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Explaining the Durable Goods Co-movement Puzzle with Non-Separable Preferences: A Bayesian Approach*

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Abstract

A standard two-sector sticky price model with flexibly priced durables depicts negative co-movement between durables and non-durables after a monetary policy shock, which is at odds with the empirical evidence. This paper proposes a new channel, non-separable preferences with a small wealth effect on labor hours, as a solution to the co-movement puzzle. In contrast to the standard model where the aggregate hours remain relatively unchanged after the contractionary policy shock, aggregate labor hours fall along with the fall in the labor wage, thereby discouraging production in both the durable and non-durable goods sectors. We further compare our model's explanatory power with two other alternatives that can resolve the puzzle by using a Bayesian approach. Based on the log marginal likelihood and cross-correlation function comparison exercises, we find evidence that the data strongly favor both the alternative specifications over our baseline model. More specifically, the model with a working capital channel and habit formation gives the best fit to the data, especially for cross-correlations between durable and non-durable consumption.

Keywords: preferences; wealth effect; monetary policy; inflation; output
JEL classification: E21, E31, E32, E52

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1 Introduction

Erceg and Levin (2006), using a VAR approach, documented that expenditures on both durable and non-durable goods decrease after a contractionary policy shock. Standard New Keynesian models with different price setting behaviors in the durable and non-durable goods sectors have failed to replicate this result. In particular, with a flexibly-priced durable goods sector, a contractionary monetary policy shock leads to a decrease in non-durables but an increase in durable goods production, leaving the aggregate production unchanged. This *co-movement puzzle* is first pointed out by Barsky, House and Kimball (2003, 2007, BHK hereafter).

We propose a new mechanism, namely, non-separable (in consumption and leisure) preferences with a small wealth effect on labor hours as a possible solution to the puzzle. By incorporating these preferences in the standard BHK setting, we find that outputs across sectors are able to comove after a monetary policy shock. Furthermore, by introducing internal habit formation in non-durable consumption, we can generate high interest-elasticity in durable output relative to non-durable output as in the data. Next, we estimate our model using Bayesian techniques and the estimated model's predictions are consistent with our intuition. Finally, using log marginal likelihood, we compare our model's fit with two competing alternative model specifications in the literature that can resolve the puzzle in isolation. The out-of-sample forecasts indicate that the data strongly support both the alternatives over our model.

The preferences adopted here is first proposed by Greenwood, Hercowitz and Huffman (1998, GHH hereafter), who induce a zero wealth effect on labor supply. In the past two decades, these preferences have been widely employed in resolving famous puzzles based on US and international data. For example, GHH demonstrated that these preferences act as a possible channel to induce positive co-movement between output, consumption, and investment after an investment-specific technology shock, which standard preferences have failed to do. Raffo (2007, 2009) identify the potential for these preferences in explaining many key features of international business cycles. Monacelli and Perotti (2008) show that these preferences can bring about a rise in consumption and the real wage after a positive government spending shock that is consistent with their VAR estimates. Recently, Jaimovich and Rebelo (2009) have introduced generalized GHH preferences that can generate positive co-movement amongst major macroeconomic aggregates after a positive news shock to future productivity. In this paper, we investigate the role of *augmented* GHH preferences in reconciling a standard two-sector model's prediction with the empirical VAR counterparts.

In addition to our proposed solution, the existing literature provides several mechanisms which can resolve the co-movement puzzle.[1] In particular, we compare our benchmark model with GHH preferences with two existing models given by Carlstrom and Fuerst (2006) and Tsai (2010). Carlstrom and Fuerst (2006) introduce nominal wage stickiness in the standard model of BHK. Sticky wages induce price stickiness in durables, giving durable goods producers less incentive to adjust prices after a contractionary monetary policy shock. This leads to a decline in durable goods production along with non-durable goods production, resolving the co-movement puzzle. Tsai (2010) solves the puzzle by incorporating a working capital channel and habit formation in non-durable consumption. After a contractionary monetary policy shock, production cost rises due to the working capital channel, leading to a fall in both durable and non-durable goods production. The consumption growth smoothing motive implied by habit formation further dampens the response of non-durable production after the shock. Similar to his paper, the mechanism suggested by our paper can solve the co-movement puzzle without directly or indirectly inducing price stickiness in the durable goods sector. Separately and more recently, Kim and Katayama (2011) also propose the non-separable preference as a possible solution for the co-movement problem. However, our approach is different from theirs in two ways. First, their specification of preferences is different from ours and, secondly our paper provides systematic evaluation across models that can resolve the co-movement puzzle using a full information econometric strategy.

With separable preferences, due to the low depreciation rate of durables, the shadow value for durables remains relatively constant following transitory shocks, which induces aggregate labor hours and thus aggregate production to remain nearly constant. Thus, a decline in non-durable goods production after a contractionary monetary policy shock must be offset by an increase in durable goods production, giving rise to the co-movement puzzle. By contrast, aggregate hours fall along with the fall in the labor wage under non-separable GHH preferences, discouraging production in both the durable and non-durable goods sectors. This makes it possible for both durable and non-durable goods production to fall simultaneouly on impact, thereby resolving the co-movement puzzle.

This paper is also related to the growing literature on the estimation of general equilibrium models using Bayesian techniques that systematically evaluate the importance of various shocks and frictions in causing business cycle fluctuations.[2] Using these techniques we find that our estimated model with intermediate habit persistence and the two alterna-

[1] Other seminal work includes Kitamura and Takamura (2010) who address the issue by incorporating sticky information in the standard BHK setting; Levin and Yun (2011) who consider the role of incomplete financial markets; and Sudo (2008) who presents an input-outut model, where non-durables act an intermediate inputs for durable production and *vice-versa*.

[2] Please see Smets and Wouters (2003, 2007), Justiniano, Primiceri and Tambalotti (2010), Lubik and Schorfheide (2006), and Rabanal and Tuesta (2010).

tive specifications can simultaneously make outputs in both sectors comove and induce high interest sensitivity in durables compared to non-durables after a monetary policy shock as in the data.

Finally, the Bayesian approach allows us to engage in a formal comparison between our model and two competing alternatives. Fernández-Villaverde and Rubio-Ramírez (2004) show that model comparisons, based on marginal likelihood, are consistent even when the models are misspecified. Rabanal and Rubio-Ramírez (2005) estimate and compare four versions of a sticky price New Keynesian model using Euro data. Another paper by Ichiue, Kurozumi and Sunakawa (2008) studies the role of an extensive margin in inflation dynamics by estimating and comparing three alternative models of labor adjustments. Following their approach, we compute each model's marginal likelihood in order to compare their explanatory power. We find that both of the competing alternatives outperform our benchmark model in fitting the data. In particular, the data strongly favor Tsai (2010) over all other specifications.

The rest of the paper is organized as follows. We present our model in Section 2 and the calibration results in Section 3. Section 4 presents the alternative models and Section 5 estimates the models. Section 6 discuss the results and compares the benchmark model with other alternatives, and Section 7 concludes.

2 Model

Our model is based on the framework developed in BHK (2007), Carlstrom and Fuerst (2006) and Tsai (2010). There are three types of agents in this economy: households, firms, and the monetary authority. We modify their models by incorporating GHH preferences. Households derive utility from the consumption of non-durable goods, durable goods and leisure. On the production side, there are two sectors: durable and non-durable goods sectors. In each sector, there is a continuum of monopolistically competitive intermediate firms, each producing a differentiated product. We describe their optimal behaviors as below.

2.1 Households

In every period, the representative household supplies labor (L_t), and chooses nondurable consumption (C_t), a durable consumption stock (D_t), and a geometric average of current and past consumption composite levels (H_t) to maximize expected lifetime utility

$$E_0 \sum_{t=0}^{\infty} \beta^t \epsilon_t^g U(C_t, C_{t-1}, D_t, D_{t-1}, L_t, H_t)$$

where β is the discount factor, and ϵ_t^g is the intertemporal preference shock that follows an AR(1) process:

$$\epsilon_t^g = \rho^g \epsilon_{t-1}^g + \eta_t^g \tag{2.1.1}$$

where $\eta_t^g \sim N(0, \sigma_g)$ and $U(C_t, C_{t-1}, D_t, D_{t-1}, L_t, H_t)$ is the augmented Jaimovich and Rebelo (2009) utility function that takes the form

$$U(C_t, C_{t-1}, D_t, D_{t-1}, L_t, H_t) = \frac{\left[(\psi_c \left(C_t - h_b C_{t-1}\right)^{\frac{\rho-1}{\rho}} + (1-\psi_c)\epsilon_t^d \left(D_t - h_b D_{t-1}\right)^{\frac{\rho-1}{\rho}})^{\frac{\rho}{\rho-1}} - \epsilon_t^l \phi L_t^{1+\nu} H_t \right]^{1-\sigma}}{1-\sigma}$$

where σ is the intertemporal elasticity of substitution, h_b is the habit persistence, ψ_c is the weight of nondurable goods in the household's consumption composite, ρ is the elasticity of substitution between durable and nondurable consumption, ν is the inverse of the Frisch labor supply elasticity, and ϵ_t^l is the intratemporal preference shock, also known as the labor supply shock, which has the following law of motion:

$$\epsilon_t^l = \rho^l \epsilon_{t-1}^l + \eta_t^l \tag{2.1.2}$$

where $\eta_t^l \sim N(0, \sigma_l)$. Also, ϵ_t^d is the durable preference shock which has the following law of motion:

$$\epsilon_t^d = \rho^d \epsilon_{t-1}^d + \eta_t^d \tag{2.1.2}$$

where $\eta_t^d \sim N(0, \sigma_d)$. The presence of H_t makes preferences time non-separable in a consumption composite of durables and non-durables and hours worked. The law of motion for H_t is

$$H_t = \left[(\psi_c \left(C_t - h_b C_{t-1}\right)^{\frac{\rho-1}{\rho}} + (1-\psi_c) \left(D_t - h_b D_{t-1}\right)^{\frac{\rho-1}{\rho}})^{\frac{\rho}{\rho-1}} \right]^{(\gamma)} H_{t-1}^{1-\gamma} \tag{2.1.3}$$

where $\gamma \in (0, 1)$.

A representative household enters period t with initial bond holdings of S_{t-1}, receives wage income, $W_t L_t$, profits, Π_t, and government transfers, T_t, and purchases non-durable goods, $P_{c,t} C_t$, durable goods, $P_{x,t} X_t$, and a risk free bond, $\frac{S_t}{R_t}$. The household's budget constraint is

$$P_{c,t}C_t + P_{x,t}X_t + P_{x,t}\left[\frac{1}{2}\phi_1\frac{(X_t-\delta D_{t-1})^2}{D_{t-1}}\right] \leq W_tN_t + \sum_{j=c,x} R_{j,t}u_{j,t}\bar{K}_{j,t}$$
$$+\Pi_t + T_t + S_{t-1} - \frac{S_t}{R_t} - \sum_{j=c,x} P_{j,t}a(u_{j,t})\bar{K}_{j,t}, t = 0, 1, .. \quad (1)$$

and the law of motion for durable goods consumption is

$$D_t = (1-\delta)D_{t-1} + X_t,$$

where S_{-1} and D_{-1} are given and δ is the depreciation rate. $R_{j,t}$, $K_{j,t}$ and $u_{j,t}$ are the rental rate of capital, productive capital stock and variable capital utilization rate in each sector $j = c, x$. Hence, the capital services in each sector is given by $K_{j,t} = u_{j,t}\bar{K}_{j,t}$. The cost of setting the capital utilization rate is given by $a(u_{j,t})$ which is increasing and convex in $u_{j,t}$. We assume $\bar{u}_j = 1, a(1) = 0$. Also, the parameter χ governs the elasticity of capital utilization and is given by $\chi = \frac{a''(1)}{a'(1)}$.

By letting $B_t = \left[\psi_c\left(C_t - h_bC_{t-1}\right)^{\frac{\rho-1}{\rho}} + (1-\psi_c)\epsilon_t^d\left(D_t - h_bD_{t-1}\right)^{\frac{\rho-1}{\rho}}\right]^{\frac{\rho}{\rho-1}}$ and $V_t = [B_t - \epsilon_t^l\phi L_t^{1+\nu}H_t]$, the first-order conditions from the household optimization problem are:

$$\Lambda_t = \psi_c\epsilon_t^g V_t^{-\sigma}B_t^{\frac{1}{\rho}}C_t^{\frac{-1}{\rho}} + \lambda_t\gamma B_t^{\frac{\rho(\gamma-1)+1}{\rho}}\psi_c C_t^{\frac{-1}{\rho}}H_{t-1}^{1-\gamma} \quad (2.1.5)$$

$$\lambda_t + \epsilon_t^g\epsilon_t^l V_t^{-\sigma}\phi L_t^{1+\nu} = \beta E_t\lambda_{t+1}(1-\gamma)B_{t+1}^{\gamma}H_t^{-\gamma} \quad (2.1.6)$$

$$\epsilon_t^g\epsilon_t^l V_t^{-\sigma}\phi(1+\nu)L_t^{\nu}H_t = \Lambda_t\frac{W_t}{P_{c,t}} \quad (2.1.7)$$

$$\Lambda_t\frac{P_{x,t}}{P_{c,t}} = \epsilon_t^g V_t^{-\sigma}B_t^{\frac{1}{\rho}}\psi_d D_t^{\frac{-1}{\rho}} + \lambda_t\gamma B_t^{\frac{\rho(\gamma-1)+1}{\rho}}\psi_d D_t^{\frac{-1}{\rho}}H_{t-1}^{(1-\gamma)} + \beta E_t(1-\delta)\Lambda_{t+1}\frac{P_{x,t+1}}{P_{c,t+1}} \quad (2.1.8)$$

$$\frac{\Lambda_t}{P_{c,t}} = \beta E_t\left[\Lambda_{t+1}\frac{R_t}{P_{c,t+1}}\right] \quad (2.1.9)$$

Here λ_t and Λ_t represent the Lagrangian multipliers for constraints (2.1.3) and (2.1.4), respectively. Equation (2.1.5) represents the marginal utility of non-durable consumption. Equations (2.1.7) represents the trade-off between non-durable consumption and leisure. Equation (2.1.8) represents the trade-off between non-durable and durable goods. Equation (2.1.9) represents the trade-off between non-durable consumption and bond holdings.

2.2 Firms

There are two types of firms: a continuum of non-durable goods producers and a continuum of durable goods producers. Non-durable goods firms set their prices à la Calvo while durable goods firms can adjust their prices frictionlessly every period. These intermediate goods firms are competitive in the factor market, and take factor prices as given. I allow the factors to move freely within and between sectors.

2.2.1 Non-durable goods firms

There is a continuum of monopolistically competitive firms in the non-durable goods sector indexed by $f \in (0,1)$ that sell non-durable goods to final goods producers. They set a price $P_{c,t}(f)$ subject to a Calvo price setting. In each period, a fraction $1-\theta_c$ of the firms in this sector reoptimize their prices regardless of the time of their last price adjustment. The remaining fraction θ_c of the firms use the same price as in the previous period.

The demand faced by each firm depends on the price of its product and the total demand for non-durable goods

$$C_t(f) = \left(\frac{P_{c,t}(f)}{P_{c,t}}\right)^{-\varepsilon} C_t, \tag{2.2.1.1}$$

where $C_t = \left[\int_0^1 C_t(f)^{\frac{\varepsilon-1}{\varepsilon}} df\right]^{\frac{\varepsilon}{\varepsilon-1}}$ is the consumption aggregator, and $P_{c,t} = \left[\int_0^1 P_{c,t}(f)^{1-\varepsilon} df\right]^{\frac{1}{1-\varepsilon}}$ represents the price index for non-durable goods.

Production requires labor input

$$C_t(f) = (K_{c,t}(f))^{\alpha}(A_t L_{c,t}(f))^{1-\alpha}, \tag{2.2.1.2}$$

where A_t denotes the aggregate productivity shock which has the following law of motion:

$$A_t = A_{t-1}e^{g_{a,t}} \tag{2.2.1.3}$$

$$g_{a,t} = \rho_a g_{a,t-1} + \eta_t^a \tag{2.2.1.4}$$

where $\eta_t^a \sim N(0, \sigma_a)$.

A non-durable good producer f chooses $P_{c,t}^*(f)$ so as to maximize its discounted profit,

$$\max_{P_{c,t}^*(f)} \sum_{j=0}^{\infty} (\beta\theta_c)^j E_t \frac{\Lambda_{t+j}}{P_{c,t+j}} \left[P_{c,t+j}(f) C_{t+j}(f) - W_{t+j} L_{c,t+j}(f) - R_{c,t+j} K_{c,t+j}(f)\right]$$

subject to the demand for its product (2.2.1.1) and production function (2.2.1.2), where Λ_{t+j} denotes the marginal utility of consumption for period $t+j$.

The first-order conditions are,

$$W_t = MC_{c,t} K_{c,t}^{\alpha} (1-\alpha)(A_t L_{c,t})^{-\alpha} A_t \tag{13}$$

$$R_{c,t} = MC_{c,t} K_{c,t}^{(\alpha-1)} (\alpha)(A_t L_{c,t})^{(1-\alpha)} \tag{14}$$

$$P_{c,t}^*(f) = \frac{\varepsilon}{\varepsilon - 1} \frac{\sum_{j=0}^{\infty} (\beta\theta_c)^j E_t \Lambda_{t+j} MC_{c,t+j} \left(\frac{1}{P_{c,t+j}}\right)^{1-\varepsilon} C_{t+j}}{\sum_{j=0}^{\infty} (\beta\theta_c)^j E_t \Lambda_{t+j} \left(\frac{1}{P_{c,t+j}}\right)^{1-\varepsilon} C_{t+j}}, \tag{15}$$

where $MC_{c,t}$ is the marginal cost in the non-durable goods sector. The non-durable price index is written as,

$$P_{c,t} = \left[(1-\theta_c) P_{c,t}^{*1-\varepsilon} + \theta_c P_{c,t-1}^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}}. \tag{2.2.1.6}$$

2.2.2 Durable goods firms

In the durable goods sector, there is a continuum of monopolistically competitive firms, and unlike the non-durable goods sector, durable goods firms reoptimize their prices every period, and face identical linear production and demand.

A durable goods firm f chooses its price $P_{x,t}^*(f)$ so as to maximize its current profit,

$$\max_{P_{x,t}^*(f)} P_{x,t}(f) X_t(f) - W_t L_{x,t}(f) - R_{x,t} K_{x,t}(f),$$

subject to the production function

$$X_t(f) = K_{x,t}^{\alpha} (A_t Z_t L_{x,t}(f))^{1-\alpha}, \tag{2.2.2.1}$$

and the demand function

$$X_t(f) = \left(\frac{P_{x,t}(f)}{P_{x,t}}\right)^{-\varepsilon} X_t, \tag{2.2.2.2}$$

where $X_t = \left[\int_0^1 X_t(f)^{\frac{\varepsilon-1}{\varepsilon}} df\right]^{\frac{\varepsilon}{\varepsilon-1}}$, $P_{x,t} = \left[\int_0^1 P_{x,t}(f)^{1-\varepsilon} df\right]^{\frac{1}{1-\varepsilon}}$, and Z_t is the relative price shock and follows:

$$Z_t = Z_{t-1}e^{g_{z,t}} \tag{2.2.2.3}$$

$$g_{z,t} = \rho_z g_{z,t-1} + \eta_t^z \tag{2.2.2.4}$$

where $\eta_t^z \sim N(0, \sigma_z)$. Note that, in equilibrium,

$$\frac{1}{Z_t} = \frac{P_{x,t}}{P_{c,t}} \tag{2.2.2.5}$$

The first-order conditions are:

$$W_t = MC_{x,t}K_{x,t}^{\alpha}(1-\alpha)(A_t Z_t L_{x,t})^{-\alpha}A_t Z_t \tag{19}$$

$$R_{x,t} = MC_{x,t}K_{x,t}^{(\alpha-1)}(\alpha)(A_t Z_t L_{x,t})^{(1-\alpha)} \tag{20}$$

$$P_{x,t}^*(f) = \frac{\varepsilon}{\varepsilon-1}\frac{W_t}{A_t Z_t}. \tag{2.2.2.6}$$

where $MC_{x,t}$ is the marginal cost in the durable goods sector.

2.3 Monetary policy and market clearing

The central bank follows the Taylor rule by adjusting the nominal interest rate in response to changes in inflation and the output gap.[3] We allow the monetary authority to partially adjust toward the optimal interest target.

$$R_t = R_{t-1}^{\rho_r}(\pi_t)^{(1-\rho_r)\phi_\pi}(Y_t)^{(1-\rho_r)\phi_y}\epsilon_t^r. \tag{2.3.1}$$

where ρ_r determines the degree of interest rate smoothing and ϵ_t^r is an i.i.d. monetary policy shock such that $\epsilon_t^r \sim N(0, \sigma_r)$.

2.4 Market Clearing

Finally, the model is closed with market clearing conditions in the labor and goods markets. The labor market equilibrium requires

$$L_t = L_{c,t} + L_{x,t}. \tag{2.4.1}$$

[3] Inflation is defined as a weighted average of nondurable goods inflation and durable goods inflation, $\widehat{\pi}_t = \frac{C}{Y}\widehat{\pi}_{ct} + \frac{X}{Y}\widehat{\pi}_{xt}$.

and the goods market equilibrium requires that

$$Y_t = C_t + X_t. \tag{2.4.2}$$

The de-trended model and the corresponding log-linear equations can be found in the appendix.

3 Calibration and Results

Table 1: Parameter values in the benchmark model

Parameter	Value	Interpretation
ν	0.33	inverse of labor supply elasticity
β	0.99	quarterly discount rate
ψ_c	0.75	utility weight on nondurables
ψ_d	0.25	utility weight on durables
θ_c	0.67	probability of not reoptimizing price
θ_x	0	perfectly flexible price
δ	0.025	quarterly durable depreciation rate
ρ_r	0.6	interest rate smoothing
ϕ_π	1.5	interest rate response to inflation
ϕ_y	0.5	interest rate response to output gap

Notes: The calibration value of the parameters in the benchmark model.

Most of the parameter values are taken from BHK (2007). We set the subjective discount factor, β, equal to 0.99, and the inverse of the Frisch labor-supply elasticity, ν, equals 0.33. The depreciation rate of durable goods, δ, is 0.025 which implies an annual depreciation rate of 10%. The intertemporal elasticity of substitution, σ, and the intratemporal elasticity of substitution between durables and non-durables, ρ, are both set equal to 1. The probability that a firm in the non-durable goods sector cannot reoptimize its price in any given period, θ_c, is set to 2/3. We assume that the monetary authority partially adjusts its policy rate toward the optimal interest target, and set $\rho_r = 0.6$. Following the literature, we set $\phi_y = 0.5$ and $\phi_\pi = 1.5$. The latter implies that the monetary policy rate responds more than one-for-one to changes in inflation, and this ensures a unique equilibrium. Table 1 summarizes the parameter values.

Throughout the section, we focus on the responses of non-durable goods consumption, durable goods consumption and aggregate production to a contractionary monetary policy shock as in the literature. We first show that there is a co-movement problem between durables and non-durables as pointed out by BHK when the preferences are separable between the consumption composite and leisure. We then show that we can resolve the co-movement problem when we have non-separable preferences between the consumption composite and leisure which are the augmented GHH preferences. For these two cases, we set $\gamma = 0$ and $\gamma = 1$, respectively, and the results can be found in Figure 1.

To obtain the intuition of the mechanism between these two preferences, let us look at the case where $\gamma = 1$. When $\gamma = \sigma = \rho = 1$, $B_t = H_t = C_t^{\psi_c} D_t^{\psi_d}$ and the period utility becomes $U(C_t, D_t, L_t, H_t) = logC_t^{\psi_c} D_t^{\psi_d} + log(1 - \epsilon_t^l \phi L_t^{1+\nu})$ which is the same class of preferences as discussed in BHK. Equation (2.1.6) becomes $\lambda_t = -\epsilon_t^g \epsilon_t^l V^{-1} \phi L_t^{1+\nu}$. Equation (2.1.5) can be simplified as $\Lambda_t = \frac{\psi_c}{C_t}$. Combining (2.1.5) and (2.1.7), we obtain the labor-leisure condition

$$\frac{\phi(1+\nu)L_t^\nu}{1-\phi L^{1+\nu}} = \frac{W_t}{P_{c,t}}\psi_c C_t^{-1} = \frac{\varepsilon - 1}{\varepsilon} A_t Z_t \frac{P_{x,t}}{P_{c,t}} \psi_c C_t^{-1}. \tag{3.1}$$

The second equality follows by substituting out W_t using the price of durable goods, $P_{x,t} = \frac{\varepsilon}{\varepsilon-1}\frac{W_t}{A_t Z_t}$. Moreover, by plugging λ_t and Λ_t into equation (2.1.8), we obtain $\psi_c C_t^{-1} \frac{P_{x,t}}{P_{c,t}} = \psi_d \epsilon_t^g \frac{1}{D_t} + \beta\psi_c(1-\delta)E_t C_{t+1}^{-1}\frac{P_{x,t+1}}{P_{c,t+1}}$. With a small depreciation rate for durable goods, changes in the stock of durable goods and its associated shadow value after a temporary policy shock are small, inducing only a small change in $\psi_c C_t^{-1}\frac{P_{x,t}}{P_{c,t}}$. Since the right-hand side of equation (3.1) changes little in response to the monetary policy shock, aggregate labor hours remain relatively constant. Therefore any fall in non-durable production is associated with a rise in durable production, and the separable reference has difficulty generating co-movement between durables and nondurables.

Next, when $\gamma = 0$ and $\rho = \sigma = 1$, we obtain the augmented GHH preferences and the period utility becomes $U(C_t, D_t, L_t, H_t) = log(C_t^{\psi_c} D_t^{\psi_d} - \epsilon_t^l \phi_h L_t^{1+\nu})$ where $H_t = H_{t-1} = H = constant$ and $\phi_h = \phi H$. If we revisit the leisure labor choice condition, equation (2.1.7) now becomes $\phi(1+\nu)L_t^\nu = \frac{W_t}{P_{c,t}}\psi_c\frac{B_t}{C_t}$. Compared to the separable preferences, the fall in non-durable goods consumption now induces a smaller wealth effect on labor supply as D_t remains relatively constant and the rise in $\frac{B_t}{C_t} = (\frac{D_t}{C_t})^{1-\psi_c}$ is smaller than the rise in C_t^{-1} following the contractionary policy shocks.[4,5] With a smaller wealth effect on the labor supply decision, aggregate labor hours fall following a contractionary policy shock and

[4] We refer to this as the augmented GHH labor-leisure condition. Unlike the typical GHH preference which only features non-durable goods consumption and induces labor supply depending only on the real wage, here labor supply depends on both the real wage and the fraction of the composite consumption to non-durable goods consumption. In the extreme case, where the composite consumption features only nondurable goods consumption (i.e., $\psi_c = 1$), we get back the typical labor leisure choice under the standard GHH preferences $\phi(1+\nu)L_t^\nu = \frac{W_t}{P_{c,t}}$. In that case, there is no wealth effect associated with labor supply decisions.

[5] The wealth effect is determined by the share of non-durable consumption over the composite consumption. As the share of non-durable consumption increases, the wealth effect decreases.

therefore allow us to solve the co-movement problem between durables and non-durables. In response to a contractionary policy shock, we observe a fall in both non-durables and durables, and aggregate output falls. This is the resolution of the co-movement puzzle.

The JR preferences nest the KPR and GHH utility functions as special cases. From our discussion above, for a small value of γ, the JR preference is able to generate a fall in aggregate labor hours following a contractionary policy shock which enables our models to generate a fall in both the durable and non-durable goods sector and thus solves the co-movement puzzle.[6]

Fig. 2 shows the labor market equilibrium under both the separable preferences and the non-separable preferences. Under separable preferences, the wealth effect and the substitution effects are roughly canceled out following the policy shocks, while under non-separable preferences, the substitution effects are larger than the wealth effect which leads to a fall in aggregate labor hours following a fall in the real wage in response to a contractionary policy shock.

Although our model can successfully resolve the co-movement puzzle, the fall in non-durables is larger than the fall in durables, which is inconsistent with the empirical finding that durables are more interest rate sensitive than nondurables. To reconcile this inconsistency between the model's prediction and the empirical findings, we add in the habit formation for non-durable consumption. In particular, $B_t = (C_t - h_b C_t - 1)^{\psi_c} D_t^{\psi_d}$ and $0 \leq h_b \leq 1$ which is the parameter governing habit persistence. The introduction of habit formation alters the propagation of policy shocks as the household dislikes large and rapid changes in non-durable goods consumption and therefore mitigates the initial fall in non-durables consumption which allows our model to generate a more interest rate sensitive durable goods response than non-durables and is consistent with the empirical findings.

4 Alternative Specifications

While several papers have used various channels in accounting for the co-movement puzzle, the existing literature lacks a formal comparison between competing alternatives using US data. We compare the explanatory power of our baseline model with *augmented* GHH preferences with two alternative channels in the literature. To this end, we extend the baseline BHK model in two different ways. First, following Carlstrom and Fuerst (2006), we introduce nominal wage rigidities and durable goods adjustment costs (Model 1). Second, in the spirit of Tsai (2010), we introduce a working capital channel in both durable and non-durable goods production and internal habit formation in non-durable goods consumption

[6]For any value of $\gamma \in (0, 0.4)$, the JR preference is able to resolve the puzzle.

(Model 2). Since the two extensions are well-known in the literature, here we only highlight the key equations in each model.

4.1 Model 1: Carlstrom and Fuerst (2006)

Carlstrom and Fuerst (2006) introduces nominal wage stickiness in the standard sticky price model of BHK to resolve the co-movement puzzle. Households have monopoly power over labor supply allowing for sticky nominal wages à la Calvo (1983). Hence the wage is set according to the following equation:

$$\hat{W}_t = \frac{\beta}{1+\beta}\hat{W}_{t+1} + \frac{1}{1+\beta}\hat{W}_{t-1} + \frac{\beta}{1+\beta}\hat{\pi}_{t+1} + \frac{(1-\theta_w\beta)(1-\theta_w)}{\theta_w}\left[\hat{W}_t^h - \hat{W}_t\right] \tag{4.1.1}$$

where $(1-\theta_w)$ denotes the fraction of households that adjust their wage at time t and $\hat{W}_t^h$ is the marginal rate of substitution. Furthermore, to smooth the behavior of durable goods consumption, we add adjustment costs in the household budget constraint along the lines of Engel and Wang (2007):

$$P_{c,t}C_t + P_{x,t}X_t + P_{x,t}\left[\frac{1}{2}\phi_1\frac{(X_t - \delta D_{t-1})^2}{D_{t-1}}\right] \leq W_tN_t + \Pi_t + T_t + S_{t-1} - \frac{S_t}{R_t}, t = 0, 1, .. \tag{4.1.2}$$

where ϕ_1 is the adjustment cost parameter. The rest of the model is the same as benchmark setting. The details of the linearized model are given in the appendix.

4.2 Model 2: Tsai (2010)

A recent paper by Tsai (2010) explores the role of financial frictions as a possible solution to the co-movement puzzle. He extends the basic BHK model to include a working capital channel to both the durable and non-durable sectors which imposes a constraint on the firms to borrow in advance in order to pay wages. The log-linearized marginal cost becomes:

$$\hat{MC}_t = \hat{W}_t + \hat{R}_t - \hat{A}_t \tag{4.2.1}$$

In addition, he adds habit formation in non-durable consumption to induce sluggish behavior in non-durables after a monetary policy shock. The new log-linearized Euler equation for non-durable consumption becomes:

$$\hat{\Lambda}_t = \left(\frac{1-\sigma}{1-h\beta}\right)\left[\hat{B}_t - h\beta E_t \hat{B}_{t+1}\right]$$
$$-\frac{1}{(1-h\beta)(1-h)}\left[\hat{C}_t - h\hat{C}_{t-1}\right] + \frac{h\beta}{(1-b\beta)(1-b)} E_t(\hat{C}_{t+1} - b\hat{C}_t) + \frac{1}{(1-\beta h)}\left(\epsilon_t^g - \beta h E_t \epsilon_{t+1}^g\right) \tag{4.2.2}$$

Again, please see the appendix for the rest of the linearized model.

5 Bayesian Estimation

In this section we describe the data, estimation methodology and the prior distributions of the parameters for all three model specifications.

5.1 Data and Methodology

Implementation of the Bayesian estimation requires several steps. The first step is writing the solution to the general equilibrium model in state-space representation:

$$x_{t+1} = h(x_t) + \eta\epsilon_{t+1}, \tag{5.1.1}$$

$$y_t = g(x_t) + \chi u_t, \tag{5.1.2}$$

where x_t is a vector of state (both predetermined and endogenous) and control variables and y_t defines the vector of observables. ϵ_t and u_t are the vectors of structural shocks and measurement errors, respectively, and are distributed as $N(0, I)$; and $h(x), g(x), \eta, \chi$ are functions of deep parameters of the model. The second step involves the formulation of the likelihood function of the solution system using the Kalman filter. The third step combines the likelihood function with the priors for the parameters to form the posterior density function. Since the posterior distribution is nonlinear and a complicated function of the deep parameters, the final step involves computing it using sampling-like methods such as the Metropolis-Hastings algorithm.[7]

The sample period ranges from 1966:02 to 2003:01, at a quarterly frequency. Our observables consist of five macro-economic time series: (i) real durable goods consumption,

[7] An and Schorfheide (2007) provide a detailed summary of applications of Bayesian methods in dynamic stochastic general equilibrium models. We use DYNARE to conduct all the estimations. The replication files are available on request.

(ii) real non-durable goods consumption, (iii) the relative price of non-durables to durables, (iv) hours worked, and (v) a short-term interest rate. The first three series are taken from the US Department of Commerce - Bureau of Economic Analysis databank. Both durable and non-durable goods consumption expenditures are deflated by their respective price deflators to obtain real variables. The hours data series is taken from the Bureau of Labor Statistics (BLS). Hours (hours and hourly compensation for the NFB sector for all persons) are adjusted to take into account the limited coverage of the NFB sector compared to GDP (the index of average hours for the NFB sector is multiplied by the Civilian Employment (16 years and over). The short-term interest rate is the Federal Funds Rate. All series are seasonally adjusted. Our demeaned set of observable variables is given by:

$$Z_t = [lN_t, dlC_t, dlD_t, lR_t, dlP_t]'$$

where l and dl stand for the log and log difference, respectively. Figure (3) plots the set of observables. The corresponding log-linearized measurement equations, mapping the observables and transformed variables, are as follows:

$$\begin{bmatrix} lN_t \\ dlC_t \\ dlX_t \\ R_t \\ dlP_t \end{bmatrix} = \begin{bmatrix} \hat{n}_t \\ (\hat{c}_t - \hat{c}_{t-1}) \\ (\hat{x}_t - \hat{x}_{t-1}) \\ \hat{r}_t \\ (\hat{p}_{c,t} - \hat{p}_{x,t}) - (\hat{p}_{c,t-1} - \hat{p}_{x,t-1}) \end{bmatrix} + \begin{bmatrix} 0 \\ \hat{g}_{a,t} \\ \hat{g}_{a,t} + \hat{g}_{z,t} \\ 0 \\ \hat{g}_{z,t} \end{bmatrix}$$

5.2 Priors

We calibrate some of the deep parameters which are difficult to identify. We set the quarterly depreciation rate and discount rate to 0.025 and 0.99, respectively. Following Schmitt-Grohé and Uribe (2008), the intertemporal elasticity of substitution parameter is set at 1. Finally, the steady state markup is set at 6. The rest of the parameters are estimated and Table 2 lists their prior distributions.

The prior distribution of the standard deviations of the two technology shocks and two preference shocks are assumed to follow Inverse Gamma distributions with means of 0.5 and 2.0, respectively. We assume that the prior mean of the standard deviation of the monetary policy shock is 0.1 which is consistent with other related studies. All the AR(1) coefficients are assumed to follow a Beta distribution with mean 0.75 and standard error 0.1.

The habit persistence parameter h_b is assumed to follow a Beta distribution with mean 0.7 and standard error 0.1. There is no clear consensus on the value of the labor elasticity in the existing literature. While micro studies indicate that the value is less than 0.5, macro studies with log separable (in consumption and leisure) preferences indicate that the value varies between 1/3 and 1. Recently, studies with non-separable preferences have implied a much higher value for this parameter. For example, Jaimovich and Rebelo (2009) calibrate it at 2.5, Schmitt-Grohé and Uribe (2008) estimate it at 6.25; and Monacelli and Perotti (2006) calibrate it at 1.25. Inspired by these studies, we assume ν has a prior mean of 0.66 which implies a value for the Frisch elasticity of 1.5 in our baseline model. Following Smets and Wouters (2007) and Christiano, Eichenbaum and Evans (2005), the adjustment cost parameter ϕ_1 is set at 4 with a standard error of 1.5.

Moving to the parameters describing the nominal rigidities, we set the Calvo probabilities at 0.66 for both the wage and price rigidities, with a standard error of around 0.10. This implies that the average durations of both the price and wage contracts are approximately around three quarters. Finally, the monetary policy shock parameters are set at standard calibration values. The coefficients for inflation and the output gap follow Normal distributions with means of 1.7 and 0.13 and standard errors of 0.3 and 0.05, respectively. The interest rate smoothing parameter is assumed to have a mean of 0.6 and a standard error of 0.20.

6 Results

6.1 Posterior Estimates

Table 3 reports the posterior estimates of all the parameters from the three specifications: baseline, Model 1 and Model 2. The posterior mean, and 5th and 95th percentiles of the posterior distribution of the parameters are obtained through the Metropolis-Hastings sampling algorithm. The results are based on 100,000 draws from the posterior distribution.[8] The plots of the prior and posterior distributions of the parameter estimates under all the models are given in Figures (4)-(6).

All the parameters are estimated to be significantly different from zero. Moreover, most of the behavioral parameter estimates are similar across the three model specifications. The key findings are as follows. Focusing on the preference parameters of the baseline model, the estimated value of the labor elasticity parameter ν is 0.74 which implies that the Frisch elasticity is around 1.35. This value is higher than 1.00 as implied by the other two model specifications. Both the baseline and Model 2 specifications estimate the intermediate habit persistence h_b (0.69 and 0.50, respectively) which is consistent with Smets and Wouters

[8] We run two chains of the MH algorithm, each with 100,000 draws. The acceptance rate is around 0.25.

(2007).

The estimate of the price stickiness parameter θ_c in the baseline case is around 0.87 and is quite close to the other two estimates (0.89, Model 1; 0.88, Model 2). This implies that the average duration of the price contract in all the three models is around 7.69 quarters, which is much longer than the 3 quarters found in Smets and Wouters (2007). Furthermore, the average duration of the wage contract implied by Model 1 is 2.56 ($\theta_w = 0.61$) which is consistent with other related studies (Smets and Wouters (2007), Justiniano, Primiceri and Tambalotti (2010, 2011)). Finally, the elasticity of the cost of changing the stock of durables ϕ_1 in Model 1 is estimated to be higher than its prior mean, around 5.52, implying an even slower response of the stock of durables to any exogenous shocks.

Turning to the estimates of the parameters governing the exogenous shocks, a few points are worth mentioning. First, both the intratemporal preference shocks and relative price shocks are estimated to be very persistent in all three specifications. Second, the absence of hump-shaped endogenous dynamics induced by internal habits is compensated by more persistent and volatile intertemporal preference shocks in Model 1. Third, while the estimate of the standard deviation of the relative price shock in the baseline case is around 4.83 and is higher than the estimates in other specifications, that of the neutral technology shock in the baseline model is somewhat lower than that in the other two models. The small wealth effect implied by the augmented GHH preferences induces a strong transmission mechanism for the relative price shocks.[9] Finally, the estimated means of the standard deviation of the monetary policy shocks are similar in all three cases (0.33, baseline; 0.31, Model 1; 0.44, Model 2).

The estimate of the interest rate smoothing parameter (0.90) is somewhat higher in the baseline model compared to the other two models (0.53, 0.63), indicating a considerable degree of smoothing. The mean of the long-run reaction coefficient to inflation is comparable across the models. However, the authorities do not appear to react very strongly to the output gap level in the short-run in any of the models.

6.2 Impulse Responses

Recall that our estimation exercise has two goals: to examine how well each estimated model can (i) explain the co-movement puzzle, and (ii) fit the data. To pursue the first goal, we plot the impulse responses of key variables to a (one standard deviation) monetary policy shock computed at the estimated posterior means of the parameters as given in Figure (7).

[9] A wealth of the literature, such as GHH (1998) and Raffo (2009), establish that the GHH preferences facilitate strong propagation of investment-specific technology shocks that are analogous to relative price shocks in this paper.

We observe that all three estimated models can resolve the co-movement puzzle. However, the internal propagation mechanisms differ across the three models.

In the baseline case, aggregate hours fall due to the small wealth effect on labor supply after a contractionary monetary policy shock (solid line in Figure (7)). This induces a fall in both durable and non-durable production, confirming our intuition from the calibration exercise in Section (2). Furthermore, internal habit persistence generates hump-shaped responses in non-durable consumption, making it less interest-sensitive than durable consumption which is consistent with the empirical VAR findings.

Model 1 introduces nominal wage stickiness in the standard sticky price model as in Carlstrom and Fuerst (2006). Given that labor is the only input, stickiness in nominal wages induces stickiness in the durable goods prices. Hence, durable goods producers have little incentive to adjust their prices as long as the wages are sticky. This causes the aggregate labor, aggregate production, non-durables and durables to fall after a contractionary policy shock (dashed-dot line in Figure (7)). Furthermore, the introduction of adjustment costs prevents the responses of durable goods consumption from moving in the opposite direction after the initial fall on impact.

Finally Model 2 explores the role of the financial frictions as in Tsai (2010). The introduction of a working capital channel imposes the firms to borrow in advance in order to pay wages. After a contractionary monetary policy shock, the marginal cost rises, discouraging production in both the durable and non-durable goods sectors, and thereby inducing a fall in the aggregate labor. Finally, the consumption smoothing motive implied by habit formation dampens the response of non-durable goods consumption to the shock (dashed-star line in Figure (7)).

6.3 Model Fit

In this section, we achieve the second goal of the estimation exercise by comparing the models' fit. One advantage of Bayesian analysis is that it can be employed to assess the relative plausibility of alternative model specifications by comparing the log marginal likelihood.[10] Table 4 reports the out-of-sample forecasts under each specification. The marginal likelihoods are based on Geweke's Harmonic Mean Estimator. Column 3 reports Bayes' factor which is the difference between the log marginal likelihood in alternative cases and the baseline case. The smaller is the number, the stronger is the evidence in favor of the baseline case.

[10]This tool has been successfully used to make comparisons across models in Lubik and Schorfheide (2006), Rabanal and Tuesta (2010), Smets and Wouters (2007) and Justiniano, Primiceri and Tambalotti (2010). Villaverde and Rubio-Ramírez (2001) argue that Bayesian inference based on marginal likelihood comparisons across models is valid even if the models are nonnested, misspecified and nonlinear.

It is quite evident that the data strongly favor Model 2 over all the specifications followed by Model 1. The marginal log-likelihood under Model 1 and Model 2 increases by 121 and 214, respectively, compared to the baseline model, which means that priors that favor the baseline model over Model 1 and Model 2 by factors of 7.6×10^{52} and 8.6×10^{92} are needed in order to accept it after observing the data. These factors are very high, and so the data strongly reject the baseline model compared to the other cases.

In a nutshell, there are key structural differences across the three models that affect the reduced form dynamics of durable consumption, non-durable consumption, hours, inflation and the interest rate and hence the models' overall fit to the actual data. Our findings suggest that Model 2 with a working capital channel not only successfully resolves the co-movement puzzle, but also outperforms the other two specifications in fitting the data.

7 Conclusion

We propose a new mechanism: non-separable preferences with a small wealth effect on labor hours to resolve the negative co-movement puzzle in outputs across durable and non-durable sectors as pointed out by BHK. Following a contractionary monetary policy shock, aggregate labor declines due to the small wealth effect, inducing a simultaneous fall in both durable and non-durable goods production. Next, we use a Bayesian approach and five macroeconomic time-series that are key to our study to estimate and compare our model's performance with two alternative models that can simultaneously resolve the puzzle. Using marginal likelihood as a model comparison device, we find that our model performs worse than Carlstrom and Fuerst (2006) and Tsai (2010). In particular, Tsai (2010) outperforms all other specifications in fitting the data.

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TECHNICAL APPENDIX

A Household's problem

Utility function is given by:

$$U(C_t, D_t, N_t) = \epsilon_t^g \left[(B_t) - \epsilon_t^l \phi N_t^{1+\nu} H_t \right]$$

s.t.

$$H_t = H_{t-1}^{(1-\gamma)} \left(B_t \right)^{\gamma}$$

where $B_t = (C_t - h_b C_t - 1)^{\psi_c} D_t^{\psi_d}$ and $\epsilon_t^g, \epsilon_t^l$ are preference shock and labor-preference shock respectively. Then the household optimization problem is:

$$Max \sum \beta^t \frac{U(C_t, D_t, N_t)^{1-\sigma}}{1-\sigma}$$

s.t.

$$P_{c,t} C_t + P_{x,t} X_t + P_{x,t} \left[\frac{1}{2} \phi_1 \frac{(X_t - \delta D_{t-1})^2}{D_{t-1}} \right] \leq W_t N_t + \Pi_t + T_t + S_{t-1} - \frac{S_t}{R_t}, t = 0, 1, .. \quad (1)$$

$$H_t = H_{t-1}^{(1-\gamma)} \left(B_t \right)^{\gamma} \quad (2)$$

$$D_t = (1 - \delta) D_{t-1} + X_t \quad (3)$$

Let $\Lambda_t, \Omega_t, \Xi_t$ represent the langrangian multipliers for constraints (1) (2) and (3) respectively. The household foc with respect to C_t, X_t, D_t, N_t, H_t are:

$$\Lambda_t = \psi_c U_t^{-\sigma} \frac{B_t}{(C_t - h_b C_{t-1})} \epsilon_t^g - h_b \beta \psi_c E_t \left[U_{t+1}^{-\sigma} \epsilon_{t+1}^g \right] \frac{B_{t+1}}{(C_{t+1} - h_b C_t)} + \gamma \psi_c \Omega_t H_{t-1}^{1-\gamma} \left(B_t \right)^{\gamma-1} \frac{B_t}{(C_t - h_b C_{t-1})}$$
$$- h_b \beta \gamma \psi_c E_t \left[\Omega_{t+1} \left(B_{t+1} \right)^{\gamma-1} \right] H_t^{1-\gamma} \frac{B_{t+1}}{(C_{t+1} - h_b C_t)} \quad (4)$$

$$\Lambda_t \frac{P_{x,t}}{P_{c,t}} + \Lambda_t \frac{P_{x,t}}{P_{c,t}} \phi_1 \frac{(X_t - \delta D_{t-1})}{D_{t-1}} = \Xi_t \quad (5)$$

$$\Xi_t - \beta(1-\delta)E_t\Xi_{t+1} = \psi_d U_t^{-\sigma}\frac{B_t}{D_t}\epsilon_t^g + \gamma\psi_d\Omega_t H_{t-1}^{(1-\gamma)}\frac{(B_t)^\gamma}{D_t} + \Lambda_t\frac{P_{x,t}}{P_{c,t}}\left[\phi_1\delta\frac{(X_t-\delta D_{t-1})}{D_{t-1}} + \frac{\phi_1}{2}\frac{(X_t-\delta D_{t-1})^2}{D_{t-1}^2}\right] \quad (6)$$

$$U_t^{-\sigma}\phi(1+\nu)N_t^\nu H_t\epsilon_t^g\epsilon_t^l = \Lambda_t\frac{W_t}{P_{c,t}} \quad (7)$$

$$\Omega_t + U_t^{-\sigma}\phi N_t^{1+\nu}\epsilon_t^g\epsilon_t^l = \beta(1-\gamma)E_t\Omega_{t+1}\left(B_{t+1}\right)^\gamma H_t^{-\gamma} \quad (8)$$

Detrend: To detrend our model, let $B_t = b_tA_tZ_t^{\varphi_d}$, $H_t = h_tA_tZ_t^{\varphi_d}$, $\frac{B_t}{C_t} = \left(\frac{b_t}{c_t}\right)(Z_t)^{\varphi_d}$, $\frac{B_t}{D_t} = \left(\frac{b_t}{d_t}\right)\left(\frac{1}{Z_t}\right)^{\varphi_c}$, $U(.)^{-\sigma} = (A_t)^{-\sigma}(Z_t)^{\varphi_d(-\sigma)}u(.)^{-\sigma}$, $\Lambda_t = (A_t)^{-\sigma}(Z_t)^{\varphi_d(1-\sigma)}\lambda_t$, $\Omega_t = (A_tZ_t^{\varphi_d})^{-\sigma}\omega_t$, $\Xi_t = \xi_t(A_t)^{-\sigma}(Z_t)^{\varphi_d(1-\sigma)-1}$ $W_t = A_tw_t$, $\frac{P_{xt}}{P_{ct}} = \frac{1}{Z_t}\frac{p_{xt}}{p_{ct}}$, then we can have the following equations.

$$\lambda_t = \psi_c u_t^{-\sigma}\frac{b_t}{(c_t - h_bc_{t-1}/g_{a,t})}\epsilon_t^g - h_b\beta\psi_cE_t\left[u_{t+1}^{-\sigma}g_{a,t+1}^{-\sigma}g_{z,t+1}^{\psi_d(1-\sigma)}\epsilon_{t+1}^g\right]\frac{b_{t+1}}{(c_{t+1}-h_bc_t/g_{a,t+1})} + \gamma\psi_c\omega_t\frac{h_{t-1}^{1-\gamma}b_t^\gamma}{(c_t-h_bc_{t-1}/g_{a,t})}\left[g_{a,t}g_{z,t}^{\psi_d}\right]^{\gamma-1} - h_b\beta\gamma\psi_c\omega_{t+1}\frac{b_{t+1}^\gamma h_t^{1-\gamma}}{(c_{t+1}-h_bc_t/g_{a,t+1})}g_{a,t+1}^{-\sigma+\gamma-1}(g_{z,t+1}^{\psi_d})^{1-\sigma+\gamma-1} \quad (D.1)$$

$$\lambda_t\frac{p_{x,t}}{p_{c,t}} + \lambda_t\frac{p_{x,t}}{p_{c,t}}\phi_1\frac{(g_{a,t}g_{z,t}x_t - \delta d_{t-1})}{d_{t-1}} = \xi_t \quad (D.2)$$

$$\xi_t - \lambda_t\frac{p_{x,t}}{p_{c,t}}\left[\phi_1(g_{a,t}g_{z,t}x_t-\delta d_{t-1})\frac{\delta}{d_{t-1}} + \frac{1}{2}\phi_1\left(g_{a,t}g_{z,t}x_t-\delta d_{t-1}\right)^2\frac{1}{d_{t-1}^2}\right] - \beta(1-\delta)E_t\xi_{t+1}g_{a,t+1}^{-\sigma}g_{z,t+1}^{\psi_d(1-\sigma)-1} = \psi_du_t^{-\sigma}\frac{b_t}{d_t}\epsilon_t^g + \gamma\psi_d\omega_th_{t-1}^{(1-\gamma)}\frac{(b_t)^\gamma}{d_t}[g_{a,t}g_{z,t}^{\psi_d}]^{\gamma-1} \quad (D.3)$$

$$u_t^{-\sigma}\phi(1+\nu)N_t^\nu h_t\epsilon_t^g\epsilon_t^l = \lambda_t\frac{w_t}{P_{c,t}} \quad (D.4)$$

$$\omega_t + u_t^{-\sigma}\phi N_t^{1+\nu}\epsilon_t^g\epsilon_t^l = \beta(1-\gamma)E_t\omega_{t+1}(g_{a,t+1}g_{z,t+1}^{\psi_d})^{\gamma-\sigma}\left(b_{t+1}\right)^\gamma h_t^{-\gamma} \quad (D.5)$$

Non-durable goods firms optimization problem gives:

$$MC_{c,t} = \frac{W_t}{A_t} \tag{A.1}$$

Durable goods firms optimization problem gives:

$$MC_{x,t} = \frac{W_t}{Z_t A_t} \tag{A.2}$$

$$MC_{x,t} = P_{x,t} \tag{A.3}$$

Combining (A.1) and (A.2):

$$\frac{MC_{x,t}}{MC_{c,t}} = \frac{1}{Z_t} = \frac{P_{x,t}}{P_{c,t}}$$

Steady state:
From (D.5),

$$\omega = \frac{u^{-\sigma}\phi N^{1+\nu}}{\beta(1-\gamma)-1} \tag{ss.1}$$

From D.1,

$$\lambda = \frac{\psi_c u^{-\sigma} b}{c(1-h_b)}(1-\beta h_b)\left[1 + \frac{\gamma\phi N^{1+\nu}}{\beta(1-\gamma)-1}\right] \tag{ss.2}$$

From D.2,

$$\lambda = \xi \tag{ss.3}$$

From D.3 and ss.1

$$\xi\left[1-\beta(1-\delta)\right] = \psi_d u^{-\sigma}\frac{b}{d}\left[1 + \frac{\gamma\phi N^{1+\nu}}{\beta(1-\gamma)-1}\right] \tag{ss.4}$$

From ss.2, ss.3 and ss.4,

$$\psi_c = \frac{\frac{c/d}{1-\beta(1-\delta)}}{\frac{1-\beta h_b}{1-h_b} + \frac{c/d}{1-\beta(1-\delta)}}$$

From D.4 and ss.4

$$\phi = \frac{\frac{\psi_d b/d}{1-\beta(1-\delta)}}{N^{1+\nu}\left[\frac{(1+\nu)h/N}{(\epsilon-1)/\epsilon} - \frac{\psi_d (b/d)\gamma}{(1-\beta(1-\delta))(\beta(1-\gamma)-1)}\right]}$$

Log-linearize:

$$
\begin{aligned}
(1-\beta h_b)\hat{\lambda}_t = & \frac{(\beta(1-\gamma)-1)}{(\beta(1-\gamma)-1)+\gamma\phi N^{1+\nu}}\left[-\sigma\hat{u}_t+\hat{b}_t-\frac{1}{1-h_b}(\hat{c}_t-h_b\hat{c}_{t-1}+h_b\hat{g}_{a,t})+\hat{\epsilon}^g_t\right] \\
& -\frac{h_b\beta(\beta(1-\gamma)-1)}{(\beta(1-\gamma)-1)+\gamma\phi N^{1+\nu}}\left[-\sigma\hat{u}_{t+1}-\sigma\hat{g}_{a,t+1}+\psi_d(1-\sigma)\hat{g}_{z,t+1}+\hat{b}_{t+1}-\frac{1}{1-h_b}(\hat{c}_{t+1}-h_b\hat{c}_t+h_b\hat{g}_{a,t+1})+\hat{\epsilon}^g_{t+1}\right] \\
& +\frac{\gamma\phi N^{1+\nu}}{\beta(1-\gamma)-1+\gamma\phi N^{1+\nu}}\left[\hat{\omega}_t+(1-\gamma)\hat{h}_{t-1}+\gamma\hat{b}_t-\frac{1}{1-h_b}(\hat{c}_t-h_b\hat{c}_{t-1}+h_b\hat{g}_{a,t})+(\gamma-1)(\hat{g}_{a,t}+\psi_d\hat{g}_{z,t})\right] \\
& -\frac{h_b\beta\gamma\phi N^{1+\nu}}{\beta(1-\gamma)-1+\gamma\phi N^{1+\nu}}\left[\hat{\omega}_{t+1}+(1-\gamma)\hat{h}_t+\gamma\hat{b}_{t+1}-\frac{1}{1-h_b}(\hat{c}_{t+1}-h_b\hat{c}_t+h_b\hat{g}_{a,t+1})+(-\sigma+\gamma-1)\hat{g}_{a,t+1}+(1-\sigma+\gamma-1)\psi_d\hat{g}_{z,t+1}\right]
\end{aligned} \tag{L.1}
$$

$$
\hat{\lambda}_t+\hat{p}_{x,t}-\hat{p}_{c,t}+\phi_1\delta(\hat{x}_t-\hat{d}_{t-1}+\hat{g}_{a,t}+\hat{g}_{z,t})=\hat{\xi}_t \tag{L.2}
$$

$$
\begin{aligned}
\hat{\xi}_t-\phi_1\delta^2(\hat{x}_t-\hat{d}_{t-1}+\hat{g}_{a,t}+\hat{g}_{z,t})-\beta(1-\delta)\left[\hat{\xi}_{t+1}-\sigma\hat{g}_{a,t+1}+(\psi_d(1-\sigma)-1)\hat{g}_{z,t+1}\right] \\
=\frac{(1-\beta(1-\delta))(\beta(1-\gamma)-1)}{(\beta(1-\gamma)-1)+\gamma\phi N^{1+\nu}}(-\sigma\hat{u}_t+\hat{b}_t-\hat{d}_t+\hat{\epsilon}^g_t) \\
+\frac{(1-\beta(1-\delta))\gamma\phi N^{1+\nu}}{(\beta(1-\gamma)-1)+\gamma\phi N^{1+\nu}}\left[\hat{\omega}_t+(1-\gamma)\hat{h}_{t-1}+\gamma\hat{b}_t-\hat{d}_t+(\gamma-1)(\hat{g}_{a,t}+\psi_d\hat{g}_{z,t})\right]
\end{aligned} \tag{L.3}
$$

$$
\frac{1}{\beta(1-\gamma)}\left[\hat{\omega}_t+(\beta(1-\gamma)-1)(-\sigma\hat{u}_t+(1+\nu)\hat{N}_t+\hat{\epsilon}^g_t+\hat{\epsilon}^l_t)\right]=\hat{\omega}_{t+1}+(\gamma-\sigma)(\hat{g}_{a,t+1}+\psi_d\hat{g}_{z,t+1})+\gamma(\hat{b}_{t+1}-\hat{h}_t) \tag{L.4}
$$

$$
\hat{\lambda}_t+\hat{w}_t-\hat{p}_{c,t}=-\sigma\hat{u}_t+\nu\hat{N}_t+\hat{h}_t+\hat{\epsilon}^g_t+\hat{\epsilon}^l_t \tag{L.5}
$$

$$
\hat{h}_t=(1-\gamma)\hat{h}_{t-1}+\gamma\hat{b}_t+(\gamma-1)(\hat{g}_{a,t}+\phi_d\hat{g}_{z,t}) \tag{L.6}
$$

$$
\hat{b}_t=\frac{\psi_c}{1-h_b}\left(\hat{c}_t-h_b\hat{c}_{t-1}+h_b\hat{g}_{a,t}\right)+\psi_d\hat{d}_t \tag{L.7}
$$

$$
\hat{u}_t=\frac{1}{(1-\phi N^{1+\nu})}\left[\hat{b}_t-\phi N^{1+\nu}((1+\nu)\hat{N}_t+\hat{h}+\hat{\epsilon}^l_t)\right] \tag{L.8}
$$

Alternative Specifications:

- Baseline (Augmented GHH): $\phi_1=0,\gamma=0$
- Model 1: $h_b=0,\gamma=1$
- Model 2: $\gamma=1,\phi_1=0$

Table 2: Priors of structural parameters

Parameter	Description	Distribution	Mean	Std. Dev
ν	inverse of Frisch elasticity	Normal	0.66	0.10
h_b	habit parameter	Beta	0.70	0.10
ϕ_1	adjustment cost	Normal	4.00	1.5
θ_c	probability of not optimizing prices	Beta	0.66	0.10
θ_w	probability of not optimizing wages	Beta	0.66	0.10
ϕ_π	Taylor rule response to inflation	Normal	1.70	0.3
ϕ_y	Taylor rule response to output	Normal	0.13	0.05
ρ_r	Taylor rule inertia	Beta	0.6	0.20
ρ_a	persistence of productivity shock	Beta	0.75	0.1
ρ_g	persistence of preference shock	Beta	0.75	0.1
ρ_l	persistence of labor supply shock	Beta	0.75	0.1
ρ_v	persistence of relative price shock	Beta	0.75	0.1
σ^a	s.d. of productivity shock	Inverse Gamma	0.50	1.00
σ^g	s.d. of preference shock	Inverse Gamma	2.00	1.00
σ^l	s.d. of labor supply shock	Inverse Gamma	2.00	1.00
σ^v	s.d. of relative price shock	Inverse Gamma	0.50	1.00
σ^r	s.d. of monetary policy shock	Inverse Gamma	0.10	1.00

Notes: This table lists the description and prior distributions of the structural parameters. The parameters θ_w and h are only used in Model 1 and Model 2 respectively. All the other parameters are used in all the three models.

Table 3: Posterior of structural parameters

Parameters	Baseline		Model 1 (CF)		Model 2 (Tsai)	
	Mean	90% interval	Mean	90% interval	Mean	90% interval
ν	0.74	[0.67,0.80]	0.96	[0.82,1.10]	0.99	[0.86, 1.12]
h_b	0.69	[0.67,0.72]	-	-	0.50	[0.42,0.58]
θ_c	0.87	[0.86,0.87]	0.89	[0.88,0.91]	0.88	[0.84, 0.92]
θ_w	-	-	0.61	[0.60,0.62]	-	-
ϕ_1	-	-	5.52	[4.20,6.75]	-	-
ϕ_π	1.02	[1.00,1.05]	1.19	[1.16, 1.23]	1.43	[1.17,1.70]
ϕ_y	0.35	[0.29,0.41]	0.04	[0.03, 0.06]	0.006	[0.0010, 0.01]
ρ_r	0.90	[0.89,0.92]	0.53	[0.50,0.56]	0.63	[0.57,0.69]
ρ_a	0.73	[0.68,0.77]	0.16	[0.11,0.20]	0.15	[0.11,0.18]
ρ_g	0.61	[0.55,0.68]	0.99	[0.98,0.99]	0.89	[0.82, 0.96]
ρ_l	0.97	[0.96,0.98]	0.83	[0.79, 0.85]	0.98	[0.96,0.99]
ρ_v	0.97	[0.96,0.97]	0.98	[0.98,0.99]	0.95	[0.93,0.97]
σ^a	0.33	[0.28,0.37]	1.12	[1.01,1.23]	1.11	[1.00,1.22]
σ^v	4.83	[4.37,5.30]	0.12	[0.10, 0.13]	0.12	[0.10,0.14]
σ^g	2.62	[2.28,2.95]	7.58	[3.97,11.22]	1.58	[1.17,2.01]
σ^r	0.33	[0.28,0.37]	0.31	[0.27, 0.34]	0.44	[0.36,0.52]
σ^l	0.58	[0.48,0.67]	2.12	[1.86,2.37]	1.15	[1.02,1.28]

Notes: This table lists the prior distributions of the structural parameters in all the three estimated models: baseline, Model 1 and Model 2. The two numbers in the parentheses are the 90% confidence intervals.

Table 4: Marginal Likelihood

Model	Log Marginal Likelihood	Bayes' Factor
Baseline	-1262.283	0
Model 1	-1140.516	121.767
Model 2	-1048.170	214.113

Notes: The table reports log marginal likelihoods from each model. The Bayes' factor is given by calculating the difference between log marginal likelihoods of the alternative specifications and the baseline specification.

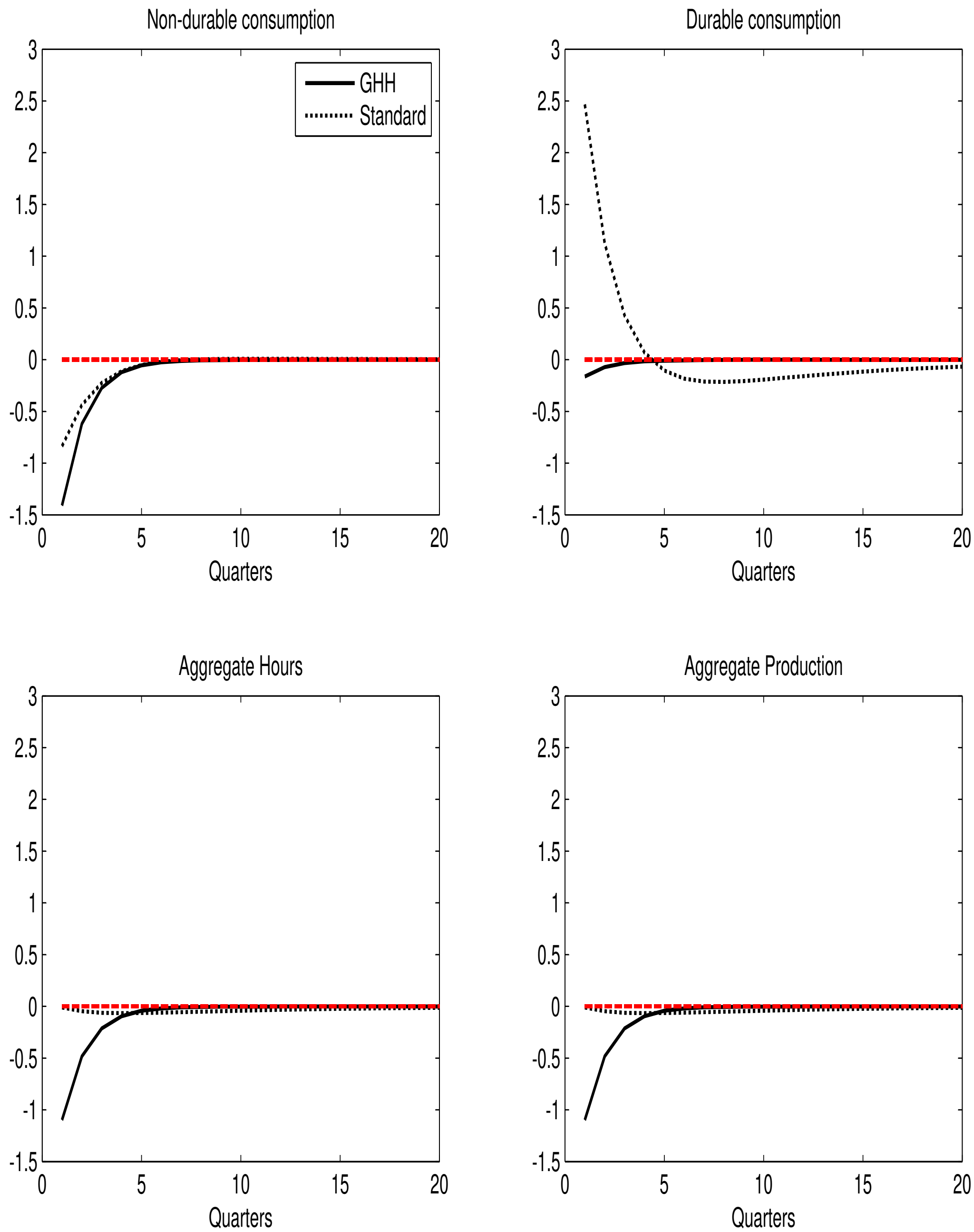

Figure 1: IRF from a unit contractionary monetary policy shock.

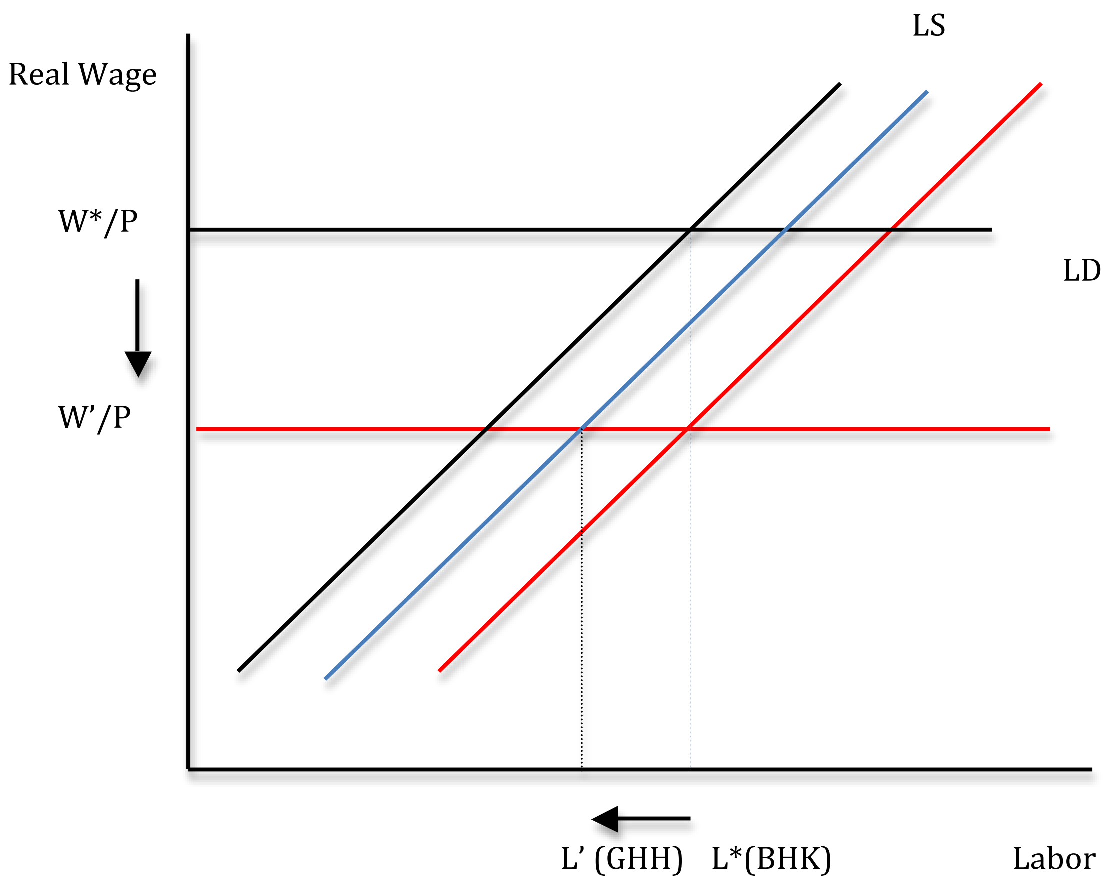

Figure 2: Labor market.

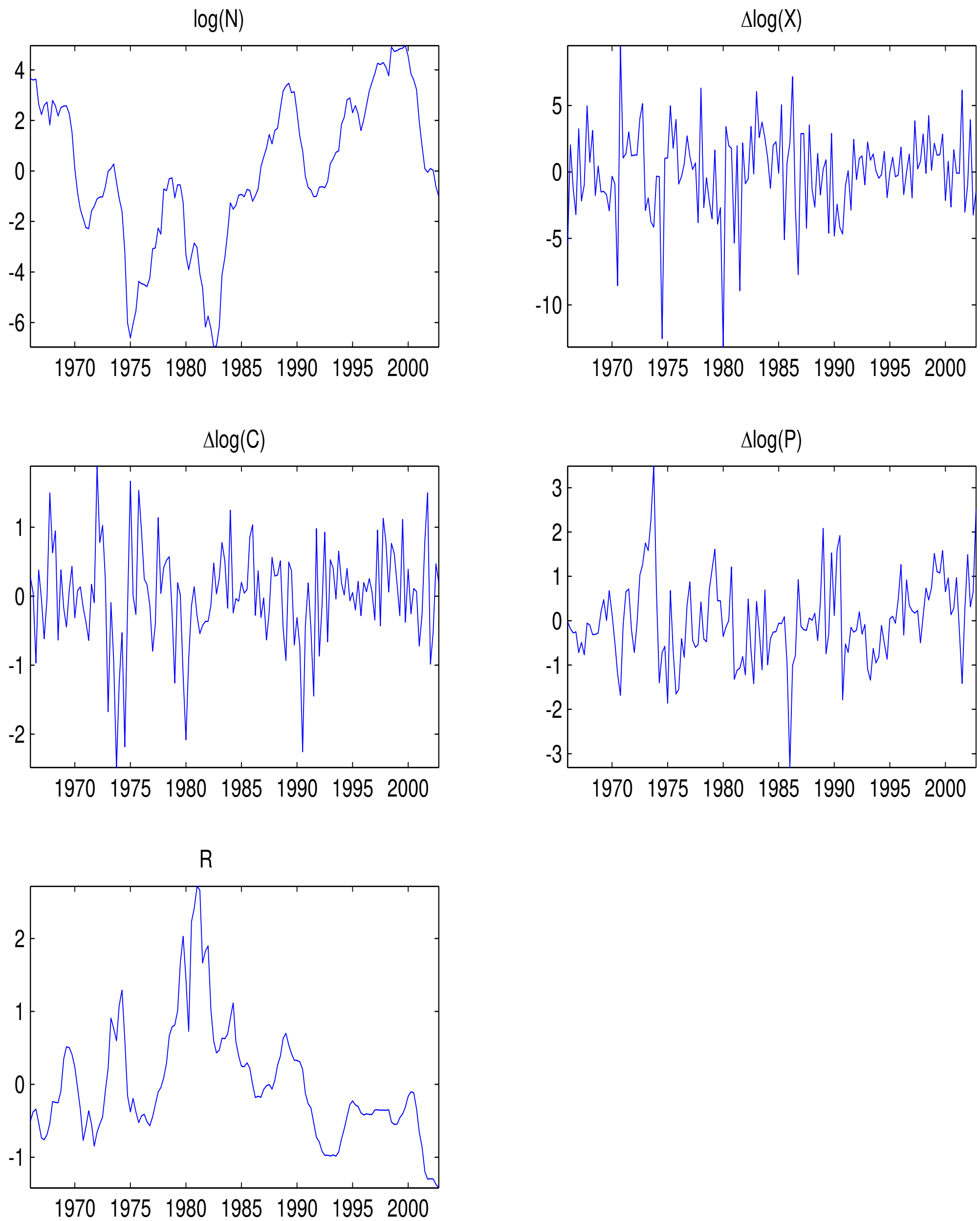

Figure 3: Observables.

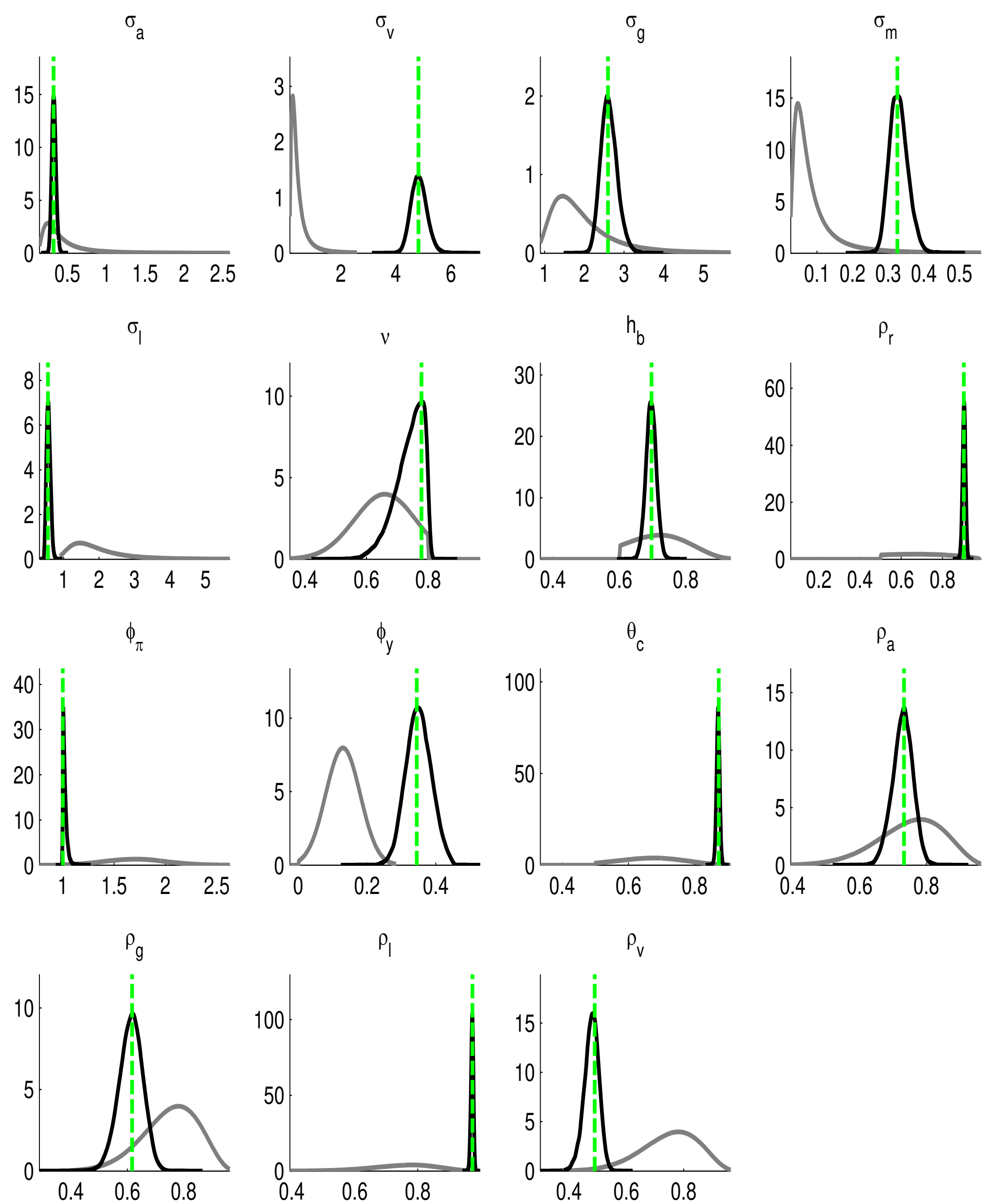

Figure 4: Prior and posterior distributions under the baseline model.

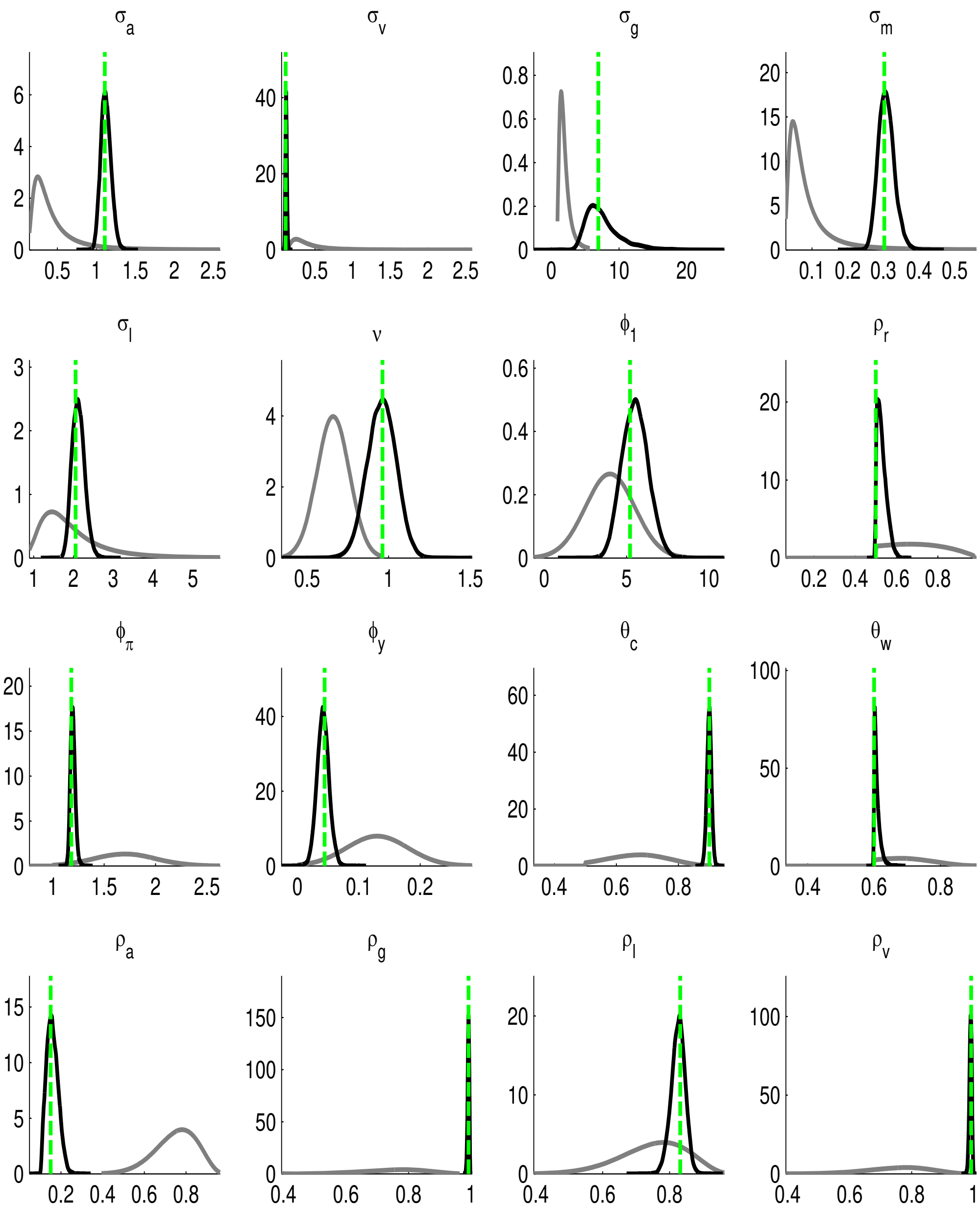

Figure 5: Prior and posterior distributions under Model 1.

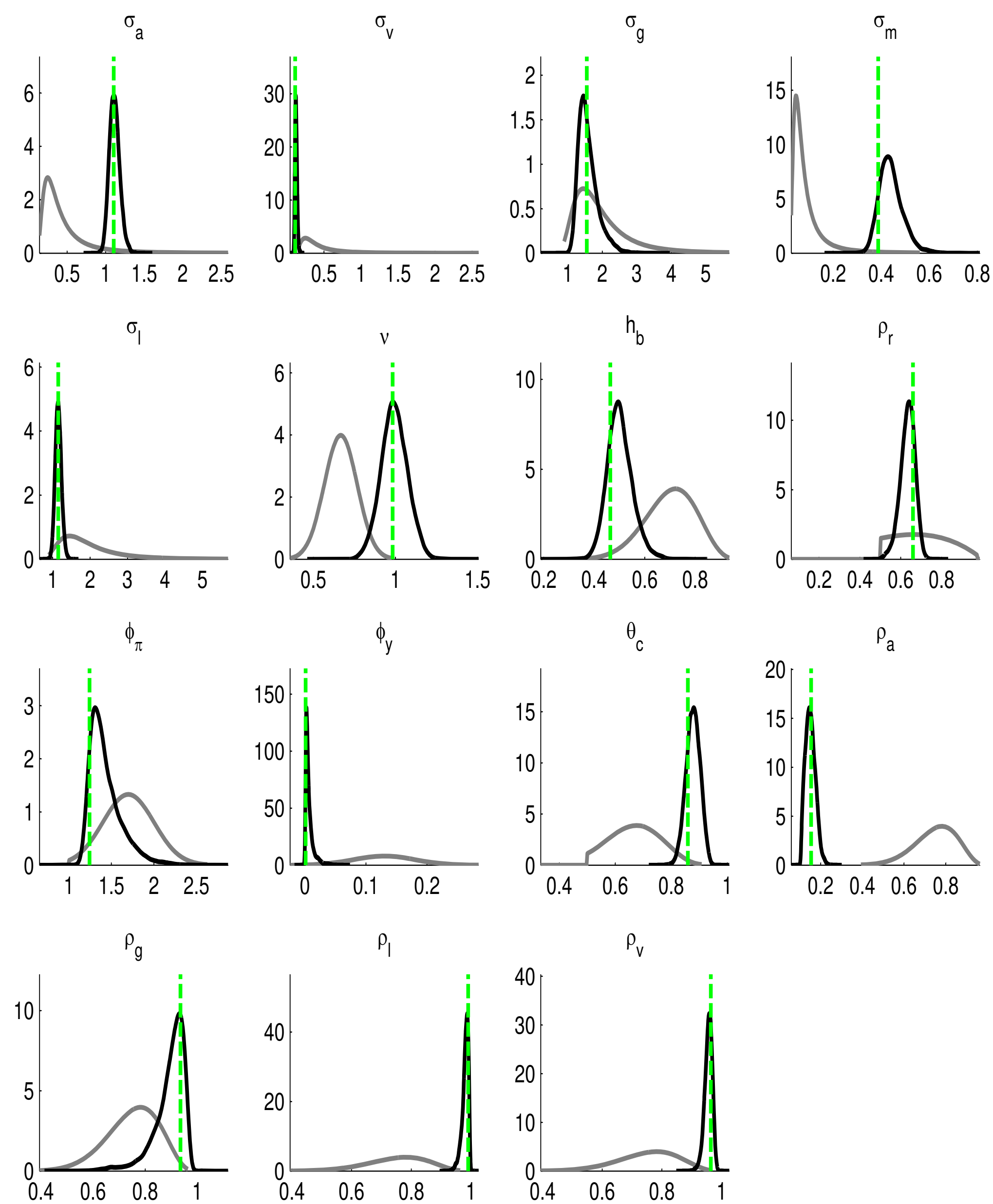

Figure 6: Prior and posterior distributions under Model 2.

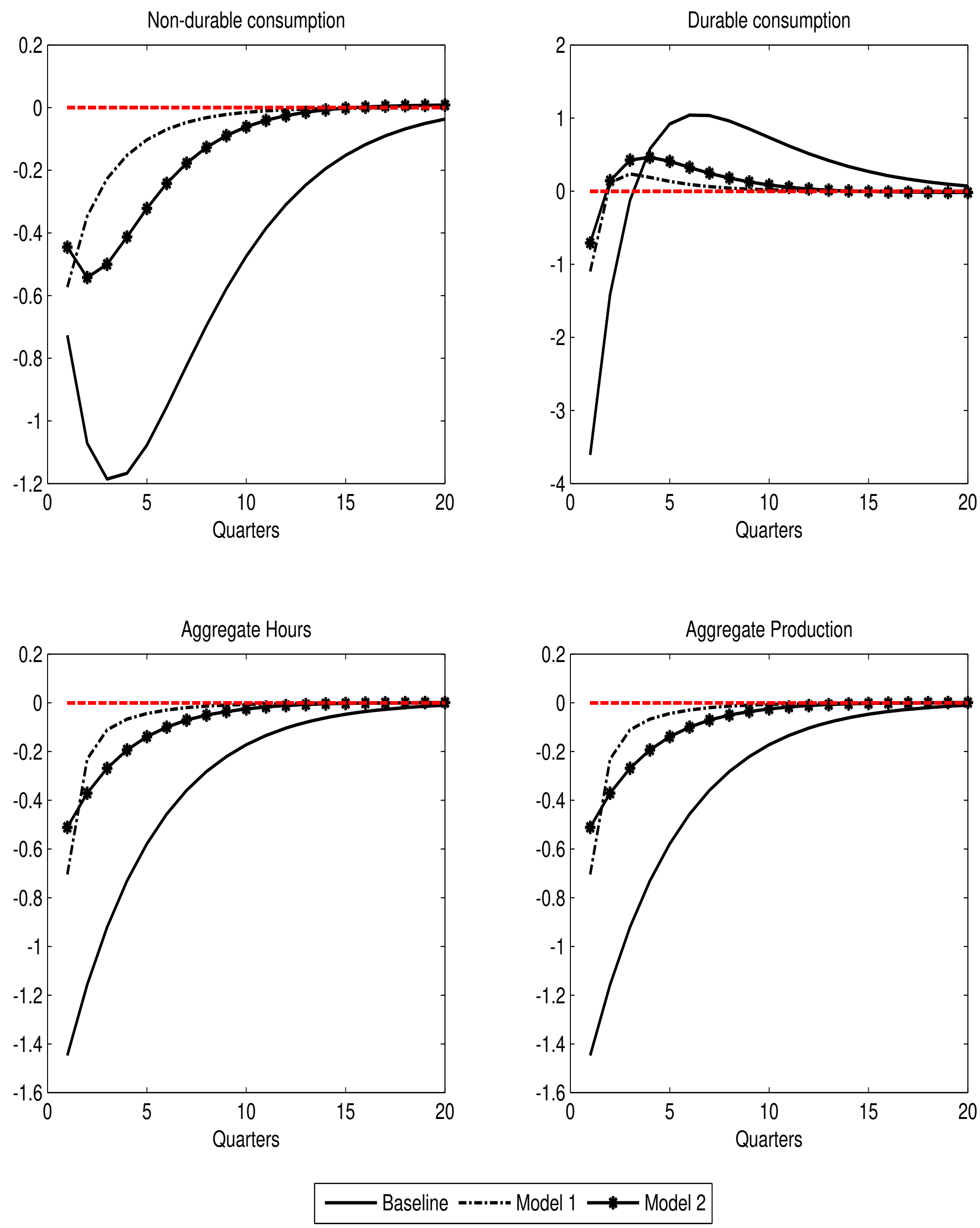

Figure 7: Estimated mean impulse responses from monetary policy shock.

Notes: Economic models' responses to a one standard deviation contractionary monetary policy shock. The estimated standard deviations of the monetary policy shock are 0.33, 0.31 and 0.44 for baseline, Model 1 and Model 2 specifications respectively. The impulse responses are computed at the posterior means of the parameters obtained under the three specifications.