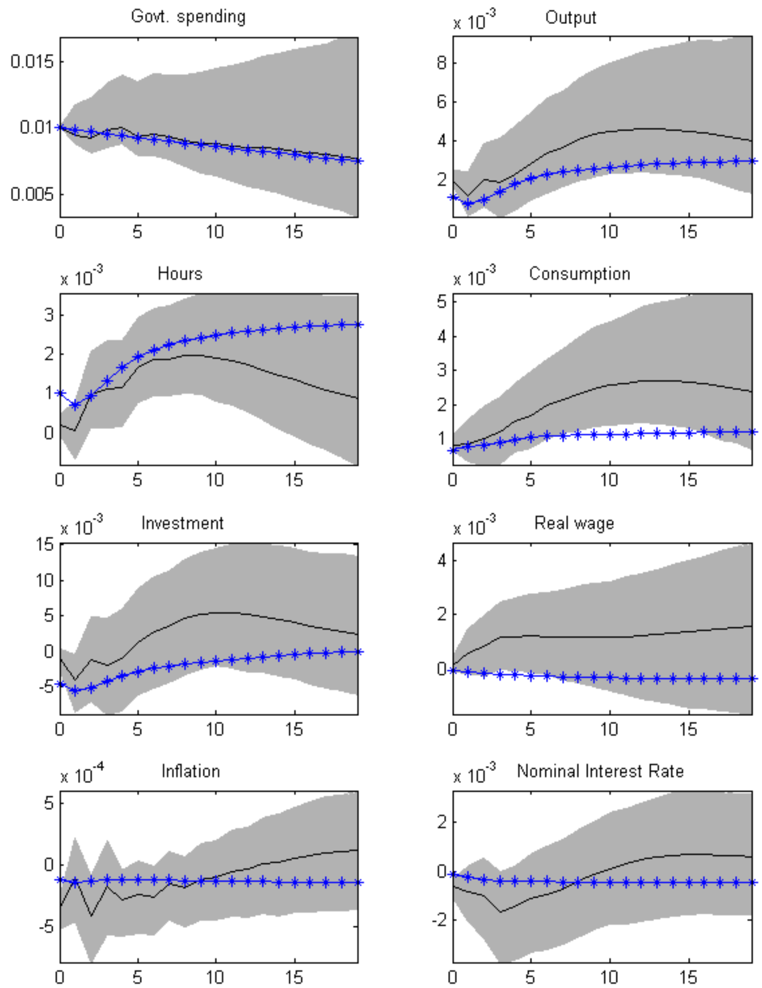

Figure 7: Impulse responses of the model estimated with superficial habits. Solid lines are the empirical responses and starred lines are the responses for the estimated model.

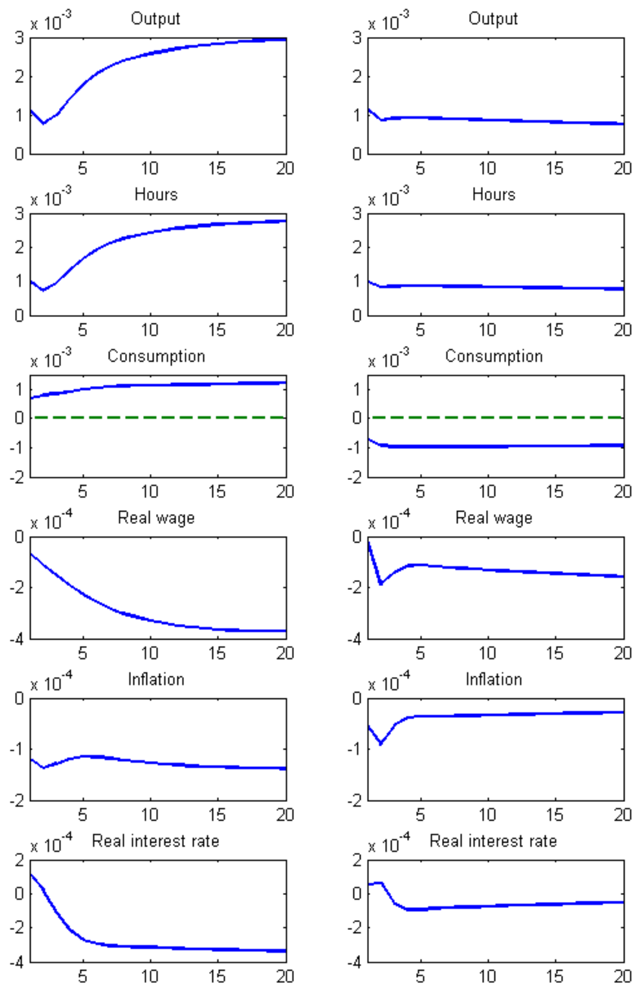

Figure 8: The left panel are the impulse response function of the model estimated with superficial habits, and the right panel are ones for the same parameter values but in addition no wage stickiness, i.e. $\tilde{\alpha} = 0$.

7 Appendix

7.1 Data Appendix

Label	Frequency	Description	Source
GDP	Q	Gross domestic product	BEA (Table 1.1.5, Line 1)
GCD	Q	Personal consumption expenditures on durable goods	BEA (Table 1.1.5, Line 3)
GCN	Q	Personal consumption expenditures on nondurable goods	BEA (Table 1.1.5, Line 4)
GCS	Q	Personal consumption expenditures on services	BEA (Table 1.1.5, Line 5)
GPI	Q	Gross private domestic investment	BEA (Table 1.1.5, Line 6)
GGE	Q	Government consumption expenditures and gross investment	BEA (Table 1.1.5, Line 20)
GDPQ	Q	Real gross domestic product	BEA (Table 1.1.6, Line 1)
P16	Q	Civilian non-institutional population, over 16	BLS (LNU00000000Q)
LBMNU	Q	Non-farm business hours worked	BLS (PRS85006033)
LBCPU	Q	Hourly non-farm business compensation	BLS (PRS85006103)
FYFF	M	Federal funds rate	St. Louis FRED
CAPUTIL	Q	Capacity utilization, Total Index	Federal Reserve Board (B50001)

Table 3: Sources of Data Series

Label	Description	Construction
GDPDEF	GDP deflator	GDPQ/GDP
G_t	Real per-capita government spending	GGE/P16/GDPDEF
Y_t	Real per-capita GDP	GDPQ/P16
h_t	Per-capita hours worked	LBMNU/P16
c_t	Real per-capita consumption	(GCN+GCS)/P16/GDPDEF
i_t	Real per-capita investment	(GPI+GCD)/P16/GDPDEF
w_t	Real wages	LBCPU/GDPDEF
π_t	Inflation	Δ GDPDEF
r_t	Fed funds rate	FYFF
u_t	Capacity utilization	CAPUTIL

Table 4: Data used in the VAR. Note that in the VAR, the logs of all series were used, except for r_t and u_t.

7.2 IRFs with and without the Ramey variable

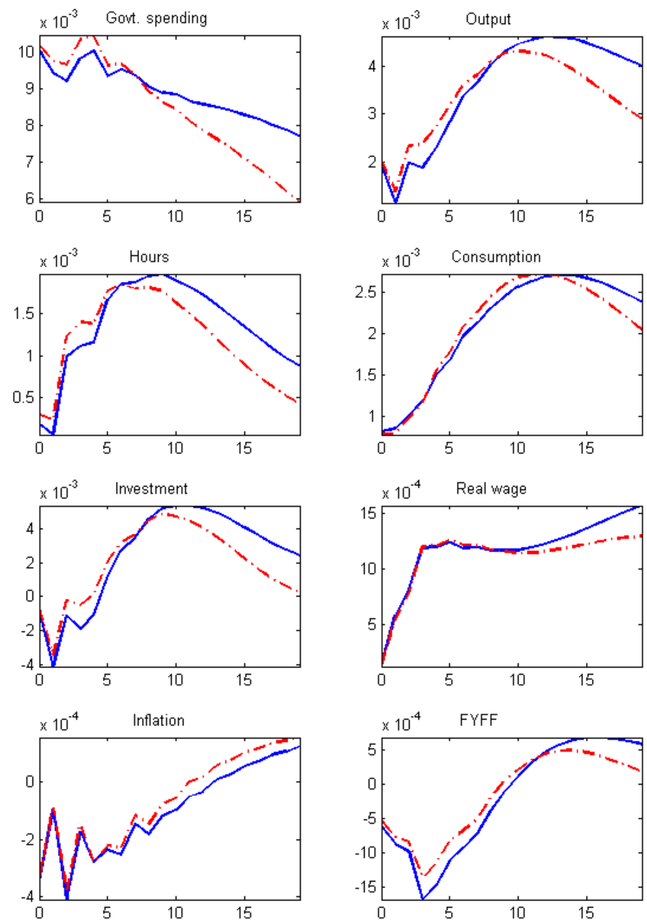

Figure 9: Impulse response function to a one standard deviation government spending shock as identified in the baseline SVAR (solid line) and impulse response function to government spending shock identified similarly but *no* Ramey variable included on the right hand side of the VAR equation (dashed line), which would be similar to the case shown in Fatas and Mihov (2001) and Blanchard and Perotti (2002).

7.3 Complete set of symmetric competitive equilibrium conditions

$$x_t^c = c_t - b^c s_{t-1}^C \tag{A-1}$$

$$x_t^g = g_t - b^g s_{t-1}^G \tag{A-2}$$

$$k_{t+1} = (1-\delta)k_t + i_t \left[1 - \mathcal{S}\left(\frac{i_t}{i_{t-1}}\right)\right] \tag{A-3}$$

$$U_x(x_t^c, h_t) = \lambda_t \tag{A-4}$$

$$-U_h(x_t^c, h_t) = \frac{\lambda_t w_t}{\tilde{\mu}_t} \tag{A-5}$$

$$\lambda_t q_t = \beta E_t \lambda_{t+1} \left[r_{t+1}^k u_{t+1} - a(u_{t+1}) + q_{t+1}(1-\delta)\right] \tag{A-6}$$

$$\lambda_t = \lambda_t q_t \left[1 - \mathcal{S}\left(\frac{i_t}{i_{t-1}}\right) - \left(\frac{i_t}{i_{t-1}}\right)\mathcal{S}'\left(\frac{i_t}{i_{t-1}}\right)\right] + \beta E_t \lambda_{t+1} q_{t+1} \left(\frac{i_{t+1}}{i_t}\right)^2 \mathcal{S}'\left(\frac{i_{t+1}}{i_t}\right) \tag{A-7}$$

$$r_t^k = a'(u_t) \tag{A-8}$$

$$f_t^1 = \left(\frac{\tilde{\eta}-1}{\tilde{\eta}}\right) \tilde{w}_t \lambda_t \left(\frac{w_t}{\tilde{w}_t}\right)^{\tilde{\eta}} h_t^d + \tilde{\alpha}\beta E_t \left(\frac{\pi_{t+1}}{\pi_t^{\tilde{\chi}}}\right)^{\tilde{\eta}-1} \left(\frac{\tilde{w}_{t+1}}{\tilde{w}_t}\right)^{\tilde{\eta}-1} f_{t+1}^1 \tag{A-9}$$

$$f_t^2 = -U_h(x_t^c, h_t) \left(\frac{w_t}{\tilde{w}_t}\right)^{\tilde{\eta}} h_t^d + \tilde{\alpha}\beta E_t \left(\frac{\pi_{t+1}}{\pi_t^{\tilde{\chi}}}\right)^{\tilde{\eta}} \left(\frac{\tilde{w}_{t+1}}{\tilde{w}_t}\right)^{\tilde{\eta}} f_{t+1}^2 \tag{A-10}$$

$$f_t^1 = f_t^2 \tag{A-11}$$

$$\lambda_t = \beta R_t E_t \frac{\lambda_{t+1}}{\pi_{t+1}} \tag{A-12}$$

$$\frac{1 - mc_t - \tilde{\nu}_t^c}{\rho^c - 1} = \beta E_t \frac{\lambda_{t+1}}{\lambda_t} \left[b^c \tilde{\nu}_{t+1}^c + \frac{\rho^c}{\rho^c - 1}\left\{1 - mc_{t+1} - \tilde{\nu}_{t+1}^c\right\}\right] \tag{A-13}$$

$$\frac{1 - mc_t - \tilde{\nu}_t^g}{\rho^g - 1} = \beta E_t \frac{\lambda_{t+1}}{\lambda_t} \left[b^g \tilde{\nu}_{t+1}^g + \frac{\rho^g}{\rho^g - 1}\left\{1 - mc_{t+1} - \tilde{\nu}_{t+1}^g\right\}\right] \tag{A-14}$$

$$1 - mc_t = \tilde{\nu}_t^i \tag{A-15}$$

$$\eta\left(\tilde{\nu}_t^c x_t^c + \tilde{\nu}_t^g x_t^g + \tilde{\nu}_t^i i_t\right) + \alpha\pi_t(\pi_t - \tilde{\pi}_t) - (c_t + g_t + i_t) = \alpha\beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t}\pi_{t+1}(\pi_{t+1} - \tilde{\pi}_{t+1})\right] \tag{A-16}$$

$$F(u_t k_t, h_t^d) - \psi = c_t + g_t + i_t + a(u_t)k_t + \frac{\alpha}{2}(\pi_t - \tilde{\pi}_t)^2 \tag{A-17}$$

$$\tilde{\pi}_t = \chi\pi_{t-1} + (1-\chi)\pi \tag{A-18}$$

$$\mathrm{mc}_t F_2(u_t k_t, h_t^d) = w_t \tag{A-19}$$

$$\mathrm{mc}_t F_1(u_t k_t, h_t^d) = r_t^k \tag{A-20}$$

$$h_t = \tilde{s}_t h_t^d \tag{A-21}$$

$$\tilde{s}_t = (1-\tilde{\alpha})\left(\frac{\tilde{w}_t}{w_t}\right)^{-\tilde{\eta}} + \tilde{\alpha}\left(\frac{w_{t-1}}{w_t}\right)^{-\tilde{\eta}}\left(\frac{\pi_t}{\pi_{t-1}^{\tilde{\chi}}}\right)^{\tilde{\eta}}\tilde{s}_{t-1} \tag{A-22}$$

$$w_t^{1-\tilde{\eta}} = (1-\tilde{\alpha})\tilde{w}_t^{1-\tilde{\eta}} + \tilde{\alpha} w_{t-1}^{1-\tilde{\eta}}\left(\frac{(\pi_{t-1})^{\tilde{\chi}}}{\pi_t}\right)^{1-\tilde{\eta}} \tag{A-23}$$

$$\tau_t = g_t \tag{A-24}$$

$$s_t^C = \rho^c s_{t-1}^C + (1-\rho^c)c_t \tag{A-25}$$

$$s_t^G = \rho^g s_{t-1}^G + (1-\rho^g)g_t \tag{A-26}$$

and the exogenous process for government spending and Taylor monetary rule.
Variables: $x_t^c, x_t^g, c_t, g_t, i_t, s_t^C, s_t^G, k_t, h_t, \lambda_t, w_t, \tilde{\mu}_t, q_t, u_t, r_t^k, \pi_t, h_t^d, \tilde{w}_t, f_t^1, f_t^2, \tilde{\nu}_t^c, \tilde{\nu}_t^i, \tilde{\nu}_t^g,$ $\text{mc}_t, \tilde{s}_t,$ $\tau_t, R_t, \tilde{\pi}_t$

7.4 Process for government spending

Based on the VAR given in Equation (1), government spending process has an MA(∞) representation, but this specification of the government spending process would involve a very large number of parameters, and so working with this estimated process would be quite involved. A second alternative is to specify the government spending process in the theoretical model with its VAR representation and use the estimated coefficients. That, however, would mean the inclusion of several additional state variables, since we have eight variables and four lags of each, and that too would make the solution of the model rather cumbersome. In this section, I closely follow the proposed diagnostic procedure shown in Christiano, Eichenbaum, and Evans (1998) to show that a first order autoregressive approximated representation of government spending, with $\tilde{\rho}_g = 0.985$, is not statistically significantly different from the VAR representation of government spending process.

The two criterion given for a good approximation of the autoregressive representation given by Christiano, Eichenbaum, and Evans (1998) are:

1. The approximated autoregressive process is not rejected by the data.
2. The dynamic response of non-spending variables to a government spending shock are not qualitatively different from the ones in the VAR.

and I closely follow their method here.[24]

The autoregressive process for government spending is given as follows

$$g_t = \tilde{\rho}_g g_{t-1} + \epsilon_t^g$$

which can be written as

$$g_t = \pi^{11}(L)\epsilon_t^g$$

with

$$\pi^{11}(L) = \frac{\rho_0}{1 - \tilde{\rho}_g L} \text{ , } \rho_0 = \pi^{11}(0)$$

To check if (1) is satisfied, I test the null hypothesis that the ith lag response of government spending to a spending shock is $\hat{\rho}_0(\tilde{\rho}_g)$ for $i = 1, 2, 3, .., \kappa$, where $\hat{\rho}_0$ is the estimated contemporaneous impact response and $\kappa = 4$.[25] I test the null hypothesis for different values of $\tilde{\rho}_g$ and the probability values of the test statistics are reported in Table ?.

While there is substantial evidence against AR(1) hypothesis for $\tilde{\rho}_g$ equal to 0.85 or 0.90, AR(1) specification with $\tilde{\rho}_g = 0.985$ is a reasonable statistical approximation to the VAR process.

Lastly, to show that the candidate specification satisfies criterion (2), Figure 10 shows the impulse response functions to a government spending shock in the system with the government

[24] A cruder test to see if government spending is given by an autoregressive process, is to jointly test the significance of all the variables except g_{t-1} in the first equation of the reduced form VAR. If H_0 is that all other variables are insignificant, the test statistics yield, $F(31, 172) = 1.32$ and $Prob > F = 0.1354$, so one can not reject the null hypothesis.

[25] The specifics of the test are exactly the same as described in footnote 16 of Christiano, Eichenbaum, and Evans (1998).

$H_0 : a_i = \hat{\rho}_0 \times \tilde{\rho}_g,\ i = 1, 2, 3, 4$			
a_i is the i th lag response of g_t to ϵ_t^g			
$\hat{\rho}_0$ is the estimated impact response of g_t to ϵ_t^g			
$\tilde{\rho}_g = 0.85$	$\tilde{\rho}_g = 0.90$	$\tilde{\rho}_g = 0.95$	$\tilde{\rho}_g = 0.985$
2.0	7.5	33.3	56.2

Table 5: Probability values for AR Wald Test

spending process specified as an autoregressive process as dashed lines. Note that in all cases the responses closely resemble the responses implied by the point estimates.

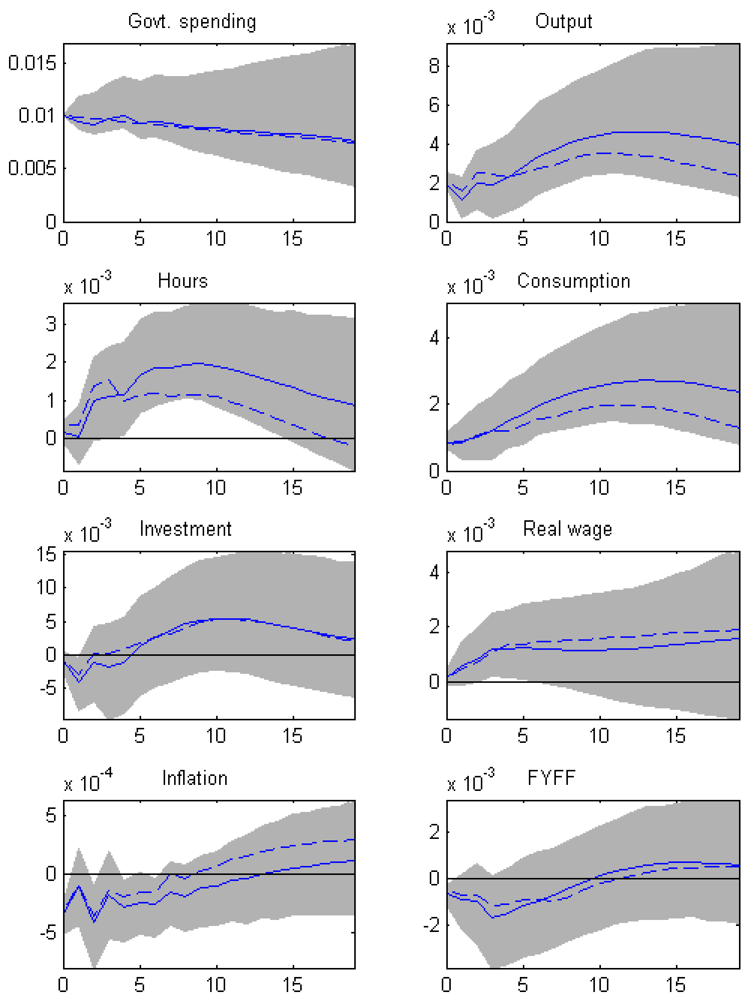

Figure 10: The impulse response functions to a government spending shock in the SVAR (solid line) and in the system with the government spending process specified as an autoregressive process (dashed line).