Credit Frictions and Household Debt in the U.S. Business Cycle: A Bayesian Approach

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Abstract

The reduction in the volatility of most U.S. macroeconomic variables during the so-called "Great Moderation" has been particularly significant for consumption and residential investment. During approximately the same period, financial markets deregulation and liberalization gave rise to an increase in the level of household debt, while reducing its volatility. This paper builds and estimates a New Keynesian Dynamic Stochastic General Equilibrium (DSGE) model featuring household heterogeneity and collateral constraints, along with nominal rigidities. The estimation exercise is performed by applying Bayesian methods over two separate samples, with a cutoff point placed in 1983. We obtain four main results: *(i)* housing preference shocks explain almost 46% of the variation in consumption after 1982, as opposed to only 14% in the previous sample; *(ii)* residential investment and household debt are also mainly explained by housing preference shocks, with a quite constant contribution over time; *(iii)* the volatility of all the structural shocks has substantially declined over time; *(iv)* prices are relatively sticky for nondurable goods, while they are flexible in the housing sector.

Keywords: Collateral constraints, Household Debt, Bayesian Estimation.

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1 Introduction

The significant reduction in the volatility of most U.S. macroeconomic variables is by now a well-documented phenomenon, that goes under the name of Great Moderation. The large reduction in the standard deviation of GDP growth over the last 30 years is perhaps the most immediate source of such evidence. Consumption of nondurable and durable goods, investment and particularly residential investment also experienced a significant reduction in time variation. A large and growing strand of the literature has provided quantitative analysis on the sources and the cyclical effects of such reduced volatility[1].

During approximately the same period of time, the U.S. financial markets underwent a process of deregulation and liberalization, which deeply modified the access to funds for households and businesses. Developments in the loan markets have substantially improved households' financing conditions. In particular, the amount of collateralized household debt has significantly increased: as documented by Dynan, Elmendorf and Sichel (2006), the ratio of household debt to disposable personal income doubled during the period 1960-2004, and the private debt/GDP ratio has grown larger than one since 2005. Interestingly, such an increase in levels (and growth rates too) has not been accompanied by a higher volatility. The data show in fact a reduction in the volatility of household debt since 1982, with a new increase after 2000. Figures 1 and 2 report the time series of both the level and the standard deviation of real per capita household debt. Table 1 reports the standard deviation of consumption, residential investment and household debt over the two samples. Table 2 reports descriptive statistics for the standard deviation of such series.

The observed coincidence between a significant macroeconomic stabilization and the evolution of financial market structures has been recently analyzed both empirically and theoretically[2]. In particular, Campbell and Hercowitz (2006) identify a low-collateral requirement era in the loan markets after the end of 1982[3]. That period also belongs to

[1] See, among others, Justiniano and Primiceri (2005) and references therein for a list of contributions.

[2] See Dynan, Elmendorf and Sichel (2006) and Campbell and Hercowitz (2006).

[3] In particular, in 1982 the Garn-St.Germain act was passed. That act allowed private saving associations to provide commercial loans, and thus coincides with a first, signficant liberalization of the U.S. financial markets.

a new era in the conduct of monetary policy, and precedes the conventional start of the Great Moderation era by a few quarters.

This paper proposes the estimation of a Dynamic Stochastic General Equilibrium (DSGE) model with household credit market imperfections. The main objective is an evaluation of the relative importance of financial markets liberalization and changes in the conduct of monetary policy in explaining the reduced volatility of nondurable consumption, residential investment and household debt. Workhorse DSGE models with nominal and real rigidities are usually mute about credit market frictions faced by households. Household debt cannot be treated in the standard New Keynesian model, since the *representative agent* assumption prevents any form of private lending. Therefore, following the seminal contribution of Kiyotaki and Moore (1997), this paper assumes a dual structure on the household side: agents belong to two different groups according to their intertemporal discount factor. The different profile of intertemporal preferences originates a shift of resources across consumers both intratemporally, and intertemporally. Household debt thus results in equilibrium from the accumulation of borrowing over time. A second modification relates households' consumption and saving decisions to their balance sheets and the availability of collateralizable durable goods. The relatively impatient agents are in fact assumed to face a collateral constraint, which puts an endogenous limit to the amount of funds they can borrow.

The introduction of these two assumptions has important consequences for the monetary transmission mechanism, which is enriched in three ways. First, the issuing of nominal debt by households generates non-neutrality of monetary policy through the effect of interest rate movements on both the cost of debt and the real value of it. Basically, any change in the policy rate produces both a direct change in the cost of servicing debt, and an indirect change in the ex-post real value of outstanding debt, via the effect of monetary policy on the inflation rate. Noticeably, this first channel is independent of nominal rigidities. Second, the existence of a collateral constraint generates a substitution effect between durable and nondurable consumption goods. Intuitively, whenever the collateral constraint tightens (because of changes in the financial markets), agents reduce their borrowing and substitute durable with nondurable consumption. Such an effect is independent of monetary policy decisions, but is likely to interact with them if monetary and financial changes happen to be contemporaneous. The third channel builds on the valuation effect of durable prices on the available amount of collateralizable goods, and hence on consumption. Any change in the relative price of durable consumption is reflected into a change in the value of the collateral, and implies - ceteris paribus - a change in the demand for durables. The relative degree of price rigidity in the two sectors influences the strength of the valuation channel.

The model is estimated on U.S. quarterly data using Bayesian methods. The first sample goes from 1965 I through 1982 IV and the second one goes from 1983 I through 2006 IV. The choice of such a split is motivated by at least two reasons. First, the last quarter of 1982 is identified in the literature as the end of a high-equity requirement era in financial markets. As documented by Campbell and Hercowitz (2006) and Dynan, Elmendorf and Sichel (2006), the Garn-St.Germain Act - passed in late 1982 - started a dramatic increase in loan-to-value ratios and originated an unprecedented development of secondary markets. The time series behaviour of household debt also changes completely after that date. It is therefore natural and somewhat necessary to split the sample in correspondence of such a break point. Moreover, the second sample leads by only four quarters the conventional beginning of the Great Moderation, usually placed at 1984 I[4].

The main results of the estimation exercise can be summarized as follows:

1. Housing preference shocks explain almost 46% of the variation in consumption after 1982, as opposed to only 14% in the previous sample. We observe a contemporaneous substantial reduction in the corresponding contribution of monetary policy shocks.

2. The volatility of residential investment and household debt is also largely explained by housing preference shocks, with a quite constant contribution over time. The role of monetary policy and productivity shocks is minor.

3. The estimated standard deviation of all the structural shocks has significantly declined over time. The estimated median values are on average 1.6 times larger in

[4] SeeMcConnell and Perez-Quiros (2000).

the first period (up until 1982) than in the second one.

4. There is a substantial degree of asymmetry in the estimated price stickiness across sectors. The median duration of prices in the nondurable sector is 8.3 quarters - in line with the existing macroeconometric evidence - while prices are almost perfectly flexible in the housing sector. The asymmetry is robust across samples.

The rest of the paper is organized as follows: Section 2 describes the model; Section 3 describes the estimation exercise and comments on the results. Section 4 concludes.

2 The model

The model describes a two-agent, two-sector economy, with agents belonging to two different groups according to their own intertemporal discount factor, along the lines of Campbell and Hercowitz (2006). Households consume two goods, durables and nondurables, produced in two different sectors of the economy. Durable goods are interpreted as housing, and serve two purposes: they can be either directly consumed or used as collateral when applying for a loan. Household debt is introduced along with the existence of a collateral constraint on the total amount of borrowing. The next two subsections describe the households' structure in detail.

2.1 The impatient agents

The representative *impatient* agent receives utility from the following instantaneous utility function:

$$U(X_t, N_t) = \log(X_t) - \frac{\upsilon}{1+\varphi} N_t^{1+\varphi} \tag{1}$$

where X_t is a constant elasticity of substitution (CES) consumption aggregator defined as follows:

$$X_t = \left[(1-\alpha)^{\frac{1}{\eta}} \left(C_t - \theta C_{t-1} \right)^{\frac{\eta-1}{\eta}} + \alpha^{\frac{1}{\eta}} D_t^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}} \tag{2}$$

About notation, C_t denotes consumption of the nondurable good, the parameter θ captures the degree of habit formation in nondurable consumption, and D_t indicates the choice of durable consumption. The term υ is a scale parameter which pins down the amount of hours in steady state, while φ denotes the inverse elasticity of labor supply. The law of motion for durables is defined as follows:

$$D_t = (1-\delta)D_{t-1} + I_t^D$$

with I_t^D denoting durable investment and D_{t-1} being the stock of durables carried over by the previous period.

The agent solves the following intertemporal maximization problem:

$$\max E_0 \sum_{t=0}^{\infty} \beta^t U(X_t, N_t) \tag{3}$$

subject to the infinite sequence of budget constraints:

$$P_{c,t}C_t + P_{d,t}(D_t - (1-\delta)D_{t-1}) - B_t = -R_{t-1}B_{t-1} + W_t N_t \tag{4}$$

where B_t is end-of-period t *nominal* private debt, issued by the impatient agent. The nominal interest rate paid on the existing amount of debt, B_{t-1}, is denoted R_{t-1}, while W_t is the nominal wage received by the agent. The budget constraint can be conveniently rewritten in *real* terms as follows:

$$C_t + q_t(D_t - (1-\delta)D_{t-1}) - b_t = -R_{t-1}\frac{b_{t-1}}{\pi_{c,t}} + \frac{W_t}{P_{c,t}}N_t \tag{5}$$

where $q_t \equiv \frac{P_{d,t}}{P_{c,t}}$ is the relative price of durables in terms of nondurable goods, $b_t \equiv \frac{B_t}{P_{c,t}}$ denotes *real* debt (in terms of nondurables), and $\pi_{c,t} \equiv \frac{P_{c,t}}{P_{c,t-1}}$ is nondurable-goods inflation.

Each impatient agent is subject to the following *collateral constraint*:

$$B_t \leq (1-\chi)P_{d,t}D_t \tag{6}$$

Following Campbell and Hercowitz (2006), Iacoviello (2005) and Monacelli (2006), we assume that the whole amount of debt is secured by collateral. The parameter $\chi \in [0,1]$ indicates the share of durable goods that cannot be used as a collateral: $(1-\chi)$ thus provides a proxy for the loan-to-value ratio. It is convenient to express (6) in terms of nondurable goods as follows:

$$b_t \leq (1-\chi)q_t D_t \tag{7}$$

It is possible to show that, whenever $\beta < \gamma$, the collateral constraints always binds in the deterministic steady state[5]. We will therefore assume throughout that the constraint is satisfied with equality in a sufficiently small neighborhood of the steady state, so that the model can be appropriately solved by taking a log-linear approximation around the equilibrium[6].

The impatient agent thus maximizes (3) subject to (5) and (7) satisfied with equality. The corresponding set of first order conditions can be written as follows:

$$q_t U_{c,t} = U_{d,t} + \beta(1-\delta)E_t\left\{U_{c,t+1}q_{t+1}\right\} + (1-\chi)\psi_t U_{c,t} q_t \tag{8}$$

$$\psi_t = 1 - \beta E_t\left\{\frac{U_{c,t+1}}{U_{c,t}}\frac{R_t}{\pi_{c,t+1}}\right\} \tag{9}$$

Where $U_{c,t}$ and $U_{d,t}$ indicate the marginal utility of nondurable and durable consumption, respectively. Denoting $\lambda_t\psi_t$ the Lagrange multiplier attached to the collateral constraint, it is natural to interpret ψ_t in (9) as the marginal value of borrowing. More precisely, any rise in ψ_t is equivalent to a tightening of the collateral constraint.

The set of optimality conditions is completed by the intratemporal trade-off between consumption and leisure:

$$-\frac{U_{n,t}}{U_{c,t}} = \frac{W_t}{P_{c,t}}$$

with $U_{n,t}$ indicating the marginal utility of working one additional unit of time. The form of such a condition is crucially affected by the labor market structure, and is the object of the next subsection.

2.2 Labor Market Structure and Wage Setting

The labor force is made up of *impatient* agents only. This assumption simplifies the model setup and allows for a closed-form computation of the steady state. More precisely, the assumption follows from the observation that the labor supply choice of the patient agents would become irrelevant once their wealth is large enough.

[5] See Appendix.

[6] The size of the neighborhood directly influences the accuracy of the approximation and is related to the magnitude of the exogenous shocks considered.

The general setup of the labor market structure follows Erceg, Henderson and Levin (2000)[7]. There exists a continuum of impatient households (indexed with j) on the unit interval, each supplying a differentiated labor service to the production sector. Each final-good producing firm (in both sectors) uses all of the services in production and perceives each household's labor supply $N_t(j)$ as an imperfect substitute for the labor service provided by another household . We assume the existence of perfectly competitive labor aggregators (or employment agencies) that combine households' specialized labor into labor services available to the intermediate firms. The labor market index N_t^i denotes the amount of labor input used by intermediate firm i:

$$N_t^i = \left(\int_0^1 \left(N_t^i(j) \right)^{\frac{1}{1+\lambda_W}} dj \right)^{1+\lambda_W}$$

where the term $\frac{1+\lambda_W}{\lambda_W}$ represents the elasticity of substitution across differentiated labor services. Labor aggregators minimize the cost of producing a given amount of N_t, taking each household's wage $W_t(j)$ as given, and sell units of N_t to the production sector at their unit cost W_t, which can be expressed as[8]:

$$W_t \equiv \left(\int_0^1 \left(W_t(j) \right)^{-\frac{1}{\lambda_W}} dj \right)^{-\lambda_W}$$

Total demand for each j-household's labor service is given by:

$$N_t^i(j) = \left(\frac{W_t(j)}{W_t} \right)^{-\frac{1+\lambda_W}{\lambda_W}} N_t^i$$

As already analyzed in Section 2.1, each impatient household maximizes the utility function (3) under (5) and (7). Regarding the choice over the nominal wage, we assume that, each period, only a fraction of households receives a signal that allows for wage changing. The probability that a specific household receives a signal in a given period t is constant and equal to $(1 - \xi_W)$. After receiving the signal, the household sets a new - optimal - nominal wage W_t^*, taking into account the probability of not being allowed to

[7] The labor market structure implictly assumes that the impatient agents are fully insured against wage income shocks, so that their actions can be summarized by the behavior of a representative (impatient) agent. Although the borrowers have limited access to the loan and mortgage markets, we assume in fact that they can trade state-contingent assets among themselves. As a consequence, their consumption and wage profile is unique.

[8] W_t can be interpreted as the aggregate wage index.

change the wage in the future. For those households that cannot re-optimize, we assume a partial-indexation scheme of the following type:

$$W_t^i = \left(\frac{P_{c,t-1}}{P_{c,t-2}}\right)^{\gamma_w} W_{t-1}^i$$

where $\gamma_w \in [0,1]$ denotes the degree of indexation to past nondurable inflation[9]. The two extreme cases of no indexation and full indexation correspond to $\gamma_w = 0$ and $\gamma_w = 1$, respectively. The optimality condition for the wage setters thus results in the following dynamic wage mark-up equation:

$$E_t \left\{ \sum_{s=0}^{\infty} \beta^s \xi_w^s N_{t+s}(i) \left[-(1+\lambda_W) U_{n,t+s} + U_{c,t+s} \frac{W_t^*}{P_{c,s}} \left(\frac{P_{c,s-1}}{P_{c,t-1}}\right)^{\gamma_w} \right] \right\} = 0 \tag{10}$$

The law of motion of the aggregate nominal wage thus reads:

$$W_t = \left((1-\xi_W)(W_t^*)^{-\frac{1}{\lambda_{W,t}}} + \xi_W \left(\frac{P_{c,t-1}}{P_{c,t-2}}\right)^{-\frac{\gamma_w}{\lambda_{W,t}}} (W_{t-1})^{-\frac{1}{\lambda_{W,t}}} \right)^{-\lambda_{W,t}} \tag{11}$$

Log-linearizing equation (10) around the deterministic steady state gives the standard formula:

$$\begin{aligned} \widehat{w}_t = {} & \left(\frac{\beta}{1+\beta}\right) E_t \left\{\widehat{w}_{t+1}\right\} + \left(\frac{\beta}{1+\beta}\right) E_t \left\{\widehat{\pi}_{c,t+1}\right\} + \left(\frac{1}{1+\beta}\right) \widehat{w}_{t-1} \\ & - \left(\frac{1+\beta\gamma_w}{1+\beta}\right) \widehat{\pi}_{c,t} + \left(\frac{\gamma_w}{1+\beta}\right) \widehat{\pi}_{c,t-1} - \left(\frac{(1-\xi_W)(1-\beta\xi_W)}{(1+\beta)\,\xi_W \left(1+\frac{1+\lambda_W}{\lambda_W}\varphi\right)}\right) \widehat{\mu}_t^w \end{aligned} \tag{12}$$

where variables with a $\widehat{}$ are expressed in log-deviations from their steady-state value. In particular, μ_t^w is the (variable) wage markup, defined as the wedge between the real wage and the marginal rate of substitution between consumption and leisure:

$$\mu_t^w = \frac{\left(-\frac{U_{n,t}}{U_{c,t}}\right)}{\frac{W_t}{P_{c,t}}}$$

The last expression corresponds to equation (10) in the case of fully flexible wages.

[9] Notice that in the impatient's budget constraint (5) the real wage is defined as the ratio between nominal wage (W_t) and nondurable price ($P_{c,t}$). According to this convention, the relevant price index for wage setting is $P_{c,t}$.

2.3 The patient agents

The representative patient agent receives utility form the following instantaneous utility function:

$$U(\widetilde{X}_t) = \log(\widetilde{X}_t)$$

where $\widetilde{X}_t$ is the CES aggregator:

$$\widetilde{X}_t = \left[(1-\alpha)^{\frac{1}{\eta}}\left(\widetilde{C}_t - \theta\widetilde{C}_{t-1}\right)^{\frac{\eta-1}{\eta}} + \alpha^{\frac{1}{\eta}}\widetilde{D}_t^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}} \tag{13}$$

Notation is analogous to the one adopted for the impatient agent, except that a $\widetilde{}$ is used to denote consumption of each good by the patient agent. In particular, $\widetilde{I}_t^D$ denotes investment in durable consumption:

$$\widetilde{D}_t = (1-\delta)\widetilde{D}_{t-1} + \widetilde{I}_t^D$$

The representative patient agent is characterized by a higher intertemporal discount factor than the impatient agent, denoted $\gamma > \beta$. The patient agents are the owners of firms and capital in the economy, and hence choose consumption plans (over nondurable and durable goods) and investment plans. Patient households choose the utilization rate of capital before renting it to firms at the (nominal) rental market rate R_t^k. Following a large strand of literature, we assume the existence of costs both in changing capital utilization and in physical investment. Denoting $\widetilde{K}_{\iota t-1}$ the stock of existing capital in sector ι at time t, the amount of effective capital that the patient agents can rent to firm j is given by:

$$K_{\iota t}(j) = u_{\iota,t}(j)\widetilde{K}_{\iota,t-1}(j)$$

where $u_{\iota t}$ indicates the degree of capital utilization chosen. The associated cost function is denoted $a(\cdot)$, so that the cost of changing capital utilization is expressed in terms of nondurable goods as follows:

$$P_{ct}a(u_{\iota,t}(j))\widetilde{K}_{\iota,t-1}(j)$$

We assume that, in steady state, $u_{\iota t} = 1$, and $a(1) = 0$. The physical capital accumulation equation reads:

$$\widetilde{K}_{\iota t} = (1-\delta_k)\widetilde{K}_{\iota t-1} + \left[1 - S_\iota\left(\frac{I_{\iota t}}{I_{\iota t-1}}\right)\right] I_{\iota t} \quad ; \quad \iota = c, d \tag{14}$$

where δ_k is the depreciation rate of capital, $I_{\iota t}$ is investment in capital, and the function $S(\cdot)$ captures adjustment costs in investment. In particular, we assume that $S'(\cdot) = 0$ and $S''(\cdot) > 0$[10].

The representative patient agent thus solves the following intertemporal maximization problem:

$$\max_{\{\widetilde{C}_t, \widetilde{D}, \widetilde{I}_t, K_t, u_t\}_{t=0}^{\infty}} E_0 \sum_{t=0}^{\infty} \gamma^t U(\widetilde{X}_t)$$

subject to:

(i) the infinite sequence of (real) budget constraints:

$$\widetilde{C}_t + q_t \widetilde{I}_t^d + I_{ct} + I_{dt} + b_t - R_{t-1} b_{t-1} = r_t^k \left[u_{c,t}(j) \widetilde{K}_{c,t-1}(j) + u_{d,t}(j) \widetilde{K}_{d,t-1}(j) \right] \quad (15)$$
$$- \left[a(u_{c,t}(j)) K_{c,t-1}(j) + a(u_{d,t}(j)) K_{d,t-1}(j) \right]$$

(where $r_t^k \equiv \frac{R_t^k}{P_{c,t}}$ is the real rental rate of capital in terms of nondurable consumption goods), and

(ii) the capital accumulation equation (14).

The first order conditions with respect to $\widetilde{C}_t$ and $\widetilde{D}_t$ can be expressed as follows:

$$q_t = \frac{\widetilde{U}_{d,t}}{\widetilde{U}_{c,t}} + \gamma(1-\delta) E_t \left\{ \frac{\widetilde{U}_{c,t+1}}{\widetilde{U}_{c,t}} q_{t+1} \right\} \quad (16)$$

$$\widetilde{U}_{c,t} = \gamma E_t \left\{ \widetilde{U}_{c,t+1} R_t \frac{1}{\pi_{c,t+1}} \right\} \quad (17)$$

with $\widetilde{U}_{ct}$ and $\widetilde{U}_{dt}$ denoting the marginal utility of nondurable and durable consumption, respectively, for the patient agent. Equation (16) is a standard optimality condition for investment in a durable good: the purchase price of a durable good is equated to the immediate payoff of the purchase (the marginal rate of substitution between durable and nondurable consumption), plus the discounted expected resale value. Equation (17) is a standard Euler equation. Turning to the choice of capital, investment and capital utilization, we define $Q_{\iota t}$ to be the ratio between the Lagrange multipliers attached to (15) and (14) respectively :

$$Q_t^j \equiv \frac{\lambda_t^k}{\lambda_t}$$

[10] See Appendix for details on the functional form of $a(\cdot)$ and $S(\cdot)$.

The first order conditions can then be rewritten as follows:

$$Q_{\iota t} = E_t \left[\gamma \frac{\widetilde{U}_{c,t+1}}{\widetilde{U}_{c,t}} \left(Q_{\iota t+1}(1-\delta_k) + r^k_{t+1} u_{\iota t+1} - a\left(u_{\iota t+1}\right) \right) \right] \tag{18}$$

$$Q_{\iota t} \left[1 - S_\iota \left(\frac{I_{\iota t}}{I_{\iota t-1}} \right) - \frac{I_{\iota t}}{I_{\iota t-1}} S\prime_\iota \left(\frac{I_{\iota t}}{I_{\iota t-1}} \right) \right] + \gamma E_t \left[Q_{\iota t+1} \frac{\widetilde{U}_{c,t+1}}{\widetilde{U}_{c,t}} \left(\frac{I_{\iota t+1}}{I_{\iota t}} \right)^2 S_\iota\prime \left(\frac{I_{\iota t+1}}{I_{\iota t}} \right) \right] = 1 \tag{19}$$

$$r^k_{t+1} = a\prime\left(u_{\iota t}\right) \tag{20}$$

Following a common practice in the literature[11], $Q_{\iota t}$ can be interpreted as Tobin's Q; it is equal to one in the absence of adjustment costs.

2.4 Firms

Production of durable and nondurable goods is modeled in the standard New Keynesian way. In each sector there exists perfectly competitive final-good firms which produce a single good out of a continuum of intermediate goods. The intermediate-good firms operate in a monopolistically competitive market, where each firm produces a single differentiated good and thus exerts some market power. Nominal rigidities are introduced in the form of staggered price setting à la Calvo (1983) in the intermediate-goods sector.

2.4.1 Final-good producers

In each production sector the perfectly competitive final-good firms produce the final consumption good $Y_{\iota t}$ using the intermediate inputs $Y_{\iota t}(j)$:

$$Y_{\iota t} = \left(\int_0^1 Y_{\iota t}^{\frac{1}{1+\lambda_{p\iota}}}(j)dj \right)^{1+\lambda_{p\iota}}$$

where $Y_{\iota t}(j)$ denotes the the quantity of intermediate good of type j demanded by the final good producer in sector ι ($\iota = C, D$) at date t. The term $\frac{1+\lambda_{p\iota}}{\lambda_{p\iota}}$ denotes the sector-specific elasticity of substitution between differentiated varieties. The demand function for each intermediate good j reads:

$$Y_{\iota t}(i) = \left(\frac{P_{\iota t}(j)}{P_{\iota t}} \right)^{-\frac{1+\lambda_{p\iota}}{\lambda_{p\iota}}} Y_{\iota t}$$

[11] See Smets and Wouters (2007) among others.

where $P_{\iota t}$ denotes the sectorial price index, which is defined using profit maximization and zero-profit conditions as follows:

$$P_{\iota t} = \left(\int_0^1 P_{\iota t}^{-\frac{1}{\lambda_{p\iota}}}(j)dj \right)^{-\lambda_{p\iota}} \tag{21}$$

Clearly, λ_{pj} represents the sectorial price markup over marginal costs.

2.4.2 Intermediate-good producers and price setting

Each intermediate-good producing firms j operates the following technology:

$$Y_{\iota t}(j) = \max \left\{ \varepsilon_t^{a\iota} \left((1-\omega) K_{\iota t}(j) \right)^{\alpha} \left(\omega N_{\iota t}(j) \right)^{1-\alpha} - \Phi_{y\iota} \overline{Y_\iota}; 0 \right\} \tag{22}$$

where $\varepsilon_t^{a\iota}$ is an exogenous stochastic process describing the evolution of productivity in each sector ι, with $\iota = C, D$:

$$\varepsilon_t^{a\iota} = \rho_{a\iota} \varepsilon_{t-1}^{a\iota} + \eta_t^{a\iota}$$

with $\eta_t^{a\iota}$ IID-Normal. The term ω in (22) denotes the fraction of impatient agents in the economy. The total amount of hours supplied to each j firm by the mass of impatient agents is therefore given by $\omega N_{\iota t}(j)$. Analogously, the total amount of capital that the impatient agents rent to firm j is $(1-\omega)K_{\iota t}(j)$. Finally, $\Phi_{y\iota}$ is a fixed cost in production, and $\overline{Y_\iota}$ is the steady state value of $Y_{\iota t}$. Labor and capital are assumed to be fully mobile across sectors, so that the nominal wage and the rental rate of capital are unique. Solving the firms' static profit-maximization problem yields the following definition of marginal cost:

$$MC_{\iota t} = \frac{1}{\varepsilon_t^{a\iota}} \left(\frac{W_t}{1-\alpha} \right)^{1-\alpha} \left(\frac{R_t^k}{\alpha} \right)^{\alpha}$$

Regarding price setting, firms change their prices à la Calvo (1983), i.e. after receiving a random price-change signal, exactly as in the case of wage-setting operated by the impatient agents. The probability that a given firm receives the signal in each period is constant and equal to $(1 - \xi_{p\iota})$. Partial indexation to past inflation is assumed for those firms that do not receive the signal. Solving the intertemporal profit-maximization problem for those firms that are allowed to reoptimize, and denoting P_t^* the newly set price, gives the following dynamic mark-up equation:

$$E_t \left\{ \sum_{s=0}^{\infty} \xi_{p\iota}^s \gamma^s \frac{\lambda_{t+s}}{\lambda_t} \frac{P_{\iota t}}{P_{\iota t+s}} Y_{\iota t+s}(j) \left[\frac{P_{\iota t}^*(j)}{P_{\iota s}} \left(\frac{P_{\iota s-1}}{P_{\iota t-1}} \right)^{\gamma_{p\iota}} - (1+\lambda_{p\iota}) MC_{j,s} \right] \right\} = 0 \tag{23}$$

where $\gamma^s \frac{\lambda_{t+s}}{\lambda_t} \frac{P_{\iota t}}{P_{\iota t+s}}$ is the stochastic discount factor for the patient agents, who run the firms. The law of motion of the price index in each sector follows from definition (21):

$$P_{\iota t} = \left((1 - \xi_{p\iota}) \left(P_{\iota t}^{*} \right)^{-\frac{1}{\lambda_{p\iota}}} + \xi_{p\iota} \left(\frac{P_{\iota t-1}}{P_{\iota t-2}} \right)^{-\frac{\gamma_{p\iota}}{\lambda_{p\iota}}} \left(P_{\iota t-1} \right)^{-\frac{1}{\lambda_{p\iota}}} \right)^{-\lambda_{p\iota}}$$

Log-linearization of (23) around the deterministic steady state yields the following sectorial New Keynesian Phillips Curve:

$$\begin{aligned} \widehat{\pi}_{\iota t} = & \left(\frac{\gamma_{p\iota}}{1 + \gamma_{p\iota}} \right) \widehat{\pi}_{\iota t-1} + \left(\frac{\gamma}{1 + \gamma\gamma_{p\iota}} \right) E_t \left\{ \widehat{\pi}_{\iota t+1} \right\} + \\ & + \left(\frac{(1 - \xi_{p\iota})(1 - \gamma\xi_{p\iota})}{(1 + \gamma)\, \xi_{p\iota}} \right) \widehat{mc}_{\iota t} \end{aligned} \tag{24}$$

where, again, a $\widehat{}$ denotes deviations of a variable from its steady state value, and $mc_{\iota t}$ is the *sectorial real* marginal cost in period t:

$$mc_{\iota t} \equiv \frac{MC_t}{P_{\iota t}}$$

2.5 Monetary policy

The monetary authority sets the short-term nominal interest rate according to the following log-linearized Taylor-type rule:

$$\widehat{r}_t = \rho_r \widehat{r}_{t-1} + (1 - \rho_r) \phi_\pi \widehat{\pi}_{c,t-1} + \phi_{\Delta\pi} \left(\widehat{\pi}_{c,t} - \widehat{\pi}_{c,t-1} \right) + \phi_{\Delta y} \left(\widehat{y}_t - \widehat{y}_{t-1} \right) + \eta_t^r \tag{25}$$

where variables in deviations from their steady state are denoted with a $\widehat{}$ and η_t^r is the monetary policy shock, which is assumed to be iid log-normally distributed. We consider nondurable inflation as a target for the central bank although, in principle, the monetary authority could specify rule (25) by targeting aggregate inflation π_t, or durable inflation π_{dt}. In particular, it is possible to recover the following relationship between aggregate and sectorial inflation rates:

$$\pi_t = \pi_{\iota t} \frac{g_{\iota t}}{g_{\iota t-1}}, \qquad \iota = c, d$$

where

$$g_{ct} \equiv \frac{P_t}{P_{ct}} = \left[(1 - \alpha) + \alpha q_t^{1-\eta} \right]^{\frac{1}{1-\eta}}$$

and

$$g_{dt} \equiv \frac{P_t}{P_{dt}} = \left[\alpha + (1 - \alpha)\, q_t^{-(1-\eta)} \right]^{\frac{1}{1-\eta}}$$

2.6 Market clearing

The goods market clearing conditions in the two sectors read:

$$Y_{ct} = \omega \widehat{C}_t + (1-\omega)\,\widetilde{C}_t + (1-\omega)\,(I_{ct} + I_{dt}) \tag{26}$$

and

$$Y_{d,t} = \omega \widehat{I}_{d,t} + (1-\omega)\widetilde{I}_{d,t} \tag{27}$$

where clearly:

$$Y_{\iota t} \equiv \int_0^1 Y_{\iota t}(j)dj = (1-\omega)^{\alpha}\omega^{1-\alpha}\varepsilon_t^{a\iota}\int_0^1 K_{\iota t}^{\alpha}(j)N_{\iota t}^{1-\alpha}(j)dj = (1-\omega)^{\alpha}\omega^{1-\alpha}K_{\iota t}^{\alpha}N_{\iota t}^{1-\alpha}$$

Finally, the labor market clearing condition reads:

$$N_{c,t} + N_{d,t} = N_t$$

3 The estimation exercise

The overall structure of the artificial economy is enriched with a number of exogenous structural shocks before performing the estimation exercise. In addition to the sectorial technological shifts ε_t^{ac} and ε_t^{ad}, and the monetary policy shock η_t^r, we consider shocks to the intertemporal discount factor, housing preference shocks that perturb the weight assigned to housing in the instantaneous utility function, sectorial investment-specific shocks, labor supply shocks, sectorial cost-push shocks, and finally shocks to the loan-to-value ratio[12]. The application of standard log-linearization solution methods permits to solve the model and cast it in state-space form; it is then immediate to compute the likelihood function using the Kalman filter. After specifying independent prior distributions for the structural parameters, the application of Markov Chain Monte Carlo (MCMC) methods delivers estimates of the posterior distributions.

The model is estimated on quarterly U.S. data. The set of observables includes nondurable consumption, residential investment, household debt, nominal interest rate, consumer price inflation, real house prices, nonresidential fixed investment, real output,

[12] Appendix A illustrates the complete model in detail.

and hours worked in the consumption-good sector[13]. The estimation is performed on two separate sub-samples, using the last quarter of 1982 as a break point. The choice of such a period is motivated by at least two reasons. First, Campbell and Hercowitz (2006) identify the Monetary Control Act of 1980 and the Garn-St.Germain Act of 1982 as two crucial events that somehow initiated a new era in the U.S. equity requirement legislation. The Garn-St.Germain Act in particular, by allowing savings and loan associations to provide commercial loans, strongly contributed to reduce equity requirements in the mortgage market. Although other events occurred in the mortgage markets in about the same period that dramatically accelerated the development of a secondary market[14], it seems reasonable to consider the last quarter of 1982 as a break point. Visual inspection of the time series behaviour of household debt confirms the validity of the choice[15]. Second, the chosen break point leads by 4 quarters the conventional starting point of the Great Moderation, usually placed at 1984 I[16]. Therefore, the two sub-samples (pre- and post- financial liberalization) should approximately coincide with two very different periods of time, characterized not only by different institutional environments in the financial markets, but also by different magnitudes in the volatility of most macroeconomic variables. The main objective of the estimation exercise is to assess the relative importance of changes in exogenous shocks and in the endogenous transmission mechanisms across periods. Noticeably, a similar exercise is reported in Smets and Wouters (2007), who make use of a standard DSGE model for the U.S. economy, providing a natural benchmark to compare the results from an enriched model to.

3.1 Calibration and Prior Distributions

Calibrated parameters Some of the structural parameters have to be calibrated and excluded from the estimation set. In particular, the agents' intertemporal discount factors are chosen as follows: the patient agent's impatience rate γ is calibrated in such a way to obtain a steady-state value of the net nominal interest rate equal to 1% on a quarterly basis. The impatient agent's rate, β, is instead fixed at 0.96: this calibration is in line with

[13] See Appendix for a detailed description of the dataset.
[14] See Gerardi, Rosen and Willen (2007) for a discussion
[15] See Figure 1.
[16] See McConnell and Perez-Quiros (2000).

the literature on heterogeneous agents models (see Krusell and Smith (1998), Campbell and Hercowitz (2006) and Iacoviello and Neri (2007))[17]. The elasticity of substitution between durable and nondurable goods is set to one, thus implying the limiting case of a Cobb-Douglas function in equations (2) and (13)[18]. The relative share of durable goods in the aggregator, α, is set to 0.4. Such a value is picked in order to obtain an equilibrium ratio between residential investment and output equal to 0.04, as empirically measured in the sample. About the loan-to-value ratio, the available data on car and mortgage loans show signs of significant changes in equity requirements across period. Looking at the reported values for LTVs may be insufficient, though, given the significant development of the secondary market for mortgages in the second sample. After 1982 households typically obtain more than one mortgage on the same home. As an example, consider a first mortgage with a down payment of 0.25 and a second mortgage, to pay the down payment on the first one, also with a 25% down payment. The two mortgages would appear as separate in the data, and the reported loan-to-value ratio would not change. However, from an economic point of view the correct measure of the down payment is $0.25 * 0.25 = 0.0625$, which corresponds to the amount actually paid by the household[19]. To reflect the observed changes in secondary markets, we calibrate the parameter χ (which in the model is a proxy for the loan-to-value ratio) to 0.75 in the first sub-sample, and to 0.92 in the second one. The depreciation rate for housing, δ, is parameterized to an annual value of 10% corresponding to a quarterly value of 0.0025[20]. The value of δ_k is instead 0.03 on a quarterly basis. The difference reflects the slower depreciation of houses relative to capital. Finally, the elasticities of substitution among differentiated goods and labor types are calibrated to yield a steady-state markup of, respectively, 16% in the nondurable sector, 10% in the durable sector, and 50% in the labor market. The share of capital in the production function, α, is set to 0.3.

[17] Notice that β cannot be determined by using steady state ratios, nor does it influence the interest rate. Thus, some degrees of freedom are left in its choice

[18] Ogaki and Reinhart (1998) report estimates for the intratemporal elasticity of substitution between durable and nondurable goods that range between 1.17 and 1.24. Changing the calibrated value of such elasticity does not significantly affect our estimates.

[19] I am indebted to Zvi Hercowitz for suggesting me this example, as well as how to measure the LTV ratio across samples.

[20] See Campbell and Hercowitz (2006) and Monacelli (2006) for a discussion on how to pick a value for δ.

Prior distributions The specification of independent priors is summarized in columns 3, 4 and 5 of Table 1. Priors are quite loose and noninformative in general, especially for the parameters governing nominal rigidities. This implies that no stand is taken a priori on the relative flexibility of prices and wages in the economy, as well as on the magnitude of other behavioural parameters. A Beta distribution is assumed for those parameters that can only assume values in the unit interval. In particular, the mean of the habit persistence parameter, θ, is set to 0.65, consistently with existing estimates (see Christiano, Eichenbaum and Evans (2005)). The inverse elasticity of substitution is assumed to follow a Gamma distribution, with mean 2 and standard deviation 0.75. Regarding nominal rigidities, we assume a Beta distribution with mean 0.5 and standard deviation 0.28 for all the parameters controlling wage and price stickiness and indexation. Such a distribution is almost flat over the unit interval, with some curvature close to the boundaries, to help the estimation process. About monetary policy, the parameters describing the Taylor rule are centered around standard values. Finally, noninformative priors are used for the standard deviations of the six structural shocks, which are assumed to follow a Uniform distribution over the interval [0,6]. The persistence parameters follow the same Beta distribution used for price and wage stickiness parameters.

3.2 Sub-sample Estimation: 1965 I-1982 IV

Column 6 of Table 3 reports the posterior median of the structural parameters over the first sub-sample[21]. The estimated degree of habit persistence is quite lower if compared to the values reported in the existing literature, possibly reflecting some averaging effect between habits of patient and impatient agents. The posterior median of the inverse elasticity of labor supply, φ, is 1.86, quite higher than 1.52, the value reported by Smets and Wouters (2007) for the sub-period 1966 I-1979 II. Regarding nominal rigidities, the median of ξ_{pc} is 0.879, corresponding to an interval of 8 quarters between two consecutive price adjustments in the nondurable-producing sector. The corresponding indexation parameter γ_{pc} is instead very low (0.08). Conversely, price stickiness is very low in

[21]Figure 5 reports prior and posterior distributions for the estimated parameters, obtained after 200,000 Metropolis-Hastings simulations. The draws were sufficient to guarantee convergence for all the parameters, according to the criteria illustrated in the Appendix. Convergence diagnostics are available from the author upon request.

the durable sector, where the estimated median for ξ_{pd} is 0.00099, equivalent to only one quarter between two price changes. The model thus captures, at least in the first sub-sample, a clear sectorial asymmetry in terms of price flexibility. Flexible prices in the durable sector are usually assumed - rather than estimated - in the literature. In particular, while Barsky, House and Kimball (2007) argue that a two-sector New Keynesian model exhibits monetary neutrality under flexible durable prices, Monacelli (2006) shows that non-neutrality arises in the same type of model when a collateral constraint is introduced. Our estimates thus support the existence of asymmetric price rigidities in the presence of credit market frictions. The results can be compared to the existing macro and microeconomic literature. On the one hand, estimated DSGE models generally report quite high estimates for the Calvo parameter, although no distinction is usually made between durable and nondurable goods. Smets and Wouters (2005) report 0.87 as the mode of the posterior distribution of the price stickiness parameter. However, existing microeconometric studies document a much lower degree of observed price stickiness in disaggregated data. Bils and Klenow (2004) report a median duration of prices of approximately 1.5 quarters, corresponding to $\xi_p = 0.3$. Recently, Nakamura and Steinsson (2006) have shown that the median duration ranges between 8 and 11 months if sales and price changes due to product substitution are excluded from the sample. The implied value for ξ_p is 0.68. The estimated degree of price stickiness is thus in line with the macroeconomic literature on one side (the nondurable sector), while confirming the intuition that prices are much more flexible in the durable sector, when the latter is identified with the housing sector[22]. The overall degree of nominal rigidities is reduced relative to standard estimated New Keynesian models. This can be at least partially explained by the presence of an additional transmission channel for monetary policy, which operates even in the absence of price and wage stickiness. Such a channel builds on the existence of nominal household debt and works through a collateral constraint which in turn hinges on the availability of durable goods. Differences in the estimated degree of nominal rigidity across sectors must therefore be somewhat related to this new channel.

Turning to wage stickiness, the posterior median of ξ_w is 0.972, with an associated

[22] See Barski, House and Kimball (2007) for an argument.

degree of wage indexation equal to 0.038. Overall, these estimates suggest a high degree of nominal rigidities in the labor market. The result is possibly influenced by the assumption that only the borrowers contribute to the labor force, without any sectorial-specific preference for hours worked in their utility function. Exploring different alternative setups for the labor market is the object of future research.

Regarding monetary policy, the estimated response to contemporaneous inflation is 1.567, while the response to output is 0.11756. The coefficient attached to the lagged interest rate is 0.819, which implies a substantial degree of persistence of monetary policy changes.

Finally, about the stochastic structure of the model, all the estimated autocorrelation coefficients of the structural shocks are higher than 0.7, with four exceptions, given by the sectorial investment-specific and cost-push shocks. The medians of ρ_i and ρ_{cp} are very low (0.027 and 0.039, respectively), while the corresponding values for ρ_{i_d} and ρ_{cp_d} are 0.367 and 0.585. Supply side shocks thus seem to have little persistence over the first sample. In terms of volatilities, the highest values are given by investment-specific shocks in both sectors ($\sigma_i = 1.0345$ and $\sigma_{i\_d} = 2.2918$), labor supply shocks ($\sigma_n = 4.042$) and cost-push shocks in the durable sector ($\sigma_{cp\_d} = 3.4427$).

3.3 Sub-sample Estimation: 1983 I-2006 IV

The last column of Table 3 reports the estimated posterior medians of the structural parameters over the second sample[23]. Estimated behavioral parameters are lower in the second sub-sample, if compared to the first one. Nominal rigidities instead seem to have increased both in the goods and in the labor market, while indexation has increased, with the only exception of the durable sector. Such evidence confirms the results reported in Smets and Wouters (2007), although the cutoff for the two sub-samples is different. In particular, the sectorial asymmetry in price stickiness is confirmed: the median of the Calvo parameters is equal to 0.88 in the nondurable sector and to 0.0024 in the durable sector. Again, the data seem to point towards price flexibility in the durable sector,

[23] Figure 6 reports prior and posterior distributions obtained after 200,000 Metropolis-Hastings simulations.

which is identified here with the housing sector.

Turning to the monetary policy parameters, the medians of the posterior distributions are quite stable across samples. We do not observe an increase in the response of the nominal interest rate to contemporaneous and lagged inflation, as economic intuition would suggest. The change in the conduct of monetary policy started in 1979 - with the appointment of Paul Volcker as Chairman of the Federal Reserve Board - should in fact be reflected in higher values of ϕ_π in the second sub-sample, in principle. However, the identification of Taylor rule parameters in DSGE models is generally problematic[24]. Posterior estimates are usually highly dependent on prior specification, and the data are not very informative. The prior and posterior plots reported in Smets and Wouters (2003) are a paradigmatic example. It is therefore hard to conclude that higher estimates for ϕ_π over the "Great Moderation" sub-samples are a clear indication of a change in monetary policy. Rather, the use of unchanged priors over the two samples suggests that the data are equally not informative about this parameter. Figure 3 illustrates the problem.

Turning to the structural shocks, we only observe a significant difference in the medians of the posterior distributions of ρ_n and ρ_{cp_d}, which move from 0.73 to 0.89 and from 0.58 to 0.79, respectively. More interestingly, the estimated volatilities of all shocks show signs of a significant reduction. The estimated median volatilities are on average 1.6 times larger in the first sub-sample relative to the second one. In particular, the standard error of monetary policy shocks is more than three times as large in the first period than in the second one. The most pronounced change is in the volatility of intertemporal preference shocks, which declined by 67%. Housing preference shocks display a 25% reduction in volatility, approximately equivalent to the decline in the volatility of loan-to-value ratio shocks. Productivity shocks also show a reduced variability, especially in the nondurable sector. Overall, the empirical evidence seems to suggest that a change occurred in the structural shocks hitting the U.S. economy after 1983, with a substantial reduction in their volatility, and a less pronounced - and less general - increase in their persistence.

Summarizing, the estimation exercise performed over the two samples leads to three main conclusions:

[24] See Canova and Sala (2006).

1. There is a substantial degree of asymmetry in the estimated price stickiness across sectors. The median duration of prices in the nondurable sector is 8.3 quarters - in line with the existing macroeconometric evidence - while prices are almost perfectly flexible in the housing sector. The asymmetry is robust across samples.

2. The estimated standard deviation of *all* the structural shocks exhibits a significant decline over time. The estimated median values are on average 1.6 times larger in the first period (up until 1982) than in the second one. No significant change is observed instead for the persistence of such shocks.

3. No significant change is observed in the estimates of the Taylor rule coefficient across periods. In fact, it is hard to conclude that the coefficients are correctly identified.

3.4 Variance decomposition and the role of shocks

Tables 4 and 5 provide the variance decomposition of the forecast error over the two samples. Generally speaking, most of the variability of consumption, residential investment and household debt is explained by housing-specific preference shocks. The relative contribution of technology shocks in both sectors is quite low. Loan-to-value ratio shocks are almost as relevant as technology shocks in the first sample, but their role is larger afterwards. More precisely, 45.69% of the volatility of consumption is explained by housing preference shocks in the second sample, as opposed to only 14.25% in the first one. The contribution of monetary policy shocks has correspondingly declined from 56.51% to 35.77%. Such a change is likely to capture the effects of mortgage markets liberalization, which provides households with more instruments to adjust their consumption profiles, thus making them less dependent on monetary policy decisions. Any increase in housing demand (due to a change in individual preferences, in this case) has a larger impact on consumption, via the availability of more credit (as implied by higher loan-to-value ratios and developed secondary markets).

The contribution of housing preference shocks has remained very large for both residential investment (from 76.92% to 73.36%) and debt (from 90.92% to 85.54%). Looking at residential investment, we observe an increase in the role of loan-to-value ratio shocks, which explain 1.4% of the variance before 1983 and 5.66% afterwards. Intuitively, deregulation and liberalization in financial markets have increased the access to funds for borrowers, thus creating a stronger link between changes in financial conditions (as captured - or proxied - by shocks to the loan-to-value ratio) and investment decisions, exactly as for consumption. Correspondingly, changes in interest rates affect less the borrowers' choice over residential investment. Finally, the role of cost-push shocks in the housing sector has increased in general, the more so in the case of residential investment (from 1.33% to 5.88%).

Overall, the variance decomposition exercise suggests the following conclusions:

1. Housing preference shocks explain most of the volatility of consumption after 1982, compensating for a contemporaneous decrease in the role played by monetary shocks;

2. Residential investment and household debt are also mainly explained by housing preference shocks, with a quite stable contribution over time;

3. The relative contribution of monetary policy and productivity shocks is minor.

3.5 Assessing the role of financial deregulation and monetary policy

Having estimated the model on the two samples, it is straightforward to evaluate the relative role played by financial deregulation and changes in the conduct of monetary policy after 1982, in explaining the volatility of consumption, residential investment and household debt. A crucial assumption concerns the magnitude of the exogenous shocks. In order to assess the pure contribution of policy changes, it is necessary to shut down any other possible source of variation in the observed variables. Therefore, we fix the volatility of the shocks to the estimates obtained over the first sample, and perform a counterfactual simulation exercise. More precisely, we calibrate all the structural parameters to the estimated values for the period 1965 IV : 1982 IV, to have a benchmark specification for our model as of 1983 I. Next, we modify the parameters that capture changes in financial market regulation and in the conduct of monetary policy, respectively. In the first case, we change the value of $(1-\chi)$ in the collateral constraint from 0.75 to 0.90.

Such a change is meant to reproduce the increased availability of credit to households that characterizes the post-1982 period[25]. The results are reported in Table 7. The effect of increasing the loan-to-value ratio alone implies a 10% decrease in the contribution of monetary policy shocks to the variability of consumption, whereas no significant change is implied in the variations of residential investment and household debt. At the same time, the role of preference shocks - and housing demand shocks in particular - is increased.

3.6 Fit of the model

The empirical performance of the model is evaluated by comparing the fit of two alternative specifications. More precisely, we estimate a one-agent version of the model, featuring the same two-sector structure, and the same type of nominal rigidities. Clearly, household debt does not appear in this modified version[26]. The application of Bayesian methods allows for model comparison in a straightforward way: the relative performance of each model is evaluated by measuring the corresponding Marginal Likelihood. Table 6 reports the estimated Marginal Likelihood of each model on the two samples, computed using the Laplace Approximation and the Modified Harmonic Mean method. The results reported in the table suggest two main conclusions. First, the complete model beats the benchmark in each sample, independently of the metric adopted. Second, both models display a higher measure of fit in the second sample. In particular, the relative change in the Marginal Likelihood is higher for the two-agent model, which is rich enough to capture the modified financial market structure of the post-1982 period.

We can thus conclude that the data point towards a model featuring collateral constraints and household debt, as opposed to a simple New Keynesian structure. Such evidence supports the ongoing debate over the role of various types of credit market frictions - in addition to nominal rigidities - in explaining business cycle fluctuations[27].

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[25] See above for an explanation.

[26] Basically, the alternative formulation boils down to a standard representative agent model with nondurable consumption goods and residential investment. No private debt arises in such a framework, and no collateral constraint is imposed on the agent.

[27] See Christiano, Motto and Rostagno (2003) for an alternative way of modelling financial frictions.

4 Conclusions

The reduction in the volatility of most U.S. macroeconomic variables during the so-called "Great Moderation" has been particularly significant for consumption and residential investment. During approximately the same period, financial markets deregulation and liberalizations gave rise to an increase in the level of household debt, while reducing its volatility. This paper builds and estimates a DSGE model featuring household heterogeneity and collateral constraints, following Kyiotaki and Moore (1997) and Campbell and Hercowitz (2006). The presence of collateral constraints faced by the relatively more impatient agents enriches the traditional transmission mechanism of monetary policy shocks along several dimensions. The estimation exercise is performed over two separate samples, corresponding to very different macroeconomic and financial environments. The results lead to four main conclusions: *(i)* housing preference shocks explain almost 46% of the variation in consumption after 1982, as opposed to only 14% in the previous sample; *(ii)* residential investment and household debt are also mainly explained by housing preference shocks, with a quite constant contribution over time; *(iii)* the volatility of all the structural shocks has substantially declined over time; *(iv)* prices are relatively sticky for durable goods, while they are flexible in the housing sector.

This paper thus contributes to the existing literature in two ways. First, it enriches the workhorse DSGE model framework with a detailed description of household credit market imperfections. Second, it provides new evidence about the ongoing debate on the Great Moderation. In particular, our estimates suggest that housing preference shocks are the main determinant of the volatility of consumption, residential investment and household debt. In particular, the role of such shocks in explaining consumption fluctuations has grown remarkably large after 1982, testifying the effects of financial market liberalization and the development of secondary loan and mortgage markets.

Future research will explore how a modified labor market structure - that includes both type of agents - alters the main conclusions of this paper.

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Appendix

Figures and Descriptive Statistics

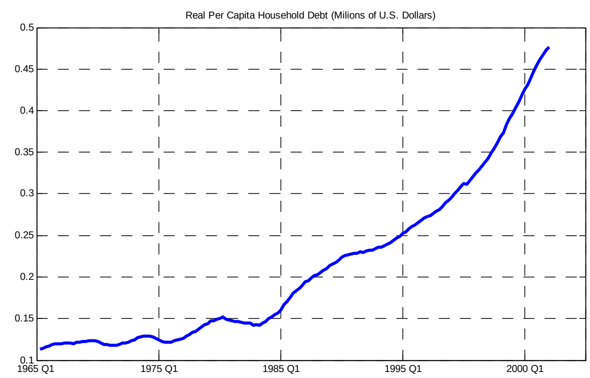


Figure 1. Household Debt in levels.

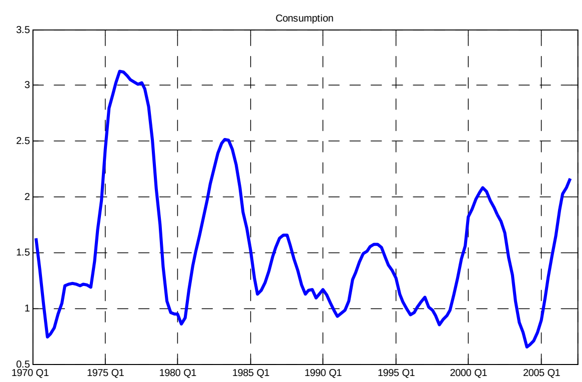


Figure 2. Standard Deviation of Consumption (computed using a 5-year moving window).

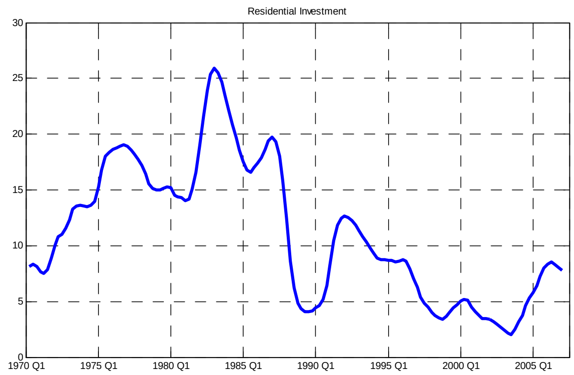


Figure 3. Standard Deviation of Residential Investment.

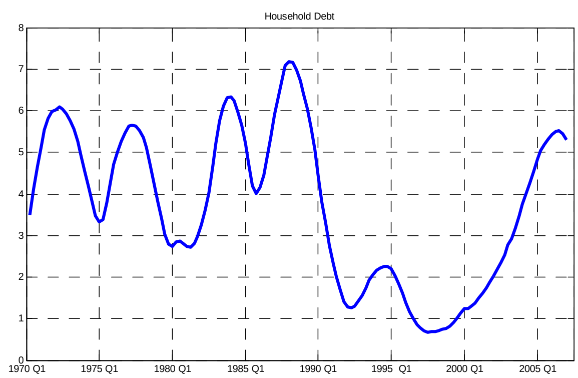


Figure 4. Standard Deviation of Household Debt.

Table 1	Percent Standard Deviation of Data*	
	1965I : 1982:IV	1983I : 2006IV
Consumption	4.04	3.71
Residential Investment	19.35	11.34
Household Debt (Total)	11.20	8.56

*Note: all variables are logged and linearly detrended.

Table 2	Time Variation: Descriptive Statistics**			
	1965I : 1982:IV		1983I : 2006IV	
	Mean	Std.Dev.	Mean	Std.Dev.
Consumption	1.63	0.48	0.99	1.30
Residential Investment	15.21	3.57	4.27	1.75
Household Debt (Total)	3.29	1.11	2.32	1.30

**The Table reports descriptive statistics for the standard deviation of the series in each sample, computed using a 5-year moving window.

The complete model

The model is enriched with a number of structural shocks in order to perform the estimation exercise. In addition to sectorial technological change and monetary policy shocks, we consider intertemporal preference shocks, housing preference shocks, sectorial investment-specific shocks, labor supply shocks, sectorial cost-push shocks, and finally shocks to the loan-to-value ratio. This section illustrates the complete model in detail.

The representative *impatient* agent solves the following intertemporal maximization problem:

$$\max E_0 \sum_{t=0}^{\infty} \varepsilon_t^b \beta^t U(X_t, N_t) \tag{28}$$

subject to (5) and (7) satisfied with equality. The intertemporal preference disturbance ε_t^b evolves exogenously according to an AR(1) process:

$$\varepsilon_t^b = \rho_b \varepsilon_{t-1}^b + \eta_t^b$$

with $\eta_t^b \sim N(0, \sigma_b)$. We introduce two types of shocks in the specification of $U(X_t, N_t)$. First, a labor supply shock in the form of an exogenous disturbance hitting labor supply:

$$U(X_t, N_t) = \log(X_t) - \frac{\upsilon \varepsilon_t^n}{1+\varphi} N_t^{1+\varphi}$$

with

$$\varepsilon_t^n = \rho_n \varepsilon_{t-1}^n + \eta_t^n,\ \eta_t^n \sim N(0, \sigma_n)$$

Second, a housing-specific preference shock that influences the weight attributed to housing services in the consumption aggregator:

$$X_t = \left[\left(1 - \left(\varepsilon_t^d \alpha\right)\right)^{\frac{1}{\eta}} \left(C_t - \theta C_{t-1}\right)^{\frac{\eta-1}{\eta}} + \left(\varepsilon_t^d \alpha\right)^{\frac{1}{\eta}} D_t^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}}$$

with

$$\varepsilon_t^d = \rho_d \varepsilon_{t-1}^d + \eta_t^d,\ \eta_t^d \sim N(0, \sigma_d)$$

Regarding the collateral constraint, the simple formulation for the provided by equation (7) can be easily extended to account for variations in equity requirements over time. Time series evidence confirms that, among other things, the average loan-to-value ratio has been increased over time, showing signs of cyclical fluctuations that reflect a more general change in financial constraints faced by households and businesses. A natural way of capturing such evolution is suggested by the interpretation of the parameter χ. As already pointed out, χ indicates the share of durable goods that cannot be used as a collateral, so that $(1-\chi)$ approximately measures the loan-to-value ratio. In a dynamic setting, the loan-to-value ratio is better interpreted as a variable, which moves over time according to some exogenous process. The collateral constraint then modifies to:

$$b_t \leq \varepsilon_t^{ltv}(1-\chi)q_t D_t \tag{29}$$

where ε_t^{ltv} denotes an exogenous stochastic term perturbing the loan-to-value ratio in period t. Such term evolves according to the following exogenous process:

$$\varepsilon_t^{ltv} = \rho_{ltv}\varepsilon_{t-1}^{ltv} + \eta_t^{ltv}, \eta_t^{ltv} \sim N(0, \sigma_{ltv})$$

Turning to the patient agent, we assume that the same shock to the intertemporal discount factor of the impatient agent, ε_t^b, is at work, so that the intertemporal utility maximization problem reads:

$$\max E_0 \sum_{t=0}^{\infty} \varepsilon_t^b \gamma^t U(\widetilde{X}_t)$$

We also assume that the housing-specific preference shock ε_t^d is common across agents:

$$\widetilde{X}_t = \left[(1-\varepsilon_t^d\alpha)^{\frac{1}{\eta}}\left(\widetilde{C}_t - \theta\widetilde{C}_{t-1}\right)^{\frac{\eta-1}{\eta}} + \left(\varepsilon_t^d\alpha\right)^{\frac{1}{\eta}}\widetilde{D}_t^{\frac{\eta-1}{\eta}}\right]^{\frac{\eta}{\eta-1}}$$

The patient agent's choice over capital and capacity utilization is also affected by exogenous disturbances. In particular, we model the existence of sector-specific shocks to the price of investment relative to nondurable consumption goods as follows:

$$\widetilde{K}_{\iota t} = (1-\delta_k)\widetilde{K}_{\iota t-1} + \varepsilon_t^{\iota i}\left[1 - S_\iota\left(\frac{I_{\iota t}}{I_{\iota t-1}}\right)\right] I_{\iota t} \quad ; \quad \iota = c, d$$

with

$$\varepsilon_t^{\iota i} = \rho_{\iota i}\varepsilon_{t-1}^{\iota i} + \eta_t^{\iota i}, \; \eta_t^{\iota i} \sim N(0, \sigma_{\iota i})$$

We assume the following functional forms:

$$S_\iota(\cdot) = \frac{\phi}{2}\left(\frac{I_{\iota t}}{I_{\iota t-1}} - 1\right)^2; \qquad \iota = c, d$$

and

$$a(\cdot) = \frac{\overline{R}_k}{\psi}\left(\left[\exp \psi \left(u_{\iota t} - 1\right)\right] - 1\right)$$

Finally, we include cost-push shocks in the sectorial specifications for the New Keynesian Phillips Curve as in Smets and Wouters (2005). The final version of equation (24) thus reads:

$$\begin{aligned}\widehat{\pi}_{\iota t} = & \left(\frac{\gamma_{p\iota}}{1+\gamma_{p\iota}}\right)\widehat{\pi}_{\iota t-1} + \left(\frac{\gamma}{1+\gamma\gamma_{p\iota}}\right)E_t\left\{\widehat{\pi}_{\iota t+1}\right\} + \\ & + \left(\frac{\left(1-\xi_{p\iota}\right)\left(1-\gamma\xi_{p\iota}\right)}{\left(1+\gamma\right)\xi_{p\iota}}\right)\widehat{mc}_{\iota t} + \varepsilon_t^{\iota p}\end{aligned} \tag{30}$$

with

$$\varepsilon_t^{\iota p} = \rho_{\iota p}\varepsilon_{t-1}^{\iota p} + \eta_t^{\iota p},\ \eta_t^{\iota p} \sim N(0, \sigma_{\iota p})$$

The Deterministic Steady State

In this section we derive the steady-state version of the model equations. First, it is immediate to show that the collateral constraint always binds in equilibrium. In fact, by evaluating the Euler equation (17) in steady state, one obtains:

$$1 = \gamma R$$

or

$$R = \frac{1}{\gamma}$$

then, evaluating equation (9) in steady state gives:

$$\begin{aligned}\psi &= 1 - \beta R \\ &= 1 - \frac{\beta}{\gamma} > 0\end{aligned}$$

where the last inequality follows from the crucial assumption about the two intertemporal discount factors:

$$\beta < \gamma$$

Therefore, the Lagrange multiplier ψ attached to the collateral constraint is strictly positive in steady state, which implies that the constraint holds with equality. Clearly, the result holds true in a sufficiently small neighborhood of the deterministic steady state;

this allows to treat the collateral constraint as binding when solving the model up to a log-linear approximation.

Next, we turn to the computation of durable and nondurable consumption. We calibrate the parameter υ in the utility function in such a way to obtain a total amount of hours worked equal to 0.3 in equilibrium[28]. It is immediate to notice that under price and wage (perfect) flexibility, the two blocks of equations for price and wage setting modify substantially. First, when $\xi_W = 0$ and $\eta_t^W = 0$, all agents are allowed to change their wage every period. Therefore, the wage setting condition boils down to the usual, competitive equivalence between the real wage and the marginal rate of substitution between consumption and leisure. However, the presence of a wage markup drives a wedge between the two terms. Thus, the optimality condition for the impatient agent is replaced by:

$$-\frac{U_N}{U_C} = w = \frac{1}{1+\lambda_{pc}}$$

where $w \equiv \frac{W}{P_c}$ is the real wage in terms of nondurable consumption, and

$$-\frac{U_N}{U_C} = wq = \frac{q}{1+\lambda_{pd}}$$

Therefore, the relative price q is pinned down by the following equation:

$$q = \frac{1+\lambda_{pd}}{1+\lambda_{pc}}$$

Next, we turn to the computation of C and D. Evaluating (8) in steady state and using (1) and (2) gives:

$$\widehat{C}/\widehat{D} = \{q\left[1-\beta\left(1-\delta\right)-\left(1-\chi\right)\psi\right]\}^{\eta}\left(\frac{1-\alpha}{\alpha}\right)\left(\frac{1}{1-\theta}\right) \tag{31}$$

By evaluating the collateral constraint - holding with equality - in steady state we obtain:

$$\frac{b}{\widehat{D}} = \left(1-\chi\right)q \tag{32}$$

Finally, the level of $\widehat{D}$ is pinned down using the impatient agent's budget constraint (5) together with (31) and (32):

$$\widehat{D} = \frac{wN}{\left(\widehat{C}/\widehat{D}\right)q+\delta-\left(1-R\right)\left(1-\chi\right)}$$

[28] We are adopting the usual normalization that the total endowment of hours equals one.

Then, clearly:

$$\widehat{C} = \left(\frac{\widehat{C}}{\widehat{D}}\right)\widehat{D}$$

The capital-labor ratios in the two sectors can be easily obtained by solving the firm's static cost-minimization problem:

$$\frac{K_j}{N_j} = \frac{w}{r^k}\frac{\alpha_j}{1-\alpha_j}\frac{\omega}{1-\omega} \tag{33}$$

Next we focus on the patient agent. Evaluating the market clearing conditions (26) and (27) in steady state and using the production functions gives:

$$Y_d = \omega\delta\widehat{D} + (1-\omega)\,\delta\widetilde{D} = \frac{((1-\omega)K_d)^{\alpha_d}\,(\omega N_d(i))^{1-\alpha_d}}{\Phi_{yd}} \tag{34}$$

and

$$Y_c = \omega\widehat{C} + (1-\omega)\,\widetilde{C} = \frac{((1-\omega)K_c)^{\alpha}\,(\omega N_c(i))^{1-\alpha}}{\Phi_{yc}} \tag{35}$$

where, by construction:

$$N_c + N_d = N = 0.3$$

Using (34) yields:

$$\widetilde{D} = \left(\frac{1}{(1-\omega)\,\delta}\right)\left\{\frac{(1-\omega)^{\alpha_d}\omega^{1-\alpha_d}\,(K_d/N_d)^{\alpha_d}\,N_d}{\Phi_{yd}} - \omega\delta\widehat{D}\right\} \tag{36}$$

Analogously, using (35) yields:

$$\widetilde{D} = \left(\frac{1}{(1-\omega)\,(\widetilde{C}/\widetilde{D})}\right)\left[\begin{array}{c}\frac{(1-\omega)^{\alpha}\omega^{1-\alpha}(K_c/N_c)^{\alpha}(N-N_d)}{\Phi_y} - \omega\widehat{C} + \\ -(1-\omega)\delta_k\left[(K_c/N_c)\,(N-N_d) + (K_d/N_d)\,N_d\right]\end{array}\right] \tag{37}$$

where the value of $\widetilde{C}/\widetilde{D}$ is obtained by using the patient agent's Euler equation (16):

$$\widetilde{C}/\widetilde{D} = \left[1-\gamma\,(1-\delta)\right]^{\eta}\left(\frac{1-\alpha}{\alpha}\right)\left(\frac{1}{1-\theta}\right) \tag{38}$$

Then, equating (36) and (37) and solving for N_d gives:

$$N_d = \frac{\delta\omega\widehat{D}\left(\frac{\widetilde{C}}{\widetilde{D}}\right) - \delta\omega\widehat{C} + N\left[\left(\frac{\delta}{\Phi_y}\right)(1-\omega)^{\alpha}\omega^{1-\alpha}\left(\frac{K_c}{N_c}\right)^{\alpha}\right]}{\left(\frac{\widetilde{C}}{\widetilde{D}}\right)\frac{(1-\omega)^{\alpha_d}\omega^{\alpha_d}(K_d/N_d)^{\alpha_d}}{\Phi_{yd}} + (\delta/\Phi_y)\,(1-\omega)^{\alpha}\omega^{1-\alpha}\left(\frac{K_c}{N_c}\right)^{\alpha} - \delta(1-\omega)\delta_k\left[\frac{K_c}{N_c} - \frac{K_d}{N_d}\right]} \tag{39}$$

and,clearly:

$$N_c = N - N_d$$

Then, using either (36) or (37) one obtains $\widetilde{D}$; the level of $\widetilde{C}$ is immediately obtained by multiplying expression (38) by $\widetilde{D}$. Finally, the level of capital and output in each sector can be easily obtained using (33), (34) and (35).

Data

The dataset includes quarterly data on: nondurable consumption, residential fixed investment, total household debt, short-term nominal interest rate, consumer price inflation, GDP. The sample is 1965 Q1: 2006 Q4. A detailed description of the original data, their source and the transformation applied follows.

- Nondurable consumption: Real Personal Consumption Expenditure: Nondurable Goods (Billions of Chained 2000 Dollars); Source: Bureau of Economic Analysis.
- Residential Fixed Investment: Real Private Residential Fixed Investment; Source: Bureau of Economic Analysis.
- Total Household Debt: Total Outstanding Household Debt-Domestic Nonfinancial Sector. Source: Federal Reserve Bank, Flow of Funds.
- Short-term nominal interest rate: 3-month Treasury bill secondary market rate. Source: Federal Reserve Bank, Board of Governors.
- Consumer Price Inflation: Quarter-on-quarter log-difference, Gross Domestic Product, Implicit Price Deflator. Source: Bureau of Economic Analysis.
- Real House Prices: New One-Family Houses Sold Including Value of Lot, divided by the Implicit Price Deflator for the Nonfarm Business Sector. Source: U. S. Census Bureau.
- Nonresidential Investment: Real Private Nonresidential Fixed Investment, Source: Bureau of Economic Analysis.
- Gross Domestic Product: Real Gross Domestic Product (Billions of Chained 2000 Dollars). Source: Bureau of Economic Analysis.
- Hours worked in the consumption-good sector: Total Nonfarm Payrolls less All Employees in the Construction Sector, multiplied by Average Weekly Hours of Production Workers. Source: Bureau of Labor Statitstics.

All series are seasonally adjusted. Nondurable consumption, residential fixed investment, household debt, nonresidential fixed investment and GDP are expressed in per capita terms by dividing with the population over 16 (Civilian Noninstitutional Population, Source: Bureau of Labor Statistics). The nominal interest rate and the inflation rate are expressed on a quarterly basis, consistently with their definition in the model. The data are expressed in log.

Detrending. The model is a purely business cycle one, and therefore does not display any trend. Once the model is log-linearized around the deterministic steady-state, all variables can be treated as deviations around the mean (the steady state). Therefore, to make the data comparable with the model-generated series, a detrending procedure must be chosen. Following Smets and Wouters (2003), all variables are linearly detrended, while inflation and the nominal interest rate are detrended by the same linear trend in inflation.

Assessing Convergence in the RWMH algorithm

The model is solved up to a log-linear approximation around the deterministic steady state. Once the solution is obtained, the model can be cast in state-space form, and the likelihood function can be computed using the Kalman filter. More precisely, the posterior distributions can be computed once independent prior distributions are specified for each one of the structural parameters to be estimated.

Markov Chain Monte Carlo (MCMC) methods are used to simulate draws from an unknown target distribution, through the generation of a Markov chain, the stationary density of which is assumed to coincide with the target density. A natural question concerns the evaluation of convergence, and the definition of some convergence diagnostics. Following Robert and Casella (1998), one can distinguish between: (i) convergence of the MC to its stationary distribution (which implies exploring the correct distribution of interest and the whole space), (ii) convergence of empirical averages to the appropriate expected values (i.e. the posterior population moments) and (iii) convergence to *iid* sampling. This subsection briefly describes two approaches to the problem of evaluating convergence[29].

Geweke (1992) suggests an empirical evaluation method based on the following intuition. Consider a vector of parameters θ, and a function of interest $g(\theta)$. We are interested in estimating $g(\theta)$ based on the sample draws. For a sufficiently large number of draws, the estimate of $g(\theta)$ based on, say, the first half of the draws, should coincide with the estimate based on the last half. A difference in the two estimates indicates that (i) either too few draws have been taken, or that (ii) the effect of the initial - arbitrary - draw θ^0 is contaminating quite a large part of the draws. Therefore, the total number of draws, S, is divided into a given number of subsets. More precisely, after discarding a fraction S_0 of the initial draws as burn-in replications, the remaining S_1 are divided into, say three subsets: S_A, S_B, S_C. Then, the middle set of replications, S_B, is dropped out, in order to make it more likely for S_A and S_C to be independent of one another. Finally, denoting $\widehat{g_{S_A}}$ and $\widehat{g_{S_C}}$ the estimates of $E\left[g(\theta)|y\right]$ using S_A and S_C respectively, it is possible to construct the numerical standard errors of the two estimates as $\frac{\widehat{\sigma}_A}{\sqrt{S_A}}$ and $\frac{\widehat{\sigma}_C}{\sqrt{S_C}}$. Then a central limit theorem can be invoked to establish that

$$CD \rightarrow N(0,1)$$

where

$$CD = \frac{\widehat{g_{S_A}} - \widehat{g_{S_C}}}{\frac{\widehat{\sigma}_A}{\sqrt{S_A}} + \frac{\widehat{\sigma}_C}{\sqrt{S_C}}}.$$

The method suggested by Brooks and Gelman (1998) is a generalization of the original method of Gelman and Rubin (1992). The method assumes that m parallel chains have been simulated, each starting at a different point, with overdispersion of the starting points over the target distribution. Convergence is assessed by comparing *between* and *within* variances.

[29] See Koop (2003) and Brooks and Gelman (1998).

Tables

Table 3. Prior and Posterior Distributions

		PRIOR			S1	S2
Parameter	Description	Distr.	Mean	S.D.	Median	Median
θ	cons. habit	Beta	0.65	0.1	0.2771	0.1771
φ	inv. el.labor supply	Gamma	2	0.75	1.8579	1.7679
ϕ_i	investment adj.	Normal	4	0.5	4.0661	4.1585
ψ	adj. cost elasticity	Gamma	0.2	0.1	0.0255	0.0136
$\xi_{p,c}$	Calvo prices (nond.)	Beta	0.5	0.28	0.8789	0.8811
$\xi_{p,d}$	Calvo prices (dur.)	Beta	0.5	0.28	0.0009	0.0024
ξ_w	Calvo wages	Beta	0.5	0.28	0.9721	0.9934
$\gamma_{p,c}$	price index. (nond.)	Beta	0.5	0.28	0.7978	0.0198
$\gamma_{p,d}$	price index. (dur.)	Beta	0.5	0.28	0.4671	0.5278
γ_w	wage indexation	Beta	0.5	0.28	0.0383	0.0121
ϕ_π	Taylor rule	Normal	1.5	0.1	1.567	1.5314
$\phi_{\Delta\pi}$	Taylor rule	Gamma	0.3	0.1	0.2646	0.2633
$\phi_{\Delta y}$	Taylor rule	Gamma	0.063	0.05	0.5455	0.4619
ρ_{ε_r}	Taylor rule	U[0,1]	0.5	0.28	0.8193	0.8588
ρ_{zc}	Tech. shock (nond.)	Beta	0.5	0.28	0.9717	0.9863
ρ_{zd}	Tech. shock (dur.)	Beta	0.5	0.28	0.9861	0.9903
ρ_b	Pref. shock (imp.)	Beta	0.5	0.28	0.9866	0.9628
ρ_{ltv}	Ltv-shock (nond.)	Beta	0.5	0.28	0.9729	0.9856
ρ_i	Inv.-specific (nond.)	Beta	0.5	0.28	0.0278	0.0251
ρ_{i_d}	Inv.-specific (dur.)	Beta	0.5	0.28	0.3676	0.3266
ρ_{hb}	Housing preference	Beta	0.5	0.28	0.9962	0.9972
ρ_n	Labor supply	Beta	0.5	0.28	0.7328	0.8902
ρ_{cp}	Cost-push (nond.)	Beta	0.5	0.28	0.0399	0.0147
ρ_{cp_d}	Cost-push(dur.)	Beta	0.5	0.28	0.5853	0.7973

Table 3 (continued). Prior and Posterior Distributions

		PRIOR	S1	S2
Parameter	Description	Distr.	Median	Median
σ_{zc}	Tech. shock (nond.)	U[0,6]	0.0063	0.0037
σ_{zd}	Tech. shock (dur.)	U[0,6]	0.0120	0.0095
σ_r	Monetary policy	U[0,6]	0.0058	0.0024
σ_{ltv}	Ltv-shock (nond.)	U[0,6]	0.0124	0.0091
σ_b	Inv.-specific (nond.)	U[0,6]	0.0846	0.0277
σ_i	Inv.-specific (dur.)	U[0,6]	1.0345	0.6530
σ_{i_d}	Inv.-specific (dur.)	U[0,6]	2.2918	1.9493
σ_{hb}	Housing preference	U[0,6]	0.0436	0.0324
σ_n	Labor supply	U[0,6]	4.0420	3.9515
σ_{cp}	Cost-push (nond.)	U[0,6]	0.0066	0.0051
σ_{cp_d}	Cost-push(dur.)	U[0,6]	3.4427	2.0272

Table 4. Variance Decomposition (1965 I : 1982 IV)

	η_{zc}	η_{zd}	η_r	η_{ltv}	η_b	η_i	η_{i_d}	η_{hb}	η_n	η_{cp}	η_{cp_d}
C	2.65	1.26	56.51	2.55	13.69	3.27	0.1	14.25	4.38	0.34	0.99
I^D	3.19	6.88	1.73	1.4	2.7	2.15	0.06	76.92	2.81	0.83	1.33
$\widehat{B}$	0.33	1.11	2.67	2.33	1.97	0.13	0.00	90.92	0.41	0.05	0.08
R	0.69	1.17	7.91	3.7	11.1	1.0	0.03	50.81	17.3	0.63	5.65
π	11.49	23.71	5.94	0.09	3.65	0.26	0.01	9.72	14.39	25.36	5.39
q	2.77	90.49	0.06	0.00	0.02	0.00	0.00	0.42	3.37	2.2	0.67
I	0.83	0.58	5.48	1.3	43.1	4.32	0.14	42.98	0.94	0.09	0.26
Y	1.5	0.81	46.35	1.12	22.71	1.45	0.05	22.06	3.02	0.34	0.59
N_c	1.84	0.76	40.83	0.95	25.93	1.69	0.06	24.38	2.84	0.22	0.5

Table 5. Variance Decomposition (1983 I : 2006 IV)

	η_{zc}	η_{zd}	η_r	η_{ltv}	η_b	η_i	η_{i_d}	η_{hb}	η_n	η_{cp}	η_{cp_d}
C	0.71	0.84	35.77	3.49	3.93	2.41	0.24	45.69	4.22	0.33	2.38
I^D	1.99	9.24	0.97	5.66	0.61	0.85	0.07	73.36	0.87	0.51	5.88
$\widehat{B}$	0.32	1.73	5.13	4.33	0.87	0.35	0.03	85.54	0.67	0.06	0.97
R	1.95	7.76	1.44	12.58	0.71	0.4	0.04	43.63	20.33	0.4	10.77
π	8.12	30.64	0.56	0.02	0.08	0.05	0.00	1.13	12.17	26.41	20.8
q	1.16	93.51	0.00	0.00	0.00	0.00	0.00	0.02	1.05	1.23	3.03
I	0.37	0.79	3.99	3.64	4.07	3.17	0.32	82.15	0.61	0.09	0.8
Y	0.42	0.34	36.95	1.69	5.22	2.84	0.29	46.17	4.21	0.35	1.51
N_c	0.87	0.35	36.18	1.59	5.31	2.89	0.29	46.59	4.16	0.33	1.43

Table 6. Marginal Likelihood

	1965 I : 1982 IV		1983 I : 2006 IV	
	Model	Benchmark	Model	Benchmark
Laplace Approximation	1544.4	1407.8	2460.6	2267.6
Modified Harmonic Mean	1540.5	1456.6	2409	2266.8

Figures

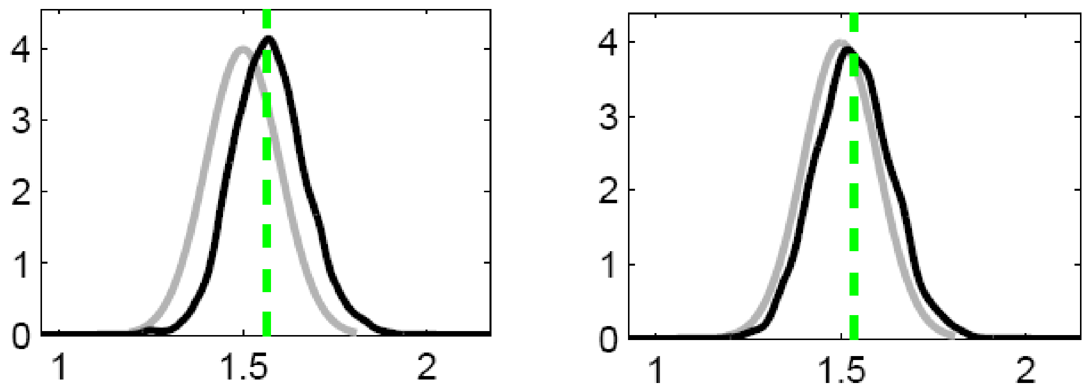


Figure 4. Prior and Posterior Distribution of ϕ_π: 1965 I - 1982 IV (left), and 1983 I - 2006 IV (right).

Grey line: Prior, Black line: Posterior, Dashed line: Posterior Mode.

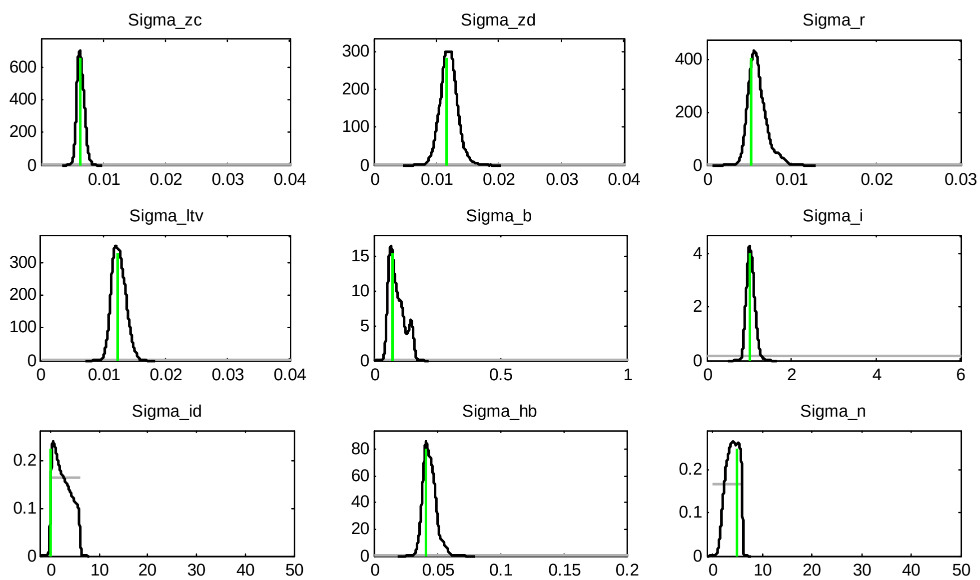


Figure 5. Priors and Posteriors (1965 I : 1982 IV). Results after 200,000 Metropolis-Hastings replications. Grey: Prior; Black: Posterior; Dashed green: Posterior Mode.

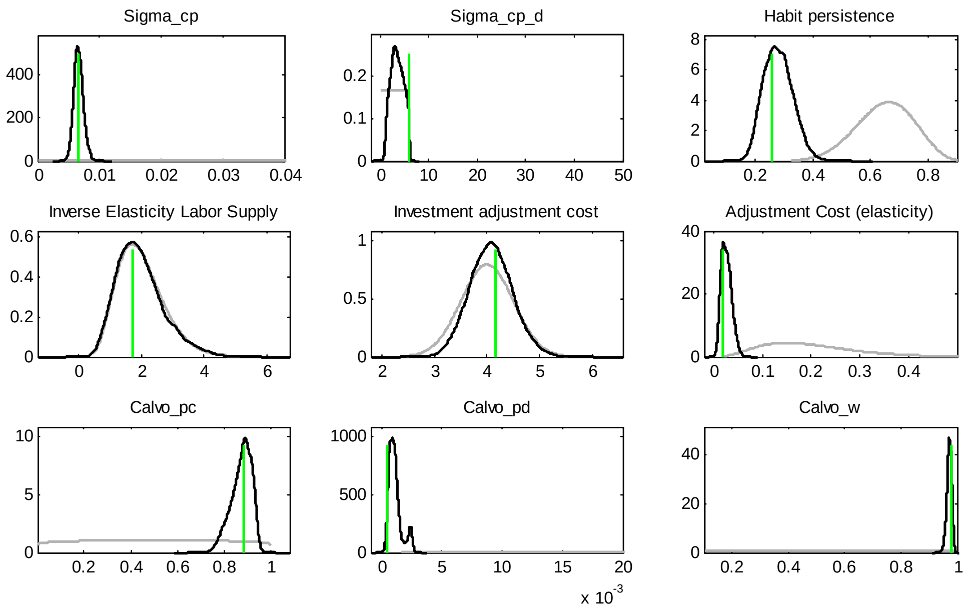
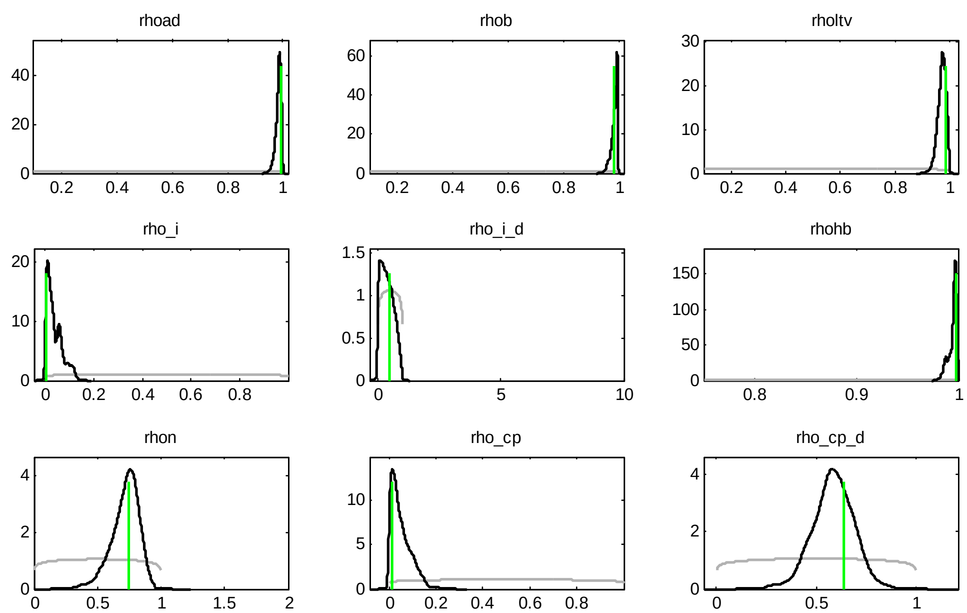


Figure 5 (continued).



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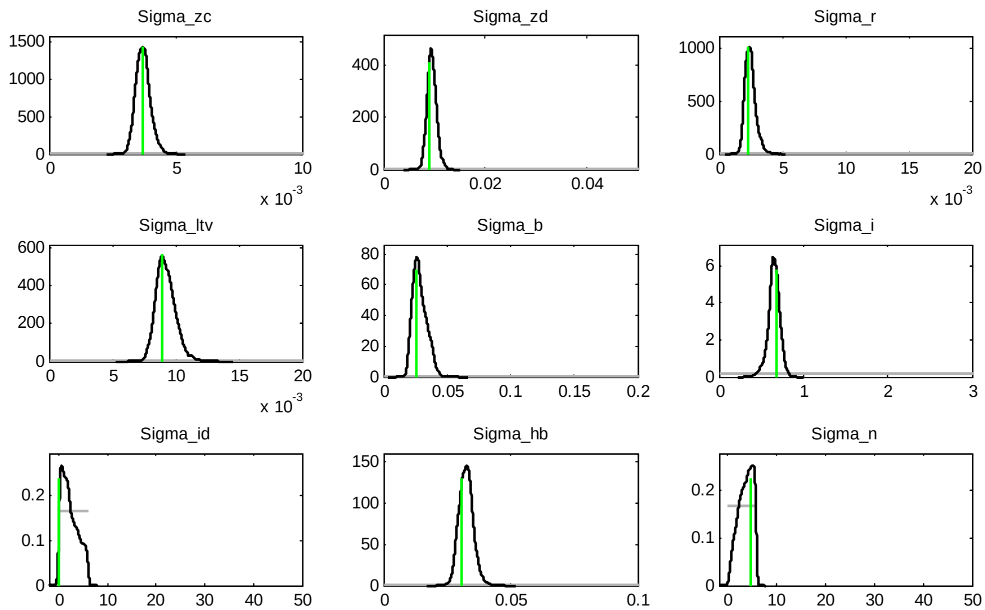

Figure 6. Sample: 1983 I : 2006 IV.

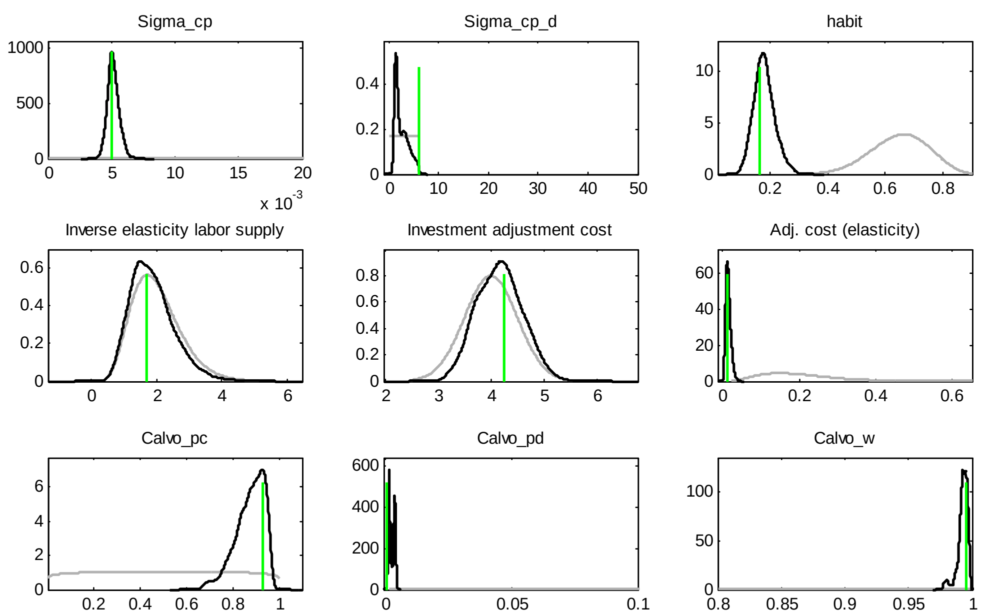

Figure 6 (continued).

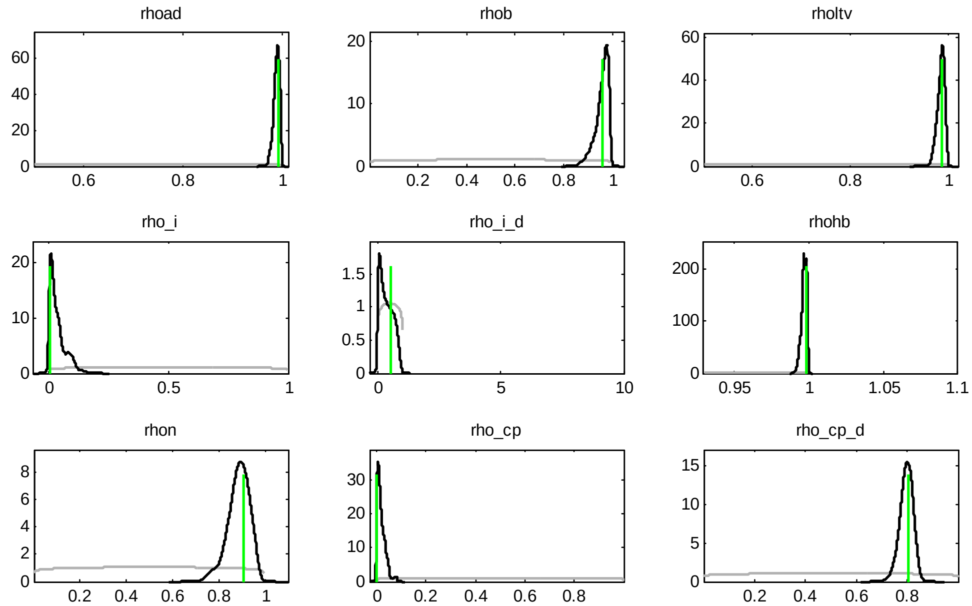

Figure 6 (continued).