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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, I find that in response to a structural unanticipated government spending shock, output, hours, consumption and wages all rise, whereas investment falls on impact. I construct and estimate a dynamic general equilibrium model featuring deep habit formation and show that it successfully explains these effects. In particular, deep habits give rise to countercyclical markups and thus act as transmission mechanism for the effects of government spending shocks on private consumption and wages. In addition, I show that deep habits significantly improve the fit of the model compared to a model with habit formation at the level of aggregate goods.

JEL Classification: C51, E32, E62

Keywords: deep habits, fiscal shocks, government spending, countercyclical markups

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1 Introduction

Recently in public debates, there is renewed interest in the role fiscal instruments play in stabilizing the 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. In this paper, I start by showing that 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.

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

Baxter and King (1993) show that in a simple real business cycle model with lump-sum taxes, when government spending rises, households face higher taxes and due to the negative wealth effects, 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. 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.²

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-

²Forni, 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. They show that allowing for this complementarity between consumption and hours worked leads to a small estimated fraction of rule of thumb consumers, and these two features can work together to give a positive response of consumption.

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.³ 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, resulting in a rise in consumption. 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.⁴

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 of a broader variety of key macroeconomic variables.⁵ 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), which has been shown to fit the data well along different dimensions. The specific departure in this paper is the introduction of deep

³In an earlier paper, 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, with strategic interactions between colluding firms.

⁴Recently, 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.

⁵Burnside, Eichenbaum, and Fisher (2004) is similar in spirit as they quantitatively match impulse response functions of several macro variables to a government spending shock. However, the fundamental difference is the identification scheme they use to identify government spending shock which relies on narrative evidence on episodes of military buildup presented in Ramey and Shapiro (1998). They 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.

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. In particular, in comparison to a model with superficial habits, the model with deep habits produces impulse responses that are significantly better at matching the magnitude and persistence of the empirical responses for all variables of interest, most notably consumption and real wages.

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. In Section 4, I provide the description of the estimation procedure used. Section 5 presents the estimation results and dynamics for both models with superficial and deep habits, Section 6 compares deep habits with other mechanisms for government spending shocks explored in the literature and finally, Section 7 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 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,

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

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 ⁶. In this specification $A(L)$ and $B(L)$ are polynomials of degree 4.⁷ The data spans 1954:3-2008:4, 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.⁸

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 signifi-

⁶This was first suggested to me by Martin Uribe. Since then Jordi Gali has made the same point in his NBER discussion of Ramey (2008).

⁷Akaike and Schwartz criterion support lags lengths of 2 and 1 respectively. The empirical results shown here are robust to these lag lengths.

⁸All the data sources are provided in the Appendix.

cantly 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 responses shown are broadly consistent with the ones shown in Blanchard and Perotti (2002), Fatas and Mihov (2001) and Gali, Lopez-Salido, and Valles (2007), which employ similar identification schemes, even though the sample size has been updated to include recent data. The impact government spending multiplier for GDP found here is 0.94, which is similar in magnitude to 0.90 found in Blanchard and Perotti (2002), and slightly greater than 1 found by Fatas and Mihov (2001). All these studies also find consumption and wages rising significantly in response to a government spending shock. Mountford and Uhlig (2002) use an agnostic identification procedure based on sign restrictions to identify government spending shocks, and find a weak positive response for consumption, and a weak, mostly insignificant response for real wages.⁹ As far as the response of investment is concerned, Blanchard and Perotti (2002) find that investment declines significantly for the first five quarters. Similarly, Fatas and Mihov (2001) also find an initial decline in the response of investment before it starts rising, even though their measure of investment excludes durable consumption. They also show that the main component of investment driving this initial drop is non-residential investment. While Mountford and Uhlig (2002) use a different identification scheme, they also find residential and non-residential investment crowded out by a government spending shock.¹⁰

⁹Studies that employ the narrative approach to identifying government spending shocks, like Ramey and Shapiro (1998) and Edelberg, Eichenbaum, and Fisher (1999), typically find product wages falling significantly and an insignificant response for wages deflated by GDP deflator. While Ramey (2008) finds consumption being crowded out, Edelberg, Eichenbaum, and Fisher (1999) and Burnside, Eichenbaum, and Fisher (2004) find an insignificant response for consumption.

¹⁰Narrative studies usually find gross private investment rising on impact and falling with a delay in response to a spending shock.

Since the findings here are very similar to the ones of Blanchard and Perotti (2002) and Fatas and Mihov (2001), this seems to suggest that the anticipation effects captured by the Ramey variable in the VAR given by equation (1) are not very significant.¹¹

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. At first sight, these responses seem counter-intuitive but have been observed by previous empirical studies as well. 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) meanwhile employ 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 Christiano, Eichenbaum, and Evans (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 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.

¹¹The appendix shows the impulse response functions for the case of both including and excluding ϵ_t^R , the Ramey variable, in equation(1). There are no significant differences between the two.

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,

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

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.¹² 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.

Households also derive utility from consumption of government provided goods, given by x_t^g here, which is separable from private consumption and leisure. This means that public spending does not affect the marginal utility of private consumption or leisure. This is a common assumption in the literature, and studies such as Aschauer (1985), Ni (1995) and McGrattan (1994) who examine whether in fact private and public consumption are substitutes or complements find mixed and inconclusive results.

The variable x_t^c is a composite of habit adjusted consumption of a continuum of differ-

¹²If $\sigma = 1$, 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.

entiated goods indexed by $i \in [0, 1]$,

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

where s_{it-1}^C 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,

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

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 movements.

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

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

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 $(W_t^j/W_t)^{-\tilde{\eta}} h_t^d$. 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,

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

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,

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

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. For-

mally, 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.¹³ 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:

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

where $\omega_t = b^c \int_0^1 P_{it} s_{it-1}^C / P_t di$. The variable a_t^j / 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 $w_t^j = w_{t-1}^j \pi_{t-1}$.

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 a univariate

¹³In steady state, u is set to be equal to 1, and so $a(u) = 0$. The parameter of interest, which determines dynamics is $a''(1)/a'(1) = \sigma_a$.

first-order autoregressive process,¹⁴

$$\hat{g}_t = \tilde{\rho}_g \hat{g}_{t-1} + \epsilon_t^g, \quad (9)$$

where ϵ_t^g is a government spending shock.¹⁵

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 additively 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,

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

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

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

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,

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

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.

¹⁴In the sensitivity analysis section, a process for government spending with feedback from other variables, as in the VAR, is also considered.

¹⁵A hatted variable denotes log deviation of a variable from its steady state.

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.

$$\hat{R}_t = \alpha_R \hat{R}_{t-1} + (1 - \alpha_R) (\alpha_\pi \hat{\pi}_t + \alpha_y \hat{y}_t). \quad (12)$$

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,

$$F(k_{it}, h_{it}) - \psi \geq a_{it}, \quad (13)$$

where a_{it} is aggregate absorption of good i and includes c_{it} , g_{it} and i_{it} . The objective of the firm is to choose contingent plans for P_{it} , h_{it} , and k_{it} 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,

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

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.

4 Estimation Strategy

In this section, the estimation methodology is discussed. To make comparison with existing studies easier, the strategy followed in this paper is to calibrate most of the parameters to match the estimates in Christiano, Eichenbaum, and Evans (2005).¹⁶ The parameters of interest in the transmission of government spending shocks are the habit formation related parameters, preference parameter and the autoregressive parameter for the government spending process, and these are all estimated.

The group of parameters that are calibrated are shown 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 0.36, which corresponds to a steady state share of capital income roughly equal to 36%. Also, the steady state labor is set at 0.5 that implies a Frisch elasticity of labor supply equal to unity and the share of government

¹⁶An additional concern is the identification of parameters, and the dynamics of the model in response to a government spending shock may fail to contain information about certain parameters.

spending in aggregate output is taken at 0.20, that 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, which implies the markup of wages over marginal rate of substitution between leisure and consumption being 5 percent. The goods elasticity of substitution, η is calibrated to be 5.3 which implies a steady state price markup of 23 percent in the case of superficial habits. However, the steady state value of markup over prices in the case with deep habits is eventually pinned down by the estimated degree of deep habits.

The capacity utilization parameter, σ_a is calibrated to be 0.01, and the investment adjustment cost is set at 2.48. These are values taken from Christiano, Eichenbaum, and Evans (2005). The wage stickiness parameter $\tilde{\alpha}$ is calibrated to be 0.92. Note, that typically utility is defined as a function of a single differentiated type of labor. However, here 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 Christiano, Eichenbaum, and Evans (2005) to obtain the same wage Phillips curve. The parameter value of 0.92 maps into the value estimated in Christiano, Eichenbaum, and Evans (2005) equal to 0.64.

The price stickiness parameter is calibrated to be 17. Recall, that price stickiness is modeled as a quadratic price adjustment cost. The mapping between the Phillips curve implied by a model with a price adjustment cost to the one arising in the Calvo-Yun price stickiness model, suggests that the average duration of price contracts is close to three quarters, as estimated in Christiano, Eichenbaum, and Evans (2005).

Lastly, the parameters in the monetary policy rule are calibrated to be consistent with post-1979 era estimates in Clarida, Gali, and Gertler (2000); the interest rate smoothing parameter is set to be 0.8, and the coefficients on inflation and output are calibrated to be 1.5 and 0.1 respectively.

The set of parameters being estimated are: $\{b^c, \rho^c, b^g, \rho^g, \sigma, \tilde{\rho}_g\}$. 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`,¹⁷ 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 $\rho_n(\cdot)$ 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

¹⁷This is an optimization routine adapted for use with DSGE models by Martin Andreasen (in Andreasen (2008)), who was kind enough to provide the MATLAB code.

the distance function L_n and the prior probability of the parameter θ .¹⁸

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

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.¹⁹

The reported estimates are the mean values and standard deviation of the Markov chain sequence of 500,000 draws, which guarantees convergence, with the first 100,000 values burnt out. These draws are generated by the Metropolis Hastings algorithm with an acceptance rate of between 20-30%.

5 Estimation Results

5.1 Parameter Estimates and Dynamics in Model with Superficial Habits

Deep habits and superficial habits give rise to the same Euler equation. However, the differences arise in the supply side of the problem. To distinguish between the two, the model was first 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

¹⁸I use flat priors, where parameters are restricted to be within the permissible domain, e.g. the deep habit parameters are restricted to be within the unit interval, $[0,1)$.

¹⁹I 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).

utility function is now,

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

where b is the superficial habit formation parameter. With superficial habits in place, the model is not very different from the standard medium scale model, considered in Christiano, Eichenbaum, and Evans (2005) and Smets and Wouters (2007) to cite a few.²⁰

The results are shown in Figure 2, and the estimates for the model with superficial habits are shown in Table 2. The habit formation parameter estimated is much higher than in previous studies and tends to 0.96. The preference parameter, σ is estimated to be 5.9 which implies an intertemporal elasticity of substitution of close to 0.17. The autoregressive parameter, $\tilde{\rho}_g$, in the government spending process is estimated to be 0.96.

Note first that even though the model has nominal rigidities in the form of price and wage stickiness, in addition to variable capacity utilization and investment adjustment cost, the responses are short-lived and not persistent enough to match the empirical evidence. Secondly, the model is able to match the increase in output and fall in investment on impact. However, the response of consumption and wages seem flat, and in the case of consumption, outside the 95% confidence bands. In Figure 4, some of the responses in the estimated model are magnified for clarification.

In the 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 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 the presence of price stickiness, as shown in Linnemann and Schabert (2003), labor demand goes up in response to a demand shock, and it is possible to see wages rise on impact depending on the monetary policy regime as characterized by the coefficients in the Taylor rule. However, they also show that price stickiness alone does not generate a sufficiently large price markup mechanism to lead consumption to rise.

²⁰The complete set of symmetric equilibrium conditions for this case are given in the Appendix.

Since output rises in response to the spending shock, where both capital and labor are inputs in the production function, and investment falls, effective capital, $u_t k_t$ 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 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.

Ultimately, since the preferences are non-separable, and σ is estimated to be greater than 1, the small rise in wages ensures that agents substitute from leisure towards consumption, and at least on impact, this overcomes the negative wealth effect and consumption rises as a result. However, as is clear in Figure 4, these effects are all very small in magnitude and do not help to quantitatively or qualitatively match the empirical responses in the long run, and for the case of consumption in particular, the discrepancy between the data and model implied responses is rather severe.

5.2 Parameter Estimates and Dynamics in Model with Deep Habits

Next the model is estimated with deep habits and Table 2 presents the estimation results.

The deep habit parameters are estimated to be 0.74 and 0.69 for habit formation in private consumption and public consumption respectively. The degree of deep habit formation in household consumption is close to estimates of habits at the level of composite good in the existing literature. 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 values of deep habit formation parameters imply the steady state value of markup of price over marginal costs being 27%, which is within the range of empirical evidence presented in Rotemberg and Woodford (1999).

The coefficient of relative risk aversion is estimated to be 4.39. This suggests that con-

sumption and leisure are substitutes, and the implied intertemporal elasticity of substitution is 0.22. Even though the empirical evidence is not so clear for this parameter, this estimated value seems to be in line with existing empirical studies.²¹

Figure 3 shows the impulse response implied by the model. 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 of the data. The model is in particular, successful in quantitatively matching the persistent responses of wages and consumption.

In addition to the wealth effects discussed in the previous section, due to deep habits, recall from equation (11), the demand faced by firm i from the public sector in period t is of the form,

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

and there is a similar demand function for private consumption. The demand function has a price-elastic component that depends on aggregate public 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, $F_2(u_t k_t, h_t^d) = \mu_t w_t$. 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.²²

²¹For instance, Barsky, Kimball, Juster, and Shapiro (1997) use microdata to estimate the intertemporal elasticity of substitution of 0.18, and Hall (1988) employs macrodata and concludes that intertemporal elasticity is most likely less than 0.2.

²²This 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,

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 significantly in response to 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 since the firms lower markups in response to an increase in aggregate demand. The drop in inflation is inertial due to the slow decay of stock of habit, and eventually reverts back to steady state as aggregate demand comes back to normal. Overall, the monetary variables do not have significant responses to a government spending shock. Given the monetary policy parameters, there is an aggressive anti-inflationary rule with a significant response to output, which leads to an increase in the real interest rate on impact. Since this rise is not significant, the households do not face large intertemporal substitution effects.

Notice that the empirical results show investment falling on impact and rising to be point-wise positive after 6 quarters. The model with deep habits is able to match the initial drop in investment, but not the subsequent rise, although the theoretical response from the baseline model is within the confidence bands. The rise in labor supply as a result of a spending shock induces a rise in marginal product of capital, and thus as the rental cost of capital goes up, there is a corresponding fall in investment.

also show this fall in the markup in response to a government spending shock in a SVAR.

6 Sensitivity Analysis

6.1 Government spending process

In the model, government spending is modeled as an AR(1) process. Next, I consider if the results are robust to the assumption of fiscal policy taking the form of a feedback rule, given by the first equation of the VAR system given in equation(1). This means, the process for government spending is,

$$\hat{g}_t = A^1(L)\hat{Y}_{t-1} + \epsilon_t^g \quad (14)$$

where $A^1(L)$ denotes the first row of $A(L)$, and $\hat{Y}_t = [\hat{g}_t \quad \hat{y}_t \quad \hat{h}_t \quad \hat{c}_t \quad \hat{i}_t \quad \hat{w}_t \quad \hat{\pi}_t \quad \hat{R}_t]'$. The values assigned to $A^1(L)$ are the same as estimated in Section 2, but the behavior of the endogenous variables appearing in the process is dictated by the model's dynamics. This explains any discrepancy between the theoretical and empirical impulse responses of g_t .

Figure 6 shows the impulse responses implied by a model with deep habits estimated with this feedback rule for government spending in place. The estimates are given in Table 2. The estimated degree of deep habit formation in public and private consumption is slightly higher than the baseline case but the preference parameter is estimated close to 3, which is lower than 4.4, the value in the baseline case. Overall, the impulse response functions once again match the empirical responses, for the most part, just as successfully as the specification with an AR(1) process for government spending.

6.2 Role of markup

The key in using deep habits as a transmission mechanism for government spending shocks, is that they induce time-varying countercyclical movements in the markup of prices over marginal costs. However, Monacelli and Perotti (2008) criticize deep habits on the basis of giving rise to *private consumption and markup responses that are counterfactually small and large, respectively*. This raises questions about the size of markup dynamics in the estimated

model with deep habits.

Figure 5 shows the response of markup, along with consumption and wages in the estimated model. Monacelli and Perotti (2008) provide empirical evidence on the response of markups in the non-financial corporate business and manufacturing sectors. In response to a 1 percentage point of GDP increase in government spending, they find consumption peaking at 0.5 percentage points of GDP and markup falling by between 0.5 and 1 percent. If the responses in the model are normalized similarly by average share of the variable in GDP, then the model predicts that consumption peaks at a little over 0.3 percentage points of GDP and the markup falls by about 0.5 percent, in response to a 1 percentage point of GDP increase in government spending. The model dynamics are thus in line with their findings.

7 Other Transmission Mechanisms for Government Spending Shocks

In standard neoclassical models, as shown in Baxter and King (1993) when government spending rises, households face higher taxes and due to the negative wealth effect, they inevitably lower their consumption and increase hours worked. In these perfectly competitive models, aggregate demand shocks, such as government spending shocks increase employment only by affecting the household's willingness to supply labor and do not affect firm's demand for labor at any given real wage. Thus, these models are unable to generate the positive response of consumption and wages to a government spending shock.

In order to get the positive responses for consumption and wages, the literature has focused on several different strategies. Linnemann (2006) gets a positive response for consumption by considering a utility function that is non-separable in leisure and consumption. When hours worked increased, since leisure and consumption are substitutes, marginal utility of consumption rises. Therefore, there is a comovement between hours worked and consumption, but wages still fall. However, Bilbiie (2006) shows that if one relies on these

non-separable preferences, it must be the case that consumption is an inferior good, and that the positive co-movement between consumption and hours is possible only if either consumption or leisure is inferior.

Bouakez and Rebei (2007) consider a simple RBC model where preferences depend on public and private spending, and households are habit forming. If private and government spending are Edgeworth complements, an increase in government spending raises the marginal utility of household consumption, allowing consumption to rise as a result of a spending shock. However, the authors also cite several empirical studies which have estimated the degree of substitutability between private and public spending and generally lead to inconclusive results.

In the two aforementioned studies, the focus has been the response of consumption, and since labor demand is unchanged, real wages fall in the model. Other modifications of the neoclassical model rely on mechanisms for government spending to shift the labor demand curve. If this shift is large enough, it can induce wages to rise, and potentially lead to a subsequent rise in consumption. Rotemberg and Woodford (1999) model imperfect competition where a small number of firms within an oligopoly collude to keep prices above marginal cost. This collusion is supported by the threat of reverting back to a lower price in the future if a member deviates. When there is an increase in current demand, the gains from undercutting relative to the losses from future punishment are raised. To prevent a breakdown of collusion, the agreement involves smaller markups in this case. Therefore in the face of higher aggregate demand, say due to an increase in government spending, the firms lower markups and increase labor demand, leading to a rise in real wages in the model. They, however do not show the response for consumption.

In Devereux, Head, and Lapham (1996), an increase in government demand raises the equilibrium number of firms that can operate in the intermediate goods sectors, where they model increasing returns to specialization. The resulting shift in labor demand can overcome the increase in labor supply to lead to a higher equilibrium wage. The results, however de-

pend on the magnitude of markup of price over marginal costs which in the model determines the degree of returns to specialization. In order to generate a comovement between hours and wages, and a rise in consumption the required markup is really high, at least 50 percent.

Alternatively, Linnemann and Schabert (2003) show that in a model with sticky prices, in response to a rise in demand due to increased government spending, firms raise labor demand, which puts upward pressure on wages, in the face of the usual negative wealth effects raising labor supply. Thus this is also a way of generating countercyclical markups. If the interest rate rule does not put significant weight on output, it is possible to see real wages increase in equilibrium, but this rise is insufficient to induce consumption to go up.

Along with sticky prices, Gali, Lopez-Salido, and Valles (2007) 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. In response to a government spending shock, the labor market structure with firms alone determining employment and price rigidities leads to a significant rise in wages. With this increase in wages, the credit constrained consumers raise their consumption. If close to half of all consumers in the economy are assumed to be credit constrained, they get a positive response for aggregate consumption to a government spending shock.

Instead of relying on credit constrained consumers, Monacelli and Perotti (2008) consider a model with sticky prices and households with preferences of the type introduced by Greenwood, Hercowitz, and Huffman (1988). These preferences imply that there is virtually no wealth effect on labor supply, and due to nominal rigidities since the government spending shock results in an increase in labor demand, this boosts wages to a greater extent than with standard preferences. Thus, agents substitute away from leisure to consumption, and it overcomes the negative wealth effect on consumption, and the response of consumption is further strengthened by the degree of complementarity between labor and consumption implied by the preferences. They show the calibrated model-implied impulse responses along

with empirical responses for only consumption, wages, markup and investment.²³ Their model can match the initial responses of consumption and wages but has trouble replicating their persistence. In addition, the model has the most difficulty matching the response for investment which is a prolonged negative response, outside the confidence bands after the first 3 quarters, relative to the short-lived response in the data.

Deep habits also relies on generating countercyclical markups, but the fall in markup is sizable relative to markup movements due to price stickiness. Therefore, there is no added assumption of non-optimizing agents or specific form of preferences needed. This paper in addition illustrates that once deep habits are embedded in a model that has been shown to fit the data along many dimensions, such as responses to technology and monetary shocks, it can also successfully explain the effects of government spending shocks on most macroeconomic variables of interest.²⁴

8 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. This paper shows that commonly used DSGE models with superficial habits are unable to match the responses of wages and consumption both qualitatively and quantitatively. Once the model is augmented with deep habits it successfully explains these effects and significantly improves the fit of the model. Deep habit formation in public and private consumption play an important role in matching the significantly positive and persistent responses of consumption and wages to a government spending shock.

²³This model in addition to GHH preferences and sticky prices also has habit formation in consumption and investment adjustment costs.

²⁴Ravn, Schmitt-Grohe, Uribe, and Uuskula (2009) show that augmenting a model with nominal rigidities with deep habits helps to account both for the price puzzle and for inflation persistence in response to a monetary shock.

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.

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Table 1: Calibrated parameters

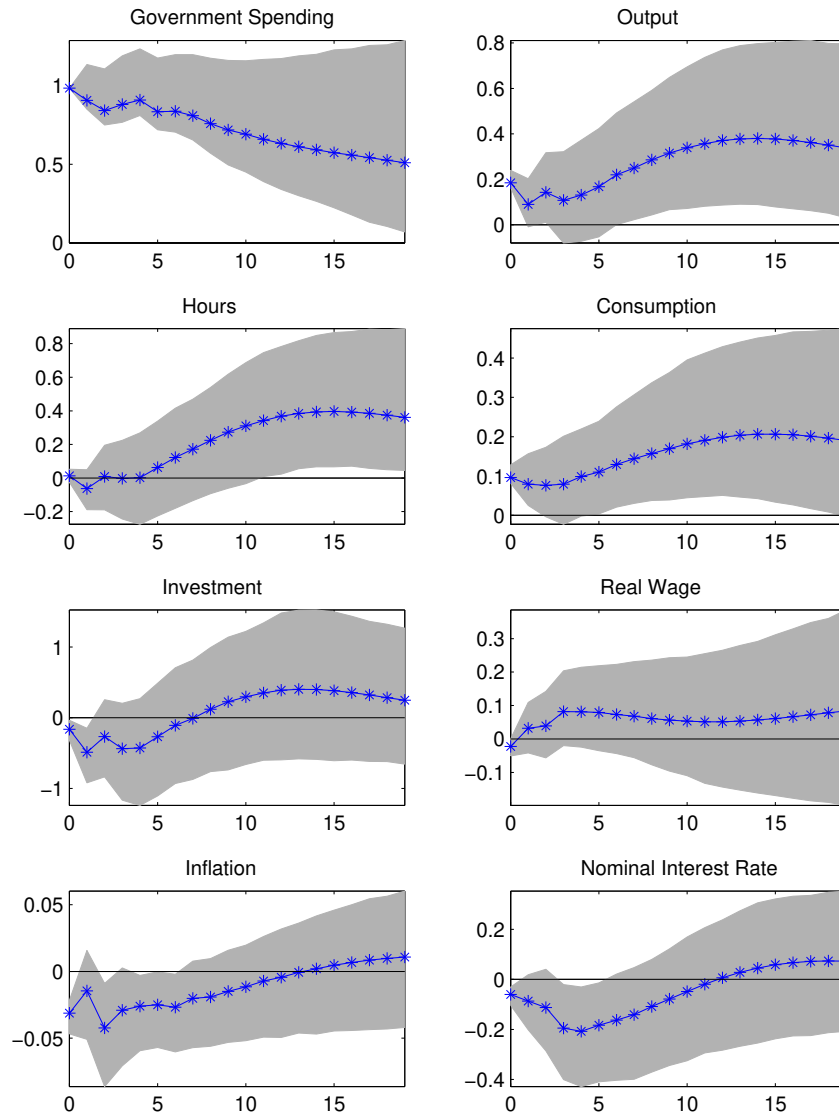
Parameter	Calibrated value
Share of govt. spending in GDP, G/Y	0.20
Depreciation rate, δ	0.025
Discount factor, β	$1.03^{-1/4}$
Wage elasticity of demand for specific labor variety, $\hat{\eta}$	21
Price elasticity of demand for specific good variety, η	5.3
Capital share, θ	0.36
Capacity utilization parameter, σ_a	0.01
Investment adjustment cost, κ	2.48
Wage stickiness parameter, $\tilde{\alpha}$	0.92
Price stickiness parameter, α	17
Interest rate smoothing parameter, α_R	0.8
Coefficient on inflation, α_π	1.5
Coefficient on output, α_Y	0.1

Table 2: Parameter estimates

Parameter	Description	Deep Habits	Superficial Habits	Deep Habits with feedback rule for g_t
b^c	Deep habit in private consumption	0.74 (0.03)	-	0.83 (0.02)
ρ^c	Speed of adj. of private habit stock	0.89 (0.01)	-	0.76 (0.03)
b^g	Deep habit in public consumption	0.69 (0.04)	-	0.72 (0.01)
ρ^g	Speed of adj. of public habit stock	0.98 (0.001)	-	0.98 (0.001)
σ	Coefficient of relative risk aversion	4.39 (0.05)	5.97 (0.15)	3.01 (0.10)
b	Superficial habit persistence parameter	-	0.96 (0.05)	-
$\tilde{\rho}^g$	AR(1) coefficient for g_t	0.97 (0.01)	0.96 (0.09)	-
$L_n(\theta)$		402.94	624.91	406.87

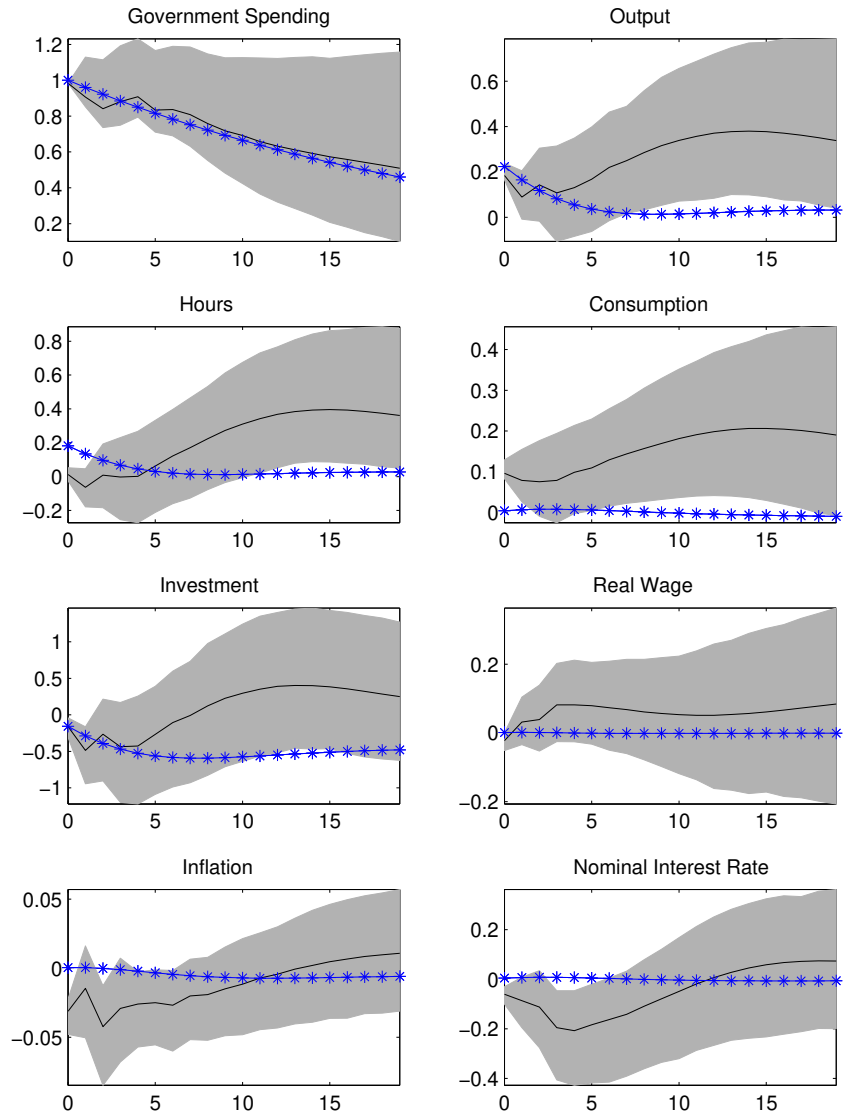
Note: The estimates reported are the mean values of the Markov chains, the values in brackets indicate the standard errors. The last row reports the impulse response function distance minimizing objective function $L_n(\theta)$, as defined in Section 4, for each model.

Figure 1: Impulse response function to a one standard deviation government spending shock as identified in the SVAR.



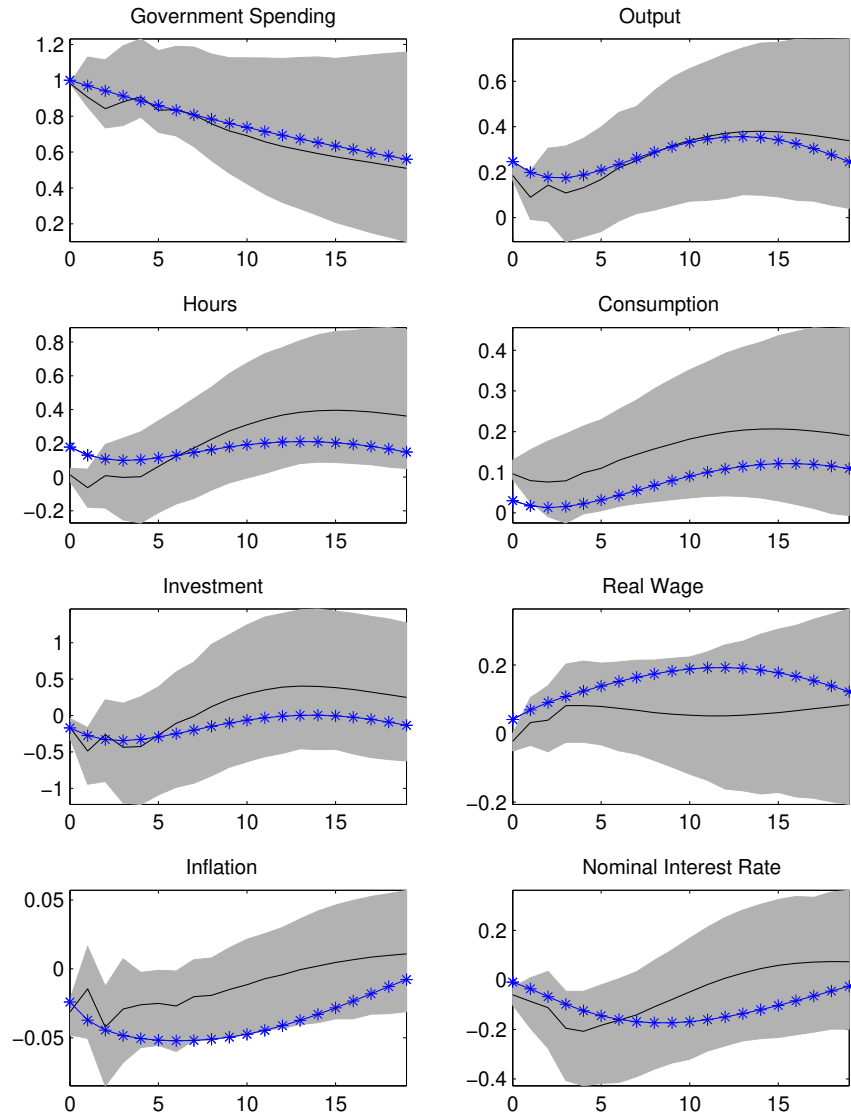
Note: The shaded gray regions are the 95 % confidence bands constructed by Monte Carlo simulations.

Figure 2: Impulse responses of the model estimated with superficial habits to a government spending shock.



Note: Solid lines are the empirical responses and starred lines are the responses for the estimated model. The vertical axis has percent deviations from steady state and the horizontal axis displays number of quarters after the shock.

Figure 3: Impulse responses of the model estimated with deep habits to a government spending shock.



Note: Solid lines are the empirical responses and starred lines are the responses for the estimated model. The vertical axis has percent deviations from steady state and the horizontal axis displays number of quarters after the shock.

Figure 4: Impulse responses of the model estimated with superficial habits for selected variables.

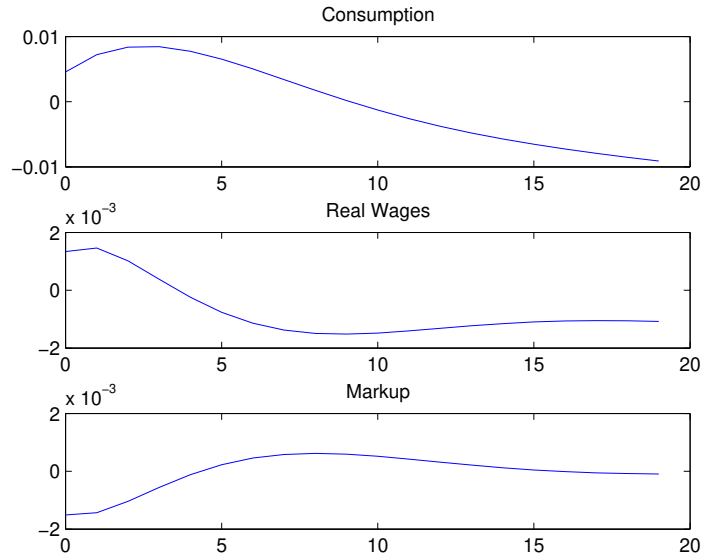


Figure 5: Impulse responses of the model estimated with deep habits for selected variables.

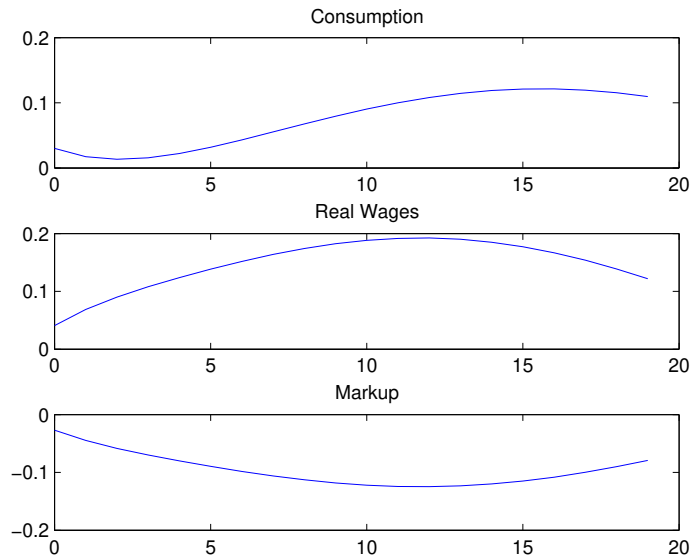
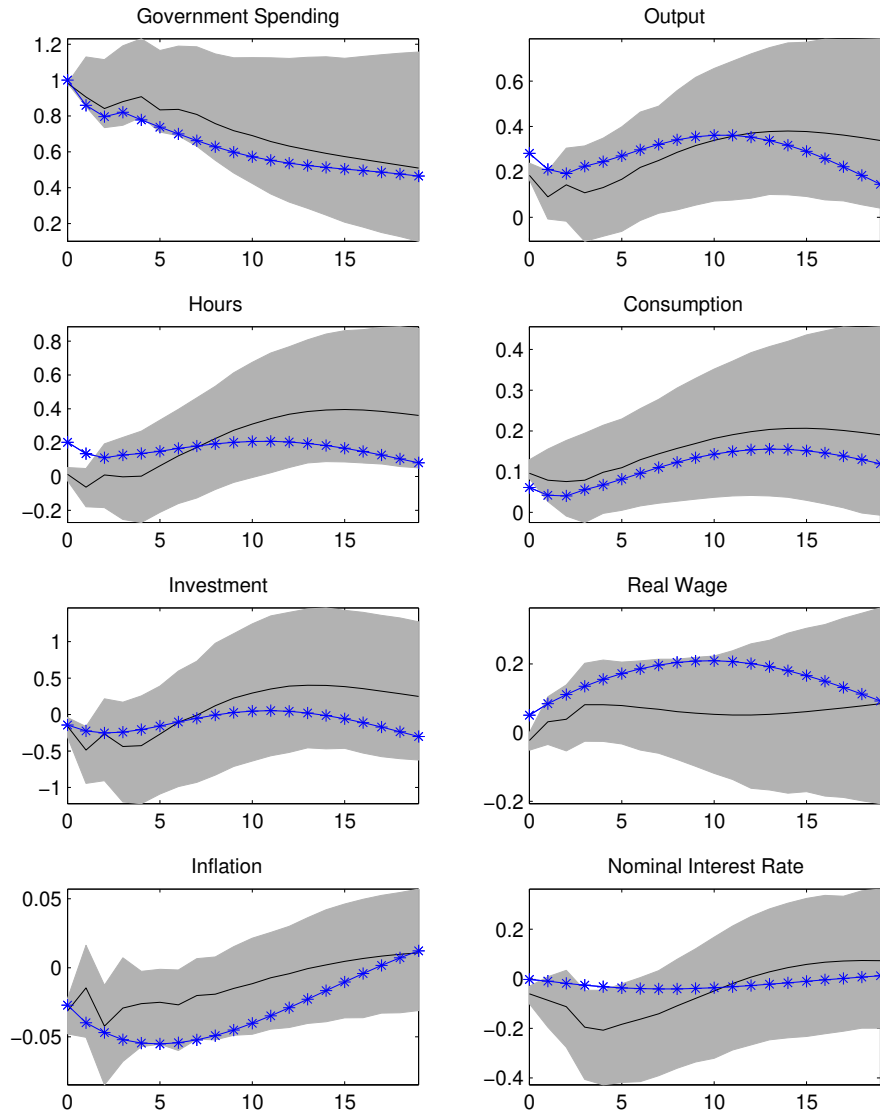


Figure 6: Impulse responses of the model with deep habits to a government spending shock, when the government spending process in the model is given by the VAR equation.



Note: Solid lines are the empirical responses and starred lines are the responses for the estimated model. The vertical axis has percent deviations from steady state and the horizontal axis displays number of quarters after the shock.

9 Not for Publication Appendix

9.1 Data Appendix

Label	Frequency	Description	Source
GDP	Q	Gross domestic product	BEA (Table 1.1.5, Line 1)
GCD	Q	Personal cons. expenditures on durable goods	BEA (Table 1.1.5, Line 3)
GCN	Q	Personal cons. expenditures on nondurable goods	BEA (Table 1.1.5, Line 4)
GCS	Q	Personal cons. 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	Govt. 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 .

9.2 Impulse response functions with and without the Ramey variable

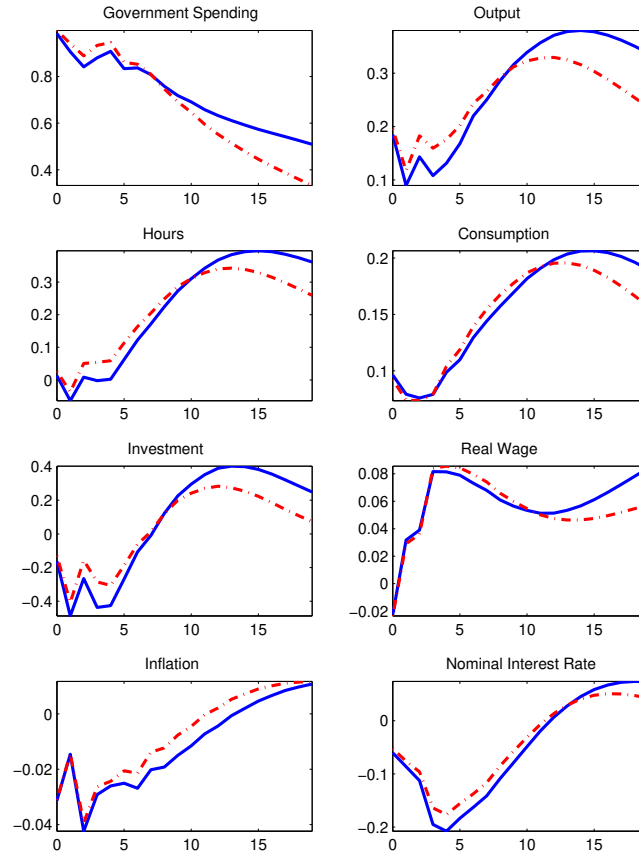


Figure 7: Impulse response function to a one standard deviation government spending shock as identified in the baseline SVAR (solid line) and impulse response function to government spending shock identified similarly but *no* Ramey variable included on the right hand side of the VAR equation (dashed line), which would be similar to the case shown in Fatas and Mihov (2001) and Blanchard and Perotti (2002).

9.3 Identification of parameters

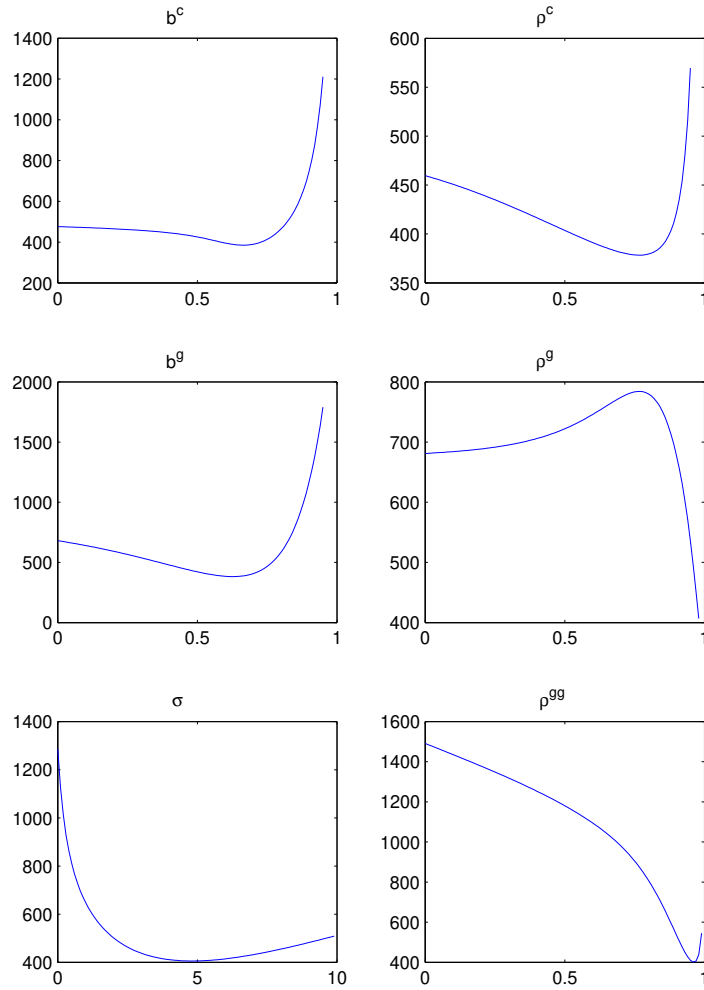


Figure 8: This figure shows a graphical exercise to see if the parameters being estimated are identified. The objective function $L_n(\theta)$, as defined in Section 4, is plotted on the y-axis while θ is varied on the x-axis. In this figure all parameters are fixed at the estimated values for the baseline model with deep habits, while one parameter in θ is varied at a time.

9.4 Complete set of symmetric competitive equilibrium conditions in a model with deep habits

$$x_t^c = c_t - b^c s_{t-1}^C \quad (\text{A-1})$$

$$x_t^g = g_t - b^g s_{t-1}^G \quad (\text{A-2})$$

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

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

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

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

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

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

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

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

$$f_t^1 = f_t^2 \quad (\text{A-11})$$

$$\lambda_t = \beta R_t E_t \frac{\lambda_{t+1}}{\pi_{t+1}} \quad (\text{A-12})$$

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

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

$$1 - mc_t = \tilde{v}_t^i \quad (\text{A-15})$$

$$\eta (\tilde{v}_t^c x_t^c + \tilde{v}_t^g x_t^g + \tilde{v}_t^i (y_t - c_t - i_t)) + \alpha \pi_t (\pi_t - \pi_{t-1}) - y_t = \alpha \beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \pi_{t+1} (\pi_{t+1} - \pi_t) \right] \quad (\text{A-16})$$

$$y_t = c_t + g_t + i_t + a(u_t)k_t \quad (\text{A-17})$$

$$F(u_t k_t, h_t^d) - \psi = c_t + g_t + i_t + a(u_t)k_t + \frac{\alpha}{2} (\pi_t - \pi_{t-1})^2 \quad (\text{A-18})$$

$$mc_t F_2(u_t k_t, h_t^d) = w_t \quad (\text{A-19})$$

$$mc_t F_1(u_t k_t, h_t^d) = r_t^k \quad (\text{A-20})$$

$$h_t = \tilde{s}_t h_t^d \quad (\text{A-21})$$

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

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

$$\tau_t = g_t \quad (\text{A-24})$$

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

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

and the exogenous process for government spending and Taylor monetary rule.

9.5 Complete set of symmetric competitive equilibrium conditions in a model with superficial habits

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

$$U_c(c_t - bc_{t-1}, h_t) = \lambda_t \quad (\text{A-2})$$

$$-U_h(c_t - bc_{t-1}, h_t) = \frac{\lambda_t w_t}{\tilde{\mu}_t} \quad (\text{A-3})$$

$$\lambda_t q_t = \beta E_t \lambda_{t+1} \left[r_{t+1}^k u_{t+1} - a(u_{t+1}) + q_{t+1}(1 - \delta) \right] \quad (\text{A-4})$$

$$\lambda_t = \lambda_t q_t \left[1 - \mathcal{S} \left(\frac{i_t}{i_{t-1}} \right) - \left(\frac{i_t}{i_{t-1}} \right) \mathcal{S}' \left(\frac{i_t}{i_{t-1}} \right) \right] + \beta E_t \lambda_{t+1} q_{t+1} \left(\frac{i_{t+1}}{i_t} \right)^2 \mathcal{S}' \left(\frac{i_{t+1}}{i_t} \right) \quad (\text{A-5})$$

$$r_t^k = a'(u_t) \quad (\text{A-6})$$

$$f_t^1 = \left(\frac{\tilde{\eta} - 1}{\tilde{\eta}} \right) \tilde{w}_t \lambda_t \left(\frac{w_t}{\tilde{w}_t} \right)^{\tilde{\eta}} h_t^d + \tilde{\alpha} \beta E_t \left(\frac{\pi_{t+1}}{\pi_t} \right)^{\tilde{\eta}-1} \left(\frac{\tilde{w}_{t+1}}{\tilde{w}_t} \right)^{\tilde{\eta}-1} f_{t+1}^1 \quad (\text{A-7})$$

$$f_t^2 = -U_h(c_t - bc_{t-1}, h_t) \left(\frac{w_t}{\tilde{w}_t} \right)^{\tilde{\eta}} h_t^d + \tilde{\alpha} \beta E_t \left(\frac{\pi_{t+1}}{\pi_t} \right)^{\tilde{\eta}} \left(\frac{\tilde{w}_{t+1}}{\tilde{w}_t} \right)^{\tilde{\eta}} f_{t+1}^2 \quad (\text{A-8})$$

$$f_t^1 = f_t^2 \quad (\text{A-9})$$

$$\lambda_t = \beta R_t E_t \frac{\lambda_{t+1}}{\pi_{t+1}} \quad (\text{A-10})$$

$$1 - mc_t = \tilde{\nu}_t \quad (\text{A-11})$$

$$(\eta \tilde{\nu}_t - 1)y_t + \alpha \pi_t (\pi_t - \pi_{t-1}) = \alpha \beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \pi_{t+1} (\pi_{t+1} - \pi_t) \right] \quad (\text{A-12})$$

$$y_t = c_t + g_t + i_t + a(u_t)k_t \quad (\text{A-13})$$

$$F(u_t k_t, h_t^d) - \psi = c_t + g_t + i_t + a(u_t)k_t + \frac{\alpha}{2} (\pi_t - \pi_{t-1})^2 \quad (\text{A-14})$$

$$mc_t F_2(u_t k_t, h_t^d) = w_t \quad (\text{A-15})$$

$$mc_t F_1(u_t k_t, h_t^d) = r_t^k \quad (\text{A-16})$$

$$h_t = \tilde{s}_t h_t^d \quad (\text{A-17})$$

$$\tilde{s}_t = (1 - \tilde{\alpha}) \left(\frac{\tilde{w}_t}{w_t} \right)^{-\bar{\eta}} + \tilde{\alpha} \left(\frac{w_{t-1}}{w_t} \right)^{-\bar{\eta}} \left(\frac{\pi_t}{\pi_{t-1}} \right)^{\bar{\eta}} \tilde{s}_{t-1} \quad (\text{A-18})$$

$$w_t^{1-\tilde{\eta}} = (1 - \tilde{\alpha})\tilde{w}_t^{1-\tilde{\eta}} + \tilde{\alpha}w_{t-1}^{1-\tilde{\eta}} \left(\frac{\pi_{t-1}}{\pi_t} \right)^{1-\tilde{\eta}} \quad (\text{A-19})$$

$$\tau_t = g_t \quad (\text{A-20})$$

and the exogenous process for government spending and Taylor monetary rule.