Propagation Mechanisms for Government Spending Shocks: A Bayesian Comparison*

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Abstract

The inability of a simple real business cycle model to predict a rise in consumption in response to increasing government spending has stimulated the development of alternative models, which have all been used to evaluate the effects of government spending shocks. We quantitatively investigate transmission mechanisms for government spending shocks proposed in the literature and use a Bayesian approach in order to identify the one that fits the data best. We find that the mechanism featuring deep habits outperforms all others considered, while the mechanism relying on non-Ricardian "rule-of-thumb" consumers provides the poorest fit.

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1 Introduction

Recently, there has been a rising interest in modeling fiscal policy and its effects on the economy. This growing research has resulted in a variety of models useful for the analysis of the fiscal policy. However, the question remains as to which model is most appropriate for analyzing the effects of fiscal policy. In this paper, within a medium-scale dynamic stochastic general equilibrium (DSGE) environment, we quantitatively investigate the several propagation mechanisms for government spending shocks proposed in the literature.

All the models we include in this investigation were developed in an attempt to resolve the inconsistency between empirical and theoretical literature predictions about the comovement between public and private expenditures conditional on a government spending shock. The response of private consumption to a public spending shock is of great importance in studying the stimulative effects of increased government spending. It is commonly believed that policies aiming at increasing government spending boost aggregate demand and consumption. While most empirical research, using various methods of identifying government spending shocks, finds supporting evidence for this (See Blanchard and Perotti (2002), Fatas and Mihov (2001), Mountford and Uhlig (2009), Fisher and Peters (2010)), many theoretical models fail to record this positive correlation between private and public consumption. The reason that traditional business cycle models fail to explain positive comovement in public and private consumption in response to a government spending shock is that rising government spending generates a negative wealth effect on consumers, which leads to a fall in private consumption. This result is not reversed by nominal rigidities or real frictions alone. For example, Linnemann and Schabert (2003) demonstrate that price stickiness alone is not sufficient to predict a rise in consumption in response to increasing government expenditures.

Ravn, Schmitt-Grohé, and Uribe (2006) note that positive correlation between government spending and private consumption can be achieved if firm markups of prices over marginal costs are countercyclical with the economic activity. In this situation, expansions in output driven by preference, government spending or productivity shocks are accompanied by declining markups. Government spending shock increases aggregate absorption and labor supply. The increase in labor supply induces a fall in the wage rate. If firms reducing markups increase labor demand more than labor supply, then wages may rise enough to override the negative wealth effect from rising public consumption. Ravn, Schmitt-Grohé, and Uribe (2006) show that endogenous countercyclical markups can be generated by assuming "deep habits" in preferences for consumption. The notion of deep habits applies when consumers form habits at individual varieties of goods, rather than at the aggregate level, as is the case in more standard models of "superficial" habit formation. The combination of deep habits and imperfect competition results in time-varying elasticity of demand: when consumption increases relative to previous periods, then everything else equal, producers have incentives to reduce markups to gain a larger share of the market to form habits and gain bigger profits in future. This effect takes place even in a model without nominal frictions.

An alternative way to model positive correlation between public and private consumption is offered by Galí, Lopez-Salido, and Vallés (2007). They introduce households who do not make optimizing decisions, and may increase consumption in response to a rise in government spending. Following the so-called rule-of-thumb, these households consume their entire disposable income in each period, because they do not participate in financial markets. Because optimizing households still experience a drop in wealth due to a rise in public spending, the rise in total consumption can only be achieved if either rule-of-thumb households increase consumption substantially, or the wage rate of optimizing households rises enough to override the negative wealth effect of a government spending shock. If the amount of tax paid does not change, the rule-of-thumb households will only increase consumption if their wage income rises. The wage income rises if the wage rate or hours worked increase. Because optimizing agents demand to work more, the wage rate tends to drop. Galí, Lopez-Salido, and Vallés (2007) rely on an important assumption that labor markets are non-competitive in such a way that both types of households always work the same hours. This assumption guarantees that the labor of rule-of-thumb households increases when government spending rise. The wage income of rule-of-thumb households then rises which induces the financially constrained households to increase consumption. Certainly, aggregate consumption in this model will only increase if the share of rule-of-thumb consumers is large enough to compensate for the drop in consumption of optimizing households. While the model in Galí, Lopez-Salido, and Vallés (2007) is a standard new-Keynesian framework, Furlanetto (2011) and Colciago (2011) show that in the presence of wage rigidities this result does not change qualitatively. Nominal wage rigidities mitigate the fall in the wage rate, reducing the negative wealth effect on optimizing households, and may also increase the disposable income of rule-of-thumb households. Thus, strong nominal wage stickiness may guarantee the positive correlation between public and private consumption for the rule-of-thumb households.

Besides the deep habit formation and the rule-of-thumb households, other modifications of a standard RBC framework have been used to resolve the problem of comovement between private and public consumption. First, Linnemann and Schabert (2004) and Bouakez and Rebei (2007) consider an environment where the household directly benefits from government spending through increased utility. They show that if public and private consumption are non-separable in the utility function, and the elasticity of substitution between public and private spending is sufficiently low, then an increase in government spending raises the marginal utility of consumption, making private consumption more attractive for households. If this effect dominates the negative wealth effect of public spending, the positive correlation of private and public consumption may be observed in response to a public spending shock. Ganelli and Tervala (2009) make the same statement in a model where public and private consumption are complements.

Baxter and King (1993), Ambler and Paquet (1996), and Linnemann and Schabert (2006) model government spending as enhancing productivity of firms. When higher government spending rises productivity, it increases the scale of production and as a result consumer welfare, which provides a possibility for consumption to rise in response to higher government spending. Linnemann and Schabert (2006) show that even if the impact of government expenditures on production is small, government expenditures can cause a rise in private consumption if the government share is not too large and public finance does not solely rely on distortionary taxation.

To summarize, the focus of this paper is on five models - the deep habits model, the model with rule-of-thumb consumers, the model where government spending influences individual preferences directly, the model with productive government expenditures, and the baseline model that does not rely on any of these mechanisms. In this paper, we estimate these models with distinct transmission mechanisms for government spending shocks, with identical data set and same priors for common parameters. Next, in order to evaluate the relative quantitative performance of these models, we compare their marginal likelihoods, and calculate Bayes factors to identify which model fits the data best.

We find that the the model with deep habits outperforms other models, while the model featuring rule-of-thumb consumers has the poorest fit. All models demonstrate a positive response of consumption to the government spending shock. Since the baseline model, with no other specific features, also yields a positive response of consumption, we conclude that modeling utility as a non-separable function of consumption and leisure is sufficient to obtain a positive consumption response to a government spending shock in an estimated DSGE model.

Linnemann (2006), Monacelli and Perotti (2008) and Bilbiie (2011) claim that the effect of government spending on consumption is highly dependent on the form of the utility function. Monacelli and Perotti (2008) claim that consumption may increase in response to a rise in public spending when the preferences are such that there is no wealth effect on labor supply. Using non-separable preferences between consumption and leisure, Linnemann (2006) demonstrates that higher fiscal spending will raise consumption when intertemporal consumption elasticity is small enough. Therefore, we also check the robustness of our results to the choice of preferences, by incorporating a separable utility function in the four models with the distinct propagation mechanisms under consideration.

The paper proceeds as follows. We describe the general framework and model specifics in Section 2. Section 4 offers the strategy for estimation and model analysis. Section 5 discusses estimation results and robustness of our findings. Finally, Section 6 concludes.

2 Models of Government Spending

All the models we consider have some common features, among which are capital adjustment costs, and variable depreciation. We assume consumption habits for all models, although exact specification may be different across models. The role of monetary policy is motivated by nominal price and wage rigidities, while monetary policy is described by a standard Taylor-type rule. There are four sources of uncertainty in addition to the government spending shock. They are the neutral and investment specific shocks, preference shock, monetary policy shock, and the and monetary policy shock. We model the economy as evolving along the balanced growth path, with the long-run trend for consumption, output, wages different from the long-run trend in capital and investment.

The specific models of government spending extend this set up in the following way: the first model incorporates deep habit formation over consumption of private and public goods. The second model introduces a share of the households being rule-of-thumb consumers. The other two models assume that government spending enhances the production technology and household utility function, respectively. Finally, the baseline model does not have any of these specific features, however, the positive response of consumption is possible because of non-separable household utility function between consumption and leisure.

2.1 Main Framework

The economy is populated by a continuum of infinitely-lived households. Each household participates in the following activities. It consumes, supplies differentiated labor services to the labor packer, accumulates capital by means of investing, rents capital to firms, pays taxes and receives dividends from ownership in firms.

2.1.1 Households.

Every household supplies a differentiated labor service to a labor packer to be aggregated according to the Dixit-Stiglitz aggregating technology:

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

where $\eta_w > 1$ is the elasticity of substitution across different types of labor, and the upper script j helps to distinguish between different types of labor. The homogenous labor h_t is then supplied to firms at a competitive real rate W_t. Households poses monopolistic power over their wages, and have the ability to set the labor specific wage rate; however, they are required to satisfy the demand for labor at this wage rate. Changes in the wage rate are associated with the cost, which is determined as

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

per dollar of the wage bill. In this formula, $\alpha_w > 0$, is the wage adjustment cost parameter, W_t^j is the individual real wage rate, π_t and π are the inflation rate at a date t and along the balance growth path, respectively.

The households own physical capital, K_t. Capital is accumulated through the process of investing. Following Fisher (2003), investment goods I_t are obtained from consumption using a stochastic linear technology, according to which at each date t, one unit of consumption can produce Υ_t units of investment. We call Υ_t the investment specific technology. Denoting $\mu_{\Upsilon,t} \equiv \Upsilon_t/\Upsilon_{t-1}$, the gross growth rate of Υ_t, the dynamics for the growth rate of the investment specific technology is

$$log\left(\frac{\mu_{\Upsilon,t+1}}{\mu_\Upsilon}\right) = \rho_\Upsilon log\left(\frac{\mu_{\Upsilon,t}}{\mu_\Upsilon}\right) + \epsilon_{t+1}^\Upsilon, \tag{1}$$

where $\epsilon_t^\Upsilon \sim i.i.d.(0, \sigma_\Upsilon^2)$, with $\sigma_\Upsilon > 0$.

Capital $u_t K_t$, where u_t determines the intensity of capital utilization, is rented out to firms at a real rental rate R_t^k. Adjusting the stock of capital is costly for households, and the cost in units of capital is

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

where $\kappa > 0$, and μ_I is the steady-state growth rate of capital and investment. This form of capital adjustment costs is derived from Ireland (2003).

Capital depreciates at a variable rate depending on how intensively it is used. Therefore, the dynamics of capital is:

$$K_{t+1} = (1 - \delta(u_t))K_t + I_t, \tag{2}$$

where $\delta(u_t)$ is the depreciation function, parameterized as follows:

$$\delta(u_t) = \delta_0 + \delta_1(u_t - u) + \frac{\delta_2}{2}(u_t - u)^2, \tag{3}$$

where $\delta_0, \delta_1, \delta_2 \geq 0$, and u is the steady state rate of capital utilization.

Households are required to pay lump-sum taxes in the amount T_t in terms of consumption. The exact tax structure is model specific and is described in details in Section 2.2. Households own shares in firms, and receive dividends with the real value Φ_t. Complete set of one-period state-contingent assets, as well as the risk-free government bonds are traded in financial markets. If households have access to financial markets,[1] then the budget constraint can be written as[2]

$$\begin{aligned} E_t r_{t,t+1} L_{t+1} + C_t + \Upsilon_t^{-1} I_t \quad &+ \quad \Upsilon_t^{-1} \mathcal{S}\left(\frac{K_{t+1}}{K_t}\right) K_t + T_t + \frac{B_{t+1}}{R_t} \\ &= \frac{L_t}{\pi_t} + R_t^k u_t K_t + \left(1 - \Psi\left(\frac{W_t^j}{W_{t-1}^j}\right)\right) W_t^j h_t^j + \Phi_t + \frac{B_t}{\pi_t}, \end{aligned} \tag{4}$$

where L_t is the payoff in period t of state-contingent assets traded in period $t-1$, $r_{t,t+1}$ is the price of a state contingent security traded at date t for a claim on consumption delivered in period $t+1$, is real consumption, and B_t is the real value of government bonds in possession of households. The new bonds are purchased at a price $1/R_t$.

Each household derives utility from a consumption measure X_t, the exact definition of which differs across the three models, and differentiated labor h_t. The life-time expected utility of households is defined as

$$E_0 \sum_{t=0}^{\infty} \beta^t d_t U(X_t, h_t),$$

where E_0 denotes expectations based on period zero information set, $0 < \beta < 1$ is the discount factor, and and d_t being the preference shock, evolving according to an $AR(1)$

[1] This is the case in all models except for the model with rule-of-thumb consumers.

[2] To simplify notation, we omit the household specific superscript i when it is possible.

process:

$$log\left(\frac{d_{t+1}}{d}\right) = \rho_d log\left(\frac{d_t}{d}\right) + \epsilon^d_{t+1}, \tag{5}$$

where $0 < \rho_d < 1$, and $\epsilon^d_t \sim i.i.d.(0, \sigma^2_d)$, with $\sigma_d > 0$. The intratemporal utility function has the following form,

$$U(X_t, h_t) \equiv \frac{(X_t(1-h_t)^\zeta)^{1-\sigma}}{1-\sigma}, \tag{6}$$

where the inverse of σ is the intertemporal elasticity of substitution, and $\zeta > 0$.

2.1.2 Firms

A continuum of monopolistically competitive firms produce differentiated intermediate goods. Each firm produces output using capital and labor services, $u_t K_t$ and h_t. The production technology is

$$F(u_t K_t, Z_t h_t) \leq Q_t (u_t K_t)^\theta (Z_t h_t)^{1-\theta} - \vartheta Z^*_t, \tag{7}$$

where $0 < \theta < 1$, variable Q_t is model specific, described in detail in Section 2.2, the process Z_t is the stochastic labor-augmenting productivity process, and $Z^*_t \vartheta$ represents the fixed costs of operating a firm in each period. The growth of productivity Z_t evolves according to

$$log\left(\frac{\mu_{z,t+1}}{\mu_z}\right) = \rho_z log\left(\frac{\mu_{z,t}}{\mu_z}\right) + \epsilon^z_{t+1}, \tag{8}$$

where $\mu_{z,t} \equiv Z_t / Z_{t-1}$ is the gross growth rate of Z_t, μ_z is the growth rate along the balanced growth path, $0 < \rho_z < 1$, and $\epsilon^z_t \sim i.i.d.(0, \sigma^2_z)$, with $\sigma_z > 0$.

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

$$E_t \sum_{s=0}^{\infty} r_{t,t+s} P^i_{t+s} \Phi^i_{t+s}, \tag{9}$$

where $r_{t,t+s} \equiv \prod_{k=1}^{s} r_{t+k-1,t+k}$, for $s \geq 1$, with $r_{t,t} \equiv 1$, and

$$\Phi^i_t = \frac{P^i_t}{P_t} a_t - R^k_t u_t K_t - W_t h_t - \Omega\left(\frac{P^i_t}{P^i_{t-1}}\right), \tag{10}$$

is the real value of dividends, where $\Omega(\cdot)$ is the cost of price changes, following Rotemberg (1982). We assume that this cost is quadratic and proportional to the stochastic trend Z^*_t:

$$\Omega\left(\frac{P^i_t}{P^i_{t-1}}\right) = \frac{\alpha_p Z^*_t}{2}\left(\frac{P^i_t}{P^i_{t-1}} - \pi\right)^2,$$

with $\alpha_p > 0$. Monopolistically competitive firms must satisfy their demands at the posted price.

2.1.3 Fiscal and monetary policy

The fiscal authority levies taxes, and develops public projects with real cost of G_t. To ensure the model has a well-defined balanced growth path, we assume that government expenditures evolve along the same stochastic trend as output and consumptions. The detrended government expenditures, $g_t = \frac{G_t}{Z_t^*}$ evolve exogenously according to the AR(1) process[3]

$$log\left(\frac{g_{t+1}}{g}\right) = \rho_g log\left(\frac{g_t}{g}\right) + \epsilon_{t+1}^g, \tag{11}$$

where $0 < \rho^g < 1$, and $\epsilon_t^g \sim i.i.d.(0, \sigma_g^2)$, with $\sigma_g > 0$.

It has been widely acknowledged that *monetary policy* is important for the effect of government spending shocks. We assume that monetary policy is described by a Taylor type rule with interest rate smoothing and response to inflation and output growth, as follows:

$$log\left(\frac{R_t}{R}\right) = \alpha_R log\left(\frac{R_{t-1}}{R}\right) + \alpha_\pi log\left(\frac{\pi_t}{\pi}\right) + \alpha_Y log\left(\frac{Y_t}{Y_{t-1}\mu_{z^*}}\right) + \epsilon_t^r, \tag{12}$$

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

2.2 Model Specific Features

In this Section, we briefly describe the three models we consider in light of the specific features. More details on the models, including the first order and market clearing conditions, are described in the Appendix.

2.2.1 Model with Deep Habits

We adopt the "fully-fledged" version of the deep habits model from Ravn, Schmitt-Grohé, and Uribe (2006), and define X_t in Equation (6) as

$$X_t = \left[\int_0^1 (C_{i,t} - b^c S_{i,t-1}^c)^{1-\frac{1}{\eta_p}} di\right]^{1/(1-\frac{1}{\eta_p})},$$

[3] We also verify our results under an alternative specification for g_t, allowing an endogenous response to the share of debt.

where index i refers to a variety of differentiated goods produced by monopolistically competitive firms, $\eta_p > 1$ is the parameter driving the elasticity of substitution between differentiated goods, $0 < b^c < \mu_{z^*}$ is the habit formation parameter for private consumption, and $S_{i,t}$ is the good-specific stock of habit, which evolves over time according to the law of motion,

$$S^c_{i,t} = \rho^c S^c_{i,t-1} + (1 - \rho^c) C_{i,t}, \tag{13}$$

with $0 \leq \rho^c \leq 1$.

Similar to Ravn, Schmitt-Grohé, and Uribe (2006), the government allocates spending over intermediate goods $G_{i,t}$ so as to maximize the quantity of a composite good X^g_t produced with intermediate goods according to the relationship

$$X^g_t = \left[\int_0^1 (G_{i,t} - b^g S^g_{i,t-1})^{1-\frac{1}{\eta_p}} \right]^{1/(1-\frac{1}{\eta_p})},$$

where $0 < b^g < \mu_{z^*}$ is the habits parameter for public goods, and the stock of habits $S^g_{i,t}$ is determined as follows

$$S^g_{i,t} = \rho^{gg} S^g_{i,t-1} + (1 - \rho^{gg}) G_{i,t}. \tag{14}$$

where $0 \leq \rho^{gg} \leq 1$. Taxation is non-distorting in the sense that households pay the lump-sum tax T_t in the amount that keeps the government budget balanced in each period. Parameter Q_t of the production function in Equation (7) is set to 1.

2.2.2 Model with Rule-of-Thumb Consumers

As in Galí, Lopez-Salido, and Vallés (2007), we assume that only a fraction $(1 - \lambda)$ of all households have access to capital markets where they can trade state-contingent bonds and accumulate capital to rent out to firms. These are known as optimizing households. Other households, the so-called rule-of-thumb consumers, do not participate in financial markets, therefore they cannot borrow or save. These households are restricted to consume out of their disposable labor income.

While optimizing households decide how much to work based on their utility, the rule-of-thumb households follow an ad-hoc rule and work exactly the same hours as the optimizing consumers:

$$h^r_t = h^o_t \equiv h_t.$$

In a symmetric equilibrium, the rule-of-thumb households providing differentiated labor services, the wage rates for both types of households coincide, thus $W^r_t = W^o_t = W_t$ at any period t.

Consumption of the rule-of-thumb households is determined by their disposable income:

$$C_t^r = \left(1 - \Psi\left(\frac{W_t}{W_{t-1}}\right)\right) W_t h_t + T_t^r, \tag{15}$$

where T_t^r is the tax burden of a rule-of-thumb households.

Utility of optimizing households is determined by Equation (6), where X_t is the habit adjusted consumption defined as follows

$$X_t = C_t^o - b^c C_{t-1}^o,$$

where $0 < b^c < \mu_{z^*}$ is the consumption habits parameter and C_t^o denotes consumption of optimizing households at date t.

Finally, parameter $Q_t \equiv 1$ in Equation (7).

2.2.3 Model with Government Spending in the Utility Function

We follow Bouakez and Rebei (2007) and define X_t in the intratemporal utility in Equation (6) as habit adjusted generalized consumption,

$$X_t = \tilde{C}_t - b^c \tilde{C}_{t-1},$$

where $b^c > 0$ is the habit formation parameter, and the effective consumption $\tilde{C}_t$ is the combination of private and public consumption, C_t and G_t:

$$\tilde{C}_t = \left[\phi C_t^{\frac{\nu-1}{\nu}} + (1-\phi) G_t^{\frac{\nu-1}{\nu}}\right]^{\frac{\nu}{\nu-1}}, \tag{16}$$

where $0 < \gamma < 1$, and $\phi, \nu > 0$. Here ν is the elasticity of substitution between private and public spending, and if $\nu = 0$, private and public consumption are perfect complements and if $\nu \to \infty$, then they become perfect substitutes.

We assume taxation is non-distorting as in the deep habits model. Households pay the lump-sum tax in the amount that keeps the government budget balanced in each period. Parameter $Q_t \equiv 1$ in Equation (7).

2.2.4 Model with Productive Government Spending

In this model, we acknowledge that government actions may directly affect the production processes. Similar to Baxter and King (1993), public capital enhances the production technology in Equation (7) through Q_t in the following way

$$Q_t = \left(\frac{G_t}{Z_t^*}\right)^{\alpha_G},$$

where $\alpha_G > 0$, gives the share of government spending in the production function.

Utility features standard superficial habit in consumption, therefore X_t in Formula (6) is defined as

$$X_t = C_t - b^c C_{t-1}.$$

Again, we assume taxation is non-distorting as in the deep habits model. Households pay the lump-sum tax amount that keeps the government budget balanced in each period.

3 Propagation Mechanisms of the Government Spending Shock

According to a standard RBC model, the government spending shock reduces resources of the economy creating a negative wealth effect. As a result, consumption falls, while output and labor increase. Bilbiie (2009) demonstrates that in this simple framework, there is no possibility for consumption to rise in response to rising government spending. This can be verified graphically using Figure 1, which shows the equilibrium in the market for labor services. The real wage rate is plotted along the vertical, and labor hours - along the horizontal axis. The solid bold line in the figure represent the supply of labor before the shock, while the bold starred line is the labor demand of firms. The supply of labor is generally determined by $w = \frac{U_2(c,1-h)}{U_1(c,1-h)}\mu$, where μ is the wage markup. The labor demand is given by $w = mcF_h(uk, h)$, where mc is the marginal cost of firms. In the standard RBC framework, μ, mc, and u equal 1 at all time and in all states of the economy. The marginal rate of substitution between consumption and leisure, $\frac{U_2(c,1-h)}{U_1(c,1-h)}$, is usually increasing both in consumption and labor. This property ensures that the labor supply is positively sloped in the figure, and a drop in consumption increases the labor supply, while an increase in consumption shifts in the labor supply.

According to the standard scenario of the RBC model, a rise in government spending is associated with the negative wealth effect, and thus reduces consumption and increases the labor supply, moving equilibrium from point 0 to 1 in Figure 1. If an equilibrium increase in consumption were a possibility in this model, this would cause labor supply to shift in, with the new equilibrium at point 2. However, this scenario is impossible in the most standard version of the model, because with reduced equilibrium labor, output would shrink leaving no possibility for consumption to expand. Therefore, the necessary condition for consumption to rise is that the new equilibrium supports larger employment, allowing output to expand enough beyond covering larger government spending. This possibility would arise in a model where labor demand increases endogenously due to rising government spending. This scenario is shown by point 3 in Figure 1. The new equilibrium implies increased labor, which may be consistent with higher equilibrium consumption.

The labor demand will increase in a model with price stickiness if it supports the idea of countercyclical price markups. Because the marginal cost is the inverse of the firm's markup, then mc and output move procyclically. In this case, an increase in output due to rising government spending is associated with larger marginal costs and increased labor demand. This mechanism is in place in the baseline model we consider.

The mechanism of the deep habits follows the same route as that of nominal price rigidity. Ravn, Schmitt-Grohé, and Uribe (2006) show that the presence of deep habits in consumption helps to magnify the effect on firms' markup. The reason is that the combination of deep habits and imperfect competition results in time-varying elasticity of demand: when consumption increases relative to previous periods, then everything else equal, producers have incentives to reduce markups to gain a larger share of the market to form habits and increase future profits.

The similar outward shift in the demand for labor leading to the new equilibrium in point 3 occurs in the model with productive government spending. bigger profits in future. This effect takes place even in a model without nominal frictions.In this case, however, the labor demand shifts out due to a rise in productivity F_h, rather than the marginal cost. If the effect of government spending on labor productivity is large enough, the rise in consumption will be an equilibrium outcome.

Another transmission mechanism is utilized in the model where government spending directly affects utility. Linnemann and Schabert (2004) and Bouakez and Rebei (2007) notice that if private and public consumption are complements in the sense that an increase in government spending raises marginal utility of consumption, then a rise in government spending increases labor supply as shown in Figure 2. With this move, a rise in consumption becomes a possibility, because it does not necessarily cause a reduction in labor supply, as shown by the new equilibrium in point 5 in the figure.

The form and calibration of the utility function plays an important role in the resulting effect of government spending shock on consumption. Linnemann (2006) explains that in an RBC setting, the necessary condition for a rise in consumption is that consumption and leisure must be substitute goods in the sense that $U_{12} < 0$.[4] Monacelli and Perotti (2008)

[4]With nominal rigidities, however, this does not have to be the case.

emphasize the importance of the wealth effect on labor supply in determining the effect of the government spending shock on consumption. The idea there is that the smaller is the shift of the labor supply curve as a result of the shock, the more likely the new equilibrium will move north-east of point 0 in Figure 1, raising both wages and hours.[5] In the example they use, consumption rises in the economy with nominal price stickiness and GHH preferences that feature no wealth effect on labor supply, and fall with KPR preferences for which the wealth effect on labor supply is significant.

The models we estimate have additional features commonly used in the estimated DSGE models, such as habits formation, investment costs, endogenous capital utilization. Adding these features complicates understanding of the propagation mechanism of the government spending shock. For example, the presence of superficial habits changes the form of the labor supply curve. Therefore, consumption habits will affect the wealth effect on labor supply and the resulting consumption behavior. Monacelli and Perotti (2008) demonstrate that adding habits to the simple RBC model without price stickiness allows to obtain positive response of consumption to the government spending shock. Endogenous capital utilization makes it possible for the labor demand to respond endogenously to rising government spending even in the standard RBC setting. Although response of capital utilization to the shock is endogenously determined, it is expected to increase when public spending rises, affecting the demand for labor in a way similar to how price stickiness or. All in all, the presence of these features to some extent may influence the consumption effect of government spending shocks.

4 Estimation and Inference

4.1 Estimation Strategy

The above models can be cast in linear state space form, a likelihood derived via a Kalman filter, which when coupled with priors on model parameters delivers posterior means for the parameter vector θ conditional upon the model. In doing so we keep the data employed in the observable equation constant across models. The data y_t is the 5×1 vector of observable variables defined as follows

$$y_t = \{\, \Delta(log(I_t)),\, \Delta(log(C_t)),\, \Delta(log(Y_t)),\, \Delta(log(P_{Y,t})),\, R_t \,\},$$

[5]Notice that larger wages are desirable for the positive effect of government spending on consumption, because of the consumption leisure substitution effect they create - the larger is the real wage rate the less expensive is consumption, making it more attractive for households.

where I_t, C_t, and Y_t are real per capita investment, consumption, and output, $P_{Y,t}$ is GDP deflator, therefore $\Delta(log(P_{Y,t}))$ measures inflation rate. Finally, R_t is the nominal interest rate, measured by the effective (annualized) Federal funds rate.[6] All the data in vector y_t appear in quarterly frequency.

The vector of estimated model parameters is defined as

$$\theta = \{\, \theta^1_{A_i},\, \theta^2,\, \theta^3 \,\},$$

where $\theta^1_{A_i}$ is the vector of model specific parameters, θ^2 is the vector of parameters common across models, and θ^3 is the vector of parameters calibrating the shock processes. These three groups of parameters consist of the following elements:

$$\theta^1_{DH} = \{\, b^c,\, \rho^c,\, b^g,\, \rho^{gg} \,\}, \qquad \theta^1_{ROT} = \{\, b^c,\, \lambda,\, \phi^b,\, \phi^g \,\},$$

$$\theta^1_{UTIL} = \{\, b^c,\, \nu,\, \phi \,\}, \qquad \theta^1_{PROD} = \{\, b^c,\, \alpha_G \,\}$$

$$\theta^2 = \{\, \alpha_p,\, \alpha_w,\, \kappa,\, \delta_2/\delta_1,\, \sigma,\, \alpha_R,\, \alpha_\pi,\, \alpha_Y \,\},$$

and

$$\theta^3 = \{\, \rho_g,\, \rho_z,\, \rho_\Upsilon,\, \rho_d,\, \sigma_g,\, \sigma_z,\, \sigma_\Upsilon,\, \sigma_d,\, \sigma_r \,\}.$$

Parameters presented in Table 1 are calibrated, either because it is done conventionally in the literature, or because estimating these parameters is problematic due to identification issues. The parameter governing the steady state share of capital is set conventionally at $\theta = 0.3$. Following Altig, Christiano, Eichenbaum, and Linde (2011), the steady state growth rate of output, μ_{z^*}, is calibrated at 1.0047, while the growth rate of the embodied technology is set at 1.0042. The steady state gross rate of inflation is calibrated as $\pi = 1.0086$, to match the average yearly rate of inflation of 3.5 percent. The intertemporal discount factor $\beta = 0.999$. This relatively high value for β ensures the steady state nominal interest rate is below 6 percent, because smaller values for β implies unrealistically large steady state nominal interest rates. The steady state rate of capital utilization is $u = 1$, while the steady state depreciation rate is fixed at a conventional value $\delta_0 = 0.025$. The actual average share of government expenditures, $sh^G = 0.2$, is used to calibrate the steady state share of government expenditures in the model. Finally, we fix the elasticity of substitution for intermediate goods and labor types, because estimating these parameters is problematic.

[6] I_t is calculated as the sum of durable consumption and private investment, C_t is private consumption of nondurable goods and services, output Y_t is measured by GDP. The real per capita variables are obtained dividing by labor force and the GDP deflator, $P_{Y,t}$. The data for output and its components obtained from the NIPA accounts, the data for the labor force are from the BLS and the Federal funds rate data is from St. Louis FRED.

We set η_p at 6 and η_w at 21, which imply the steady state markups of 20 and 5 percent correspondingly.

Tables 3 and 4 show the prior distribution of the estimated parameters in the five models, in column 2 of the tables. These distributions are chosen from beta, gamma or inverse gamma distributions. All parameters with bounded support have a beta prior distribution with mean 0.5 and standard deviation of 0.2. Gamma and inverse gamma distributions are chosen as priors for parameters bounded from below, such as parameters of the nominal rigidities, investment costs, standard deviations of shocks and others. The priors for these parameters are centered at different values, dictated by the common knowledge generated by the empirical literature. The prior distribution for standard deviations of shock processes are modeled as inverse gamma distributions with means 0.1 and standard deviations 1.

4.2 Model Comparison

To evaluate the relative quantitative performance of the models, we estimate and compare their marginal likelihoods. Suppose $Y_T = \{y_t\}_{t=1}^{T}$ is the observed history of vector y_t up to period T, and $Y_0 = \emptyset$. The posterior probability of model A_i is determined by Bayes formula

$$p(A_i|Y_T) = P(A_i)p(Y_T|A_i), \tag{17}$$

where $P(A_i)$ is the prior probability, and $p(Y_T|A_i)$ is the marginal probability of Y_T, or the likelihood function. For any two models, A_i and A_j the posterior odds ratio is defined as

$$\frac{p(A_i|Y_T)}{p(A_j|Y_T)} = \frac{P(A_i)}{P(A_j)}\left[\frac{p(Y_T|A_i)}{p(Y_T|A_j)}\right], \tag{18}$$

where $\frac{P(A_i)}{P(A_j)}$ is the ratio of prior probabilities of the two models, called the prior odds ratio, and $\left[\frac{p(Y_T|A_i)}{p(y_T|A_j)}\right]$ is the ratio of marginal likelihoods of the two models, or *the Bayes factor*. Denoting $L(i|j)$ the loss incurred if choosing model A_i when model A_j is true, the expected posterior loss from choosing model A_i is $P(A_j|Y_T)L(i|j)$. Then, one should choose model A_i if the expected posterior loss from choosing it is smaller than that of the alternative model, or $P(A_j|Y_T)L(i|j) < P(A_i|Y_T)L(j|i)$. This expression can be rewritten as follows

$$\frac{p(A_i|Y_T)}{p(A_j|Y_T)} > \frac{L(i|j)}{L(j|i)},$$

the right hand side of which is usually called the Bayes critical value. Model A_i should be preferred to model A_j if the posterior odds ratio exceeds the Bayes critical value. Combining this expression and Equation (18), one can obtain that

$$\frac{p(Y_T|A_i)}{p(Y_T|A_j)} > \frac{L(i|j)}{L(j|i)} \frac{P(A_j)}{P(A_1)}.$$

If the researcher has prior beliefs about the validity of the two models, and is able to evaluate the relative cost of making a mistake regarding what the true model is, then the posterior odds ratio will provide enough information to choose the model that better explains the data Y_T. When there is no strong evidence regarding the prior odds or the Bayes critical value, it is reasonable to set $L(i|j) = L(j|i)$, and $P(A_i) = P(A_j)$. In this case, the model with the larger marginal likelihood should be chosen as the preferred model.

Since we do not want to create a bias in favor of any model, we assume all five models have equal prior probabilities, and the same expected posterior losses. We thus compare the models' marginal likelihoods, and leave it to the readers to adjust the reported results about the best fitted model using their prior beliefs.

To calculate the model's marginal likelihood, we implement the Harmonic mean estimator of Gelfand and Day (1994), described in detail by Geweke (1999). Gelfand and Day notice that for any p.d.f. $f(\theta)$ with the support in Θ, the posterior mean of

$$\frac{f(\theta)}{p(\theta|A_i)p(Y_T|\theta, A_i)} \tag{19}$$

coincides with the inverse of the marginal likelihood of the model:

$$E\left[\frac{f(\theta)}{p(\theta|A_i)p(Y_T|\theta, A_i)}|Y_T, A_i\right] = P^{-1}(Y_T|A_i).$$

Suppose the support of $f(\theta)$ is $\hat{\Theta}_M = \{\theta : (\theta - \hat{\theta}_M)'\hat{\Sigma}_M^{-1}(\theta - \hat{\theta}_M) \leq \chi^2_{1-p}(k)\}$, where p is any number on interval $(0, 1)$, $\hat{\theta}_M = \frac{\sum_{m=1}^{M} \theta^{(m)}}{M}$ and $\hat{\Sigma}_M = \frac{\sum_{m=1}^{M}(\theta^{(m)} - \hat{\theta}_M)(\theta^{(m)} - \hat{\theta}_M)'}{M}$, and $\chi^2_{1-p}(k)$ is the p-value of the χ^2 distribution with k degrees of freedom. Geweke (1999) shows that $f(\theta)$ defined on $\hat{\Theta}_M$ as

$$f(\theta) = p^{-1}(2\pi)^{-k/2}|\hat{\Sigma}_M|^{-1/2}exp[-(1/2)(\theta - \hat{\theta}_M)'\hat{\Sigma}_M^{-1}(\theta - \hat{\theta}_M)], \tag{20}$$

will guarantee the boundedness of expression (19), and thus the posterior mean will exist as long as the posterior density $p(\theta|Y_T, A_i)$ is uniformly bounded away from zero on every compact subset of Θ.

To calculate the posterior expectation of the expression in (19), we evaluate the mean value of the elements of the Markov chain used to calculate the parameter estimate. As noted in Geweke (1999), the estimator may sometimes be very unstable. To confirm the stability of our results, we compute the marginal likelihood for different values of p.

5 Estimation Results

5.1 Model Comparison

The results of the model comparison exercise are presented in Table 2. The first column indicates the value of p used to calculate the marginal likelihood. Column 2 presents the estimate of the log marginal likelihood for the model with deep habits. Columns 3 - 6 show marginal likelihood less that of the deep habits model; therefore negative numbers indicate poorer fit of a model.

Table 2 reveals that the resulting model marginal likelihood values are very similar for all values of p. The log marginal likelihood of the deep habits model is the largest, and varies around 3854 depending on the value of p. The models with productive government spending, government spending in utility, and the baseline model show very similar log marginal likelihood numbers, which are smaller that that of the deep habit by approximately 13. The model with the poorest fit is that with rule-of-thumb consumers, reporting the log marginal likelihood that is smaller than that in the deep habits model by almost 70.

Table 2 clearly identifies the model with with deep habits as the one with the best performance at describing the data. The log marginal likelihood of this model exceeds that of the second-best model (model with government spending in the utility function) by approximately 12, which translates in the Bayes factor of e^{12}, much greater than 1000. This is considered decisive in favor of the model with deep habits, according to Jeffreys (1961). Interestingly, the explanatory power of the baseline model that does not rely on any specific modeling assumptions makes it comparable to two models in the set we study. While the baseline model demonstrates slightly poorer fit than the other two models, with the Bayes factor $e^{1.3}$ at largest, the difference between these models is "barely worth mentioning", according to the classification in Jeffreys (1961). Moreover, the results suggest that having the rule-of-thumb consumers does not help improve the fit of the baseline model to the data.

5.2 Parameter Estimates

Tables 3 and 4 report the estimated parameters in the five models. The estimates are obtained as mean values over $900,000$ out of 1 million elements of the Markov chain generated using the Random walk Metropolis-Hastings algorithm. The starting element for this Markov chain is determined as the mean value of the last 500 thousand draws of another (1 million elements long) Markov chain with the starting element coinciding with the mean of the prior. The proposal distribution is multivariate normal with the variance-covariance matrix $c\Sigma$, where Σ is determined as the inverse of the numerical Hessian evaluated at the starting element, and $c > 0$ is a parameter that is adjusted to achieve the acceptance rate in the range between 22 and 40 percent.[7] The observation of the trace and cumulative sum (CUSUM) plots verify that Markov chains are stationary. Figures 7 - 11 show the plots of the estimated posterior distributions together with the priors (black curves). The plots demonstrate that the prior distributions are wide, and that posterior distributions are well defined and different from the priors.

Table 3 documents the estimates of model specific parameters and common parameters other than identifying the shock processes. Although the models have different sets of model specific parameters, consumption habits parameter is present in all the models. However, this parameter in the deep habits models has a slightly different meaning, because it refers to the habits for the individual good, rather than the aggregate consumption as in the other models. Consumption habit parameters for the deep habits model and the rule-of-thumb model are relatively large(0.92 and 0.73 respectively), which is well within the range reported in the literature. The estimates in models with government spending in utility is very small ($b^c = 0.05$), which may be due to the fact that in this model, the persistent government spending that directly influence utility, generates enough inertia in the dynamics of consumption. Interestingly, Bouakez and Rebei (2007) also report a relatively small habit parameter in a similar model ($b^c = 0.25$). The baseline model and the model with productive government spending report moderate habit formation parameters of approximately 0.4.

The degree of deep habit for public consumption is considerable, $b^g = 0.73$, and the stock of habit for private consumption depreciates more slowly, than that for public consumption ($\rho^c = 0.97$ and $\rho^{gg} = 0.32$). Model specific parameter for the rule-of-thumb model, which determines the share of population living hand-to-mouth given by λ, is estimated to be 0.1. This number is relatively small compared with the literature. For example, Cogan, Cwik, Taylor, and Wieland (2010) find $\lambda = 0.29$, and using the European data, Forni, Monteforte, and Sessa (2009) estimate $\lambda = 0.34$, while Coenen and Straub (2005) report $\lambda = 0.246$. The estimates for the model with government spending in utility are ν and ϕ. The elasticity of substitution between public and private consumption in the model where government spending enters utility, is 0.37, which is similar to $\nu = 0.3$ estimated in Bouakez and Rebei (2007). Parameter ϕ has the posterior mean of 0.67 indicating that private consumption is more valued by individuals than public goods. The mean of the specific parameter in the model with productive government spending, α_G, is estimated at 0.11. This value is larger

[7]See Robert and Casella (2005).

than the one calibrated in the study by Baxter and King (1993).

The rest of Table 3 presents the estimates of the common model parameters. While there is some variation, the parameters are generally consistent across the models. The estimate of the price rigidity parameter α_p is in the range of 20 to 40 in all models. With the exception of the rule-of-thumb model, all models demonstrate the wage rigidity parameter above 70. Investment costs parameter is greater than 4 in all models. For all models except the model with government spending in the utility function, utility parameter σ turns out to be close to 1, which implies an intertemporal elasticity of substitution close to 1. Parameters of the monetary policy rule in all models imply that the rule is inertial, with α_R varying between approximately 0.7 and 0.8. The response of the policy interest rate to inflation is moderate, with α_π varying 0.25 and 0.5.[8]. The estimates imply that the long term response of interest rates to inflation, $\alpha_\pi/(1-\alpha_R)$, is between 1.2 and 1.9 in all models. The response of the interest rate to output growth, measured by α_Y is fairly consistent across the models.

Table 4 reports the estimates of autocorrelation and standard deviation of the shock processes. The estimates for the government spending, investment specific, and monetary policy shocks are similar across the models. The autocorrelation for the government spending shock is consistently in the range of approximately 0.2 - 0.4, and the standard deviation is 0.02 to 0.03 in all models. The standard deviation of the monetary policy shock is between 0.002 and 0.003. The autocorrelation of the investment specific shock lies within the range of 0.3 - 0.5, and the standard deviation is around 0.03. However, the models provide quite different estimates for the neutral technology and preference processes. It is important to understand that neither model can perfectly describe the properties of the data. When an estimated model is missing an internal mechanism to replicate some properties of the data, such as autocorrelations and volatilities, then shock processes will need to be adjusted to replicate observed correlations in the data.

5.3 Impulse Responses and Moments

There has been a lot of debate in the literature about the effect of increased government spending on private consumption. The models we investigate in this paper were all developed to introduce a channel to allow consumption to rise in response to an unexpected increase in government spending, which is observed in empirical structural VAR models. The literature has still not come to an agreement in this issue. While some authors find evidence favoring the positive response (see Ravn, Schmitt-Grohé, and Uribe (2007), Bouakez and Rebei (2007), Zubairy (2010)), others fail to find it in their estimated models (see for

[8]While the response to inflation is less than 1, there is no indeterminacy of the equilibrium, because the long-run interest rate response to inflation, $\frac{\alpha_\pi}{1-\alpha_R}$ is still greater than 1.

example Leeper, Plante, and Traum (2010), Coenen and Straub (2005)). We address this debate by comparing responses of consumption to the government spending shock across the estimated models. Figure 3 plots the impulse response of consumption to a 1 percent increase in government spending in the five models, shown as percentage deviations from trend, with quarters along the horizontal axis. The graphs suggest that in three models, those featuring deep habits, rule of thumb, and where government spending enters utility, a positive government spending shock induces a contemporaneous rise in consumption. The response of consumption in the deep habits model is significantly positive. The magnitude of the response is small, however consistent with Zubairy (2010), who report that the deep habits model underestimates consumption response compared with the data. Consumption responses in the models with rule of thumb consumers and where government spending enters utility are larger at 7 to 10 basis points, which is more in line with empirical studies finding that consumption rises by approximately 0.1 percent in response to a 1 percent government spending shock (see for example Monacelli and Perotti (2008)).

The baseline model shows that the median response of consumption to the government spending shock is negative, although not significantly different from 0. An important implication of this result is that positive response of consumption is a possibility even in the baseline model, where all models specific features are absent. The model with productive government spending displays similar results. The response of consumption is insignificant, however the median response of consumption to the government spending shock is now positive. Given that parameter estimates for the two models are very similar, the positive median response is clearly due to the fact that the government spending shock enhances productivity and magnifies the rise in the labor demand. However, this effect is not large enough to ensure significant positive response.

It is possible to relate insignificant consumption response in the two models to the fact that the posterior distribution of σ covers both ranges where it is smaller or larger than one. When $\sigma > 1$, consumption and leisure are substitutes, because $U_{12} < 0$. Therefore, an increase in hours worked h and the corresponding drop in leisure raise marginal utility of consumption, making it more desirable for households to raise consumption. When $\sigma \in (0, 1)$, consumption and leisure are complements in the sense that $U_{12} > 0$, and the opposite is true: a rise in labor would bring the marginal utility down, providing incentives for the households to reduce consumption. It is important to note that a significant portion (almost 50 percent) of the parameter draws from the posterior distribution justifies a positive response of consumption to the government spending shock in the baseline model. This suggests that an increase in consumption after the shock can be achieved in a conventional DSGE model like the baseline model without relying on any of the four mechanisms studies in this paper.

Another observation one can make by comparing consumption responses across the models is that a larger rise in consumption is associated with the larger estimate of σ. On the one hand, larger σ implies smaller intertemporal elasticity of substitution, resulting in more desire to smooth consumption over time. On the other hand, σ determines the degree of substitutability between consumption and leisure ($U_{12}(1-h)/U_2 = \zeta(1-\sigma)$). When $\sigma > 1$, then the larger σ, the more negative is the labor elasticity of marginal utility in steady state, implying that an increase in hours raises the marginal utility of consumption to a bigger extent with larger σ. As a result, the larger adjustment in consumption should be observed. This can be seen from the log linear approximation to the Euler equation. Ignoring habit formation for simplicity, it can be written as

$$E_t\hat{c}_{t+1} - \hat{c} \sim \frac{\sigma-1}{\sigma}\zeta(E_t\hat{h}_{t+1} - \hat{h}_t) + \frac{\beta}{\sigma}(\hat{R}_t - E_t\hat{\pi}_{t+1}) - E_t\hat{\mu}_{z^*,t+1}.$$

One can see from this equation, that the larger is σ, the smaller is responsiveness of consumption to changes in the real interest rate (consumption smoothing), and the larger is responsiveness to changes in labor.

Consumption responses shown in Figure 3 allow us to conclude that consumption rises in response to the government spending shock in the best fitting model featuring deep habits. While the magnitude of the consumption response varies significantly across models, we find that the models agree much more about the response of output to the government spending shock. Figure 4 shows output responses to a 1 percent increase in government spending across the five models. The responses are shown in percentage deviations from the non-stochastic trend, with quarters along the horizontal axis. The resulting responses are very robust across the models, demonstrating that output increases by about 25 basis points after the shock. Given that the steady state share of government spending was fixed at 0.2, this translates into a government spending multiplier of approximately 1.25 in all models.[9] The robustness of output response has an interesting implication: If a researcher is interested in the government spending multiplier of output rather than consumption, it is safe to use any of the models that we analyze in this paper.

While it is clear that the best fitting model does not perfectly match the impulse responses obtained with structural VAR models, it is important to understand that the Bayesian estimation procedure we utilize is not intended to produce the closest to the data impulse responses. Bayesian estimation is the full information approach to model estimation, which means that effectively, it is trying to match all moments and cross-correlations of the data

[9] The multiplier is computed as the response of output divided by the steady state ratio of public spending to output.

and the model. To better understand the quality of data fit by the models, we compare moments and cross-correlations predicted by the estimated model and data in Tables 5 and 6. Table 5 reports unconditional moments and autocorrelations of model variables. The upper part of the table shows unconditional standard deviation of a variable divided by the standard deviation of output for the five models with the data. Similar to the data, all models report larger volatility of investment and a smaller volatility of consumption relative to output. Comparing model statistics with the data (in the last column), one may notice that although all five models underpredict the relative volatilities of investment, inflation and the interest rate, they match relative volatility of consumption very closely. The only exception is the model with the rule of thumb consumers, for which consumption turns out to be as volatile as output and much more volatile than in the data. The inability to match the volatility of consumption growth may be a factor contributing to the relatively poor fit of the rule of thumb model.

Table 6 reports the contribution of the government spending shock to the overall volatility of macroeconomic variables implied by each model. Each column in the table shows model implied standard deviation of a variable when government spending is the only source of uncertainty, relative to the unconditional standard deviation of this variable assuming all sources of uncertainly are present, in percentages. The results show that the government spending shock contributes approximately 20 percent of output volatility in all models, while the contribution to all other variables is smaller. Specifically, the contribution of the government spending shock to consumption is quite small, not exceeding 15 percent, which points to the limited power of government spending shocks in explaining consumption fluctuations well documented in other studies. One may also note that this contribution is very different across models, and varies from approximately 1 to almost 13 percent.

5.4 Robustness of the Results: The Role of Preferences

Interestingly, as Figure 3 shows, a positive consumption response to a government spending shock is reported even in the baseline model, in the absence of all model specific features. This result is dictated by the specific *non-separable* form of the utility function we use for all models under consideration, given by Equation 6. The importance of the utility function has been pointed out by others. For instance, using non-separable preferences between consumption and leisure, Linnemann (2006), Monacelli and Perotti (2008) and Bilbiie (2011) demonstrate that higher fiscal spending can lead to an rise in consumption. This stems from the fact that with non-separable utility function considered here and in those papers, marginal utility of consumption is decreasing in leisure, i.e. $U_{ch} > 0$ and consumption and hours worked are complements. So intuitively, in response to a government spending shock, we see a rise in hours worked, due to an increase in labor supply driven by negative wealth effects and an increase in labor demand due to price stickiness. This rise in hours raises the marginal utility of consumption, leading to a rise in consumption and we can potentially see a simultaneous rise in labor and consumption in response to a government spending shock.

In order to evaluate the contribution of this utility function in generating positive response of consumption in the other four models, we depart from the non-separable form we have used thus far and estimate our four models assuming an additively *separable* utility function, where $U_{ch} = 0$, given by:

$$U(X_t, h_t) = log(X_t) - \frac{h_t^{1+\zeta}}{1+\zeta},$$

where $\zeta > 0$. The resulting impulse responses of consumption and output are shown in Figures 5 and 6. One can conclude from the figures that while models's predictions regarding the effect of government spending on output do not change much, the consumption effect of the government spending shock are highly sensitive to the choice of the utility function. Specifically, consumption response changes to the opposite in the deep habits model and in the model with productive government spending. Consumption just slightly rises in the model with rule-of-thumb consumers and in the model where government spending enters utility. Table 7 provides model comparison results for this exercise. The numbers in the table suggest that the deep habits model remains the model with the best fit of the data, and relative rankings are not affected by the choice of the utility function. Interestingly, comparison of column 2 in Tables 2 and 7 reveals that the non-separable utility function used in our baseline model helps improve the fit of the best fitting model, relative to a separable utility function.

6 Conclusion

In an attempt to explain a positive correlation between private and public consumption observed in structural VAR models, the literature has developed different transmission mechanisms of shocks to government spending into macroeconomic fluctuations. In this paper, we quantitatively explore these mechanisms. We find that out of four models included in this study, the model with deep habits provides the best fit to data, based on marginal likelihood. The model with the poorest fit features rule-of-thumb consumers who exhibit non-Ricardian behavior. While all the models we estimate can generate a positive response of consumption to a rise in government spending, we find that non-separable utility in consumption and leisure plays an important role in delivering this result. Although adding deep-habits considerably improves the fit of the model, the positive effect of government spending on consumption can be achieved without modeling deep habits, and by assuming a non-separable utility function alone.

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7 Tables and Figures

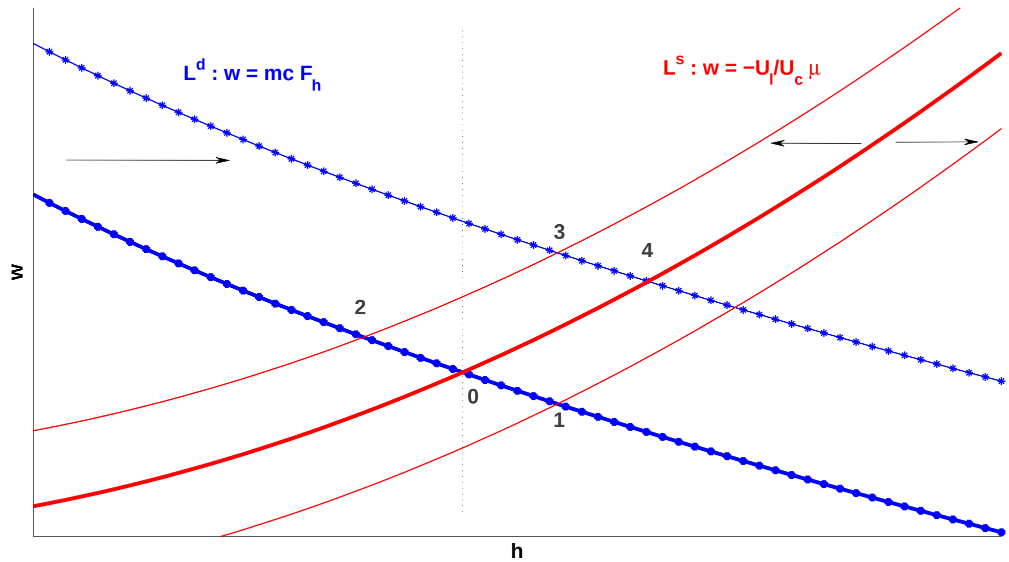

Figure 1: Effect of the government spending shock in labor market.

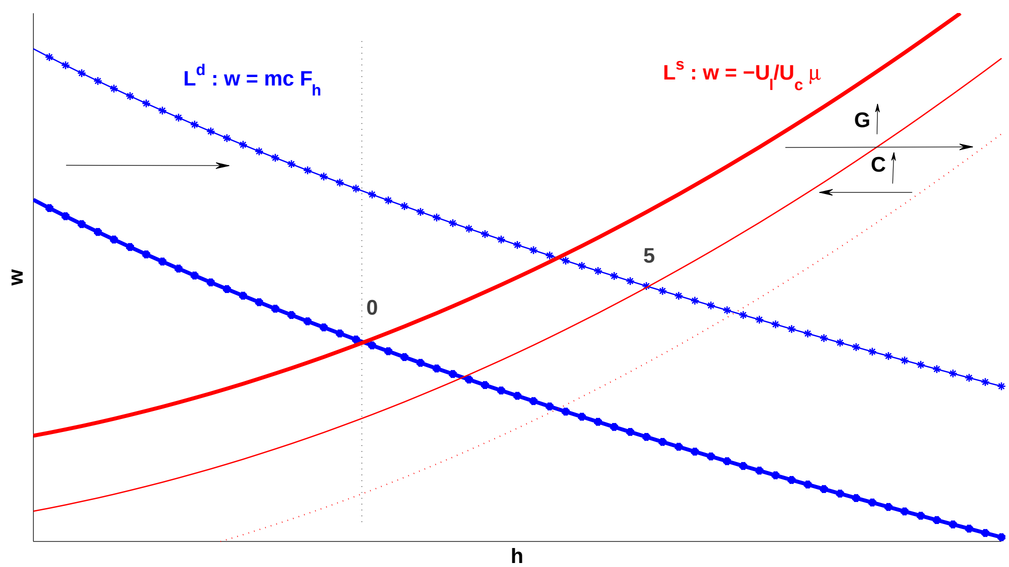

Figure 2: Effect of the government spending shock in labor market in the model where government affects utility.

Table 1: Calibration of common parameters and steady state values

θ	Production: capital share	0.3
μ_{z^*}	Growth of output	1.0047
μ_Υ	Growth of investment specific technology	1.0042
π	Inflation	1.0086
β	Intertemporal discount factor	0.999
δ_0	Depreciation rate	0.025
u	Rate of capital utilization	1
h	Labor	0.5
sh^G	Share of government spending	0.2
η_p	Prices: elasticity of substitution	6
η_w	Wages: elasticity of substitution	21

Table 2: Model marginal likelihood.

p	Deep Habits (DH)	ROT vs. DH	G in U vs. DH	G in F vs. DH	Baseline vs. DH
0.1	3852.4	-69.0	-12.4	-12.9	-13.7
0.5	3854.5	-69.0	-12.4	-12.8	-13.7
0.9	3856.4	-68.8	-12.2	-12.4	-13.5

Notes. Table shows logarithm of marginal likelihood of a model evaluated using Geweke (1999) procedure. The first column is the parameter p in the Geweke estimator that specifies the supplementary p.d.f $f(\theta)$ in Equation (20). The second column shows the marginal likelihood in the model with deep habits. Columns 3-6 present the log of marginal likelihood of a model relative to the best fitted model, so that negative numbers indicate more poor fit. ROT = for rule-of-thumb model, G in U = model with government spending in the utility function, G in F = the model with government spending in the production technology, "Baseline" refers to the baseline model without specific features.

Table 3: Parameter Estimates: Part I.

Parameter	Prior distribution		DH	ROT	G in U	G in F	Baseline
	Type	Mean (st.d.)	Mean (st.d.)	Mean (st.d.)	Mean (st.d.)	Mean (st.d)	Mean (st.d.)
b^c	B	0.5	0.9258	-	-	-	-
		(0.2)	(0.0420)	(-)	(-)	(-)	(-)
ρ^c	B	0.5	0.9712	-	-	-	-
		(0.2)	(0.0097)	(-)	(-)	(-)	(-)
b^g	B	0.7	0.7306	-	-	-	-
		(0.2)	(0.1037)	(-)	(-)	(-)	(-)
ρ^{gg}	B	0.5	0.3168	-	-	-	-
		(0.2)	(0.1939)	(-)	(-)	(-)	(-)
λ	B	0.2	-	0.1048	-	-	-
		(0.1)	(-)	(0.0221)	(-)	(-)	(-)
μ	G	0.5	-	-	0.3701	-	-
		(0.2)	(-)	(-)	(0.0441)	(-)	(-)
ϕ	B	0.5	-	-	0.6740	-	-
		(0.2)	(-)	(-)	(0.0720)	(0.0000)	(-)
α_G	B	0.2	-	-	-	0.1167	-
		(0.1)	(-)	(-)	(-)	(0.0394)	(-)
b	G	0.5	-	0.7339	0.0500	0.4212	0.4163
		(0.1)	(-)	(0.0375)	(0.0121)	(0.0459)	(0.0421)
α_p	G	20.0	26.5059	26.6201	33.4430	29.1135	35.1754
		(5.0)	(5.1960)	(4.2853)	(6.1045)	(4.2189)	(4.4884)
α_w	G	100.0	79.0204	45.9581	115.3117	129.4898	120.7557
		(30.0)	(19.5005)	(13.9681)	(31.5877)	(35.0566)	(34.4208)
σ	G	3.0	1.1096	1.5041	2.2965	1.0345	1.0393
		(1.0)	(0.0346)	(0.2062)	(0.3217)	(0.1129)	(0.1107)
κ	G	3.0	9.3073	11.2510	4.1245	15.4484	15.2620
		(1.0)	(0.9292)	(0.9851)	(0.5029)	(1.1159)	(1.1302)
δ_2/δ_1	G	2.0	6.7019	2.7804	6.6895	1.0545	1.0063
		(1.5)	(2.0643)	(0.8399)	(2.1846)	(0.1865)	(0.1741)
α_R	B	0.5	0.7345	0.8167	0.7755	0.7670	0.7682
		(0.2)	(0.0274)	(0.0199)	(0.0181)	(0.0179)	(0.0179)
α_π	G	1.0	0.4857	0.3448	0.2791	0.3735	0.3780
		(0.5)	(0.0436)	(0.0321)	(0.0217)	(0.0311)	(0.0298)
α_Y	G	0.2	0.0353	0.0571	0.0655	0.0297	0.0236
		(0.1)	(0.0073)	(0.0107)	(0.0101)	(0.0081)	(0.0069)

Notes. Table shows prior distributions and Bayesian estimates of parameters across different models. Notation in the second columns is as follows: B = beta, G = gamma, I = inverse gamma distributions. Estimates are presented as mean values and standard deviations across the last $900,000$ out of 1 million elements of a Markov chain generated using the Metropolis Hastings algorithm. Kalman filter is used to evaluate the likelihood of the data.

Table 4: Parameter Estimates: Part II

Parameter	Prior distribution		DH	ROT	G in U	G in F	Baseline
	Type	Mean (st.d.)	Mean (st.d.)	Mean (st.d.)	Mean (st.d.)	Mean (st.d)	Mean (st.d.)
ρ_z	B	0.5	0.0877	0.8466	0.2318	0.0965	0.0905
		(0.2)	(0.0446)	(0.0369)	(0.0930)	(0.0380)	(0.0364)
ρ_v	B	0.5	0.3902	0.4293	0.5053	0.4340	0.4308
		(0.2)	(0.0547)	(0.0429)	(0.0454)	(0.0435)	(0.0430)
ρ_g	B	0.5	0.2793	0.3837	0.3130	0.1753	0.1696
		(0.2)	(0.0503)	(0.0648)	(0.0786)	(0.0590)	(0.0566)
ρ_d	B	0.5	0.2602	0.0214	0.1996	0.9313	0.9326
		(0.2)	(0.0654)	(0.0121)	(0.0655)	(0.0181)	(0.0175)
σ_g	I	0.1	0.0243	0.0315	0.0293	0.0214	0.0210
		(1.0)	(0.0023)	(0.0037)	(0.0039)	(0.0019)	(0.0018)
σ_z	I	0.1	0.0474	0.0072	0.0266	0.0250	0.0247
		(1.0)	(0.0078)	(0.0012)	(0.0044)	(0.0021)	(0.0020)
σ_v	I	0.1	0.0307	0.0306	0.0133	0.0321	0.0317
		(1.0)	(0.0056)	(0.0041)	(0.0014)	(0.0040)	(0.0039)
σ_d	I	0.1	0.0401	0.0881	0.0161	0.0389	0.0395
		(1.0)	(0.0120)	(0.0248)	(0.0025)	(0.0074)	(0.0077)
σ_r	I	0.1	0.0030	0.0030	0.0023	0.0029	0.0028
		(1.0)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)

Notes. Table shows prior distributions and Bayesian estimates of parameters across different models. Notation in the second columns is as follows: B = beta, G = gamma, I = inverse gamma distributions. Estimates are presented as mean values and standard deviations across the last 900,000 out of 1 million elements of a Markov chain generated using the Metropolis Hastings algorithm. Kalman filter is used to evaluate the likelihood of the data.

Table 5: Unconditional moments in the models and data

	Deep Habits	ROT	G in Utility	Productive G	Baseline	Data
	Std. Deviation Relative to Output Growth					
Output growth	1.0	1.0	1.0	1.0	1.0	1.0
Investment growth	2.0	2.5	1.9	2.5	2.5	3.7
Consumption growth	0.5	1.0	0.8	0.8	0.7	0.6
Inflation	0.2	0.3	0.3	0.3	0.3	0.6
Interest rate	1.3	2.0	1.6	1.6	1.6	3.5
	Autocorrelation					
Output growth	0.04	0.36	0.07	0.27	0.26	0.27
Investment growth	0.21	0.57	0.21	0.56	0.54	0.31
Consumption growth	0.12	0.17	0.05	0.24	0.23	0.24
Inflation	0.85	0.86	0.97	0.89	0.88	0.84
Interest rate	0.96	0.88	0.99	0.96	0.97	0.95

Notes: The table shows the standard deviations of a variable as a fraction of that of output growth, and the autocorrelation of a variable, specifically $corr(X_t, X_{t-1})$.

Table 6: Contribution of the government spending shock to model volatility, %

	Deep Habits	ROT	G in Utility	Productive G	Baseline
Output growth	17.85	38.12	23.30	25.28	25.99
Investment growth	2.54	2.50	3.53	2.58	4.51
Consumption growth	5.09	10.23	12.44	0.86	0.45
Inflation	6.18	11.50	1.45	2.66	2.75
Interest rate	5.75	10.28	3.43	4.83	3.92

Notes: The table shows the standard deviations in a model with government spending shock as a ratio of unconditional model implied standard deviation, in percentages.

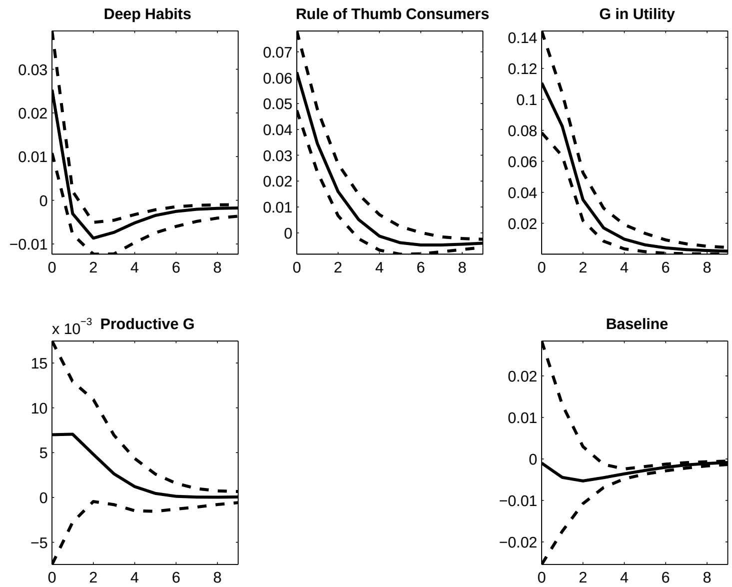

Figure 3: Consumption responses to the government spending shock

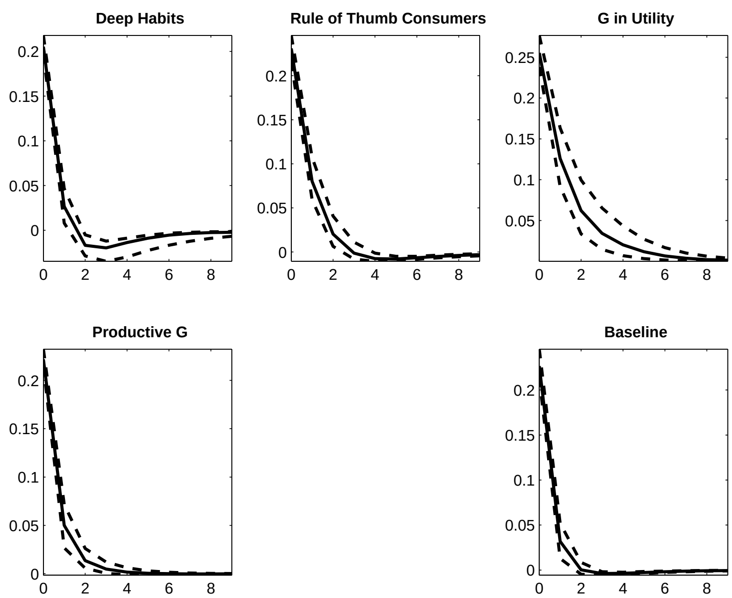

Figure 4: Output responses to the government spending shock

Notes: Each graph shows an impulse response to the government spending shock in percentage deviations from trend. Quarters are along the horizontal axis, and percentages are on the vertical axis. Each response is calculated as the median value of the impulse response distribution created by a random subsample of 100 elements of a Markov chain obtain as part of the model estimation procedure. The dashed lines show the 5^{th} and 95^{th} quantile of this distribution.

Table 7: Marginal likelihood of models with separable utility.

p	DH	ROT vs. DH	G in Utility vs. DH	Productive G vs. DH
0.1	3836.6	-57.4	-6.0	-4.0
0.5	3838.6	-57.3	-5.2	-3.7
0.9	3840.6	-57.1	-5.3	-3.6

Notes. Table shows logarithm of marginal likelihood of a model evaluated using Geweke (1999) procedure. The first column is the parameter p in the Geweke estimator that specifies the supplementary p.d.f $f(\theta)$ in Equation (20). The second column shows the marginal likelihood in the model with deep habits. Columns 3-5 present the log of marginal likelihood of a model relative to the best fitted model, so that negative numbers indicate more poor fit. ROT = for rule-of-thumb model, G in U = model with government spending in the utility function, G in F = the model with government spending in the production technology.

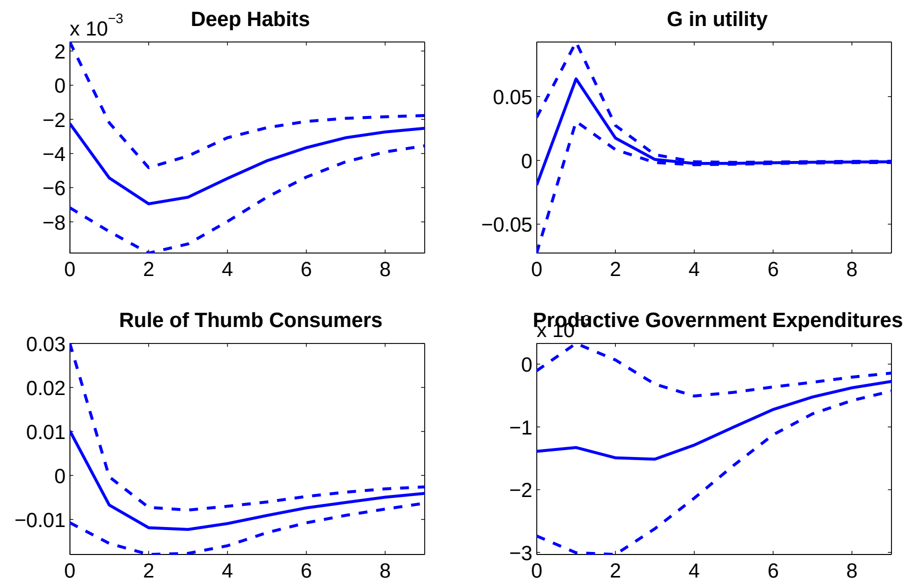

Figure 5: Consumption response to the government spending shock in models with additively separable utility

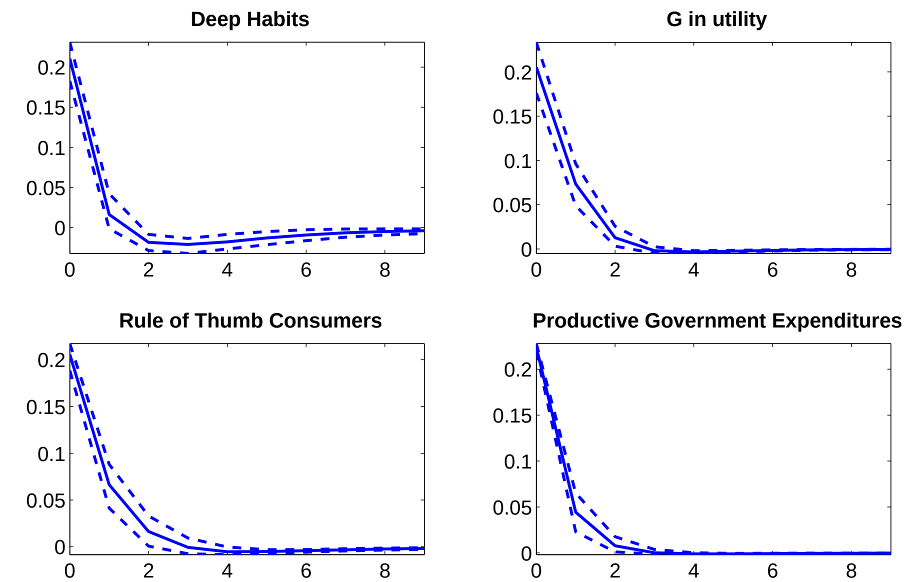

Figure 6: Output response to the government spending shock in models with additively separable utility.

Notes: Each graph shows an impulse response to the government spending shock in percentage deviations from trend. Quarters are along the horizontal axis, and percentages are on the vertical axis. Each response is calculated as the median value of the impulse response distribution created by a random subsample of 100 elements of a Markov chain obtain as part of the model estimation procedure. The dashed lines show the 5^{th} and 95^{th} quantile of this distribution.

8 Appendix

8.1 Symmetric Equilibrium in Stationary Variables

Stationary transformations of model variables are presented in Table 8.1.

Original variable	Stationarized variable	How stationary variable was obtained
$\Psi(\cdot)$, $\Omega(\cdot)$	$\psi(\cdot)$, $\omega(\cdot)$	divided by Z^*
R_t^k	r_t^k	multiplied by Υ_t
K_{t+1}, I_t	k_{t+1}, i_t	divided by $Z_t^*\Upsilon_t$
Y_t, C_t, X_t, W_t, G_t	y_t, c_t, x_t, w_t, g_t	divided by Z_t^*

Stationary version of the intratemporal utility $U(X_t, h_t)$ is obtained through transformation $u(x_t, h_t) = \frac{U(X_t,h_t)}{(Z_t^*)^{1-\sigma}}$; therefore $u(x_t, h_t)$ is defined as

$$u(x_t, h_t) = \frac{x_t^{1-\sigma}}{1-\sigma} h_t^{1+\zeta}. \tag{21}$$

For the steady state to exist, the following two relationships must hold between the growth rates of shocks and model variables:

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

Denote $\tilde{\beta}_t = \beta(\mu_{z,t}^*)^{1-\sigma}$. Then, The F.O.C. w.r.t. state contingent assets pins down $r_{t,t+1}$:

$$r_{t,t+1} = \tilde{\beta}_{t+1} \frac{\xi_{t+1}}{\xi_t \pi_{t+1} \mu_{z^*,t+1}},$$

where ξ_t is the lagrange multiplier in stationary terms. Optimization by firms provides the following two F.O.C.s

$$r_t^k = mc_t q_t \theta (\frac{u_t k_t}{h_t \mu_{I,t}})^{\theta-1}, \tag{22}$$

$$w_t = mc_t q_t (1-\theta) (\frac{u_t k_t}{h_t \mu_{I,t}})^{\theta}, \tag{23}$$

where mc_t is the stationary marginal costs of firms. Given the assumed functional form for $\delta(u_t)$ in Equation (3), the optimal choice of capital services supplied by households implies

$$r_t^k = \delta_1 + \delta_2(u_t - u). \tag{24}$$

The dynamics of capital in stationary variables is

$$k_{t+1} = (1 - \delta(u_t)) \frac{k_t}{\mu_{I,t}} + i_t. \tag{25}$$

The costs of capital, price and wage adjustments can be written in stationary variables as:

$$\mathcal{S}\left(\frac{k_{t+1}}{k_t}\mu_{I,t+1}\right) = \frac{\kappa}{2}\left(\frac{k_{t+1}}{k_t}\mu_{I,t+1} - \mu_I\right)^2,$$

$$\omega\left(\pi_t\right) = \frac{\alpha_p}{2}\left(\pi_t - \pi\right)^2,$$

$$\psi\left(\frac{w_t}{w_{t-1}}\mu_{z^*,t}\pi_t\right) = \frac{\alpha_w}{2}\left(\frac{w_t}{w_{t-1}}\mu_{z^*,t}\pi_t - \mu_{z^*}\pi\right)^2.$$

The optimal choice of capital is driven by the following F.O.C.:

$$1+\mathcal{S}'\left(\frac{k_{t+1}}{k_t}\mu_{I,t+1}\right) = E_t\tilde{\beta}_{t+1}\frac{\xi_{t+1}}{\xi_t\mu_{I,t+1}}[u_{t+1}r^k_{t+1}+1-\delta(u_{t+1})-s\mathcal{S}'\left(\frac{k_{t+2}}{k_{t+1}}\mu_{I,t+2}\right)\frac{k_{t+2}}{k_{t+1}}\mu_{I,t+2}-s\mathcal{S}\left(\frac{k_{t+2}}{k_{t+1}}\mu_{I,t+2}\right)], \tag{26}$$

where ξ_t is the stationarized lagrange multiplier next to the household's budget constraint.

The optimality condition for the choice of the wage rate is

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

$$E_t\tilde{\beta}_{t+1}\frac{\xi_{t+1}}{\xi_t}\psi'\left(\frac{w_{t+1}}{w_t}\mu_{z^*,t+1}\pi_{t+1}\right)\left(\frac{w_{t+1}}{w_t}\right)^2\mu_{z^*,t+1}\pi_{t+1}h_{t+1}, \tag{27}$$

where $\tilde{\mu}$ is the lagrange multiplier for the constraint on labor demand in the optimal choice of the wage rate by households. The optimal choice of state-contingent assets by optimizing households implies

$$\xi_t = R_t E_t\tilde{\beta}_{t+1}\frac{\xi_{t+1}}{\mu_{z^*,t+1}\pi_{t+1}}. \tag{28}$$

The monetary policy rule in terms of stationary variables is

$$log\left(\frac{R_t}{R}\right) = \alpha_R log\left(\frac{R_{t-1}}{R}\right) + \alpha_\pi log\left(\frac{\pi_t}{\pi}\right) + \alpha_Y log\left(\frac{y_t}{y_{t-1}}\frac{\mu_{z^*,t}}{\mu_{z^*}}\right) + log(\epsilon^r_t), \tag{29}$$

The aggregate market clearing condition in the market for goods is

$$y_t = c_t + g_t + i_t + \psi\left(\frac{w_t}{w_{t-1}}\mu_{z^*,t}\pi_t\right)w_t h_t + \omega\left(\pi_t\right) + \mathcal{S}\left(\frac{k_{t+1}}{k_t}\mu_{I,t+1}\right)k_t \tag{30}$$

where

$$y_t = q_t\left(\frac{u_t k_t}{\mu_{I,t}}\right)^\theta h_t^{1-\theta} - \vartheta. \tag{31}$$

8.1.1 Deep Habits Model: Equilibrium

Effective stationarized consumption in the deep habits model is

$$x_t = c_t - b^c\frac{s^c_{t-1}}{\mu_{z^*,t}}, \tag{32}$$

where the stock of habit s_t^c is

$$s_t^c = \rho^c \frac{s_{t-1}^c}{\mu_{z^*,t}} + (1-\rho^c)c_t. \tag{33}$$

Household optimality condition for the choice of consumption

$$\xi_t = d_t u_1(x_t, h_t). \tag{34}$$

Household optimality condition for the labor decision

$$w_t(1-\psi(\frac{w_t}{w_{t-1}}\mu_{z^*,t}\pi_t))\xi_t = d_t u_2(x_t, h_t)\mu_t. \tag{35}$$

The optimal choice of prices by firms results in the following Phillips curve equation

$$\pi_t\omega'(\pi_t) = (1-\eta_p+\eta_p mc_t)(y_t-\omega(\pi_t))-\eta_p(\tilde{\nu}_t^c x_t+\tilde{\nu}_t^g x_t^g-(1-mc_t)(c_t+g_t))+E_t\tilde{\beta}_{t+1}\frac{\xi_{t+1}}{\xi_t}\pi_{t+1}\omega'(\pi_{t+1}), \tag{36}$$

where

$$x_t^g = g_t - b^g \frac{s_{t-1}^g}{\mu_{z^*,t}}, \tag{37}$$

$$s_t^g = \rho^{gg} \frac{s_{t-1}^g}{\mu_{z^*,t}} + (1-\rho^{gg})g_t, \tag{38}$$

$$(\tilde{\nu}_t^c + mc_t - 1) = E_t\tilde{\beta}_{t+1}\frac{\xi_{t+1}}{\xi_t\mu_{z^*,t+1}}[\rho^c(\tilde{\nu}_{t+1}^c + mc_{t+1} - 1) + (1-\rho^c)b^c\tilde{\nu}_{t+1}^c], \tag{39}$$

$$(\tilde{\nu}_t^g + mc_t - 1) = E_t\tilde{\beta}_{t+1}\frac{\xi_{t+1}}{\xi_t\mu_{z^*,t+1}}[\rho^g(\tilde{\nu}_{t+1}^g + mc_{t+1} - 1) + (1-\rho^g)b^g\tilde{\nu}_{t+1}^g], \tag{40}$$

A symmetric competitive equilibrium is the sequence of 23 variables,

$$\{y_t, r_t^k, mc_t, u_t, i_t, k_{t+1}, w_t, \xi_t, R_t, c_t, h_t, \mu_t, \pi_t, x_t, x_t^g, s_t^c, s_t^g, \tilde{\upsilon}_t^c, \tilde{\upsilon}_t^g, d_t, g_t, \mu_{z,t}, \mu_{\Upsilon,t}\}_{t=0}^{\infty}$$

that satisfies the system of 23 Equations (22) - (31), (32) - (40), as well as (8), (1), (5), and (11), for each sequence of innovations $\{\epsilon_t^{\Upsilon}, \epsilon_t^z, \epsilon_t^g, \epsilon_t^d, \epsilon_t^R\}_{t=0}^{\infty}$.

8.1.2 Model with rule-of-thumb Consumers: Equilibrium

The aggregate consumption c_t is

$$c_t = (1-\lambda)c_t^o + \lambda c_t^r, \tag{41}$$

where

$$c_t^r = w_t h_t(1-\psi(\frac{w_t}{w_{t-1}}\mu_{z^*,t}\pi_t)) - \tau^r,$$

where τ^r is the lump-sum tax, and c_t^o is consumption of optimizing households. Effective stationarized consumption of optimizing households entering utility in (21) is

$$x_t^o = c_t^o - b^c \frac{c_{t-1}^o}{\mu_{z^*,t}}.$$

The optimality condition for the choice of consumption by optimizing households is

$$\xi_t = d_t u_1(x_t^o, h_t) - E_t \frac{\tilde{\beta}_{t+1} b^c}{\mu_{z^*,t+1}} d_{t+1} u_1(x_{t+1}^o, h_{t+1}). \tag{42}$$

The optimality condition for the choice of labor by optimizing households is

$$w_t(1 - \Phi(\frac{w_t}{w_{t-1}} \mu_{z^*,t} \pi_t))\xi_t = d_t u_2(x_t^o, 1 - h_t)\mu_t. \tag{43}$$

The Phillips curve is

$$\pi_t \omega'(\pi_t) = (1 - \eta_p + \eta_p mc_t)(y_t - \omega(\pi_t)) + E_t \tilde{\beta}_{t+1} \frac{\xi_{t+1}}{\xi_t} \pi_{t+1} \omega'(\pi_{t+1}). \tag{44}$$

A symmetric competitive equilibrium is the sequence of 19 variables,

$$\{y_t, r_t^k, mc_t, u_t, i_t, k_{t+1}, w_t, \xi_t, R_t, c_t, h_t, \mu_t, \pi_t, c_t^o, d_t, g_t, \mu_{z,t}, \mu_{\Upsilon,t}\}_{t=0}^{\infty}$$

that satisfies the system of 19 Equations (22) - (31), (41) - (44), as well as (8), (1), (5), and (11), for each sequence of innovations $\{\epsilon_t^{\Upsilon}, \epsilon_t^z, \epsilon_t^g, \epsilon_t^d, \epsilon_t^R\}_{t=0}^{\infty}$.

8.1.3 Model with Government Spending in the Utility Function: Equilibrium

Effective stationarized consumption is

$$x_t = \tilde{c}_t - b^c \frac{\tilde{c}_{t-1}}{\mu_{z^*,t}},$$

where

$$\tilde{c}_t = \left(\phi c_t^{(\nu-1)/\nu} + (1-\phi) g_t^{(\nu-1)/\nu}\right)^{\nu/(\nu-1)}.$$

The household's optimality condition for the labor decision is

$$w_t(1 - \psi(\frac{w_t}{w_{t-1}} \mu_{z^*,t} \pi_t))\xi_t = d_t u_2(x_t, h_t)\mu_t. \tag{45}$$

The household's optimality condition for consumption choice is

$$\xi_t = d_t u_1(x_t, h_t) - E_t \tilde{\beta}_{t+1} d_{t+1} u_1(x_{t+1}, h_{t+1}) \frac{b^c}{\mu_{z^*,t+1}}. \tag{46}$$

The Phillips curve is

$$\pi_t \omega'(\pi_t) = (1 - \eta_p + \eta_p mc_t)(y_t - \omega(\pi_t)) + E_t \tilde{\beta}_{t+1} \frac{\xi_{t+1}}{\xi_t} \pi_{t+1} \omega'(\pi_{t+1}). \tag{47}$$

A symmetric competitive equilibrium is the sequence of 17 variables,

$$\{y_t, r_t^k, mc_t, u_t, i_t, k_{t+1}, w_t, \xi_t, R_t, c_t, h_t, \mu_t, \pi_t, d_t, g_t, \mu_{z,t}, \mu_{\Upsilon,t}\}_{t=0}^{\infty}$$

that satisfies the system of 20 Equations (22) - (31), (45) - (47), as well as (8), (1), (5), and (11), for each sequence of innovations $\{\epsilon_t^{\Upsilon}, \epsilon_t^z, \epsilon_t^g, \epsilon_t^d, \epsilon_t^R\}_{t=0}^{\infty}$.

8.1.4 Model with Productive Government Spending: Equilibrium

The stationarized production technology q_t is determined by $q_t = (k_t^g)^{\alpha_G}$. Effective stationarized consumption is

$$x_t = c_t - b^c \frac{c_{t-1}}{\mu_{z^*,t}},$$

Household's optimality condition for the labor decision is

$$w_t(1 - \psi(\frac{w_t}{w_{t-1}} \mu_{z^*,t} \pi_t))\xi_t = d_t u_2(x_t, h_t) \mu_t. \tag{48}$$

The household's optimality condition for the consumption decision is

$$\xi_t = d_t u_1(x_t, h_t) - E_t \tilde{\beta}_{t+1} d_{t+1} u_1(x_{t+1}, h_{t+1}) \frac{b^c}{\mu_{z^*,t+1}}. \tag{49}$$

The Phillips curve is

$$\pi_t \omega'(\pi_t) = (1 - \eta_p + \eta_p mc_t)(y_t - \omega(\pi_t)) + E_t \tilde{\beta}_{t+1} \frac{\xi_{t+1}}{\xi_t} \pi_{t+1} \omega'(\pi_{t+1}). \tag{50}$$

A symmetric competitive equilibrium is the sequence of 17 variables,

$$\{y_t, r_t^k, mc_t, u_t, i_t, k_{t+1}, w_t, \xi_t, R_t, c_t, h_t, \mu_t, \pi_t, d_t, g_t, \mu_{z,t}, \mu_{\Upsilon,t}\}_{t=0}^{\infty}$$

that satisfies the system of 20 Equations (22) - (31), (48) - (50), as well as (8), (1), (5), and (11), for each sequence of innovations $\{\epsilon_t^{\Upsilon}, \epsilon_t^z, \epsilon_t^g, \epsilon_t^d, \epsilon_t^R\}_{t=0}^{\infty}$.

8.2 Steady State

The following steady-state relationships hold for all four models:

$$\tilde{\beta} = \beta(\mu_{z^*})^{1-\sigma},$$

$$\mu_z = \frac{\mu_{z^*}}{\mu_{\Upsilon}^{\frac{\theta}{1-\theta}}},$$

$$\mu_I = \mu_\Upsilon * \mu_{z^*},$$
$$R = \frac{\pi \mu_{z*}}{\tilde{\beta}},$$
$$r^k = \frac{\mu_I}{\tilde{\beta}} - 1 + \delta_0,$$
$$\mu = \frac{\eta_w}{\eta_w - 1},$$
$$\delta_1 = r^k.$$

Model-specific steady states are determined as follows.

8.2.1 Model with Deep Habits

The steady state ratios of investment and consumption to output are

$$s^i = \theta \frac{\mu_I - (1 - \delta_0)}{r^k}, \qquad s^c = 1 - sh^G - s^i.$$

The following four formulas are helpful in determining steady state marginal costs of firms:

$$aa^c = 1 - \frac{b^c(1-\rho^c)}{\mu_{z^*} - \rho^c}, \qquad bb^c = 1 - \frac{b^c(1-\rho^c)}{\frac{\mu_{z*}}{\tilde{\beta}} - \rho^c},$$

$$aa^g = 1 - \frac{b^g(1-\rho^{gg})}{\mu_{z^*} - \rho^{gg}}, \qquad bb^g = 1 - \frac{b^g(1-\rho^{gg})}{\frac{\mu_{z*}}{\tilde{\beta}} - \rho^{gg}},$$

In terms of aa^c, bb^c, aa^g, bb^g, the steady state marginal costs are

$$mc = 1 - \frac{1}{\eta_p}\left(\frac{1}{s^c aa^c/bb^c + s^g aa^g/bb^g + s^i}\right).$$

Also,

$$\tilde{\upsilon}^c = \frac{1 - mc}{bb^c}, \qquad \tilde{\upsilon}^g = \frac{1 - mc}{bb^g}.$$

To pin down remaining variables, it is convenient to find the following ratios first:

$$k = h\frac{\mu_I}{u}\left(\frac{r^k}{\theta mc}\right)^{\frac{1}{\theta - 1}},$$

$$i = h\left(1 - \frac{1-\delta_0}{\mu_I}\right)(k/h),$$

$$y = hmc\left(\frac{u(k/h)}{\mu_I}\right)^\theta,$$

$$\vartheta = h(1 - mc)\left(\frac{u(k/h)}{\mu_I}\right)^\theta,$$

$$g = sh^G y,$$

$$c = y - i - g,$$

$$s^c = \frac{(1-\rho^c)c}{1-\rho^c/\mu_{z^*}},$$

Now, the steady state labor and the wage rate can be calculated as follows

$$w = mc(1-\theta)(\frac{uk}{h\mu_I})^{\theta}.$$

$$\zeta = \frac{w(1-h)}{\mu}\frac{1}{c - b^c\frac{s^c}{\mu_{z^*}}}$$

Assuming the balanced government budget, the lump-sum tax is $t = g$. Finally, the stocks of public habits is

$$s^g = \frac{(1-\rho^{gg})g}{1-\rho^{gg}/\mu_{z^*}},$$

and the Lagrangian on the households' budget constraint is

$$\xi = d(c - s^c\frac{b^c}{\mu_{z^*}})^{-\sigma}(1-h)^{\zeta(1-\sigma)}.$$

8.2.2 Model with rule-of-thumb Consumers

The similar strategy applies to calculating the steady state for the Rule-of-Thumb model:

$$mc = 1 - \frac{1}{\eta_p},$$

$$k = h\frac{\mu_I}{u}(\frac{r^k}{\theta mc})^{\frac{1}{\theta-1}},$$

$$i = h(1 - \frac{1-\delta_0}{\mu_I})(k/h),$$

$$w = mc(1-\theta)(\frac{u(k/h)}{\mu_I})^{\theta},$$

$$y = hmc(\frac{u(k/h)}{\mu_I})^{\theta},$$

$$\vartheta = (1-mc)(\frac{u(k/h)}{\mu_I})^{\theta},$$

$$g = sh^G y,$$

$$c = y - i - g,$$

$$\zeta = \frac{wh}{\mu c}\frac{(1-\tilde{\beta}\frac{b^c}{\mu_{z^*}})}{(1-\frac{b^c}{\mu_{z^*}})},$$

$$\xi = d(c(1-\frac{b^c}{\mu_{z^*}}))^{-\sigma}(1-h)^{\zeta(1-\sigma)}(1-\tilde{\beta}\frac{b^c}{\mu_{z^*}}).$$

The steady state tax of the rule-of-thumb households is $t^r = wh - c$, and $c^o = c$.

8.2.3 Model with Government Spending in the Utility Function

$$mc = 1 - \frac{1}{\eta_p}.$$

$$(k/y) = \frac{\theta\mu_I}{ur^k},$$

$$(i/y) = (1-\frac{1-\delta_0}{\mu_I})(k/y),$$

$$(c/y) = 1 - sh^G - (i/y),$$

$$y = (mc(\frac{(k/y)u}{\mu_I})^{\theta}h^{1-\theta}(sh^G)^{\alpha^G})^{\frac{1}{1-\theta-\alpha^G}},$$

Once y is known, i, c and k can be trivially recovered.

$$\tilde{c} = [\phi c^{(\nu-1})/\nu + (1-\phi)g^{(\nu-1)/\nu}]^{\nu/(\nu-1)}$$

$$\zeta = \frac{1-h}{\tilde{c}}\frac{w}{\mu}(\frac{c}{\tilde{c}})^{-\frac{1}{\nu}}\frac{1-\tilde{\beta}\frac{b^c}{\mu_{z^*}}}{1-\frac{b^c}{\mu_{z^*}}},$$

$$\xi = d\phi(\frac{c}{\tilde{c}})^{-1/\nu}(1-h)^{\zeta(1-\sigma)}(\tilde{c}(1-\frac{b^c}{\mu_{z^*}}))^{-\sigma}(1-\tilde{\beta}\frac{b^c}{\mu_{z^*}})$$

8.2.4 Model with Productive Government Spending

$$mc = 1 - \frac{1}{\eta_p}.$$

$$(k/y) = \frac{\theta\mu_I}{ur^k},$$

$$(i/y) = (1-\frac{1-\delta_0}{\mu_I})(k/y),$$

$$(c/y) = 1 - sh^G - (i/y),$$

$$y = (mc(\frac{u(k/y)}{h\mu_I})^{\theta}h(sh^G)^{\alpha_G})^{1/(1-\theta-\alpha_G)}$$

Once y is known, i, c and k can be trivially recovered.

$$w = (1-\theta)y/h$$

$$\zeta = \frac{1-h}{c}\frac{w}{\mu}\frac{1-\tilde{\beta}\frac{b^c}{\mu_{z^*}}}{1-\frac{b^c}{\mu_{z^*}}}h$$

$$\xi = d(c(1-\frac{b^c}{\mu_{z^*}}))^{-\sigma}(1-h)^{\zeta(1-\sigma)}(1-\tilde{\beta}\frac{b^c}{\mu_{z^*}})$$

8.3 Supplementary

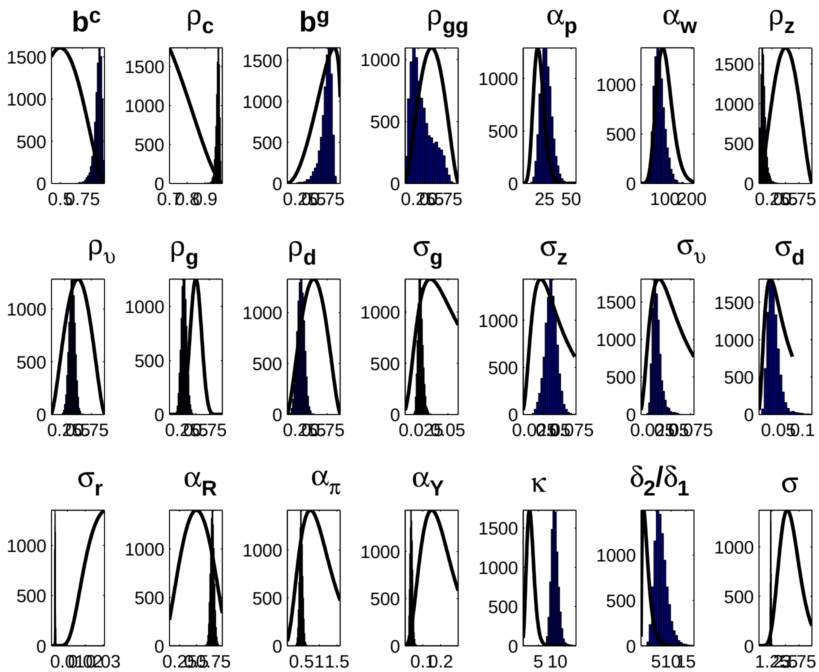

Figure 7: Model with deep habits: Prior and posterior distributions.

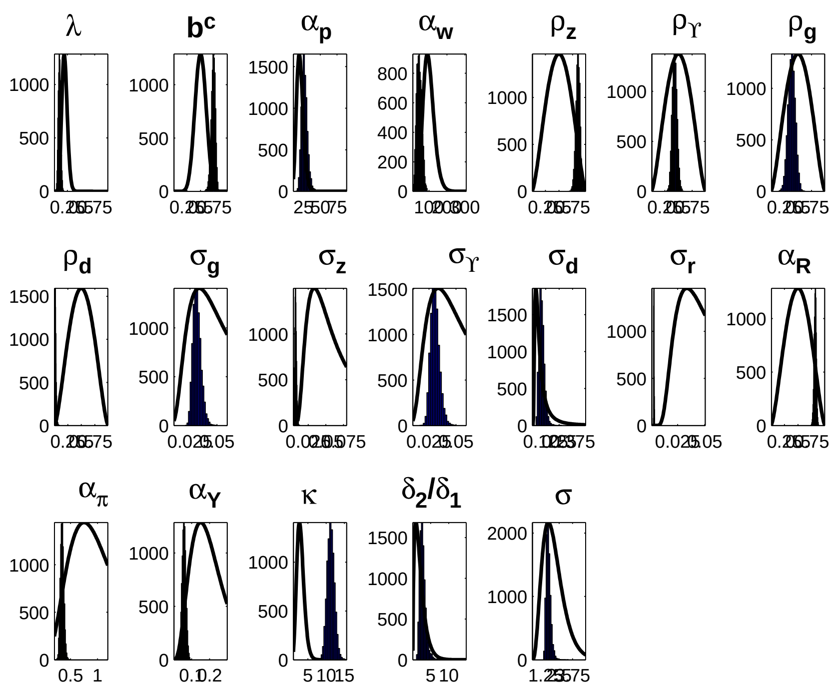

Figure 8: Model with rule-of-thumb consumers: Prior and posterior distributions .

Notes. Black curve is the prior distribution, blue histogram is the posterior distribution.

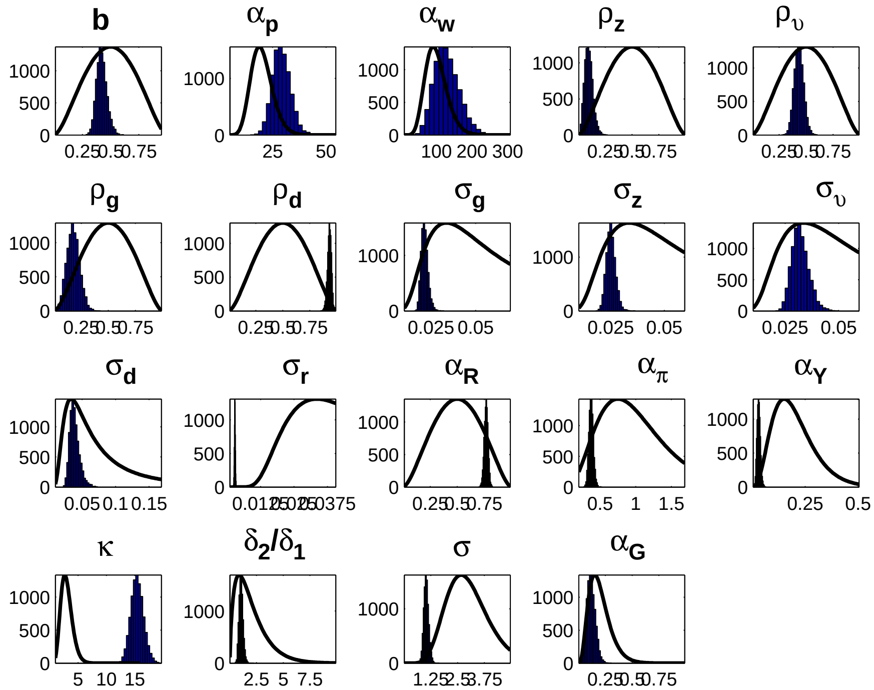

Figure 9: Model with productive government spending: Prior and posterior distributions.

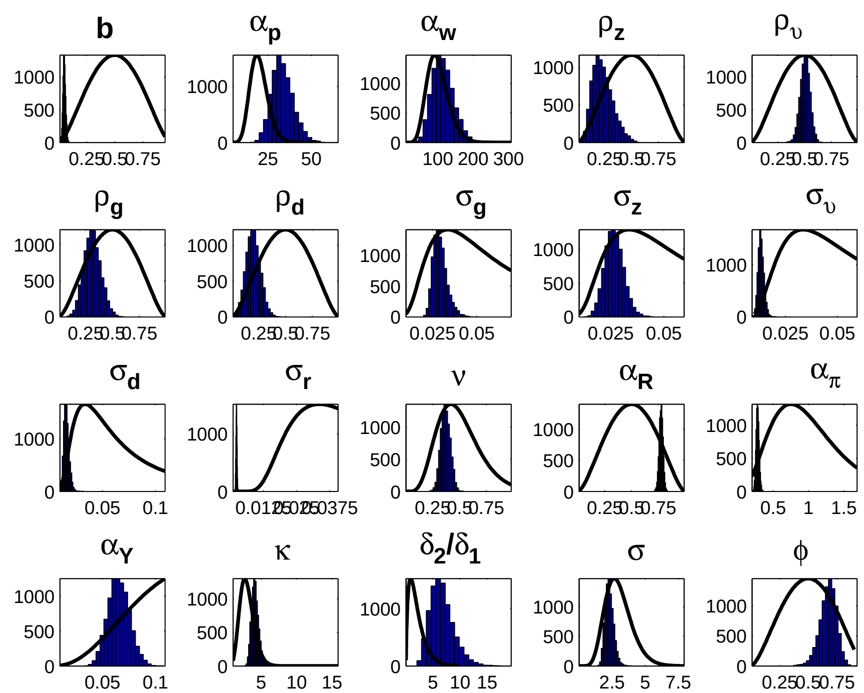

Figure 10: Model with government spending in the utility function: Prior and posterior distributions.

Notes. Black curve is the prior distribution, blue histogram is the posterior distribution.

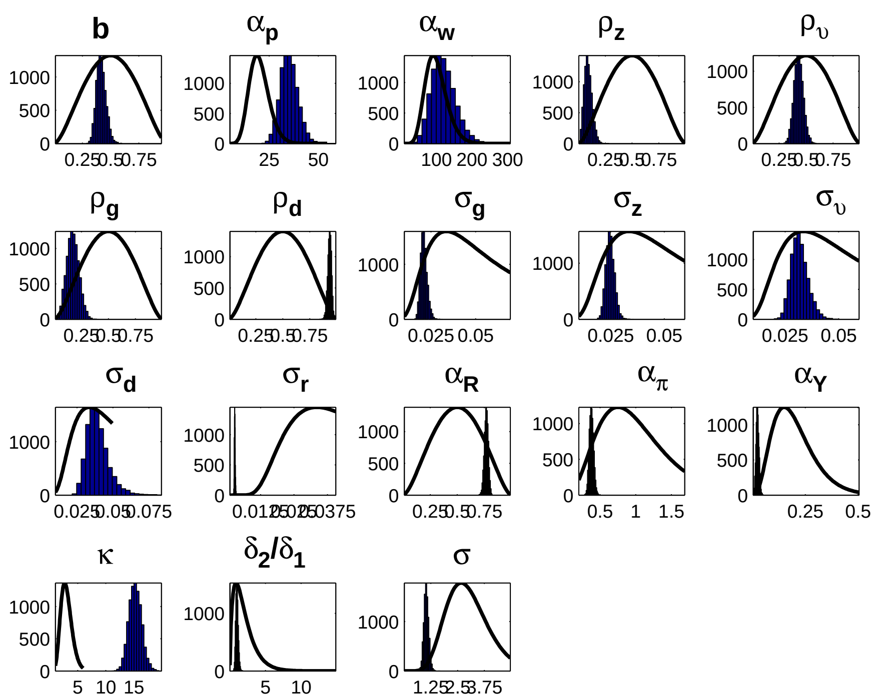

Figure 11: Baseline model: Prior and posterior distributions.

Notes. Black curve is the prior distribution, blue histogram is the posterior distribution.

Table 8: Parameter estimates in models with separable utility. Part I

Parameter	Prior distribution		Deep Habits	ROT	G in Utility	Productive G
	Type	Mean (st.d.)	Mean (st.d.)	Mean (st.d.)	Mean (st.d.)	Mean (st.d)
b^c	B	0.5	0.9033	-	-	-
		(0.2)	(0.0466)	(-)	(-)	(-)
ρ^c	B	0.5	0.9793	-	-	-
		(0.2)	(0.0055)	(-)	(-)	(-)
b^g	B	0.5	0.6691	-	-	-
		(0.2)	(0.0853)	(-)	(-)	(-)
ρ^{gg}	B	0.5	0.7052	-	-	-
		(0.2)	(0.1567)	(-)	(-)	(-)
λ	B	0.2	-	0.1451	-	-
		(0.1)	(-)	(0.0281)	(-)	(-)
ϕ^b	I	0.3	-	0.1713	-	-
		(0.5)	(-)	(0.1080)	(-)	(-)
ϕ^g	I	0.5	-	0.5380	-	-
		(0.2)	(-)	(0.1726)	(-)	(-)
μ	G	0.5	-	-	0.6059	-
		(0.2)	(-)	(-)	(0.0699)	(-)
b	B	0.5	-	0.7354	0.2469	0.4283
		(0.2)	(-)	(0.0421)	(0.0175)	(0.0394)
α_p	G	20.0	37.6657	37.5540	37.5277	46.5457
		(5.0)	(6.5999)	(5.4777)	(5.9640)	(6.5625)
α_w	G	100.0	136.1792	104.6959	69.7475	97.7371
		(30.0)	(32.8072)	(30.4888)	(25.4067)	(34.8347)
κ	G	3.0	10.0784	10.6580	13.9639	14.5407
		(1.0)	(1.4028)	(1.0368)	(1.2471)	(1.1536)
δ_2/δ_1	G	2.0	4.7279	2.8379	1.4314	1.1232
		(1.5)	(1.7877)	(0.9757)	(0.3870)	(0.2117)
ζ	G	1.0	1.1874	0.7609	0.6498	0.6653
		(0.2)	(0.2378)	(0.1524)	(0.1342)	(0.1366)
α_R	B	0.5	0.7480	0.8053	0.7725	0.7670
		(0.2)	(0.0338)	(0.0219)	(0.0193)	(0.0186)
α_π	G	1.0	0.4878	0.3142	0.3842	0.4070
		(0.5)	(0.0441)	(0.0301)	(0.0338)	(0.0335)
α_Y	G	0.2	0.0380	0.0560	0.0120	0.0201
		(0.1)	(0.0099)	(0.0113)	(0.0046)	(0.0065)

Notes. Table shows prior distributions and Bayesian estimates of parameters across different models. Notation in the second columns is as follows: B = beta, G = gamma, I = inverse gamma distributions. Estimates are presented as mean values and standard deviations across the last 900,000 out of 1 million elements of a Markov chain generated using the Metropolis Hastings algorithm. Kalman filter is used to evaluate the likelihood of the data.

Table 9: Parameter estimates in models with additively separable utility. Part II

Parameter	Prior distribution		Deep Habits	ROT	G in Utility	Productive G
	Type	Mean (st.d.)	Mean (st.d.)	Mean (st.d.)	Mean (st.d.)	Mean (st.d)
ρ_z	B	0.5	0.2698	0.8908	0.3293	0.1723
		(0.2)	(0.0807)	(0.0312)	(0.0525)	(0.0488)
ρ_v	B	0.5	0.3135	0.4337	0.4368	0.4352
		(0.2)	(0.0648)	(0.0461)	(0.0433)	(0.0417)
ρ_g	B	0.5	0.1788	0.3921	0.2135	0.1884
		(0.2)	(0.0599)	(0.0623)	(0.0634)	(0.0600)
ρ_d	B	0.5	0.3318	0.0252	0.9440	0.9421
		(0.2)	(0.0582)	(0.0147)	(0.0181)	(0.0170)
σ_g	I	0.1	0.0205	0.0324	0.0208	0.0216
		(1.0)	(0.0020)	(0.0037)	(0.0020)	(0.0020)
σ_z	I	0.1	0.0223	0.0063	0.0238	0.0216
		(1.0)	(0.0049)	(0.0010)	(0.0027)	(0.0021)
σ_v	I	0.1	0.0415	0.0294	0.0313	0.0310
		(1.0)	(0.0110)	(0.0041)	(0.0037)	(0.0038)
σ_d	I	0.1	0.0327	0.0673	0.0490	0.0460
		(1.0)	(0.0055)	(0.0150)	(0.0149)	(0.0112)
σ_r	I	0.1	0.0031	0.0030	0.0028	0.0029
		(1.0)	(0.0002)	(0.0002)	(0.0002)	(0.0002)

Notes. Table shows prior distributions and Bayesian estimates of parameters across different models. Notation in the second columns is as follows: B = beta, G = gamma, I = inverse gamma distributions. Estimates are presented as mean values and standard deviations across the last $900,000$ out of 1 million elements of a Markov chain generated using the Metropolis Hastings algorithm. Kalman filter is used to evaluate the likelihood of the data.