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IT'S ALL IN THE PERSISTENCE**

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DEEP VERSUS SUPERFICIAL HABIT: IT'S ALL IN THE PERSISTENCE*

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Abstract

Bayesian estimation is employed to investigate whether deep as opposed to superficial habit improves the fit of a dynamic stochastic general equilibrium model. If the stock of superficial habit features the additional persistence typical of deep habit, the two specifications are virtually as good. Introducing deep habit in public consumption does not improve the model's fit.

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1 Introduction

The assumption that agents form habit in consumption has become a standard feature of dynamic stochastic general equilibrium (DSGE) models (see e.g. the canonical models of Christiano et al., 2005; Smets and Wouters, 2007). Such a feature was introduced on empirical grounds to enable these models to match the hump-shaped response of consumption obtained in empirical exercises employing vector-autoregressions (VARs).

There exist several forms of habit, which in turn affect the model’s equilibrium conditions in different ways. While *internal* habit captures inertia in household’s consumption decisions, *external* habit captures preference interdependence across households (i.e. keeping up with the Joneses). However, as shown by Dennis (2009), up to a first-order approximation of the model, whether habit is internal or external has empirically little effect on its business cycle characteristics.¹ Ravn et al. (2006) introduce in the DSGE literature the idea that agents may form habit not on the overall consumption level, but separately over a continuum of varieties of goods. Whether agents form habit on a composite good – i.e. they exhibit *superficial habit* (SH) – or on categories of goods – known as *deep habit* (DH) – has potentially important consequences for the propagation mechanism of macroeconomic shocks. In fact, whereas in the symmetric equilibrium both habit specifications affect the demand side of the model in the same indistinguishable way, DH also alters the supply side of the model. This occurs because firms incorporate in their decisions that the demand they will face tomorrow is partly a function of the current firm-specific demand they are able to attract today. Regardless of the presence of price stickiness, this in turn implies that the price mark-up exhibits a counter-cyclical behavior, although Jacob (2014) shows that this mechanism is more muted for high levels of price stickiness.²

In this paper, we use Bayesian estimation techniques to determine the extent to which assuming DH as opposed to SH enhance an otherwise standard DSGE model’s ability to fit US data. Assessing these features requires particular care as DSGE models incorporating

¹This is true both for the additive and multiplicative version of habit.

²Mark-ups are counter-cyclical due to the action of two contemporaneous effects: an *intra-temporal effect* (or *price-elasticity effect*) and an *inter-temporal effect*. The intra-temporal effect arises because the price elasticity of demand becomes procyclical and this represents a determinant for the mark-up to become countercyclical, as long as the latter is inversely related to the former. The inter-temporal effect is brought about by the expectation of future sales coupled with the notion that consumers form habit at the variety level. In response to, say, an expansionary demand shock, firms are inclined to give up some of the current per-unit profits – by temporarily lowering their mark-up – in order to expand their customer base and make higher profits in the future. This distinctive feature of deep habit has recently been exploited in several contributions. For instance, Di Pace and Faccini (2012) introduce it in a DSGE model with labor search-match frictions to generate amplification in the response of labor market variables. Leith et al. (2009, 2012) and Cantore et al. (2012) study the implications of deep and/or superficial habit for optimal monetary policy. Cantore et al. (2014a) use deep habit to generate amplification in the case of a fiscal stimulus.

DH typically assume, on one hand, that this is present also in government consumption and, on the other hand, that there is an additional persistence in the stock of habit. Thus, in order to evaluate the individual and joint contribution of each of these issues, and for the sake of robustness, we estimate a battery of four different permutations of a DSGE model with two alternative datasets, and two alternative data transformations, for a total of sixteen estimation rounds.

In the empirical literature there are only a few studies that are tangential to ours. As far as DH is concerned, in the microeconomic literature, Verhelst and Van den Poel (2013) find some evidence of DH formation by estimating a spatial panel model using scanner data from a large European retailer. Ravn et al. (2006) estimate the DH parameters via Generalized Method of Moments (GMM) methods. Zubairy (2014) estimates the DH parameters within the Bayesian estimation of a medium-scale DSGE model. Kormilitsina and Zubairy (2013) compare various mechanisms that may deliver the private consumption crowding-in result in response to a government spending shock. However, they compare, among other things, a model with DH jointly in private and public consumption (including the additional persistence in the stock of habit) with a canonical model with SH only in private consumption and no persistence in the stock of habit.

We perform a systematic likelihood-race-based assessment of each individual model feature. The analysis disentangles the contributions of habit (of either form) in private consumption and of deep habit in government consumption. In addition, it unveils that the additional persistence in the stock of habit proves crucial for our conclusions. In fact, first, if the model accounts for an additional persistence also in the stock of SH, as implemented in the seminal paper of Fuhrer (2000) and widely used in the DH specification, there is no empirical support in favor of the deep over the superficial form of habit. In other words, analogously to what Dennis (2009) finds for internal versus external habit, also DH is virtually as good as SH at fitting the data. Second, the additional persistence in the stock of habit, improves the model's marginal likelihood. Third, introducing deep habit in public consumption do not improve (nor worsen) the fit of the model.

Inspecting impulse response functions helps us rationalize these results. In fact, after introducing the additional persistence in the stock of habit, at the posterior mean of parameter values, all model variants produce very similar responses to all demand and supply shocks with the exception of the government spending shock. This has, however, a small role in the model's variance decomposition.

The remainder of the paper is structured as follows. Section 2 presents the model. Section 3 presents the empirical strategy using Bayesian methods. Section 4 presents the results of the empirical analysis. Finally, Section 5 concludes. Technical details and robustness exercises are appended to the paper.

2 Model

The model builds on the standard DSGE literature. It is an New-Keynesian model with Rotemberg price and wage stickiness, convex investment adjustment costs, variable capital utilization and (deep or superficial) habit formation only in private or also in government consumption.

2.1 Households

A continuum of identical households $j \in [0, 1]$ has preferences over differentiated consumption varieties $i \in [0, 1]$ and derive utility from $(X_t^c)^j$, i.e. a habit-adjusted composite of differentiated consumption goods.

Households exhibit external habit formation in consumption, i.e. they catch up with the Joneses, either on the consumption level of each variety of good (*deep habit*) in the spirit of Ravn et al. (2006), or on the overall level of consumption (*superficial habit*) as in Fuhrer (2000), which is now quite a standard feature of DSGE models.

The consumption composite is given by

$$(X_t^c)^j = \begin{cases} \left[\int_0^1 (C_{it}^j - \tilde{\theta}^c S_{it-1}^c)^{1 - \frac{1}{e_t^P \eta}} di \right]^{\frac{1}{1 - \frac{1}{e_t^P \eta}}} & \text{under deep habit,} \\ \left[\int_0^1 (C_{it}^j)^{1 - \frac{1}{e_t^P \eta}} di \right]^{\frac{1}{1 - \frac{1}{e_t^P \eta}}} - \hat{\theta}^c S_{t-1}^c & \text{under superficial habit,} \end{cases} \quad (1)$$

where $\tilde{\theta}^c \in (0, 1)$ is the degree of deep habit formation on each variety, $\hat{\theta}^c \in (0, 1)$ is the degree of superficial habit formation on aggregate consumption, η is the intratemporal elasticity of substitution, e^P is a price mark-up shock, S_{it-1}^c denotes the stock of habit in the consumption of good i , and S_{t-1}^c denotes the stock of habit in aggregate consumption. The stocks of habit evolve over time according to

$$\begin{aligned} S_{it}^c &= \tilde{\varrho}^c S_{it-1}^c + (1 - \tilde{\varrho}^c) C_{it} && \text{under deep habit,} \\ S_t^c &= \hat{\varrho}^c S_{t-1}^c + (1 - \hat{\varrho}^c) C_t && \text{under superficial habit,} \end{aligned} \quad (2)$$

where $\tilde{\varrho}^c \in (0, 1)$ and $\hat{\varrho}^c \in (0, 1)$ imply persistence in the stocks of habit. While Fuhrer (2000) allows for persistence in the stock of superficial habit in the way described in equation (2), in the vast majority of DSGE models published in the last decade the implicit assumption is that $\hat{\varrho}^c = 0$ and hence $S_t^c = C_t$. On the contrary those DSGE models employing deep habit (see e.g. Zubairy, 2014) allow for persistence in the stock of deep habit formation.

The optimal level of demand for each variety, C_{it}^j , for a given composite is obtained by

minimizing total expenditure $\int_0^1 P_{it} C_{it}^j di$ over C_{it}^j , subject to (1). This leads to

$$C_{it}^j = \begin{cases} \left(\frac{P_{it}}{P_t}\right)^{-e_t^P \eta} (X_t^c)^j + \tilde{\theta}^c S_{it-1}^c & \text{under deep habit,} \\ \left(\frac{P_{it}}{P_t}\right)^{-e_t^P \eta} (X_t^c)^j & \text{under superficial habit,} \end{cases} \quad (3)$$

where P_{it} is the price of variety i , and $P_t \equiv \left[\int_0^1 P_{it}^{1-e_t^P \eta} di\right]^{\frac{1}{1-e_t^P \eta}}$ is the nominal price index. The main difference about deep habit relative to superficial habit is that while in the former case the good-specific demand has a price-elastic component, $\left(\frac{P_{it}}{P_t}\right)^{-e_t^P \eta} (X_t^c)^j$, and a price-inelastic component, $\tilde{\theta}^c S_{it-1}^c$ – which imply a counter-cyclical effect on the price mark-up also in the absence of price stickiness – in the latter case the price-inelastic component is absent, hence the price mark-up is constant in the absence of price stickiness. Multiplying (3) by P_{it} and integrating, real consumption expenditure, C_t^j , can be written as

$$C_t^j = (X_t^c)^j + \Omega_t, \quad (4)$$

where

$$\Omega_t = \begin{cases} \tilde{\theta}^c \int_0^1 \frac{P_{it}}{P_t} S_{it-1}^c di & \text{under deep habit,} \\ 0 & \text{under superficial habit.} \end{cases} \quad (5)$$

Each household j is a monopolistic provider of a differentiated labor service and supplies labor H_t^j to satisfy demand,

$$H_t^j = \left(\frac{w_t^j}{w_t}\right)^{-e_t^W \tilde{\eta}} H_t, \quad (6)$$

where w_t^j is the real wage charged by household j , w_t is the average real wage in the economy, $\tilde{\eta}$ is the intra-temporal elasticity of substitution between labor services, e_t^W is a wage mark-up shock, and H_t is average demand of labor services by firms. Similarly to Zubairy (2014), let us also assume that there is a Rotemberg quadratic cost of adjusting the nominal wage, W_t^j , appearing in the households' budget constraint, which is zero at the steady state, and that this is proportional to the average real value of labor services as in Furlanetto (2011),

$$\frac{\xi^W}{2} \left(\frac{W_t^j}{W_{t-1}^j} - \bar{\Pi}\right)^2 w_t H_t = \frac{\xi^W}{2} \left(\frac{w_t^j}{w_{t-1}^j} \Pi_t - \bar{\Pi}\right)^2 w_t H_t, \quad (7)$$

where ξ^W is the wage adjustment cost parameter, $\Pi_t \equiv \frac{P_t}{P_{t-1}}$ is the gross inflation rate, $\bar{\Pi}$ is its value at the steady state and w_t is the average real wage.

Households hold K_t^j capital holdings, evolving according to

$$K_{t+1}^j = (1 - \delta)K_t^j + e_t^I I_t^j \left[1 - S \left(\frac{I_t^j}{I_{t-1}^j} \right) \right], \quad (8)$$

where δ is the capital depreciation rate, I_t^j is investment, $S(\cdot)$ represents an investment adjustment cost satisfying $S(1) = S'(1) = 0$ and $S''(1) > 0$, and e_t^I is an investment-specific technology shock. Households can also control the utilization rate of capital. In particular using capital at rate u_t^j entails a cost of $a(u_t^j) K_t^j$ units of composite good, satisfying $a(u) = 0$, where u is the steady-state utilization rate, conventionally assumed to be equal to unity. Investment is also a composite of goods, i.e. $I_t^j = \left[\int_0^1 (I_{it}^j)^{1 - \frac{1}{e_t^P \eta}} di \right]^{\frac{1}{1 - \frac{1}{e_t^P \eta}}}$, but does not feature habit formation. Expenditure minimization leads to the optimal level of demand of private investment goods for each variety i ,

$$I_{it}^j = \left(\frac{P_{it}}{P_t} \right)^{-e_t^P \eta} I_t^j. \quad (9)$$

Households buy consumption goods, C_t^j ; pay a lump-sum tax net of government transfers, τ_t^L ; invest in investment goods, I_t^j and nominal private bond holdings, B_t^j ; bear the wage adjustment cost defined in equation (7) as well as the capital utilization cost $a(u_t^j) K_t^j$; and receive the hourly wage, w_t^j , the rental rate R_t^K on utilized capital $u_t^j K_t^j$, the return on nominal private bond holdings, R_t , and firms' profits, $\int_0^1 J_{it} di$, hence their budget constraint reads as

$$\begin{aligned} (X_t^c)^j + \Omega_t + I_t^j + \tau_t^L + \frac{\xi^W}{2} \left(\frac{w_t^j}{w_{t-1}^j} \Pi_t - \bar{\Pi} \right)^2 H_t + a(u_t^j) K_t^j + \frac{B_t^j}{P_t} = \\ w_t^j H_t^j + R_t^K u_t^j K_t^j + \frac{R_{t-1} B_{t-1}^j}{P_t} + \int_0^1 J_{it} di, \end{aligned} \quad (10)$$

Households' inter-temporal utility maximization problem is

$$\max_{\{X_t^j, K_{t+1}^j, u_t^j, I_t^j, B_{t+1}^j, w_t^j\}} E_t \sum_{s=0}^{\infty} e_{t+s}^B \beta^{t+s} U((X_{t+s})^j, 1 - H_{t+s}^j), \quad (11)$$

where $\beta \in (0, 1)$ is the discount factor, e_t^B is a preference shock, and $U(\cdot)$ is a well-behaved instantaneous utility function, subject to constraints (6), (8) and (10).

At the symmetric equilibrium, the first-order condition (FOC) with respect to (w.r.t.) the private consumption composite X_t^j implies that the Lagrange multiplier on the house-

hold's budget constraint (10) is equal to $\Lambda_t = U_{X^c,t}$, where $U_{X^c,t}$ is the marginal utility of consumption. Let $\Lambda_t^j Q_t^j$ be the multiplier on the capital accumulation equation (8), and Q_t^j represent Tobin's Q . Then, the FOC w.r.t. capital, K_{t+1}^j , implies

$$Q_t = E_t \left\{ D_{t,t+1} \left[u_{t+1} R_{t+1}^K - a(u_{t+1}) + (1 - \delta) Q_{t+1} \right] \right\}, \quad (12)$$

where $D_{t,t+1} \equiv \beta E_t \left[\frac{e_{t+1}^B U_{X^c,t+1}}{e_t^B U_{X^c,t}} \right]$ is the stochastic discount factor. The FOC w.r.t. u_t implies that the cost of marginally increasing the utilization rate of capital is equal to the return of capital itself, $a'(u_t) = R_t^K$, while the FOC w.r.t. investment, I_t^j , yields

$$e_t^I Q_t \left(1 - S \left(\frac{I_t}{I_{t-1}} \right) - S' \left(\frac{I_t}{I_{t-1}} \right) \frac{I_t}{I_{t-1}} \right) + E_t \left(e_{t+1}^I D_{t,t+1} Q_{t+1} S' \left(\frac{I_{t+1}}{I_t} \right) \left(\frac{I_{t+1}}{I_t} \right)^2 \right) = 1,$$

and the FOC w.r.t. private bond holdings delivers the Euler equation,

$$1 = E_t \left[D_{t,t+1} \frac{R_t}{\Pi_{t+1}} \right]. \quad (13)$$

Finally the FOC w.r.t w_t delivers the wage setting equation, which at the symmetric equilibrium reads as

$$(e_t^W \tilde{\eta} - 1) w_t - e_t^W \tilde{\eta} \frac{w_t}{\tilde{\mu}_t} + \xi^W (\Pi_t^W - \bar{\Pi}) w_t \Pi_t^W = E_t \left[D_{t,t+1} \xi^W (\Pi_{t+1}^W - \bar{\Pi}) w_{t+1} \Pi_t^W \frac{H_{t+1}}{H_t} \right],$$

where $\tilde{\mu}_t \equiv \frac{w_t}{MRS_t}$ is the wage mark-up and $MRS_t \equiv -\frac{U_{H,t}}{U_{C,t}}$ is the marginal rate of substitution between leisure and consumption.

2.2 Government

Habit can be present also in government consumption. From a technical point of view this is entirely analogous to how these are introduced in private consumption. As shown in Section 2.1 for households' demand of consumption goods, while superficial habit affects only the demand side of the economy, deep habit affects also the supply side of the economy because the firm-specific demand incorporates a price-inelastic term, which is a function of deep habit parameters. As we show below, this is the case also for government's demand. Therefore, deep habit in government consumption affect dynamics also with a standard utility function not featuring government consumption, such as the one employed in this paper, or if government consumption enters linearly.³

³On the contrary, superficial habit in government consumption would only affect dynamics only if the habit-adjusted government consumption composite, X_t^g , entered the utility function multiplicatively. In fact, if government consumption does not enter the utility function – or if it enters linearly – households'

From an intuitive point of view, Ravn et al. (2006) justify the use of deep habit in government consumption by assuming that private households value government spending in goods in a way analogous to private consumption and that households derive habit on consumption of government-provided goods. Alternatively, as in Ravn et al. (2012) and Leith et al. (2009), one can also argue that public goods are local in nature and households care about the provision of individual public goods in their constituency relative to other constituencies. For example, controversies over “post-code lotteries” in health care and other local services (Cummins et al., 2007) and comparisons of regional per capita government spending levels (MacKay, 2001) suggest that households care about their local government spending levels relative to those in other constituencies.

In each period t , the government allocates spending $P_t G_t$ over differentiated goods sold by firms in a monopolistic market to maximize the quantity of a habit-adjusted composite good:

$$X_t^g = \left[\int_0^1 (G_{it} - \tilde{\theta}^g S_{it-1}^g)^{1 - \frac{1}{e_t^P \eta}} di \right]^{\frac{1}{1 - \frac{1}{e_t^P \eta}}}, \quad (14)$$

subject to the budget constraint $\int_0^1 P_{it} G_{it} di \leq P_t G_t$, where $\tilde{\theta}^g$ is the degree of deep habit formation in government spending and S_{it-1}^g denotes the good-specific stock of habit for this expenditure, which evolve as

$$S_{it}^g = \tilde{\rho}^g S_{it-1}^g + (1 - \tilde{\rho}^g) G_{it}, \quad (15)$$

and exhibits persistence $\tilde{\rho}^g$. At the optimum,

$$G_{it} = \left(\frac{P_{it}}{P_t} \right)^{-e_t^P \eta} X_t^g + \tilde{\theta}^g S_{it-1}^g. \quad (16)$$

Aggregate real government consumption, G_t , is an exogenous process and the government budget constraint equates government spending to lump-sum taxes, $G_t = \tau_t^L$. The standard case of no habit in government consumption is obtained by setting $\tilde{\theta}^g = \tilde{\rho}^g = 0$.

2.3 Firms

A continuum of monopolistically competitive firms indexed by $i \in [0, 1]$ rents capital services, \tilde{K}_{it} , and hires labor, H_{it} to produce differentiated goods Y_{it} with convex technology $F(A_t, H_{it}, \tilde{K}_{it})$, where A_t is a labor-augmenting technology shock, which are sold at price

first-order conditions will not depend on X_t^g as well as those of the firms. Only aggregate government consumption, G_t (typically an exogenous process), will affect dynamics through the economy’s resource constraint and the government budget constraint. Utility-enhancing government consumption is beyond the scope of this paper.

P_{it} . Firms face quadratic price adjustment costs $\frac{\xi^P}{2} \left(\frac{P_{it}}{P_{it-1}} - 1 \right)^2 Y_t$, as in Rotemberg (1982) – where parameter ξ measures the degree of price stickiness – and maximize the flow of discounted profits,

$$J_{it} = E_t \left\{ \sum_{s=0}^{\infty} D_{t,t+s} \left[\begin{aligned} & \frac{P_{it+s}}{P_{t+s}} (C_{it+s} + G_{it+s} + I_{it+s}) \\ & - \frac{W_{it+s}}{P_{t+s}} H_{it+s} - R_{t+s}^K \tilde{K}_{it+s} - \frac{\xi}{2} \left(\frac{P_{it+s}}{P_{it+s-1}} - 1 \right)^2 Y_t \end{aligned} \right] \right\}. \quad (17)$$

Under deep habit, the discounted profits in equation (17) have to be maximized w.r.t. \tilde{K}_{it} , H_{it} , C_{it} , S_{it}^c , G_{it} , S_{it}^g and P_{it} subject to the following firm-specific demands for good i :

$$C_{it} = \left(\frac{P_{it}}{P_t} \right)^{-e_t^P \eta} X_t^c + \tilde{\theta}^c S_{it-1}^c, \quad (18)$$

$$G_{it} = \left(\frac{P_{it}}{P_t} \right)^{-e_t^P \eta} X_t^g + \tilde{\theta}^g S_{it-1}^g, \quad (19)$$

$$I_{it} = \left(\frac{P_{it}}{P_t} \right)^{-e_t^P \eta} I_t, \quad (20)$$

obtained integrating equations (3), (16), and (9), respectively across j , along the law of motions of the stocks of habit (2) and (15), and the firm's resource constraint,

$$C_{it+s} + G_{it+s} + I_{it+s} = F(A_t, H_{it}, \tilde{K}_{it}) - FC = Y_{it}, \quad (21)$$

where FC are fixed production costs, set to ensure that the free entry condition of long-run zero profits is satisfied. The corresponding first-order conditions for this problem, evaluated at the symmetric equilibrium, are:

$$R_t^K = MC_t F_{\tilde{K},t}, \quad (22)$$

$$\frac{W_t}{P_t} = MC_t F_{H,t}, \quad (23)$$

$$\nu_t^c = 1 - MC_t + (1 - \varrho^c) \lambda_t^c, \quad (24)$$

$$\lambda_t^c = E_t D_{t,t+1} (\theta^c \nu_{t+1}^c + \varrho^c \lambda_{t+1}^c), \quad (25)$$

$$\nu_t^g = 1 - MC_t + (1 - \varrho^g) \lambda_t^g, \quad (26)$$

$$\lambda_t^g = E_t D_{t,t+1} (\theta^g \nu_{t+1}^g + \varrho^g \lambda_{t+1}^g), \quad (27)$$

$$\begin{aligned} & C_{it} + G_{it} - e_t^P \eta (\nu_t^c X_t^c + \nu_t^g X_t^g) + (1 - e_t^P \eta) I_t + e_t^P \eta MC_t I_t \\ & - \xi^P (\Pi_t - 1) \Pi_t Y_t + \xi^P E_t \{ D_{t,t+1} [(\Pi_{t+1} - 1) \Pi_{t+1}] Y_{t+1} = 0 \}. \end{aligned} \quad (28)$$

Variables MC_t , ν_t^c , λ_t^c , ν_t^g , λ_t^g are the Lagrange multipliers associated with constraints (21), (18), (2), (19) and (15), respectively.

Under superficial habit, the evolution of the stocks of habit is not relevant for firms as it can be seen by integrating equations (3) and (16) across j . In addition, $C_{it} = \left(\frac{P_{it}}{P_t}\right)^{-e_t^P \eta} X_t^c = \left(\frac{P_{it}}{P_t}\right)^{-e_t^P \eta} C_t$ and $G_{it} = \left(\frac{P_{it}}{P_t}\right)^{-e_t^P \eta} X_t^g = \left(\frac{P_{it}}{P_t}\right)^{-e_t^P \eta} G_t$. As a result, equations (18), (19) and (20) collapse to the standard Dixit-Stiglitz firm-specific demand,

$$Y_{it} = C_{it+s} + G_{it+s} + I_{it+s} = \left(\frac{P_{it}}{P_t}\right)^{-e_t^P \eta} Y_t. \quad (29)$$

In this case, the discounted profits in equation (17) can simply be maximized w.r.t. K_{it+s}^p , H_{it+s} , and P_{it+s} subject to the resource constraint (21), taking (29) into account. As a result, equilibrium conditions (22) and (23) remain unchanged relative to the deep-habit case, while (24)-(28) collapse to a standard price-setting equation under Rotemberg adjustment costs,

$$1 - e_t^P \eta + \frac{e_t^P \eta}{\mu_t} - \xi^P (\Pi_t - 1) \Pi_t + \xi^P E_t \left[D_{t,t+1} (\Pi_{t+1} - 1) \Pi_{t+1} \frac{Y_{t+1}}{Y_t} \right] = 0. \quad (30)$$

In both cases of deep and superficial habit, MC_t is the shadow value of output and represents the firm's real marginal cost. Let MC_t^n denote the nominal marginal cost. The gross mark-up charged by final good firm i can be defined as $\mu_{it} \equiv P_{it}/MC_t^n = \frac{P_{it}}{P_t} / \frac{MC_t^n}{P_t} = p_{it}/MC_t$, where $p_{it} = \frac{P_{it}}{P_t}$. In the symmetric equilibrium all final good firms charge the same price, $P_{it} = P_t$, hence the relative price is unity, $p_{it} = 1$. It follows that, in the symmetric equilibrium, the mark-up is simply the inverse of the marginal cost. In Appendix (A) we analytically show the effects that deep habit have on countercyclical responses of the price mark-up to aggregate demand shocks in a simplified version of the model.⁴

2.4 Monetary policy

Monetary policy is set according to a Taylor-type interest-rate rule,

$$\log \left(\frac{R_t}{\bar{R}} \right) = \rho_r \log \left(\frac{R_{t-1}}{\bar{R}} \right) + (1 - \rho_r) \left[\rho_\pi \log \left(\frac{\Pi_t}{\bar{\Pi}} \right) + \rho_y \log \left(\frac{Y_t}{Y_t^f} \right) \right] + \epsilon_t^M, \quad (31)$$

⁴From (A.1) the demand function facing each individual firm features an additive price-inelastic term. It follows that, in addition to the internal optimum we use in our set-up, there arises the possibility of an alternative equilibrium in which the monopolistic firm sets an infinite price. However Schmitt-Grohé and Uribe (2007) show that if consumers have good-specific subsistence points, this strategy is suboptimal for the firm. But in the absence of such subsistence points (as in our model), whether one can rule out this alternative equilibrium remains an open question.

where Y_t^f is the level of output that would prevail in the flexible-price benchmark, ρ_r is the interest rate smoothing parameter, ρ_π and ρ_y are the monetary responses to inflation and the output gap, respectively, and ϵ_t^M is a mean zero, i.i.d. monetary policy shock with standard deviation σ^M .

2.5 Equilibrium

In equilibrium all markets clear. The model is completed by the resource constraint,

$$Y_t = C_t + I_t + G_t + \frac{\xi^P}{2} (\Pi_t - 1)^2 Y_t + \frac{\xi^W}{2} (\Pi_t^W - \bar{\Pi})^2 w_t H_t + a(u_t) K_t, \quad (32)$$

and the following autoregressive processes for exogenous shocks:

$$\log\left(\frac{\varkappa_t}{\bar{\varkappa}}\right) = \rho_\varkappa \log\left(\frac{\varkappa_t}{\bar{\varkappa}}\right) + \epsilon_t^\varkappa, \quad (33)$$

where $\varkappa = \{A, G, e^B, e^P, e^W, e^I\}$, ρ_\varkappa are autoregressive parameters and ϵ_t^\varkappa are mean zero, i.i.d. random shocks with standard deviations σ^\varkappa . The symmetric equilibrium of identical households and firms is set out in Appendix B.

2.6 Functional forms

The utility function specializes as $U(X_t, 1 - H_t) = \frac{[X_t^{(1-\varrho)}(1-H_t)^\varrho]^{1-\sigma_c} - 1}{1-\sigma_c}$, where $\sigma_c > 0$ is the coefficient of relative risk aversion, and ω is a preference parameter that determine the relative weight of leisure and the consumption composite in utility.

Investment adjustment costs are quadratic as in Christiano et al. (2005): $S\left(\frac{I_t}{I_{t-1}}\right) = \frac{\gamma}{2} \left(\frac{I_t}{I_{t-1}} - 1\right)^2$, $\gamma > 0$, which satisfy $S(1) = S'(1) = 0$ and $S''(1) = \gamma > 0$, where γ represents the elasticity of the marginal investment adjustment cost to changes in investment.

The cost of capital utilization is $a(u_t) = \gamma_1 (u_t - 1) + \frac{\gamma_2}{2} (u_t - 1)^2$. Following the literature, we normalize the steady-state utilization rate to unity, $u = 1$. It follows that $a(u) = 0$, $a'(u) = \gamma_1$, $a''(u) = \gamma_2$ and the elasticity of the marginal utilization cost to changes in the utilization rate is $\frac{a''(u)u}{a'(u)} = \frac{\gamma_2}{\gamma_1} \equiv \sigma_u$, which is what we estimate.

The production function is a conventional Cobb-Douglas: $F(A_t, H_t, \tilde{K}_t) = (A_t H_t)^\alpha \tilde{K}_t^{1-\alpha}$, where, $\tilde{K}_t \equiv u_t K_t$, and α represents the labor share of income.

3 Bayesian estimation

3.1 Data

The model is log-linearized around a non-stochastic steady state and estimated by Bayesian methods using US quarterly data over the Great Moderation period 1984:Q1-2008:Q3.⁵ Although observations on all variables are available at least from 1955 onwards, we focus on this period because it is characterized by a single monetary policy regime.⁶ Extending the sample period to include the Great Recession may yield biased estimates due to the nonlinearities induced by the fact that the nominal interest rate in the US reached the zero lower bound (Galí et al., 2011). Seven observables correspond to the seven structural shocks present in the model: hours of work, private consumption, private investment, government spending, real wage, inflation, nominal interest rate. Data sources and transformations are discussed in Appendix C. Here we want to point out that, with the exception of private consumption and investment, the construction of the remaining five observables is standard and closely follows the dataset of Smets and Wouters (2007). The construction of private consumption and investment varies in the literature. While Smets and Wouters (2007) and Mountford and Uhlig (2009), amongst others, use private consumption expenditure (BEA Table 1.1.5) and private fixed investment (BEA Table 5.3.5) for consumption and investment, respectively; other authors in the literature, such as Galí et al. (2007) and Zubairy (2014), amongst others, define private consumption only on non-durable goods and services and include consumption of durables in the series of private investment. Hence, in addition to the “standard” (STD) dataset as in Smets and Wouters (2007), we construct an “alternative” (ALT) dataset where the data for private investment include both gross private domestic investment (BEA Table 1.1.5) and private consumption expenditure in durable goods, while private consumption only features consumption expenditure in non-durables and services. Given that one of our aims is to compare different specifications of habit formation for consumption we deem appropriate to use both data specifications in order to check the robustness of our results.

3.2 Data filtering and measurement equations

Various authors (see Canova, 2013, Canova and Ferroni, 2011, Ferroni, 2011, Castelnuovo, 2013, Gorodnichenko and Ng, 2010 and Delle Chiaie, 2009, amongst others) have dis-

⁵We prefer to opt for Bayesian estimation as opposed to impulse-response matching as identification issues are more likely to arise with the latter. In particular Canova and Sala (2009) demonstrate that even in the absence of invertibility problems, identification deficiencies may make impulse response matching exercises problematic and inference erratic.

⁶We performed all the estimations present in this paper with the extended datasets going back to 1955 and the main results of the paper are unchanged. Results are available upon request.

cussed and showed how the arbitrariness of the choice of the statistical filter, applied to detrend macroeconomic times series, might have strong effects on the structural estimation of DSGE models. Therefore, for the sake of robustness, we apply two different filters to the observables in the estimation. In particular, as far as the real variables in the observables are concerned, we consider (i) the first difference filter (FD), which emphasizes high frequency movements and dampen medium run and business cycles fluctuations, and (ii) the Hodrick-Prescott (HP) (1600) filter that wipes out the fluctuations with periodicity larger than 32 quarters and leave fluctuations with shorter horizons unchanged. Hence, for each model variant presented below, we perform four different estimations using two dataset (STD, ALT) and two filters (FD, HP(1600)).

The corresponding measurement equations, for the FD case, are:

$$\begin{aligned}
\Delta c_{obs,t}^i &= \Delta \log(c_t^c) + t, \\
\Delta i_{obs,t}^i &= \Delta \log(i_t^c) + t, \\
\Delta g_{obs,t} &= \Delta \log(g_t^c) + t, \\
\Delta w_{obs,t} &= \Delta \log(w_t^c) + t, \\
h_{obs,t} &= \log(h_t^c), \\
\pi_{obs,t} &= \log(\pi_t^c) + t_\pi, \\
rn_{obs,t} &= \log(r_{n,t}^c) + t_{rn},
\end{aligned}$$

where $i = STD, ALT$, $x_{obs,t}$ is the observable corresponding to variable X in the DSGE model, and $\log(x^c)$ corresponds to the log-deviation from steady state of variable X in the model, where t , t_π and t_{rn} are constants that capture the mean of the observables. The equation of hours does not feature a constant as we demean the series prior to estimation.

For the HP filter case, calling \tilde{x}_{obs} the HP filtered series for x , the measurement equations are:

$$\begin{aligned}
\tilde{c}_{obs,t}^i &= \log(c_t^c), \\
\tilde{i}_{obs,t}^i &= \log(i_t^c), \\
\tilde{g}_{obs,t} &= \log(g_t^c), \\
\tilde{w}_{obs,t} &= \log(w_t^c), \\
h_{obs,t} &= \log(h_t^c), \\
\pi_{obs,t} &= \log(\pi_t^c) + t_\pi, \\
rn_{obs,t} &= \log(r_{n,t}^c) + t_{rn}.
\end{aligned}$$

Model	SH in C	DH in C	DH in G	No $\hat{\rho}^c$ in SH
A	✓			
B		✓		
C		✓	✓	
D	✓			✓

Table 1: Models specifications

3.3 Model battery

The aims of our estimation exercise can be summarized in two questions:

1. Conditional on the presence of the additional persistence in the stock of habit, does deep habit in private consumption fit the data better than superficial habit?
2. Does deep habit in government consumption improve the fit of the model?

In order to provide an answer to these questions we set-up and estimate a battery of modifications of the model in order to compare log-likelihoods and their predictions. The various model specifications considered are summarized in Table 1.

Model A presents superficial habit in private consumption, Model B features deep habit only in private consumption and Model C has deep habit in both private and public consumption.⁷ Model D is a variant of the model with superficial habit in private consumption where we set the persistence in the stock of habit $\hat{\rho}^c = 0$, as common in recent standard specifications of superficial habit.

3.4 Estimation procedure

The joint posterior distribution of the estimated parameters is obtained in two stages. First, the posterior mode and the Hessian matrix are obtained via standard numerical optimization routines.⁸ The Hessian matrix is then used in the Metropolis-Hastings (MH) algorithm to generate a sample from the posterior distribution. Two parallel chains are used in the Monte-Carlo-Markov-Chain Metropolis-Hastings (MCMC-MH) algorithm. For each chain, 150,000 random draws from the posterior density are obtained via the MCMC-MH algorithm (although the first 20% ‘burn-in’ observations are discarded), with the variance-covariance matrix of the perturbation term in the algorithm being adjusted in order to obtain reasonable acceptance rates (between 20%-40%). For each model the marginal likelihood is calculated using the modified harmonic mean estimator.

⁷We do not consider the case in which there is superficial habit in both private and public consumption because it can be showed that, in absence of government consumption in the utility function, this would be equivalent to model A as explained in Section 2.2.

⁸We use the Sims solver available in Dynare.

Calibrated parameter	Symbol	Value
Subjective discount factor	β	0.99
Capital depreciation rate	δ	0.025
Labor share of income	α	0.67
Government-expenditure-output ratio	g_y	0.20
Intratemporal elasticity of substitution between labour services	$\tilde{\eta}$	21
Targeted steady state relationship		
Hours worked	H	0.33
Price mark-up	μ	1.20

Table 2: Calibrated Parameters

3.5 Calibrated parameters

A number of structural parameters are kept fixed in the estimation procedure, in accordance with the usual practice in the literature (see Table 2). In particular, conventional values are used for the subjective discount factor, $\beta = 0.99$, which implies an annual real interest rate of 4%; the capital depreciation rate, $\delta = 0.025$, which implies an annual depreciation of 10%; the Cobb-Douglas parameter, $\alpha = 0.67$, which corresponds to a labor share of income of 2/3; and the steady-state share of government consumption in GDP, $g_y = 0.20$. As regards the intratemporal elasticity of substitution between labor services, we follow Zubairy (2014) and set $\tilde{\eta} = 21$.

The steady-state values of hours worked, H , and the price mark-up, μ , are jointly determined by the relative weight of leisure in the utility function, ϱ , the intratemporal elasticity of substitution in the goods market, η , and by whether habit is deep or superficial (together with the degree of habit formation). Hence, we set fixed steady-state targets of $H = 0.33$ and $\mu = 1.20$, such that households' members work on average 1/3 of their time and firms earn a price mark-up of 20% over the marginal cost, while ϱ and η adjust to accommodate these targets. A similar strategy applies to fixed costs in production, FC , which are set to satisfy the zero-profit free entry condition of in the long run.

3.6 Priors

The choice of priors for the estimation of structural parameters and shocks is presented in Table 3. For parameters commonly found in DSGE models we use priors in line with Smets and Wouters (2007). In particular, as regards the shocks, we assume a beta distribution for the autoregressive parameters and an inverse gamma distribution for the standard deviations. For investment adjustment costs, variable capital utilization, Rotemberg price and wage adjustment costs we assume a normal distribution centered around values found in the literature. For the deep and superficial habit parameters we assume a beta distribution

Parameters		Prior		
		Functional Form	Mean	Std
AR technology	ρ_A	beta	0.5	0.2
AR government spending	ρ_G	beta	0.5	0.2
AR investment specific	ρ_I	beta	0.5	0.2
AR preference	ρ_B	beta	0.5	0.2
AR price mark-up	ρ_P	beta	0.5	0.2
AR wage mark-up	ρ_W	beta	0.5	0.2
Investment adjustment costs	γ	normal	2	0.5
Variable capital utilization	σ_u	normal	2.5	0.5
Relative risk aversion	σ_c	normal	1.5	0.375
Persistence of habit in G	$\tilde{\rho}^G$	beta	0.7	0.1
Degree of habit in G	$\tilde{\theta}^G$	beta	0.7	0.1
Persistence of habit in C	$\tilde{\rho}^C$ or $\hat{\rho}^C$	beta	0.7	0.1
Degree of habit in C	$\tilde{\theta}^C$ or $\hat{\theta}^C$	beta	0.7	0.1
Rotemberg prices	ξ	normal	30	0.5
Rotemberg wages	ξ^W	normal	100	10
Inflation weight in Taylor rule	ρ_π	normal	1.5	0.25
Interest rate smoothing	ρ_r	beta	0.75	0.1
Output gap weight in Taylor rule	ρ_y	beta	0.125	0.05
Average real t	t	normal	0.465	0.1
Average inflation	t_π	normal	0.638	0.1
Average interest rate	t_{rn}	normal	1.352	0.1
Shocks				
Technology	ϵ^A	inv. gamma	0.1	2
Government spending	ϵ^G	inv. gamma	0.5	2
Monetary Policy	ϵ^M	inv. gamma	0.1	2
Preference	ϵ^B	inv. gamma	0.1	2
Investment-specific	ϵ^I	inv. gamma	0.1	2
Price Mark-up	ϵ^W	inv. gamma	0.1	2
Wage Mark-up	ϵ^P	inv. gamma	0.1	2

Table 3: Priors used in the estimation

centered around the common value of 0.70. The parameters of the Taylor rule have a normal prior for the inflation weight and a beta prior for the interest rate smoothing and the output gap, following again Smets and Wouters (2007). The constants in the measurement equations have a normal prior centered around the mean of the corresponding observable in the sample period.⁹

⁹For the real variables we assume the same constant in the measurement equations and we take the average of the four series (consumption, investment, real wages and government spending) as prior mean.

Models				
		A	B	D
STD	FD	-593.51	-594.35	-606.03
	HP	-539.97	-538.24	-549.48
ALT	FD	-599.91	-601.69	-607.23
	HP	-545.63	-543.20	-548.20

Table 4: Deep vs superficial habit

4 Results

In what follows we first use marginal likelihoods comparisons across model variants, data sets and data filtering, to answer our empirical questions, then we report the estimates of structural parameters and shocks, and discuss impulse response functions.

4.1 Does deep habit in private consumption fit the data better than superficial habit?

The comparison of deep habit against the more common superficial habit formulation present in the literature is based on a likelihood race across versions of the model differing only by the presence of the two different habit formulations.

We compare three different model specifications, i.e. A, B and D, in order to see if the introduction of deep habit improves the model fit. All three models have habit only in private consumption. Model A and D present SH in consumption and the only difference between the two is the presence (A) or not (D) of the persistence in the stock of SH, $\hat{\rho}^c$. Model B has instead DH in private consumption and the usual specification with persistence in the stock of DH. In Table 4 we present the log-likelihood density of the three model variants under the two data sets and two filtering procedures.

To interpret the marginal log-likelihood (LL) differences we appeal to Jeffries (1996) who judges that a Bayes Factor (BF) of 3-10 is “slight evidence” in favor of model i over j . This corresponds to a LL difference in the range $[\ln 3, \ln 10] = [1.10, 2.30]$. A BF of 10-100 or a LL range of $[2.30, 4.61]$ is “strong to very strong evidence”; a BF over 100 (LL over 4.61) is “decisive evidence”.

Three main points can be highlighted from this first set of results. First, there is clear evidence (more pronounced with the STD dataset) that DH are preferred to SH in their standard formulation (i.e. when $\hat{\rho}^c = 0$) as Model B has a significantly higher LL than Model D. We perform this comparison because the two models exhibit the standard formulations of SH and DH in the literature. However it should be emphasized that this is not a “fair race” as model A has an additional source of persistence. In fact, the

Models			
		B	C
STD	FD	-594.35	-594.70
	HP	-538.2470	-537.92
ALT	FD	-601.69	-602.25
	HP	-543.20	-542.77

Table 5: Habit in government spending?

second point is that Model A and B cannot be ranked in terms of LL as their difference is always less than significant with all four datasets/data transformations. The last point is a consequence of the first two: the SH specification with persistence in the stock of habit (A) is strictly preferred to that without it (D). Hence the first novel result of this paper is that DH does indeed fit the data better than the standard SH specification, but the main reason is the presence of the extra inertia introduced in consumption by the additional persistence in the stock of habit instead of the habit specification itself. Indeed when we introduce the same additional persistence in the SH specification the difference in data fitting becomes statistically insignificant.

4.2 Does deep habit in government consumption improve the fit of the model?

The next question we explore is whether introducing habit in government consumption improves the fit of the model. In particular, we compare the DH model variant with and without DH in government consumption (Models C and B). Results in Table 5 are very robust across datasets and filters and show that having habit in government spending does not improve (nor worsen) the model's fit.

4.3 Estimation of parameters and shocks

Table 6 presents parameter estimates and shocks across model variants A to D with the STD dataset and the FD filter. In Appendix D we report those of each model variant using the alternative set of data (ALT) and the two different filters (FD and HP).

Three main remarks are worth making on these estimates. First, all parameters and shock estimates are rather robust across different model specifications. In the Appendix we show that the estimates are also quite robust across datasets and filters. Second, the immediate impact of deep habit captured by parameters θ^C and θ^G is similar for private and public consumption, but the persistence of the stocks of habit (and therefore the long-run impact) is slightly higher for public consumption. Third, for standard structural

Parameters	Models			
	A	B	C	D
ρ_A	0.9787	0.9787	0.9787	0.9531
ρ_G	0.9686	0.9685	0.9681	0.9687
ρ_I	0.8042	0.8056	0.8075	0.8132
ρ_B	0.8309	0.8344	0.8324	0.6163
ρ_P	0.9417	0.9309	0.9268	0.9373
ρ_W	0.9424	0.9432	0.9461	0.9306
γ	2.2708	2.3131	2.3642	2.2076
σ_u	3.2392	3.2439	3.2553	3.3153
σ_c	1.9460	2.0224	2.0237	2.0258
$\tilde{\varrho}^G$	calib=0	calib=0	0.6855	calib=0
$\tilde{\theta}^G$	calib=0	calib=0	0.6591	calib=0
$\tilde{\varrho}^C$ or $\hat{\varrho}^C$	0.7273	0.7184	0.7134	calib=0
$\tilde{\theta}^C$ or $\hat{\theta}^C$	0.6657	0.6602	0.6642	0.5614
ξ	37.235	36.169	35.660	36.686
ξ^W	82.656	82.651	83.955	85.637
ρ_π	2.294	2.2510	2.2346	2.2994
ρ_r	0.8202	0.8214	0.8220	0.8123
ρ_y	0.0306	0.0319	0.0328	0.0274
t	0.4082	0.4074	0.4063	0.4140
t_π	0.6553	0.6536	0.6547	0.6354
t_{rn}	1.2891	1.2862	1.2865	1.2598
Shocks				
ϵ^A	0.669592	0.669215	0.6696	0.6726
ϵ^G	0.8672	0.8662	0.8688	0.8665
ϵ^M	0.1525	0.1510	0.150	0.1571
ϵ^B	1.5481	1.5524	1.5733	1.2311
ϵ^I	1.7329	1.7166	1.7217	1.7059
ϵ^W	1.2489	1.4500	1.5848	1.2397
ϵ^P	2.6464	2.6271	2.6462	2.6887
ML	-593.5153	-594.3549	-594.7046	-606.0304

Table 6: Estimated parameters and structural shocks across model variants. STD data and FD of real observables.

parameters and shocks we obtain results in line with available estimates in the literature.

4.4 Impulse response functions

A straightforward way to assess the extent to which the model features under investigation matter from a practical viewpoint is inspecting how macroeconomic variables respond to structural shocks across model specifications. In Figure 1 we report the posterior median of impulse response functions (IRFs) of key macroeconomic variables to all structural shocks

Observable	Shocks of Estimated Model C						
	Technology	Gov. Spending	Mon. Policy	Price mark-up	Preference	Inv. specific	Wage mark-up
Hours worked	2.19	1.3	0.78	34.87	0.53	5.03	55.31
Inflation	8.49	0.34	17.94	18.75	9.57	24.6	20.31
Interest rate	7	0.59	9.88	11.96	8.52	40.27	21.78
Consumption	10.57	0.51	7.35	10.94	25.14	2.9	42.6
Gov. Spending	0	100	0	0	0	0	0
Investment	7.31	0.03	1.32	24.3	5.85	37.8	23.39
Real wage	10.53	0.08	2.29	44.13	6.22	0.79	35.96

Table 7: Unconditional variance decomposition - Model C (in percent)

we employed in the Bayesian estimation of all model variants (using the baseline dataset and filter).¹⁰

In order to allow comparability of the results we normalize IRFs in order the shocks to be of size 1%. In all cases, whether the persistence in the stock of superficial habit is assumed or not visibly affects the persistence, and hence the shape, of the responses of private consumption and, to a somewhat smaller extent, that of private investment and real output. This visually reflects the fact that the marginal likelihood of models featuring the additional persistence in the stock of habit is significantly higher and that this feature – accounted for by seminal papers such as Fuhrer (2000) but somewhat neglected by later papers – is important to capture the persistence present in the data.

Whether habit is superficial or deep affect the IRFs in the case of a government spending shock – especially if habit is present also in government consumption – but leaves the IRFs in the cases of all other shocks virtually unaffected. Such a finding is also helpful in clarifying the likelihood-race results of the previous section. The fact that, once the persistence in the stock of habit is accounted for, the marginal likelihood of a model with deep habit does not significantly differ from that of a model with superficial habit is the consequence of the fact that model dynamics are very similar across the two habit specifications for the vast majority of shocks, namely all but the government spending shock.

In Table 7 we report the unconditional variance decomposition of all observable variables for model C (results for all other models are similar and available upon request). The table unveils that the government spending shock has a limited role in explaining the business cycle fluctuations of the observable variables relative to the other shocks, in particular the price and wage mark-up shocks, as already shown by Smets and Wouters (2007).

¹⁰The IRFs obtained using the other three combinations of dataset/filters do not differ qualitatively and are available upon request

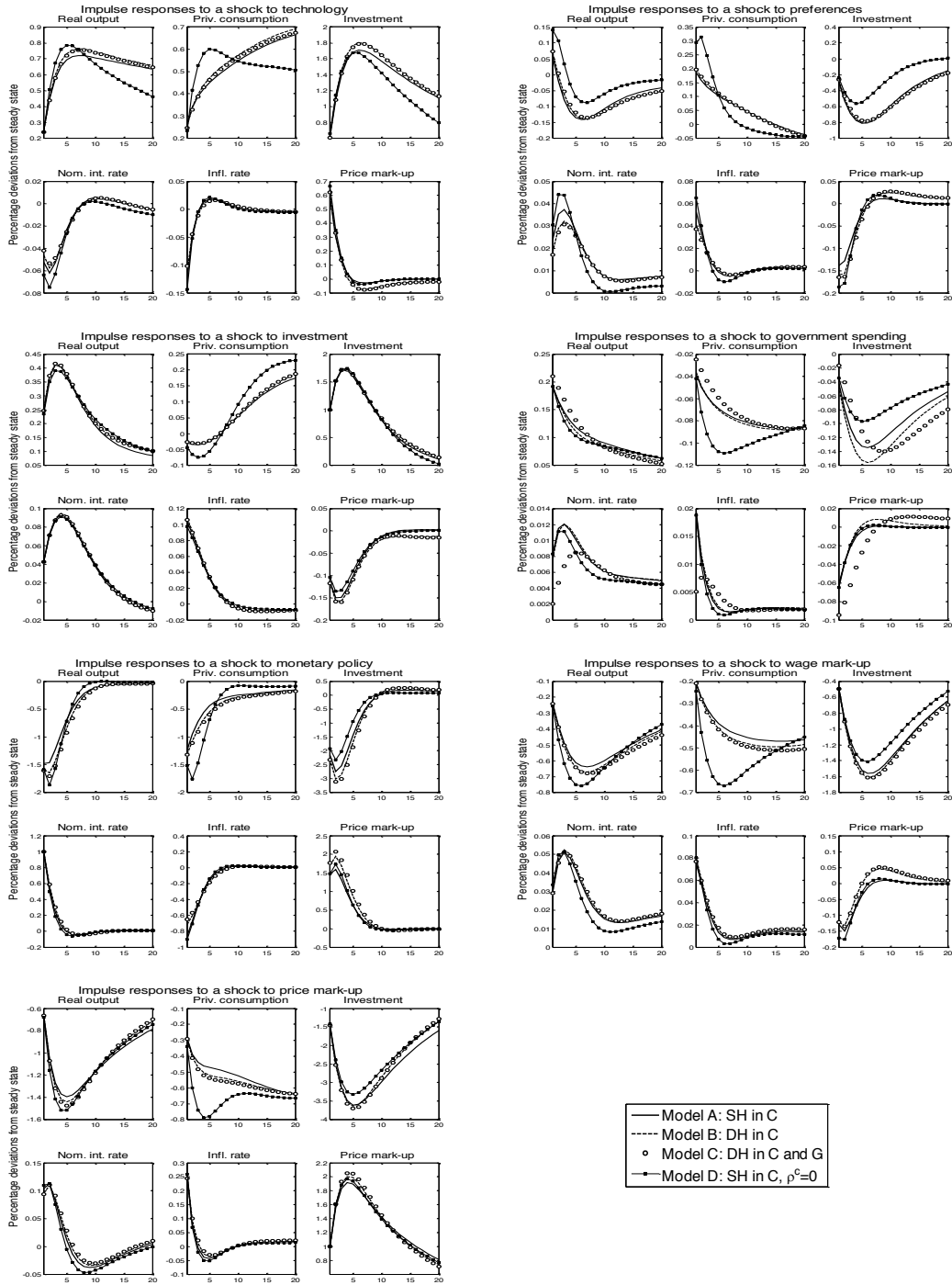


Figure 1: Posterior median impulse responses of selected macroeconomic variables to all structural shocks (the size of shocks is 1%; quarters on the x-axes)

5 Concluding remarks

In this paper we use Bayesian estimation techniques to empirically assess the extent to which assuming DH as opposed to SH enhance an otherwise standard DSGE model’s ability to fit US data. In particular, we disentangle the individual contributions of habit (of either form) in private and of deep habit in government consumption, and the additional persistence in the stock of habit.

The analysis is conducted, first via the estimation of a battery of four different permutations of a DSGE model with two alternative datasets, and two alternative data transformations; second, via a systematic and robust likelihood-race-based evaluation of each individual model feature; third, via the inspection of the transmission mechanism of seven standard structural shocks.

We find that DH does indeed seem to fit the data better than the standard SH specification, but we argue that the main reason is the presence of the extra inertia introduced in consumption by the additional persistence in the stock of habit that is typically assumed in the DH specification itself. In fact we demonstrate that, if the model accounts for an additional persistence also in the stock of SH, the two forms of habit are virtually as good at fitting the data. The additional persistence in the stock of habit *per se* statistically improves the model’s goodness of fit.

Introducing deep habit in public consumption does not improve (nor worsen) the fit of the model and, at the posterior mean, all model variants produce very similar responses to all demand and supply shocks with the exception of the government spending shock, which has, however, a small role in the variance decomposition of the estimated model.

It is worth acknowledging that a microeconomic approach to this research questions – e.g. similar to that of Verhelst and Van den Poel (2013) – may yield different answers. Our analysis employs a macroeconomic approach and hence investigates whether such model features work in a significant different way when it comes to explaining business cycle fluctuations of aggregate variables.

As regards habit in government consumption, we believe that future research should focus on its implications for fiscal shocks. An earlier version of this paper (Cantore et al., 2014b) provides a preliminary insight on this issue in conjunction with that on the complementarity between public and private consumption. The latter, however, requires augmenting the model to account for a richer fiscal sector. In fact, as shown by Fève et al. (2013), in order to obtain an unbiased estimate of the elasticity of substitution between public and private goods, government spending needs to be endogenized, at least via the introduction of an automatic-stabilizer component in the spending rule.

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Appendix

A Deep habit and more strongly countercyclical mark-ups

Under deep habit the mark-up is more strongly counter-cyclical relative to standard sticky-price models with superficial habit due to the co-existence of two effects: an *intra-temporal effect* and an *inter-temporal effect*. To understand how the mechanism works, let us consider, without loss of generality, a stripped-down version of the model with *flexible prices*, no capital and no persistence in the stock of external habit. Then, let us derive an analytical expression of the price mark-up in the symmetric equilibrium.

In this setting, the aggregate demand faced by firm i is $Y_{it} = C_{it} + G_{it}$, where

$$C_{it} = \left(\frac{P_{it}}{P_t}\right)^{-\eta} X_t^c + \tilde{\theta}^c C_{it-1} = \left(\frac{\mu_{it}}{\mu_t}\right)^{-\eta} X_t^c + \tilde{\theta}^c C_{it-1}, \quad (\text{A.1})$$

$$G_{it} = \left(\frac{P_{it}}{P_t}\right)^{-\eta} X_t^g + \tilde{\theta}^g G_{it-1} = \left(\frac{\mu_{it}}{\mu_t}\right)^{-\eta} X_t^g + \tilde{\theta}^g G_{it-1}, \quad (\text{A.2})$$

Profits of firms i can be expressed as $J_{it} = E_t \sum_{j=0}^{\infty} D_{t,t+j} \left(\frac{P_{it+j}}{P_{t+j}} - MC_{t+j}\right) Y_{it+j} = E_t \sum_{j=0}^{\infty} D_{t,t+j} \frac{\mu_{it+j} - 1}{\mu_{t+j}} Y_{it+j}$. Maximizing profits J_{it} with respect to C_{it} , G_{it} and μ_{it} subject to the firm-specific demands for private and public goods (A.1) and (A.2) yields the following first-order conditions:

$$\nu_{it}^c = \frac{\mu_{it} - 1}{\mu_t} + \tilde{\theta}^c E_t D_{t,t+1} \nu_{it+1}^c, \quad (\text{A.3})$$

$$\nu_{it}^g = \frac{\mu_{it} - 1}{\mu_t} + \tilde{\theta}^g E_t D_{t,t+1} \nu_{it+1}^g, \quad (\text{A.4})$$

$$C_{it} + G_{it} = \eta \left(\frac{\mu_{it}}{\mu_t} \right)^{-\eta-1} (\nu_{it}^c X_t^c + \nu_{it}^g X_t^g), \quad (\text{A.5})$$

where ν_{it}^c and ν_{it}^g are the Lagrange multipliers associated to constraint (A.3) and (A.4) and represent the shadow value of selling an extra unit in period t to households and the government, respectively. In the symmetric equilibrium, equations (A.1)-(A.5) become

$$X_t^c = C_t - \tilde{\theta}^c C_{t-1}, \quad (\text{A.6})$$

$$X_t^g = G_t - \tilde{\theta}^g G_{t-1}, \quad (\text{A.7})$$

$$\nu_t^c = \tilde{\theta}^c E_t D_{t,t+1} \nu_{t+1}^c + 1 - \frac{1}{\mu_t}, \quad (\text{A.8})$$

$$\nu_t^g = \tilde{\theta}^g E_t D_{t,t+1} \nu_{t+1}^g + 1 - \frac{1}{\mu_t}, \quad (\text{A.9})$$

$$C_t + G_t = \eta (\nu_t^c X_t^c + \nu_t^g X_t^g), \quad (\text{A.10})$$

respectively. Combining equations (A.6)-(A.10), the mark-up can be written as

$$\mu_t = \left[1 - \frac{1}{\eta \left(1 - \frac{\theta^c C_{t-1} + \theta^g G_{t-1}}{C_t + G_t} \right)} + \frac{X_t^c}{X_t^c + X_t^g} \tilde{\theta}^c E_t D_{t,t+1} \nu_{t+1}^c + \frac{X_t^g}{X_t^c + X_t^g} \tilde{\theta}^g E_t D_{t,t+1} \nu_{t+1}^g \right]^{-1}.$$

It is easy to show that term $\eta \left(1 - \frac{\tilde{\theta}^c C_{t-1} + \tilde{\theta}^g G_{t-1}}{C_t + G_t} \right) \equiv \epsilon_t$ represents the price elasticity of demand in the symmetric equilibrium. In fact, $\epsilon_{it} = -\frac{\partial Y_{it}}{\partial P_{it}} \frac{P_{it}}{Y_{it}} = \eta \left(1 - \frac{\tilde{\theta}^c C_{it-1} + \tilde{\theta}^g G_{it-1}}{C_{it} + G_{it}} \right)$. Under deep habit, ϵ_t is less than the intratemporal elasticity of substitution, η , and an increase in aggregate demand, for instance due to an increase in G_t , relative to habitual demand $\tilde{\theta}^c C_{it-1} + \tilde{\theta}^g G_{it-1}$ makes ϵ_t increase. In other words, ϵ_t displays a procyclical behavior. This feature is known as *price-elasticity* (or *intra-temporal*) *effect* and it is one determinant for the mark-up being counter-cyclical.

Terms $\tilde{\theta}^c E_t D_{t,t+1} \nu_{t+1}^c$ and $\tilde{\theta}^g E_t D_{t,t+1} \nu_{t+1}^g$ represent the present value of future per-unit profits induced by a unit increase in current sales towards households and the government, respectively. The two terms enter the expression of the mark-up as a weighted average, in which the weights, $\frac{X_t^c}{X_t^c + X_t^g}$ and $\frac{X_t^g}{X_t^c + X_t^g}$, are the shares of habit-adjusted demand of households and the government in aggregate habit-adjusted demand. If future per-unit profits ν_{t+1}^c and ν_{t+1}^g are expected to be high, the current mark-up falls. This is known as *inter-temporal effect*. Intuitively, the awareness of high future profits coupled with the

notion that consumers form habit at the variety level, makes firms inclined to give up some of the current profits – by temporarily lowering their mark-up – in order to *lock-in new consumers into customer/firm relationships* and charge them higher mark-ups in the future.

Clearly, in the absence of deep habit, i.e. if $\tilde{\theta}^c = \tilde{\theta}^g = 0$, the price elasticity of demand is constantly equal to the intratemporal elasticity of substitution, $\epsilon_t = \eta$, and the mark-up, in this flexi-price version of the model, is also constant and equal to $\mu_t = \frac{\eta}{\eta-1}$.

B Symmetric equilibrium

B.1 Utility function and marginal utilities

$$U_t = \frac{\left[(X_t^c)^{(1-\varrho)} (1 - H_t)^\varrho \right]^{1-\sigma_c} - 1}{1 - \sigma_c} \quad (\text{B.1})$$

$$U_{X^c,t} = \nu_x^{\frac{1}{\sigma_c}} (1 - \varrho) (X_t^c)^{(1-\varrho)(1-\sigma_c)-1} (1 - H_t)^\varrho (1-\sigma_c) \quad (\text{B.2})$$

$$U_{H,t} = -\varrho (X_t^c)^{(1-\varrho)(1-\sigma_c)} (1 - H_t)^{\varrho(1-\sigma_c)-1} \quad (\text{B.3})$$

B.2 Euler equation

$$1 = E_t \left[D_{t,t+1} \frac{R_t}{\Pi_{t+1}} \right] \quad (\text{B.4})$$

$$D_{t,t+1} = \beta \frac{e_{t+1}^B U_{X^c,t+1}}{e_t^B U_{X^c,t}} \quad (\text{B.5})$$

B.3 Wage-setting equation

$$(e_t^W \tilde{\eta} - 1) w_t - e_t^W \tilde{\eta} \frac{w_t}{\tilde{\mu}_t} + \xi^W (\Pi_t^W - \bar{\Pi}) w_t \Pi_t^W = E_t \left[D_{t,t+1} \xi^W (\Pi_{t+1}^W - \bar{\Pi}) w_{t+1} \Pi_t^W \frac{H_{t+1}}{H_t} \right] \quad (\text{B.6})$$

$$\tilde{\mu}_t = \frac{w_t}{MRS_t} \quad (\text{B.7})$$

$$MRS_t = -\frac{U_{H,t}}{U_{C,t}} \quad (\text{B.8})$$

B.4 Capital accumulation and investment decisions

$$K_{t+1} = (1 - \delta)K_t + e_t^I I_t \left[1 - S \left(\frac{I_t}{I_{t-1}} \right) \right] \quad (\text{B.9})$$

$$Q_t = E_t \left\{ D_{t,t+1} \left[u_{t+1} R_{t+1}^K - a(u_{t+1}) + (1 - \delta)Q_{t+1} \right] \right\} \quad (\text{B.10})$$

$$e_t^I Q_t \left(1 - S \left(\frac{I_t}{I_{t-1}} \right) - S' \left(\frac{I_t}{I_{t-1}} \right) \frac{I_t}{I_{t-1}} \right) + E_t \left(D_{t,t+1} e_{t+1}^I Q_{t+1} S' \left(\frac{I_{t+1}}{I_t} \right) \left(\frac{I_{t+1}}{I_t} \right)^2 \right) = 1 \quad (\text{B.11})$$

$$a'(u_t) = R_t^K \quad (\text{B.12})$$

$$S \left(\frac{I_t}{I_{t-1}} \right) = \frac{\gamma}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 \quad (\text{B.13})$$

$$S' \left(\frac{I_t}{I_{t-1}} \right) = \gamma \left(\frac{I_t}{I_{t-1}} - 1 \right) \quad (\text{B.14})$$

$$a(u_t) = \gamma_1 (u_t - 1) + \frac{\gamma_2}{2} (u_t - 1)^2 \quad (\text{B.15})$$

$$a'(u_t) = \gamma_1 + \gamma_2 (u_t - 1) \quad (\text{B.16})$$

B.5 Habit dynamics

$$X_t^c = \begin{cases} C_t - \tilde{\theta}^c S_{t-1}^c & \text{under deep habit} \\ C_t - \hat{\theta}^c S_{t-1}^c & \text{under superficial habit} \end{cases} \quad (\text{B.17})$$

$$S_t^c = \tilde{\varrho}^c S_{t-1}^c + (1 - \tilde{\varrho}^c) C_t \quad \text{under deep habit} \quad (\text{B.18})$$

$$S_t^c = \hat{\varrho}^c S_{t-1}^c + (1 - \hat{\varrho}^c) C_t \quad \text{under superficial habit}$$

$$X_t^g = C_t - \tilde{\theta}^g S_{t-1}^g \quad (\text{B.19})$$

$$S_t^g = \tilde{\varrho}^g S_{t-1}^g + (1 - \tilde{\varrho}^g) G_t \quad (\text{B.20})$$

B.6 Production function, marginal products and factor demands

$$F(A_t, H_t, u_t, K_t) = (A_t H_t)^\alpha (u_t K_t)^{1-\alpha} \quad (\text{B.21})$$

$$Y_t = F(A_t, H_t, u_t, K_t) - FC \quad (\text{B.22})$$

$$F_{H,t} = \alpha \frac{F(A_t, H_t, u_t, K_t)}{H_t} \quad (\text{B.23})$$

$$F_{\tilde{K},t} = (1 - \alpha) \frac{F(A_t, H_t, u_t, K_t)}{u_t K_t} \quad (\text{B.24})$$

$$R_t^K = MC_t F_{\tilde{K},t} \quad (\text{B.25})$$

$$\frac{W_t}{P_t} = MC_t F_{H,t} \quad (\text{B.26})$$

B.7 Price-setting under deep habit

$$\nu_t^c = 1 - MC_t + (1 - \tilde{\varrho}^c) \lambda_t^c \quad (\text{B.27})$$

$$\lambda_t^c = E_t D_{t,t+1} (\tilde{\theta}^c \nu_{t+1}^c + \tilde{\varrho}^c \lambda_{t+1}^c) \quad (\text{B.28})$$

$$\nu_t^g = 1 - MC_t + (1 - \tilde{\varrho}^g) \lambda_t^g \quad (\text{B.29})$$

$$\lambda_t^g = E_t D_{t,t+1} (\tilde{\theta}^g \nu_{t+1}^g + \tilde{\varrho}^g \lambda_{t+1}^g) \quad (\text{B.30})$$

$$C_{it} + G_{it} - e_t^P \eta (\nu_t^c X_t^c + \nu_t^g X_t^g) + (1 - e_t^P \eta) I_t + e_t^P \eta MC_t I_t - \xi^P (\Pi_t - 1) \Pi_t Y_t + \xi^P E_t \{ D_{t,t+1} [(\Pi_{t+1} - 1) \Pi_{t+1}] Y_{t+1} = 0 \}. \quad (\text{B.31})$$

B.8 Price-setting under superficial habit

$$1 - e_t^P \eta + \frac{e_t^P \eta}{\mu_t} - \xi^P (\Pi_t - 1) \Pi_t + \xi^P E_t \left[D_{t,t+1} (\Pi_{t+1} - 1) \Pi_{t+1} \frac{Y_{t+1}}{Y_t} \right] = 0 \quad (\text{B.32})$$

B.9 Taylor rule

$$\log \left(\frac{R_t}{\bar{R}} \right) = \rho_R \log \left(\frac{R_t}{\bar{R}} \right) + (1 - \rho_R) \left[\rho_\Pi \log \left(\frac{\Pi_t}{\bar{\Pi}} \right) + \rho_Y \log \left(\frac{Y_t}{\bar{Y}} \right) \right] + e_t^M \quad (\text{B.33})$$

B.10 Resource constraint and autoregressive processes

$$Y_t = C_t + I_t + G_t + \frac{\xi^P}{2} (\Pi_t - 1)^2 Y_t + \frac{\xi^W}{2} (\Pi_t^W - \bar{\Pi})^2 w_t H_t + a(u_t) K_t \quad (\text{B.34})$$

$$\log \left(\frac{G_t}{\bar{G}} \right) = \rho_G \log \left(\frac{G_{t-1}}{\bar{G}} \right) + e_t^G \quad (\text{B.35})$$

$$\log \left(\frac{A_t}{\bar{A}} \right) = \rho_A \log \left(\frac{A_{t-1}}{\bar{A}} \right) + e_t^A \quad (\text{B.36})$$

$$\log \left(\frac{e_t^I}{\bar{e}^I} \right) = \rho_{e^I} \log \left(\frac{e_{t-1}^I}{\bar{e}^I} \right) + e_t^I \quad (\text{B.37})$$

$$\log \left(\frac{e_t^P}{\bar{e}^P} \right) = \rho_{e^P} \log \left(\frac{e_{t-1}^P}{\bar{e}^P} \right) + e_t^P \quad (\text{B.38})$$

$$\log \left(\frac{e_t^B}{\bar{e}^B} \right) = \rho_{e^B} \log \left(\frac{e_{t-1}^B}{\bar{e}^B} \right) + e_t^B \quad (\text{B.39})$$

$$\log \left(\frac{e_t^W}{\bar{e}^W} \right) = \rho_{e^W} \log \left(\frac{e_{t-1}^W}{\bar{e}^W} \right) + e_t^W \quad (\text{B.40})$$

C Data sources and construction

In this section we describe the data sources and how we constructed the observables to be used in the estimation. In table C we present the original dataset and the data sources.

Label	Description	Source	Frequency
GDP	Nominal GDP	BEA Table 1.1.5	Q
PCE	Personal Consumption expenditure (total)	BEA Table 1.1.5	Q
PCE_D	Personal Consumption expenditure on durables	BEA Table 1.1.5	Q
PCE_ND	Personal Consumption expenditure on non durables	BEA Table 1.1.5	Q
PCE_S	Personal Consumption expenditure on services	BEA Table 1.1.5	Q
PFI	Private Fixed Investment	BEA Table 5.3.5	Q
GPDI	Gross Private Domestic Investment	BEA Table 1.1.5	Q
GCE	Government consumption expenditure and gross investment	BEA Table 1.1.5	Q
RGDP	Real GDP (base year 2005)	BEA Table 1.1.6	Q
CNP16OV	Civilian non-institutional population, over 16	BLS	Q
CE16OV	Civilian Employment sixteen years and over	BLS	Q
LBMNU	Non-farm business hours worked	BLS	Q
LBCPU	Hourly non-farm business compensation	BLS	Q
FFR	Federal Funds Rate	St. Louis FRED	Q

Table 8: Data sources

From these sources data we constructed 5 common “raw” observables¹¹ and two different measures of consumption and investment as showed in table C and we considered the subsample 1984:Q1-2008:Q2 in the estimation.

Hence the two set of observables used in the estimation will be:

$$\begin{aligned}
obs^{sw} &= [g_{obs}, h_{obs}, w_{obs}, rn_{obs}, \pi_{obs}, c_{obs}^{sw}, i_{obs}^{sw}] \\
obs^{nsw} &= [g_{obs}, h_{obs}, w_{obs}, rn_{obs}, \pi_{obs}, c_{obs}^{nsw}, i_{obs}^{nsw}]
\end{aligned}$$

As discussed in the paper for the estimation we apply two statistical filters to both sets of data (only on the real variables). In figures 2-5 we plot the observables with FD and HP(1600) filter.

¹¹Note that the resulting series of hours (as in table C) is then demeaned before it is used for the estimation.

Variable	Description	Construction
GDP_Deflator	GDP deflator	$\frac{GDP}{RGDP} 100$
index	Population index	$\frac{CNP16OV}{CNP16OV_{2005:2}}$
CE16OV_index	Employment index	$\frac{CE16OV}{CE16OV_{2005:2}} 100$
g_{obs}	Real per capita government spending	$LN(\frac{GCE}{GDP_{Deflator}})100$
h_{obs}	Per capita hours worked	$LN(\frac{LBMNU * CE16OV_{index}}{100 index})100$
w_{obs}	Real wage	$LN(\frac{LBCPU}{GDP_{Deflator}})100$
rn_{obs}	Quarterly Federal Funds rate	$\frac{FFR}{4}$
π_{obs}	Inflation	$\Delta GDP_{Deflator} 100$
c_{obs}^{sw}	Real per capita consumption	$LN(\frac{PCE_{index}}{GDP_{Deflator}})100$
i_{obs}^{sw}	Real per capita investment	$LN(\frac{PFI}{GDP_{Deflator}})100$
c_{obs}^{nsw}	Real per capita consumption	$LN(\frac{PCE_{ND} + PCE_S}{GDP_{Deflator}})100$
i_{obs}^{nsw}	Real per capita investment	$LN(\frac{GPD I + PCE_D}{GDP_{Deflator}})100$

Table 9: Data transformations - observables

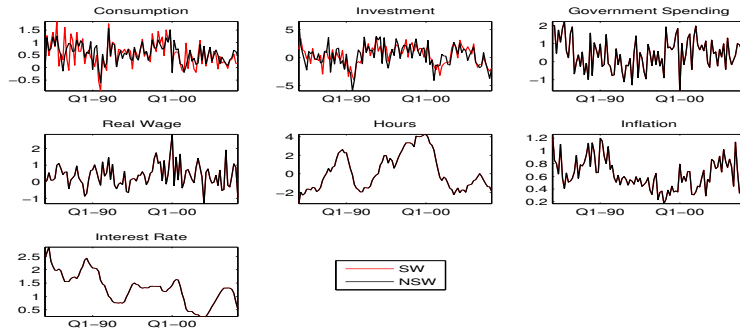


Figure 2: Observables (FD)

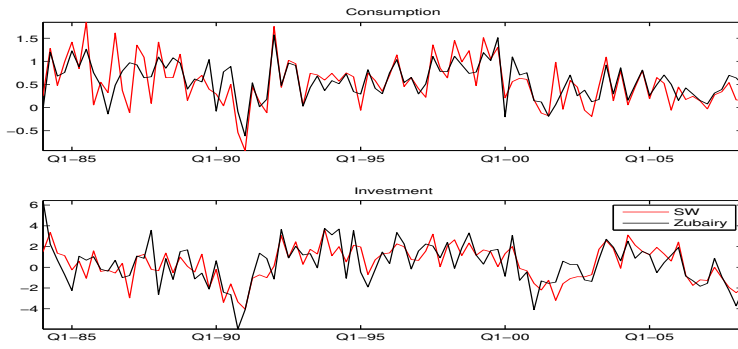


Figure 3: Consumption and investment series (FD)

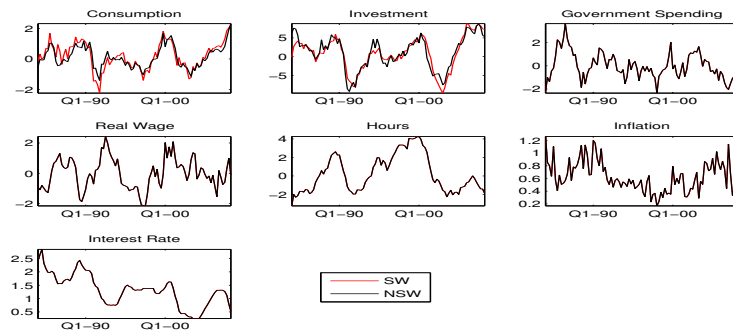


Figure 4: Observables (HP)

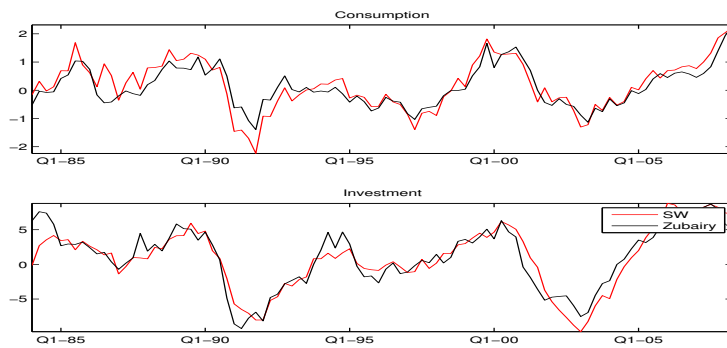


Figure 5: Consumption and investment series (HP)

D Estimation Results

Parameters	Models			
	A	B	C	D
ρ_A	0.9709	0.9695	0.9693	0.9596
ρ_G	0.7381	0.7394	0.7340	0.7373
ρ_I	0.7226	0.7104	0.7068	0.7105
ρ_B	0.7650	0.7473	0.7385	0.7188
ρ_P	0.8906	0.8773	0.8687	0.8889
ρ_W	0.4284	0.4183	0.4193	0.3670
γ	2.4689	2.5657	2.5951	2.5934
σ_u	3.1766	3.1932	3.1994	3.2183
σ_c	2.1272	2.1049	2.1079	1.8473
$\hat{\theta}^G$	calib=0	calib=0	0.6942	calib=0
$\hat{\theta}^G$	calib=0	calib=0	0.6788	calib=0
$\hat{\theta}^C$ or $\hat{\theta}^C$	0.6570	0.6405	0.6367	calib=0
$\hat{\theta}^C$ or $\hat{\theta}^C$	0.5636	0.5833	0.5926	0.4865
ξ	36.7735	35.9601	35.9973	35.9810
ξ^W	104.3675	105.1817	106.0197	104.1704
ρ_π	2.2412	2.1980	2.1590	2.2563
ρ_r	0.8053	0.8077	0.8071	0.8032
ρ_y	0.1247	0.1410	0.1457	0.1381
t_π	0.6426	0.6416	0.6421	0.6434
t_{rn}	1.2758	1.2755	1.2759	1.2881
Shocks				
ϵ^A	0.6360	0.6363	0.6381	0.6365
ϵ^G	0.7183	0.7187	0.7186	0.7160
ϵ^M	0.1446	0.1407	0.1382	0.1453
ϵ^B	1.3860	1.4504	1.4771	1.3924
ϵ^I	2.2043	2.2964	2.3202	2.2533
ϵ^W	1.0087	1.1222	1.2305	0.9794
ϵ^P	3.9941	4.0367	4.0664	4.0860
ML	-539.9773	-538.2470	-537.9248	-549.4810

Table 10: Parameters and structural shocks estimated across model variants. STD data and HP(1600) filtering of the real observables.

Parameters	Models			
	A	B	C	D
ρ_A	0.9608	0.9602	0.9601	0.9496
ρ_G	0.9676	0.9674	0.9677	0.9678
ρ_I	0.8025	0.8066	0.8063	0.8145
ρ_B	0.8159	0.8160	0.8202	0.7434
ρ_P	0.9203	0.9069	0.9029	0.9211
ρ_W	0.9415	0.9424	0.9465	0.9225
γ	1.6480	1.7175	1.7888	1.6552
σ_u	3.1707	3.2044	3.2159	3.2289
σ_c	1.9340	1.9610	1.9453	1.8414
$\hat{\theta}^G$	calib=0	calib=0	0.6858	calib=0
$\hat{\theta}^G$	calib=0	calib=0	0.6534	calib=0
$\hat{\theta}^C$ or $\hat{\theta}^C$	0.6905	0.6660	0.6707	calib=0
$\hat{\theta}^C$ or $\hat{\theta}^C$	0.7438	0.7369	0.7427	0.6389
ξ	36.0894	34.9338	34.4068	36.0669
ξ^W	86.2432	86.3253	87.2246	88.2235
ρ_π	2.4499	2.3941	2.3715	2.4374
ρ_r	0.8187	0.8224	0.8242	0.8125
ρ_y	0.0361	0.0390	0.0406	0.0348
t	0.4099	0.4104	0.4106	0.4264
t_π	0.6480	0.6461	0.6481	0.6376
t_{rn}	1.2877	1.2861	1.2904	1.2707
Shocks				
ϵ^A	0.6095	0.6101	0.6099	0.6099
ϵ^G	0.8688	0.8679	0.8692	0.8663
ϵ^M	0.1558	0.1537	0.1519	0.1596
ϵ^B	1.8265	1.8204	1.8771	1.3742
ϵ^I	1.7792	1.7757	1.7981	1.7778
ϵ^W	1.2371	1.4745	1.6258	1.2203
ϵ^P	2.9273	2.9214	2.9362	2.8954
ML	-599.9163	-601.6984	-602.2528	-607.2366

Table 11: Parameters and structural shocks estimated across model variants. ALT data and FD of the real observables.

Parameters	Models			
	A	B	C	D
ρ_A	0.9576	0.9546	0.9543	0.9531
ρ_G	0.7372	0.7365	0.7346	0.7347
ρ_I	0.7345	0.7135	0.7048	0.7172
ρ_B	0.7580	0.7400	0.7308	0.7057
ρ_P	0.8814	0.8705	0.8613	0.8766
ρ_W	0.3555	0.3457	0.3508	0.3007
γ	1.8950	2.0314	2.0952	1.9988
σ_u	3.0889	3.1411	3.1470	3.1318
σ_c	2.0622	2.0208	2.0329	1.9306
$\tilde{\theta}^G$	calib=0	calib=0	0.6974	calib=0
$\hat{\theta}^G$	calib=0	calib=0	0.6784	calib=0
$\tilde{\theta}^C$ or $\hat{\theta}^C$	0.5811	0.5587	0.5518	calib=0
$\hat{\theta}^C$ or $\tilde{\theta}^C$	0.6504	0.6665	0.6765	0.6174
ξ	36.2212	34.9925	34.6468	35.9260
ξ^W	104.6730	105.5217	106.2437	103.9160
ρ_π	2.2444	2.1768	2.1445	2.2414
ρ_r	0.8094	0.8115	0.8114	0.8093
ρ_y	0.1361	0.1500	0.1531	0.1521
t_π	0.6390	0.6374	0.6360	0.6374
t_{rn}	1.2784	1.2765	1.2773	1.2832
Shocks				
ϵ^A	0.5963	0.5983	0.5978	0.5961
ϵ^G	0.7161	0.7192	0.7195	0.7193
ϵ^{MPS}	0.1471	0.1437	0.1413	0.1476
ϵ^B	1.5806	1.6449	1.6894	1.5862
ϵ^I	2.2238	2.3622	2.4251	2.3162
ϵ^W	0.9702	1.0922	1.2067	0.9508
ϵ^P	4.3262	4.3640	4.3582	4.3814
ML	-545.6395	-543.2001	-542.7740	-548.2063

Table 12: Parameters and structural shocks estimated across model variants. ALT data and HP(1600) filtering of the real observables.