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## Do central banks react to house prices?

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*Daria Finocchiaro and Virginia Queijo von Heideken*

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# DO CENTRAL BANKS REACT TO HOUSE PRICES?\*

Daria Finocchiaro and Virginia Queijo von Heideken<sup>†</sup>

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## Abstract

The substantial fluctuations in house prices recently experienced by many industrialized economies have stimulated a vivid debate on the possible implications for monetary policy. In this paper, we ask whether the U.S. Fed, the Bank of Japan and the Bank of England have reacted to house prices. We study the responses of these central banks by estimating a structural model for each country where credit constrained agents borrow against real estate. The main result is that house price movements did play a separate role in the U.K. and Japanese central bank reaction functions, while they did not in the U.S.

*Keywords:* House prices, monetary policy, DSGE models, Bayesian estimation

*JEL codes:* E31, E44, E52, E58

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## 1 Introduction

In the last few decades, house prices have undergone major medium-run fluctuations in many industrialized economies. Boom-bust cycles in house prices, coupled with a substantial increase in household indebtedness, have drawn the attention of both policymakers and academics towards the developments in housing markets and their impact on economic activity and on financial stability. Real house prices rose more than 30% in the U.S. between 1995 and 2006 (Figure 1).<sup>1</sup> In the U.K., house prices peaked in 1989, lost almost 40% of their value by 1995, and have continuously increased since then (Figure 2).<sup>2</sup> The experience of Japan is also dramatic. Property prices increased almost 40% in the five years before 1991 and have fallen since then (Figure 3). Since borrowing for housing constitutes the largest part of households' debt in most countries, the increase in indebtedness has made the overall macroeconomic situation more exposed to house price fluctuations. In this context, two kinds of questions have been posed in the policy debate:

1. Should central banks react to asset prices?
2. Do central banks respond to house prices? And if so, what are the business cycle implications of a central bank reacting to house prices?

In this paper, we take a positive rather than normative stand and thus address the second question. Specifically, we ask whether house prices entered directly in the monetary policy rule of the U.S. Fed, the Bank of Japan and the Bank of England. The main contributions of the paper are twofold. First, we add to the debate on monetary policy and asset prices by performing a rigorous structural estimation and formal model comparison. Using this approach, we are also able to investigate the business cycle implications of a central bank reacting to house prices. Second, we

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<sup>1</sup>The data used in this paper does not include the housing market swings experienced in the U.S. in 2007.

<sup>2</sup>The financial liberalization of mortgage lending institutions in the 1980s contributed to the increase in housing prices during this period.

contribute to the scarce empirical literature on estimated DSGE models for the U.K. and Japan. Our estimated models are used to identify the shocks behind the business cycles of these two economies.

Modeling-wise, we study the response of central banks in an environment where credit constrained agents borrow against their collateral, thereby amplifying business cycle fluctuations. We structurally estimate the model with Bayesian methods using data between 1983Q1-2006Q4 for the U.S. and the U.K. and between 1970Q1-1995Q4 for Japan.<sup>3</sup> The results show that house price movements did not play a separate role in the Fed reaction function in the last twenty years, while they did in the U.K. and Japan.

A large academic literature studies theoretically the optimal response of central banks to asset prices. Among others, Bernanke and Gertler (2001) argue that inflation targeting policymakers should not respond to asset prices, except insofar as they signal changes in expected inflation. On the other hand, Cecchetti, Genberg, Lipsky, and Wadhvani (2000) arrive at the opposite conclusion and argue that central banks can improve macroeconomic performance by responding to asset price misalignments. Both Bernanke and Gertler (2001) and Cecchetti, Genberg, Lipsky, and Wadhvani (2000) conduct their optimal policy analysis in frameworks where asset price booms and busts exacerbate output fluctuations in response to aggregate shocks via their effect on firms' balance sheets. Moreover, both papers focus on stock market bubbles. Closer to the spirit of Kiyotaki and Moore (1997), Mendicino and Pescatori (2004) and Monacelli (2006) study optimal monetary policy in a model where impatient households borrow in nominal terms using real estate as collateral. Mendicino and Pescatori (2004) suggest that a positive reaction to house prices is welfare reducing. Monacelli (2006) finds that the Ramsey-optimal policy is an intermediate case between strict nondurables inflation targeting and strict durables price targeting.

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<sup>3</sup>We do not consider data after 1995 in the case of Japan as the nominal interest rate has been close to its zero lower bound since then.

Fewer studies have tackled the positive empirical question and estimated central banks' reaction functions with asset prices. Bernanke and Gertler (1999) apply GMM methods to estimate Taylor type rules for the Federal Reserve and the Bank of Japan. Their estimated response coefficient on asset price is not significant over the period 1979-1997, neither for the U.S. nor for Japan. However, according to their estimates, the Bank of Japan reinforced the asset price boom by strongly reacting to stock returns with a negative coefficient during the bubble period (1979-1989) and attempted to stabilize the stock market after that date reacting with a positive coefficient. Chadha, Sarno, and Valente (2003) also use GMM to estimate Taylor type rules using data since 1979 and find that the Fed and the Bank of England have directly responded to stock prices while the Bank of Japan has not. Rigobon and Sack (2003) point out that adding stock prices to Taylor rules creates an endogeneity problem. Moreover, they stress that addressing such a problem through instrumental variables is quite a complex task since it would be difficult to find instruments that affect the stock market without having an impact on interest rates. Using an identification strategy that relies on heteroskedasticity in interest rates and stock returns, they show that in the U.S., a 5% rise in stock returns increases the likelihood of a 25 basis points tightening by more than 50%. Using a different identification strategy and allowing for nonlinearities in the central bank response to asset prices, D'Agostino, Sala, and Surico (2005) show that the Fed reacts much more strongly to the stock market index during periods of high asset prices volatility.

Instead of dealing with the endogeneity problem that would arise estimating Taylor rules with asset prices in a univariate setting, our paper relies on full information methods and estimate a full-fledged DSGE model where house price fluctuations affect firms' and households' balance sheets. Using full information methods, we can deal with the endogeneity problem and use the cross equation restrictions implied by the model to identify the parameters of interests. Moreover, we can infer the business cycle implications of a central bank that reacts to house price inflation.

Contrary to the previous literature, we focus on house prices rather than stock returns. Empirically, house and stock prices are highly correlated (Figures 1-3) and swings in both kinds of assets have been highlighted as key factors behind business cycles.<sup>4</sup> However, differently from most assets, real estate serves two important functions, which makes the whole economy vulnerable to house price movements. Houses are durable goods which provide services for households. As a result, a major share of households' wealth is held in this form. According to numerous empirical studies (e.g., Carroll, Otsuka, and Slacalek (2006)), house price fluctuations have a greater impact on aggregate spending than stock returns. Moreover, a large share of bank assets uses housing as collateral. Since bank lending is highly dependent on collateral values, there is a positive relation between credit and house prices (the bank credit channel). Moreover, house price inflation, but not stock price inflation, has a better predictive content for both inflation and output (e.g., Stock and Watson (2003) and Filardo (2000)).

From a methodological point of view, our paper is closely related to Lubik and Schorfheide (2007) who estimate a small-scale general equilibrium model of a small open economy and compare different Taylor rules using Bayesian methods. They use posterior odds tests to investigate whether central banks respond to exchange rates in the case of Australia, New Zealand, Canada and the U.K. We perform the same kind of exercise in a medium-scale model but instead test for the response to house prices.

A growing number of papers structurally estimate DSGE models. However, most of these studies are limited to the U.S. and the Euro area and, except for Iacoviello (2005) and Iacoviello and Neri (2007), none of them introduces a housing sector. As for applications to the U.S. economy and the Euro area, Smets and Wouters (2003, 2007), Adolfson, Laséen, Lindé, and Villani (2007), Queijo von Heideken (2007a) and Iacoviello and Neri (2007), all use Bayesian methods to estimate

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<sup>4</sup>Once we detrend the data, these two series do not exhibit a positive correlation in the U.S. and the U.K. Since we use detrended data in our analysis, this excludes the possibility that our results capture the response of central banks to stock prices rather than to house prices.



medium-scale DSGE models. In the case of the U.K., DiCecio and Nelson (2007) estimate the model of Christiano, Eichenbaum, and Evans (2005) using a minimum-distance estimation procedure. For Japan, Iiboshi, Nishiyama, and Watanabe (2007) and Sugo and Ueda (2007) estimate medium-scale DSGE models using Bayesian methods.

On theoretical grounds, we follow rather closely Iacoviello (2005) who develops a monetary business cycle model with nominal loans and collateral constraints tied to housing values. The mechanism in our model features a dynamic interaction between credit limits and asset prices as in Kiyotaki and Moore (1997). In the model, changes in house prices affect the borrowing capacity of borrowers, while movements in consumer prices influence the real value of their nominal debt. Another related paper is Iacoviello and Neri (2007), which develops a model with collateral constraints and estimate it using Bayesian methods for the U.S. As opposed to our model, however, theirs does not include a credit constrained entrepreneurial sector but instead includes housing investment in a two-sector economy. In their paper, the main purpose is to identify the determinants of house price movements and measure the spillovers from the housing market to the rest of the economy. In our paper, we are mostly interested in empirically testing whether central banks have reacted to house price movements in the past.

The paper is organized as follows. Section 2 describes the model. In Section 3, we present the data, the estimation methodology and the results. We check the robustness of our results in Section 4. Section 5 concludes.

## 2 The model

The model we estimate follows the work of Iacoviello (2005) who incorporates nominal loans and collateral constraints into a monetary business cycle model. The presence of nominal debt contracts and a borrowing constraint are at the heart of debt deflation and collateral effects which enrich

the transmission mechanism of the model. Changes in house prices affect the capacity to borrow (collateral effect), while movements in consumer prices influence the real value of their debt (debt deflation). For instance, after a positive demand shock, the resulting increase in house prices raises the capacity to borrow, thereby further stimulating demand. In the same way, the resulting increase in consumer prices transfers wealth from lenders to borrowers. Since borrowers have a higher propensity to consume in the model, this raises aggregate demand yet further.

The economy is populated by three kinds of agents: entrepreneurs and patient and impatient households. These agents discount future utility at different rates and borrow using housing as collateral. Entrepreneurs consume a nondurable final good and produce an intermediate good combining capital, real estate and the labor of both kinds of households. Households consume a nondurable good, own real estate and work for the entrepreneurs in a monopolistically competitive labor market. Real estate is in fixed supply. A retail sector is introduced to generate nominal rigidity. The central bank manages monetary policy using a Taylor-type interest rate rule. We enrich the dynamics of the model by introducing habit formation in consumption, sticky wages, price and wage indexation and seven structural shocks. In the following subsections, the model is described in more detail.

## 2.1 Patient and impatient households

There are two kinds of households, patient ("P") and impatient ("NP"). Each group has a continuum of agents indexed by  $i \in (0, 1)$ . Impatient households discount the future more heavily than patient ones ( $\beta^{NP} < \beta^P$ ). Both groups maximize a lifetime utility function given by:

$$MaxE_0 \sum_{t=0}^{\infty} z_t (\beta^A)^t \left( \ln (c_{i,t}^A - \zeta C_{i,t-1}^A) + j_t \ln h_{i,t}^A - \frac{(l_{i,t}^A)^\eta}{\eta} \right), \text{ for } A = P, NP$$

where  $c$  is consumption,  $h$  housing,  $l$  hours of work and  $\zeta$  the degree of habit formation with respect to aggregate consumption of each group ( $C$ ).<sup>5</sup> The variables  $z$  and  $j$  represent shocks to aggregate demand and housing demand, which both follow AR(1) processes.

Households are price setters in the labor market. Wages can only be optimally readjusted with probability  $1 - \theta_w$ . Wages of households that cannot re-optimize are fully indexed to past inflation. Workers set nominal wages maximizing their objective function subject to the intertemporal budget constraint and the following labor demand equations:

$$l_{i,t}^A = \left( \frac{w_{i,t}^A}{w_t^A} \right)^{\frac{\lambda_t}{1-\lambda_t}} L_t^A, \text{ for } A = P, NP$$

where  $\lambda$  is a time varying wage markup,  $w$  are nominal wages and  $L$  denote the aggregate labor supply of each group. Following Christiano, Eichenbaum, and Evans (2005), we assume that households buy securities with payoffs contingent on whether they can reoptimize their wages. This ensures that, in equilibrium, households within each group are homogenous in consumption and asset holdings.

Households face the following budget constraint:

$$c_{i,t}^A + q_t \Delta h_{i,t}^A + \frac{R_{t-1}}{\pi_t} b_{i,t-1}^A = b_{i,t}^A + \frac{w_{i,t}^A}{P_t} l_{i,t}^A + F_{i,t}^A + T_{i,t}^A, \text{ for } A = P, NP \text{ and } F^{NP} = 0$$

where  $q$  denotes real house prices,  $b$  real debt (loans if  $b$  is negative),<sup>6</sup>  $F$  lump-sum profits received by patient households from retailers and  $T$  net cash inflows from participating in state-contingent security markets.

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<sup>5</sup>Real balances do not enter households' utility function since we assume a cashless limiting economy as in Woodford (2003).

<sup>6</sup>We assume loan contracts with duration of only one period. This implies flexible interest rates on loans. Even though this is a reasonable assumption for the U.K., where mortgage loans are primarily extended on a floating rate basis, it is not the case in the U.S. where fixed rate contracts are more widely used. In Japan, interest rates are mainly tied to market rates or fixed between one and five years.

Impatient households can borrow up to a limit defined by the following borrowing constraint:

$$b_{i,t}^{NP} \leq m^{NP} E_t \left( q_{t+1} h_{i,t}^{NP} \frac{\pi_{t+1}}{R_t} \right).$$

Given that  $\beta^{NP} < \beta^P$ , this constraint holds with equality in steady state.<sup>7</sup> As in Iacoviello (2005), we assume that uncertainty is sufficiently small to make the borrowing constraint always bind in the loglinearized model. It is straightforward to see that movements in house prices affect the borrowing capacity of impatient households through a collateral effect, while movements in consumer prices influence the real cost of their debt.

## 2.2 Entrepreneurs and retailers

Entrepreneurs combine labor ( $L$ ), capital ( $K$ ) and real estate ( $h$ ) to produce an intermediate good. We follow Iacoviello and Neri (2007) and assume that the types of labor supplied by the two kinds of households are not perfect substitutes. This simplifying assumption allows us to analytically compute the steady state of the model and disregard the complex interaction between borrowing constraints and labor supply decisions that would otherwise arise.

Entrepreneurs are risk adverse and maximize their discounted utility:

$$Max E_0 \sum_{t=0}^{\infty} \gamma^t \log c_t,$$

subject to a Cobb-Douglas production function, the flow of funds and borrowing constraint:

$$Y_t = a_t K_{t-1}^{\mu} h_{t-1}^{\nu} L_t^{P\alpha(1-\mu-\nu)} L_t^{NP(1-\alpha)(1-\mu-\nu)},$$

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<sup>7</sup>In steady state,  $\beta^P - \beta^{NP} = (1 - \zeta) c^{NP} \chi^{NP}$ , where  $\chi^{NP}$  is the multiplier associated with the borrowing constraint. Since we assume  $\beta^P - \beta^{NP} > 0$ ,  $\chi^{NP}$  must be greater than zero in steady state which implies that the borrowing constraint holds with equality.

$$\frac{Y_t}{X_t} + b_t = c_t + q_t \Delta h_t + \frac{R_{t-1}}{\pi_{t-1}} b_{t-1} + \frac{w_t^P}{P_t} L_t^P + \frac{w_t^{NP}}{P_t} L_t^{NP} + \frac{I_t}{s_t} + \psi \left( \frac{I_t}{K_{t-1}} - \delta \right)^2 \frac{K_{t-1}}{2\delta s_t},$$

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

$$b_t \leq m E_t \left( q_{t+1} h_t \frac{\pi_{t+1}}{R_t} \right),$$

where  $a$  represents an AR(1) technology shock,  $X$  denotes the markup of final over intermediate good ( $X \equiv \frac{P}{P^w}$ ),  $s$  is an investment-specific technological shock which follows an AR(1) process and the last term in the flow of funds represents adjustment costs for capital installation.<sup>8</sup> Since by assumption  $\gamma < \beta^P$ , the borrowing constraint holds with equality in steady state.<sup>9</sup> As in the case of impatient households, we assume the constraint to always be binding, also outside the steady state.

Nominal rigidities are introduced by assuming that the intermediate good is transformed into a composite final good by a continuum of retailers indexed by  $n$ . Each retailer buys the intermediate good  $Y_t$  from the entrepreneurs at a price  $P_t^w$  and transforms it without costs into differentiated goods  $Y_t(n)$  which are sold at a price  $P_t(n)$ . The differentiated goods are then aggregated into a final good  $Y^f$  according to a Dixit-Stiglitz aggregator:

$$Y_t^f = \left[ \int_0^1 Y_t(n)^{\frac{1}{u_t}} dn \right]^{u_t},$$

where  $u$  is a time varying gross markup. The retail sector is monopolistically competitive and prices are sticky. With probability  $1 - \theta$ , the price of an individual firm can be optimally adjusted and the prices that are not re-optimized are fully indexed to past inflation.

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<sup>8</sup>We also tried a specification of the model with adjustment costs in the real estate sector. However, preliminary estimations of the model show that these costs do not play an important role in the dynamic of housing investments. These results are in line with Iacoviello (2005) and Iacoviello and Neri (2007).

<sup>9</sup>As in the case of impatient households, in steady state  $\beta^P - \gamma = c\chi$ , where  $\chi$  is the multiplier associated with the borrowing constraint. This implies that in steady state the borrowing constraint holds with equality.

### 2.3 Monetary policy

Monetary policy is conducted according to a Taylor-type rule:

$$\hat{r}_t = \rho \hat{r}_{t-1} + (1 - \rho) [\Gamma_p E_t \hat{\pi}_{t+1} + \Gamma_y \hat{y}_t + \Gamma_q \Delta \hat{q}_t] + \hat{m}_t,$$

where variables with a circumflex (" ^ ") represent log-deviations from the steady state and  $\hat{m}$  is an *iid* shock which captures a non-systematic component in the policy rule. In the sensitivity analysis, we try different specifications of the rule. As already described, the main purpose of the paper is to establish whether house prices do play a separate role in monetary policy.

### 2.4 Market equilibrium

Market equilibrium implies that all the optimality conditions corresponding to the above maximization problems are satisfied. In addition, real estate, goods and loan markets clear:

$$\begin{aligned} H &= h_t + h_t^P + h_t^{NP} \\ Y_t &= C_t + C_t^P + C_t^{NP} + \frac{I_t}{s_t} + \psi \left( \frac{I_t}{K_{t-1}} - \delta \right)^2 \frac{K_{t-1}}{2\delta s_t} \\ b_t + b_t^P + b_t^{NP} &= 0, \end{aligned}$$

where  $H$  is the fix supply of housing.

### 2.5 Shock structure

There are seven structural shocks in the economy: productivity, investment, housing demand, preferences, monetary, price markup and wage markup. The first four shocks follow stochastic processes given by:

$$v_t = (1 - \rho_v) v + \rho_v v_{t-1} + \varepsilon_{v,t},$$

while the two markup shocks and the monetary shock are *iid*:

$$v_t = v + \varepsilon_{v,t}.$$

The variances of the  $\varepsilon_v$  shocks are denoted by  $\sigma_v^2$ .

The model is loglinearized around its deterministic steady state and solved numerically using the methods described in Sims (2002). In Appendix A, we report the whole system of loglinearized equations.

### 3 Estimation results

We estimate the model for the U.S., U.K. and Japan using Markov Chain Monte Carlo (MCMC) simulation methods to conduct inference about the structural parameters.<sup>10</sup>

The data used for the estimation corresponds to seven variables in the model: real consumption, real investment, hours worked, real wages, real house prices, inflation and nominal interest rates.<sup>11</sup> A detailed description of the data can be found in Appendix B. For the U.S. and the U.K., we use quarterly data between 1983:Q1-2006:Q4. We choose this period since we can treat the period after 1983 as a single regime in both countries.<sup>12</sup> For Japan, we use data between 1970:Q1-1995:Q4 since after 1995, the nominal interest rate has been close to its zero lower bound. All series were detrended using a linear trend and seasonally adjusted prior to estimation.<sup>13</sup>

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<sup>10</sup>To check convergence, we run five different chains with a total of 100,000 draws each. We initialized the MCMC procedure using importance resampling. Convergence was monitored calculating the potential scale reduction as described in Gelman, Carlin, Stern, and Rubin (2004) and plotting each chain.

<sup>11</sup>For house prices, we use data on residential house prices. Since housing is also used by entrepreneurs in the model, an aggregated index computed of both residential and commercial house prices could also be used. However, using residential house prices is a good approximation since this series is highly correlated with commercial house prices (considering detrended data).

<sup>12</sup>In the case of the U.K., Queijo von Heideken (2007b) shows that there is some evidence of a regime switch after 1997, when the Bank of England was officially granted operational independence. However, we follow the literature estimating DSGE models and use data over a long sample where a constant-parameter policy reaction function may be a good approximation. DiCecio and Nelson (2007) use approximately the same period and argue that the data after 1979, when the Thatcher government first took office, can be considered as one regime.

<sup>13</sup>We detrend the series of hours worked in Japan using a kinked linear trend to take into account the effect of the

### 3.1 Prior distributions

The model has a total of 32 free parameters. Nine of these are calibrated, because they cannot be identified from the detrended data.<sup>14</sup> The discount factors  $\beta^P$ ,  $\beta^{NP}$  and  $\gamma$  are set at 0.9925, 0.97 and 0.98, respectively.<sup>15</sup> The choice of the discount factor for patient households,  $\beta^P$ , implies that the annual real interest rate in steady state is three percent. The steady state rate of depreciation of capital,  $\delta$ , is set equal to 0.03, which corresponds to an annual rate of depreciation of twelve percent. The steady state price and wage markups are calibrated at twenty percent, while the coefficients in the production function  $\mu$  and  $\nu$  are set to 0.35 and 0.035. Last, we fix the average housing weight in the utility function,  $j$ , to calibrate steady state ratios of commercial and residential real estate to annual output around 70% and 145%, in consistency with the data.<sup>16</sup>

The priors for the remaining 23 parameters are set equal for the three countries since, in all these cases, we have relatively loose priors. We report the priors in Table 1. All shocks have an inverse gamma distribution with mean 0.01 and standard deviation 0.2. For the autoregressive coefficients of the shocks, we select a beta distribution with mean 0.85 and standard deviation 0.10.

For the behavioral parameters, we choose priors in line with results in the existing literature. The habit persistence parameter  $\zeta$  is assumed to be beta distributed with mean 0.50 and standard deviation 0.20. We select a dispersed prior for this parameter since our posterior mean was lower than in other papers. The prior for the elasticity of labor supply  $\eta$  is normally distributed with mean 2 and standard error 0.75.

The Calvo parameters  $\theta$  and  $\theta_w$ , the probability of not adjusting prices and wages, have a beta prior with mean 0.70 and standard deviation 0.15. These priors imply that, on average, prices and

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*jitan*, a decrease in the number of statutory workdays per week which took place between 1988 and 1993.

<sup>14</sup>We use the same calibration for the three countries since the parameters we chose are included in the range of values usually used in country-specific studies.

<sup>15</sup>These are the same values used in Iacoviello and Neri (2007) which guarantee that the borrowing constraints bind.

<sup>16</sup>This is in line with data from the Flow of Funds accounts both for the U.S. and the U.K. However, these ratios will also depend on the estimated loan-to-value ratios  $(m, m^{NP})$ .



wages are adjusted every ten months.

There is a lot of uncertainty around the parameter  $\psi$  governing the adjustment costs in capital. Bernanke, Gertler, and Gilchrist (1999) set this parameter equal to 0.25, while King and Wolman (1996) use a value of 2 based on estimations of Chirinko (1993). We choose a gamma distribution with mean 2 and standard error 1.

We assume loan-to-value ratios  $m$  and  $m^{NP}$  to be beta distributed with mean 0.80 and standard deviation 0.05. Tsatsaronis and Zhu (2004) show that the maximum loan-to-value ratio for the U.S. and Japan is around 80% and somewhat higher for the U.K. Moreover, Iacoviello (2005) estimates these parameters to be 0.89 and 0.55 using U.S. data and minimizing the distance between the model and data impulse responses.<sup>17</sup>

The labor income share of the unconstrained agents,  $\alpha$ , is beta distributed with mean 0.64 and standard deviation 0.10. This is the value estimated in Iacoviello (2005) and consistent with other studies.

For the interest rate rule, we assume an autoregressive parameter  $\rho$ , beta distributed with mean 0.70 and standard deviation 0.10. The prior for the response coefficient of the interest rate to inflation  $\Gamma_\pi$ , is gamma distributed with mean 1.70 and standard deviation 0.20, while the response to output  $\Gamma_y$ , is gamma distributed with mean 0.125 and standard deviation 0.10. For the main parameter of interest, namely the response of the interest rate to house prices  $\Gamma_q$ , we postulate a gamma distribution with mean 0.15 and standard deviation 0.10. In the robustness analysis, we estimate the model with a different prior for this parameter.

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<sup>17</sup>Iacoviello and Neri (2007) calibrate  $m^{NP}$  to 0.85.

## 3.2 General estimation results and posterior distributions

### 3.2.1 U.S.

We start by reporting the results for the U.S. Table 1 shows the mean and 95% posterior probability intervals for the benchmark model and for the same model estimated with the restriction  $\Gamma_q = 0$ . In both cases, the nominal interest rate entails a standard smoothing component and the mean reactions to expected inflation and output are around 1.95 and 0.09, in line with other studies. In the model where the interest rate reacts to house prices, the posterior mean of  $\Gamma_q$  is 0.08. However, looking at the posterior estimates of  $\Gamma_q$  may be misleading since the results may be influenced by the choice of our prior. In the next subsection, we report posterior odds ratios which take this fact into account and penalize models with unneeded free parameters.

The estimation of the structural parameters is robust to both specifications of the monetary policy and, in general, consistent with the previous literature. However, the habit persistence parameter  $\zeta$  is lower than in other studies. This result reflects the fact that the model is able to generate hump-shaped responses of consumption to supply shocks, even without habit persistence. For instance, as discussed later, after a positive technology shock, the decrease in inflation inflates the real value of the debt for borrowers, thereby diminishing the initial increase in their consumption.

The elasticity of labor supply has a mean larger than the prior and around 3. Price and wage stickiness are in line with the priors and previous studies. Prices adjust, on average, after seven quarters while wages adjust after 3 quarters. Adjustment costs are estimated to be around 0.8.

Constrained agents have a labor income share  $(1 - \alpha)$  around 29%<sup>18</sup> and, on average, they borrow up to 70% of their housing stock. Entrepreneurs, on the other hand, borrow on average up to 56% of their housing stock. This result is opposite to Iacoviello (2005) who estimates loan-to-

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<sup>18</sup>This result is in line with macro estimates of the fraction of disposable income that goes to rule-of-thumb consumers.

value ratios for entrepreneurs higher than for households, suggesting that entrepreneurs' real state can be used more easily as collateral.<sup>19</sup>

All shocks are very persistent, especially technology and housing preference shocks. It is important to mention that housing preference shocks are larger than the rest and extremely persistent. One might thus wonder if an AR(1) specification for this shock is not overly restrictive.<sup>20</sup>

### 3.2.2 *U.K.*

Table 2 shows the posterior distribution for the case of the U.K. According to our estimates, the Bank of England has reacted less aggressively to output and expected inflation and more strongly to house price inflation than the Fed. The mean value of  $\Gamma_q$  is 0.12.

The estimates of the other structural parameters are robust to the choice of monetary policy rule and, in general, similar to those in the U.S. However, there are some exceptions. Prices and wages adjust more often in the U.K. and adjustment costs in capital are larger. Our results are in line with Nelson and Nikolov (2004), who also find that contract durations for prices in the U.K. are shorter than in the U.S. DiCecio and Nelson (2007) find absence of wage stickiness in the U.K.

Concerning the shocks affecting the economy, investment shocks are more persistent in the U.K., and technology, prices and housing preference shocks are also larger in this country. As in the case of the U.S., housing shocks are the largest and extremely persistent.

### 3.2.3 *Japan*

The results for Japan are shown in Table 3. The main difference as compared to the U.S. and the U.K. is the estimated response of the interest rate to house prices movements. The mean value of

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<sup>19</sup>In interpreting this result, we should take into account that neither our data nor Iacoviello's data include commercial housing. This might distort the estimates of the loan-to-value ratio for entrepreneurs.

<sup>20</sup>For instance, we could think that housing preference shocks follow an AR(2) process instead.

$\Gamma_q$  is 0.19, two times larger than in the case of the U.S.

Another difference is the flexibility of prices and wages. According to our estimation, prices and wages adjust every eleven and five months, respectively, similarly to the U.K., and more often than in the U.S. This is consistent with Iiboshi, Nishiyama, and Watanabe (2007) who estimate prices and wages to be more flexible in Japan than in the U.S. and Europe. Moreover, capital adjustment costs are much larger than in the two other countries. Finally, the size of shocks is, in general, much larger in Japan, especially housing and markup shocks. Specifically, a one standard deviation shock to housing preferences in Japan moves house prices 2%.

### 3.3 Model comparison

To investigate whether the Fed, the Bank of England and the Bank of Japan responded to house price inflation over the sample periods, we calculate the log marginal data density for the two model specifications when  $\Gamma_q = 0$  and  $\Gamma_q > 0$ , and compute posterior odds ratios. As mentioned before, posterior odds ratios penalize models with unneeded free parameters.

Table 4 reports the log marginal data density and posterior odd ratios for the three countries. Two results emerge from this table. First, the Bank of Japan and the Bank of England did react to house price inflation in the sample periods. The marginal data densities are larger when  $\Gamma_q > 0$  and the posterior odds ratios of the hypothesis  $\Gamma_q = 0$  against  $\Gamma_q > 0$  are 0.02 and 0.006 respectively, indicating evidence in favor of the unrestricted model.<sup>21</sup>

Second, there is at best very slightly evidence that the Fed did not directly respond to house price inflation in the last 23 years. The fact that the posterior for  $\Gamma_q$  in the unrestricted model is different from zero is related to the choice of our prior. Once we take this into account, the

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<sup>21</sup>In the case of Japan, we also estimate the model using data between 1970:Q1 and 1990:Q4, before the housing market crash. The posterior mean of  $\Gamma_q$  is 0.10, somewhat lower than before and the model comparison analysis is inconclusive. From this result, one might infer that the response to house price inflation of the Bank of Japan has been stronger after the crash. However, a detailed investigation of this kind is beyond the purpose of this paper.

marginal data density prefers the restricted model.

### 3.4 Impulse response functions

In this subsection, we compare the reaction of some key variables to different shocks under the two monetary rules:  $\Gamma_q = 0$  and  $\Gamma_q > 0$ . These results are shown in Figure 4 through Figure 6.<sup>22</sup>

After a tightening of monetary policy, aggregate demand, house prices and inflation fall. As mentioned in Section 2, in our model, the transmission mechanism of monetary policy is enriched by two additional channels compared to a standard new Keynesian DSGE: debt deflation and collateral effect. This propagation mechanism is qualitatively similar for the three countries and is not affected by the inclusion of house prices in the monetary policy rule. However, the impact response to monetary policy of inflation is larger in Japan, despite the fact that the estimated magnitude of the shock is similar to the one in the U.K. This result is not surprising given that, according to our estimation results, Japan has a higher degree of wage flexibility which causes a larger decrease in marginal costs on impact.

Housing preference shocks are equivalent to house price shocks, since the supply of housing is fixed in the model. A positive house price shock increases the spending capacity of borrowers, via the collateral effect described above, thus boosting demand. This has a positive impact on consumer prices which reinforces the initial effect through a debt deflation mechanism. As inflation goes up, the central bank raises the nominal interest rate, thereby dampening the initial increase in inflation and output. The increase in the real interest rate is larger when monetary policy reacts to house prices. In Japan, where the response of the monetary authority to house prices is stronger, the larger increase in interest rates when  $\Gamma_q > 0$ , counterbalances the debt deflation and collateral effects for the household sector. This mechanism causes almost a one percent fall in consumption

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<sup>22</sup>Responses are presented in percentage points. The shocks are set to one standard deviation.

for impatient households. In this case, a substitution effect<sup>23</sup> between housing and consumption dominates, causing a negative response of consumption to house prices. It is important to stress that after a housing shock, the three countries show a smaller response of output and inflation in the model where the central bank responds to house prices. To see if this has implications for output and inflation volatility, in Section 3.6 we study the business cycle implications of reacting to house price inflation.

In the case of supply shocks, collateral and debt deflation effects work in opposite directions. For instance, the increase in asset prices after a technology shock increases the borrowing capacity of borrowers. On the other hand, the decline in inflation transfers wealth from borrowers to lenders. It turns out that the first effect dominates and total spending increases. Interestingly, for the three countries, the propagation mechanism after a technology shock is not affected by a central bank that responds to house prices.

### 3.5 Variance decomposition

To analyze the importance of the different shocks in the data, we perform variance decomposition analysis. In Tables 5, 6 and 7, we report the variance decomposition 1, 4 and 20 periods ahead for the U.S., the U.K. and Japan. For the U.S., we limit ourselves to the case  $\Gamma_q = 0$ , since the evidence from the model comparison analysis prefers this model. For the U.K. and Japan, we instead report the results for the model with  $\Gamma_q > 0$  since this is preferred by the data.

Tables 5 reports the variance decomposition analysis for the U.S. House price movements are mostly driven by house preference shocks at all horizons, while technology shocks explain about 22% of house price fluctuations in the long run. Monetary policy shocks explain 11% of the variation in house prices in the short run, but this effect disappears at longer horizons. In the medium

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<sup>23</sup>A housing preference shock changes the marginal rate of substitution between consumption and housing.

and long run, output, consumption and inflation variations are mainly explained by two supply shocks: technology and price markups. Together, these shocks account for about 83% of output variation and 89% of inflation variation after five years. However, at short horizons, monetary and preferences shocks also play a role in explaining consumption and output fluctuations. Investment shocks mainly drive fluctuations in the investment series at all horizons.

The results for the U.K. are shown in Table 6. House price movements are mostly explained by housing preferences shocks. In contrast to the U.S., technology and monetary policy shocks play a much smaller role for house price fluctuations. As in the U.S., supply shocks explain most of the variations of output, consumption and inflation in the medium/long run while monetary shocks play a role only in the short term. However, in the U.K., technology shocks play a smaller role than in the U.S. for the volatility of most of the variables. For example, technology shocks explain only 6% of inflation variation in the long run, while they drive almost 40% in the U.S.

Table 7 shows the results for Japan. The first thing to notice is that technology shocks have a much larger effect on house prices than in the U.S. and the U.K.: technology shocks explain one third of the variation in house prices in the long run. Second, and given the estimated stronger reaction to house price inflation of the Bank of Japan, housing shocks are more important for explaining interest rate movements. In the long run, housing shocks explain 9% of the variability in the interest rate, while in the U.S. they account for 2%. In Japan technology and price markup shocks are also the main source of variations for output, consumption and inflation. Technology shocks are even more important in capturing the fluctuations of output in the long run and explain up to 78% of GDP variation after 20 quarters.

### 3.6 Business cycle implications of reacting to house prices

In order to understand the business cycle implications of a central bank responding to house prices, we perform a counterfactual analysis and simulate the economy when  $\Gamma_q > 0$  and  $\Gamma_q = 0$ , keeping all the other parameters fixed. We simulate the model for the three countries using a sample of 1,000 draws of the model where the central bank reacts to house prices ( $\Gamma_q > 0$ ), and generating 100 simulations for 75 periods. Table 8 shows that for given parameters, whether a central bank reacts to house price inflation or not has no significant impact on inflation volatility, while it reduces the variability of output in the three countries under study. However, these results do not necessarily have normative implications, for at least two reasons. First, in our counterfactual experiment, we keep the other parameters in the Taylor rule fixed. It may be the case that different values of the response of the monetary authority to expected inflation or output have the same effect on output and inflation volatility as a positive coefficient on house price inflation. Second, just studying output and inflation volatility could be misleading. A more accurate approach would be to derive a microfounded loss function for the monetary authority. However, this is left to future research.

## 4 Robustness

In order to check the robustness of our results, we reestimate the model in four ways, using three alternative interest rate rules, and changing the prior for  $\Gamma_q$ .<sup>24</sup> Tables 9-11 show the posterior distribution of the monetary policy parameters under the alternative models for the three countries.

### *Lower prior*

First, we reestimate the model using a lower prior mean for  $\Gamma_q$ . We choose a gamma distribution with mean 0.10 and standard deviation 0.10. This works as a good robustness check since the mode

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<sup>24</sup>In results not reported here, we also estimate the model using expected inflation one year ahead,  $E_t\pi_{t+4}$ , in the Taylor rule. The results in this case are analogous to those using  $E_t\pi_{t+1}$ .



of the prior is at zero, which shifts the results in favor of finding a lower response to house price movements. However, the results are the same as before with the only difference being a slightly movement to the left of the posterior distribution of  $\Gamma_q$ . This is consistent with our findings that the Fed did not react to house price movements in the sample. In the case of the U.K., the evidence in favor of the unrestricted model is not as strong as before since the log marginal data density for the unrestricted model is lower than before. For Japan, there is still clear evidence that the Bank of Japan reacted to house prices inflation.

*Expected inflation and house price levels*

Second, we reestimate the model using the following modified Taylor rule:

$$\hat{r}_t = \rho \hat{r}_{t-1} + (1 - \rho) [\Gamma_p E_t \hat{\pi}_{t+1} + \Gamma_y \hat{y}_t + \Gamma_{qq} \hat{q}_t] + \hat{m}_t. \quad (\text{Rule 2})$$

This specification assumes that central banks react to house price levels rather than house price inflation. We set a prior distribution for  $\Gamma_{qq}$  equal to that for  $\Gamma_q$ . Under Rule 2, the estimation of all parameters is robust to the monetary policy rule and similar to the benchmark model. For the three countries, the response of the interest rate to house price levels is close to zero and the posterior odds ratios prefer the model where  $\Gamma_{qq} = 0$ . The large decrease in the marginal likelihood indicates that none of the Fed, the Bank of England or the Bank of Japan have responded to house price levels.

*Contemporaneous inflation and house price inflation*

We next use an interest rate rule of the type:

$$\hat{r}_t = \rho \hat{r}_{t-1} + (1 - \rho) [\Gamma_p \hat{\pi}_t + \Gamma_y \hat{y}_t + \Gamma_q \Delta \hat{q}_t] + \hat{m}_t, \quad (\text{Rule 3})$$

where the monetary authority reacts to contemporaneous, rather than expected, inflation. In this

case, the posterior distribution of the structural parameters is similar to that reported in Section 3 for the three countries. The only exception is the Calvo parameter for prices which is slightly lower in the U.K. and Japan, as compared to the benchmark case.

Looking at the policy parameters, the estimates of the interest rate smoothing parameter  $\rho$ , and the response to output are similar to the one in the benchmark model for the three countries. However, the estimated response to contemporaneous inflation is lower than the response to future inflation. The estimated response to house price inflation is similar to the benchmark case for the U.S. and the U.K., while it is much larger for Japan.

Posterior odds tests confirm our result that the Bank of Japan reacted to house price inflation, while the Fed did not. In the case of the U.K., the data slightly prefers the model with  $\Gamma_q = 0$ . However, the marginal data density is lower than in the benchmark model, confirming our result that the Bank of England reacted to both future inflation and house price movements.

#### *House price levels and house price inflation*

Last, we reestimate the model using the following interest rate rule:

$$\hat{r}_t = \rho \hat{r}_{t-1} + (1 - \rho) [\Gamma_p \hat{\pi}_t + \Gamma_y \hat{y}_t + \Gamma_q \Delta \hat{q}_t + \Gamma_{qq} \hat{q}_t] + \hat{m}_t. \quad (\text{Rule 4})$$

With this specification, we are testing whether central banks respond to a combination of house price levels as well as their movements. As before, we set a prior distribution for  $\Gamma_{qq}$  equal to the one for  $\Gamma_q$ . As in the case of Rule 2, the response of the interest rate to house price levels is very low. This translates into lower marginal data densities in the case when  $\Gamma_{qq} > 0$ , penalizing the unrestricted model. As a result, this model is rejected in the three countries.

The above results strengthen our conclusion that the Fed neither reacted to house prices nor house price inflation in the last decades. In Japan and the U.K., however, the central banks reacted

to house price inflation when setting its monetary policy.

## 5 Conclusions

In this paper, we ask whether the Bank of England, the Bank of Japan or the Federal Reserve have reacted to changes in house prices. To deal with the endogeneity problem that would arise estimating Taylor rules with asset prices in a single equation setting, we use full information methods. We specify a medium-scale DSGE model based on Iacoviello (2005), but enriched by a number of modifications to improve its empirical fit. In this model economy, business cycle fluctuations are amplified because credit constrained agents borrow using real estate as collateral. We estimate the model with Bayesian methods and employ posterior odds ratios tests to perform model comparison. Our main result is that house price movements did not play a separate role in the Fed reaction function over the sample period, while they did in the U.K. and Japan. This result is robust to different specifications of the estimated monetary policy rule. Remarkably, house prices display larger variation in the UK and Japan over the period considered. Moreover, according to Detken and Smets (2004), between 1970 and 2002, these two countries have mainly experienced "high cost" asset prices booms, while, over the same sample period, asset price booms were not followed by a sharp drop in real GDP in the U.S.

Our results contribute to the scarce empirical literature on estimated DSGE models for the U.K. and Japan and help us determine the shocks behind business cycles in those countries. For these two countries, we estimate a lower degree of price and wage stickiness compared to the U.S. In all three countries, supply shocks play a major role in explaining business cycle fluctuations.

Our structural investigation allows us to identify the business cycle implications of a central bank reacting to house prices. According to our results, such a central bank is able to better protect

the economy from turbulences stemming from real estate markets.<sup>25</sup> However, it is important to stress that this is true only when house price movements are generated by house price shocks. In practice, it is difficult for a central bank to know with certainty which shock causes observed fluctuations in house prices. Moreover, according to the results of our counterfactual experiment, whether a central bank reacts to house price inflation or not has no significant impact on inflation volatility, while it reduces the variability of output in the three countries under study. However, as discussed at some length in Section 3, it would be misleading to draw normative conclusions from this result. Answering the question of whether a central bank should react to house prices is left to future research.

Last, the model we estimate includes only one-period loan contracts. As a result, we might overestimate the response of the economy to monetary policy in a country like the U.S., where fixed rate mortgage loans are widely used. It would be interesting to study how a richer financial structure would affect our results.

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<sup>25</sup>One related question is to what extent house price inflation is driven by fundamental or nonfundamental changes. In our paper, all movements in house prices are caused by fundamental shocks.

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## A The log-linearized model

The model is loglinearized around its deterministic steady state where variables with a circumflex (" ^ ") represent log-deviations from the steady state. The first order conditions for patient and impatient households' choice of consumption, real state and wages are:

$$\hat{z}_t - \hat{c}_t^P + \zeta \hat{c}_{t-1}^P = E_t (\hat{r}_t - \hat{\pi}_{t+1} + \hat{z}_{t+1} - \hat{c}_{t+1}^P + \zeta \hat{c}_t^P)$$

$$\hat{q}_t = \beta^P E_t \hat{q}_{t+1} + (1 - \beta^P) \hat{j}_t + \iota \hat{h}_t + \iota^{NP} \hat{h}_t^{NP} + \frac{\hat{c}_t^P - \zeta \hat{c}_{t-1}^P}{(1 - \zeta)} - \beta' E_t \left( \frac{\hat{c}_{t+1}^P - \zeta \hat{c}_t^{NP}}{(1 - \zeta)} \right) + \beta' E_t (\hat{z}_{t+1} - \hat{z}_t)$$

$$\begin{aligned} \hat{w}_t^{Pr} &= \frac{1}{1 + \beta^P} \hat{w}_{t-1}^{Pr} + \frac{\beta^P}{1 + \beta^P} E_t \hat{w}_{t+1}^{Pr} - \hat{\pi}_t + \frac{\beta^P}{1 + \beta^P} E_t \hat{\pi}_{t+1} + \frac{1}{1 + \beta^P} \hat{\pi}_{t-1} \\ &+ \frac{1}{1 + \beta^P} \frac{(1 - \theta_w \beta^P) (1 - \theta_w)}{\theta_w \left( 1 - (\eta - 1) \frac{\lambda}{1 - \lambda} \right)} \left[ (1 - \zeta)^{-1} (\hat{c}_t^P - \zeta \hat{c}_{t-1}^P) + (\eta - 1) \hat{l}_t^P - \hat{w}_t^{Pr} \right] + \hat{\lambda}_t \end{aligned}$$

$$\begin{aligned} \hat{q}_t &= \gamma_h E_t \hat{q}_{t+1} + (1 - \gamma_h) (\hat{j}_t + \hat{z}_t - \hat{h}_t^{NP}) - (1 - m^{NP} \beta') (\hat{z}_t - \omega E_t (\hat{z}_{t+1})) \\ &- m^{NP} \beta^P (\hat{r}_t - E_t \hat{\pi}_{t+1}) + (1 - m^{NP} \beta^P) \left( \frac{\hat{c}_t^{NP} - \zeta \hat{c}_{t-1}^{NP}}{(1 - \zeta)} - \omega \frac{E_t (\hat{c}_{t+1}^{NP} - \zeta \hat{c}_t^{NP})}{(1 - \zeta)} \right) \end{aligned}$$

$$\begin{aligned} \hat{w}_t^{NPr} &= \frac{1}{1 + \beta^{NP}} \hat{w}_{t-1}^{NPr} + \frac{\beta^{NP}}{1 + \beta^{NP}} E_t \hat{w}_{t+1}^{NPr} - \hat{\pi}_t + \frac{\beta^{NP}}{1 + \beta^{NP}} E_t \hat{\pi}_{t+1} + \frac{1}{1 + \beta^{NP}} \hat{\pi}_{t-1} \\ &+ \frac{1}{1 + \beta^{NP}} \frac{(1 - \theta_w \beta^{NP}) (1 - \theta_w)}{\theta_w \left( 1 - (\eta - 1) \frac{\lambda}{1 - \lambda} \right)} \left[ (1 - \zeta)^{-1} (\hat{c}_t^{NP} - \zeta \hat{c}_{t-1}^{NP}) + (\eta - 1) \hat{l}_t^{NP} - \hat{w}_t^{NPr} \right] \\ &+ \frac{(1 - \theta_w \beta^{NP}) (1 + \beta^P)}{(1 - \theta_w \beta^P) (1 + \beta^{NP})} \hat{\lambda}_t, \end{aligned}$$



where

$$\begin{aligned}\iota &= (1 - \beta^P) \frac{h}{h^P}, \\ \iota^{NP} &= (1 - \beta^P) \frac{h^{NP}}{h^P}, \\ \omega &= \frac{(\beta^{NP} - m^{NP} \beta^{NP})}{1 - m^{NP} \beta^P},\end{aligned}$$

and  $\hat{w}_t^P$  and  $\hat{w}_t^{NP}$  denote real wages. The budget and borrowing constraints for impatient households are:

$$\begin{aligned}\frac{b^{NP}}{Y} \hat{b}_t^{NP} + s^{NP} (\hat{y}_t - \hat{x}_t) &= \frac{C^{NP}}{Y} \hat{c}_t^{NP} + \frac{qh^{NP}}{Y} \Delta \hat{h}_t^{NP} + \frac{Rb^{NP}}{Y} (\hat{b}_{t-1}^{NP} - \hat{\pi}_t + \hat{r}_t) \\ \hat{b}_t^{NP} &= E_t (\hat{q}_{t+1} + \hat{h}_t^{NP} + \hat{\pi}_{t+1} - \hat{r}_t).\end{aligned}$$

The first order conditions for entrepreneurs' choice of investment, real state, and labor are:

$$\begin{aligned}\hat{u}_t - \hat{k}_{t-1} &= \gamma E_t (\hat{u}_{t+1} - \hat{k}_t) + \frac{1 - (1 - \delta) \gamma}{\psi} E_t (\hat{y}_{t+1} - \hat{x}_{t+1} - \hat{k}_t) \\ &+ \frac{\hat{c}_t - E_t \hat{c}_{t+1}}{\psi} + \frac{\hat{s}_t - (1 - \delta) \gamma E_t \hat{s}_{t+1}}{\psi} - \frac{\hat{z}_t - E_t \hat{z}_{t+1}}{\psi}\end{aligned}$$

$$\hat{q}_t = \gamma_e E_t \hat{q}_{t+1} + (1 - \gamma_e) E_t (\hat{y}_{t+1} - \hat{x}_{t+1} - \hat{h}_t) - m \beta^P (\hat{r}_t - \hat{\pi}_{t+1}) - (1 - m \beta^P) E_t (\hat{c}_{t+1} - \hat{c}_t - \hat{z}_{t+1} + \hat{z}_t)$$

$$\hat{l}_t^A = \hat{y}_t - \hat{x}_t - \hat{w}_t^{Ar} \text{ for } A = P, NP$$

The budget and borrowing constraints for entrepreneurs are:

$$\begin{aligned}(\hat{y}_t - \hat{x}_t) (1 - s^P - s^{NP}) + \frac{b}{Y} \hat{b}_t &= \frac{C}{Y} \hat{c}_t + \frac{qh}{Y} \Delta \hat{h}_t + \frac{Rb}{Y} (\hat{b}_{t-1} - \hat{\pi}_t + \hat{r}_{t-1}) + \frac{I}{Y} (\hat{u}_t - \hat{s}_t) \\ \hat{b}_t &= E_t (\hat{q}_{t+1} + \hat{h}_t + \hat{\pi}_{t+1} - \hat{r}_t).\end{aligned}$$

The production technology and capital accumulation are given by:

$$\hat{y}_t = \frac{1}{\mu + \nu} \left( \hat{a}_t + \mu \hat{k}_{t-1} + \nu \hat{h}_{t-1} \right) - \frac{(1 - \mu - \nu)}{\mu + \nu} \hat{x}_t - \frac{(1 - \mu - \nu)}{\mu + \nu} \left( \alpha \hat{w}_t^{Pr} + (1 - \alpha) \hat{w}_t^{NPr} \right)$$

$$\hat{k}_t = \delta \hat{i}_t + (1 - \delta) \hat{k}_{t-1}.$$

Retailers choose prices so that:

$$\hat{\pi}_t = \frac{1}{1 + \beta^P} \hat{\pi}_{t-1} + \frac{\beta^P}{1 + \beta^P} \hat{\pi}_{t+1} - \frac{1}{1 + \beta^P} \frac{(1 - \theta \beta^P)(1 - \theta)}{\theta} \hat{x}_t + \hat{u}_t.$$

Monetary policy is given by:

$$\hat{r}_t = \rho \hat{r}_{t-1} + (1 - \rho) [\Gamma_p E_t \hat{\pi}_{t+1} + \Gamma_y \hat{y}_t + \Gamma_q \Delta \hat{q}_t] + \hat{m}_t.$$

The market clearing condition is:

$$\hat{y}_t = \frac{C}{Y} \hat{c}_t + \frac{C^P}{Y} \hat{c}_t^P + \frac{C^{NP}}{Y} \hat{c}_t^{NP} + \frac{I}{Y} \hat{i}_t.$$

The structural shocks are:

$$\hat{z}_t = \rho_z \hat{z}_{t-1} + \varepsilon_{zt}$$

$$\hat{s}_t = \rho_s \hat{s}_{t-1} + \varepsilon_{st}$$

$$\hat{j}_t = \rho_j \hat{j}_{t-1} + \varepsilon_{jt}$$

$$\hat{a}_t = \rho_a \hat{a}_{t-1} + \varepsilon_{at}.$$

## B The data

The data used for the estimation corresponds to seven variables of the model: real consumption, real investment, hours worked, nominal interest rate, inflation, real wages and real housing prices. All series were detrended using a linear trend and seasonally adjusted previous to estimation. Inflation is calculated as the difference of the GDP deflator. Nominal wages and house prices are converted into real terms using the GDP deflator

### B.1 US

For the U.S. we use data between 1983:Q1-2006:Q4. Data on real personal consumption expenditures (B002RA3), real gross private domestic investment (B006RA3) and GDP implicit price deflator (B191RG3), was taken from the Bureau of Economic Analysis of the U.S. Department of Commerce. Average weekly hours (CES0500000005) and average hourly earnings (CES0500000006) of production workers in the private sector were obtained from the Bureau of Labor Statistics. For house prices, we use the price index of new one-family houses sold including the value of the lot from the U.S. Census Bureau. The nominal interest rate is the Federal Funds Rate.

### B.2 UK

The data for the U.K. also covers the period 1983Q1-2006Q4. Data on households final consumption expenditure (ABJR), total gross fixed capital formation (NPQT), GDP at market prices deflator (YBGB), total actual weekly hours of work (YBUS) and wages and salaries (ROYJ HN) was taken from National Statistics U.K. House prices are the prices of all residential properties obtained from the Nationwide Building Society. For the nominal interest rate, we use the quarterly average of the official bank rate (IUQABEDR) of the Bank of England.

### B.3 Japan

In the case of Japan, we use data between 1970:Q1-1995:Q4 since after 1995 the nominal interest rates have been close to its zero lower bound. Data on private consumption, private non-residential investment and GDP deflator was obtained from the Official Cabinet. Aggregate weekly hours of work (non-agricultural industries) was obtained from the Statistic Bureau, Ministry of Internal Affairs and Communications. For nominal wages, we use monthly earnings in the private sector from the OECD database. For house prices, we use residential house prices obtained from the BIS database. For the nominal interest rate, we use the call money rate from the IFS database.

## C Tables and figures

Table 1: U.S. Data

	Dist.	Prior		Posterior $\Gamma_q = 0$			Posterior $\Gamma_q > 0$		
		Mean	SE	5%	Mean	95%	5%	Mean	95%
$\zeta$	beta	0.5	0.2	0.01	0.04	0.09	0.01	0.04	0.09
$\theta$	beta	0.7	0.15	0.83	0.86	0.89	0.83	0.86	0.89
$\theta_w$	beta	0.7	0.15	0.60	0.70	0.81	0.60	0.70	0.82
$\psi$	gamma	2	1	0.66	0.77	0.87	0.66	0.78	0.88
$m$	beta	0.8	0.05	0.49	0.56	0.62	0.49	0.56	0.62
$m^{NP}$	beta	0.8	0.05	0.63	0.70	0.77	0.63	0.70	0.77
$\alpha$	beta	0.64	0.1	0.57	0.71	0.83	0.59	0.72	0.84
$\eta$	normal	2	0.75	2.20	3.16	4.19	2.14	3.12	4.16
$\rho$	beta	0.7	0.1	0.61	0.67	0.73	0.61	0.67	0.73
$\Gamma_p$	gamma	1.7	0.2	1.69	1.94	2.22	1.70	1.96	2.25
$\Gamma_y$	gamma	0.125	0.1	0.06	0.09	0.12	0.06	0.09	0.12
$\Gamma_q$	gamma	0.15	0.1	-	-	-	0.02	0.08	0.16
$\rho_a$	beta	0.85	0.1	0.970	0.972	0.976	0.969	0.972	0.976
$\rho_j$	beta	0.85	0.1	0.954	0.979	0.995	0.948	0.975	0.994
$\rho_z$	beta	0.85	0.1	0.848	0.876	0.914	0.846	0.873	0.913
$\rho_s$	beta	0.85	0.1	0.811	0.845	0.879	0.811	0.846	0.882
$\sigma_a$	i-gamma	0.01	0.2	0.0046	0.0052	0.0059	0.0046	0.0052	0.0059
$\sigma_u$	i-gamma	0.01	0.2	0.0013	0.0015	0.0017	0.0013	0.0015	0.0017
$\sigma_j$	i-gamma	0.01	0.2	0.0226	0.0488	0.0853	0.0246	0.0543	0.0951
$\sigma_m$	i-gamma	0.01	0.2	0.0017	0.0020	0.0024	0.0017	0.0021	0.0025
$\sigma_z$	i-gamma	0.01	0.2	0.0073	0.0088	0.0107	0.0074	0.0089	0.0107
$\sigma_s$	i-gamma	0.01	0.2	0.0223	0.0264	0.0308	0.0224	0.0266	0.0312
$\sigma_\lambda$	i-gamma	0.01	0.2	0.0015	0.0017	0.0020	0.0015	0.0017	0.0020

**Table 2: U.K. Data**

	Dist.	Prior		Posterior $\Gamma_q = 0$			Posterior $\Gamma_q > 0$		
		Mean	SE	5%	Mean	95%	5%	Mean	95%
$\zeta$	beta	0.5	0.2	0.01	0.06	0.14	0.01	0.06	0.14
$\theta$	beta	0.7	0.15	0.75	0.79	0.84	0.71	0.77	0.81
$\theta_w$	beta	0.7	0.15	0.42	0.51	0.61	0.41	0.50	0.60
$\psi$	gamma	2	1	1.03	1.35	1.72	1.05	1.38	1.76
$m$	beta	0.8	0.05	0.46	0.53	0.59	0.48	0.55	0.62
$m^{NP}$	beta	0.8	0.05	0.64	0.71	0.78	0.66	0.73	0.80
$\alpha$	beta	0.64	0.1	0.50	0.67	0.82	0.54	0.70	0.84
$\eta$	normal	2	0.75	1.64	2.33	3.17	1.77	2.47	3.31
$\rho$	beta	0.7	0.1	0.63	0.69	0.75	0.65	0.71	0.76
$\Gamma_p$	gamma	1.7	0.2	1.40	1.58	1.81	1.46	1.67	1.93
$\Gamma_y$	gamma	0.125	0.1	0.002	0.02	0.03	0.002	0.01	0.03
$\Gamma_q$	gamma	0.15	0.1	-	-	-	0.06	0.12	0.18
$\rho_a$	beta	0.85	0.1	0.935	0.962	0.981	0.928	0.956	0.978
$\rho_j$	beta	0.85	0.1	0.986	0.994	0.999	0.980	0.991	0.998
$\rho_z$	beta	0.85	0.1	0.871	0.906	0.935	0.867	0.900	0.930
$\rho_s$	beta	0.85	0.1	0.905	0.951	0.989	0.913	0.958	0.992
$\sigma_a$	i-gamma	0.01	0.2	0.0074	0.0083	0.0094	0.0074	0.0084	0.0095
$\sigma_u$	i-gamma	0.01	0.2	0.0047	0.0054	0.0062	0.0049	0.0056	0.0065
$\sigma_j$	i-gamma	0.01	0.2	0.0413	0.0626	0.0948	0.0456	0.0758	0.1202
$\sigma_m$	i-gamma	0.01	0.2	0.0021	0.0025	0.0029	0.0020	0.0024	0.0028
$\sigma_z$	i-gamma	0.01	0.2	0.0115	0.0142	0.0176	0.0124	0.0153	0.0187
$\sigma_s$	i-gamma	0.01	0.2	0.0256	0.0314	0.038	0.0263	0.0321	0.0387
$\sigma_\lambda$	i-gamma	0.01	0.2	0.0042	0.0049	0.0057	0.0043	0.0049	0.0057

**Table 3: Japanese Data**

	Dist.	Prior		Posterior $\Gamma_q = 0$			Posterior $\Gamma_q > 0$		
		Mean	SE	5%	Mean	95%	5%	Mean	95%
$\zeta$	beta	0.5	0.2	0.01	0.02	0.05	0.01	0.02	0.06
$\theta$	beta	0.7	0.15	0.67	0.71	0.76	0.68	0.73	0.78
$\theta_w$	beta	0.7	0.15	0.26	0.35	0.46	0.29	0.40	0.53
$\Psi$	gamma	2	1	2.71	3.16	3.62	2.60	3.07	3.56
$m$	beta	0.8	0.05	0.57	0.63	0.68	0.57	0.63	0.69
$m^{NP}$	beta	0.8	0.05	0.68	0.73	0.78	0.66	0.72	0.78
$\alpha$	beta	0.64	0.1	0.52	0.68	0.82	0.58	0.72	0.84
$\eta$	normal	2	0.75	2.00	2.88	3.84	1.88	2.76	3.75
$\rho$	beta	0.7	0.1	0.72	0.77	0.80	0.73	0.77	0.81
$\Gamma_p$	gamma	1.70	0.2	1.68	1.94	2.23	1.72	1.99	2.27
$\Gamma_y$	gamma	0.125	0.1	0.003	0.02	0.04	0.003	0.02	0.04
$\Gamma_q$	gamma	0.15	0.1	-	-	-	0.09	0.19	0.29
$\rho_a$	beta	0.85	0.1	0.941	0.964	0.985	0.942	0.966	0.989
$\rho_j$	beta	0.85	0.1	0.931	0.957	0.980	0.920	0.948	0.973
$\rho_z$	beta	0.85	0.1	0.812	0.843	0.871	0.811	0.845	0.883
$\rho_s$	beta	0.85	0.1	0.909	0.937	0.964	0.908	0.938	0.967
$\sigma_a$	i-gamma	0.01	0.2	0.0110	0.0123	0.0139	0.0109	0.0123	0.0139
$\sigma_u$	i-gamma	0.01	0.2	0.0049	0.0057	0.0066	0.0048	0.0056	0.0064
$\sigma_j$	i-gamma	0.01	0.2	0.0946	0.1665	0.2510	0.1168	0.1924	0.2807
$\sigma_m$	i-gamma	0.01	0.2	0.0022	0.0026	0.0031	0.0022	0.0026	0.0031
$\sigma_z$	i-gamma	0.01	0.2	0.0101	0.0121	0.0145	0.0107	0.0127	0.0152
$\sigma_s$	i-gamma	0.01	0.2	0.0428	0.0507	0.0591	0.0413	0.049	0.0575
$\sigma_\lambda$	i-gamma	0.01	0.2	0.0093	0.0109	0.0128	0.0090	0.0105	0.0123

**Table 4: Posterior Odds**

Country	Log marginal data density		Posterior odds
	$\Gamma_q = 0$	$\Gamma_q > 0$	
U.S.	2452.6	2452.1	1.61
U.K.	2075.1	2078.9	0.02
Japan	2192.8	2200.3	0.006

Notes: The table reports posterior odds of the hypothesis  $\Gamma_q = 0$  versus  $\Gamma_q > 0$

**Table 5: U.S. Variance decomposition** ( $\Gamma_q = 0$ )

	$\epsilon_a$	$\epsilon_u$	$\epsilon_j$	$\epsilon_m$	$\epsilon_z$	$\epsilon_s$	$\epsilon_w$
	1 period ahead						
Real House Price	0.12	0.11	0.56	0.11	0.08	0.00	0.01
	[0.08,0.16]	[0.08,0.16]	[0.48,0.65]	[0.08,0.15]	[0.05,0.15]	[0,0]	[0,0.01]
Output	0.19	0.37	0.04	0.29	0.07	0.02	0.01
	[0.12,0.27]	[0.29,0.45]	[0.03,0.07]	[0.23,0.36]	[0.05,0.12]	[0.01,0.03]	[0,0.01]
Inflation	0.02	0.97	0.00	0.00	0.00	0.00	0.00
	[0.01,0.04]	[0.94,0.98]	[0,0]	[0,0.01]	[0,0.01]	[0,0]	[0,0.01]
Nominal Interest Rate	0.00	0.30	0.00	0.69	0.01	0.00	0.00
	[0,0]	[0.22,0.39]	[0,0]	[0.6,0.77]	[0,0.01]	[0,0]	[0,0]
Agg. Consumption	0.21	0.33	0.00	0.27	0.17	0.00	0.01
	[0.14,0.29]	[0.25,0.4]	[0,0.01]	[0.22,0.34]	[0.12,0.24]	[0,0.01]	[0,0.01]
	4 periods ahead						
Real House Price	0.17	0.11	0.57	0.04	0.10	0.00	0.01
	[0.12,0.23]	[0.07,0.16]	[0.47,0.65]	[0.03,0.05]	[0.06,0.175]	[0,0.01]	[0,0.01]
Output	0.32	0.42	0.03	0.14	0.04	0.02	0.01
	[0.22,0.43]	[0.33,0.52]	[0.02,0.05]	[0.11,0.18]	[0.03,0.07]	[0.01,0.03]	[0.01,0.02]
Inflation	0.14	0.80	0.00	0.01	0.02	0.00	0.01
	[0.09,0.21]	[0.72,0.87]	[0,0.01]	[0.01,0.03]	[0.01,0.04]	[0,0]	[0.01,0.02]
Nominal Interest Rate	0.05	0.55	0.01	0.33	0.04	0.00	0.01
	[0.03,0.08]	[0.46,0.63]	[0.01,0.02]	[0.26,0.415]	[0.03,0.07]	[0,0.01]	[0,0.01]
Agg. Consumption	0.35	0.38	0.00	0.13	0.11	0.01	0.01
	[0.25,0.46]	[0.3,0.47]	[0,0.01]	[0.1,0.17]	[0.08,0.16]	[0,0.01]	[0.01,0.02]
	20 periods ahead						
Real House Price	0.22	0.03	0.64	0.01	0.06	0.02	0.00
	[0.15,0.34]	[0.02,0.06]	[0.46,0.74]	[0.01,0.02]	[0.03,0.14]	[0.01,0.03]	[0,0.01]
Output	0.62	0.21	0.02	0.06	0.02	0.05	0.01
	[0.51,0.705]	[0.15,0.3]	[0.01,0.03]	[0.04,0.08]	[0.01,0.03]	[0.04,0.09]	[0.01,0.03]
Inflation	0.39	0.50	0.00	0.01	0.05	0.02	0.02
	[0.27,0.53]	[0.365,0.62]	[0,0.01]	[0,0.03]	[0.03,0.09]	[0.01,0.04]	[0.01,0.03]
Nominal Interest Rate	0.30	0.34	0.02	0.17	0.12	0.01	0.02
	[0.2,0.43]	[0.25,0.43]	[0.01,0.03]	[0.13,0.24]	[0.07,0.18]	[0.01,0.03]	[0.01,0.03]
Agg. Consumption	0.65	0.18	0.00	0.05	0.05	0.05	0.01
	[0.56,0.73]	[0.12,0.25]	[0,0]	[0.04,0.07]	[0.03,0.07]	[0.03,0.08]	[0.01,0.03]

Notes: The table reports median and 95 percent probability intervals (in brackets)



**Table 6: U.K. Variance decomposition ( $\Gamma_q > 0$ )**

	$\epsilon_a$	$\epsilon_u$	$\epsilon_j$	$\epsilon_m$	$\epsilon_z$	$\epsilon_s$	$\epsilon_w$
	1 period ahead						
Real House Price	0.07	0.13	0.71	0.04	0.05	0.00	0.00
	[0.04,0.1]	[0.09,0.19]	[0.62,0.77]	[0.03,0.05]	[0.02,0.09]	[0,0.01]	[0,0.01]
Output	0.18	0.55	0.03	0.14	0.08	0.00	0.01
	[0.12,0.26]	[0.45,0.64]	[0.01,0.06]	[0.11,0.19]	[0.05,0.12]	[0,0.01]	[0,0.01]
Inflation	0.01	0.96	0.00	0.01	0.01	0.00	0.01
	[0.01,0.02]	[0.93,0.98]	[0,0]	[0,0.02]	[0,0.02]	[0,0]	[0,0.01]
Nominal Interest Rate	0.00	0.61	0.08	0.30	0.00	0.00	0.00
	[0,0]	[0.51,0.69]	[0.03,0.16]	[0.23,0.39]	[0,0.01]	[0,0]	[0,0.01]
Agg. Consumption	0.18	0.51	0.00	0.14	0.13	0.01	0.01
	[0.12,0.25]	[0.41,0.6]	[0,0.02]	[0.1,0.18]	[0.09,0.2]	[0.01,0.03]	[0,0.01]
	4 periods ahead						
Real House Price	0.08	0.09	0.73	0.01	0.07	0.00	0.01
	[0.06,0.12]	[0.06,0.14]	[0.65,0.79]	[0.01,0.02]	[0.04,0.12]	[0,0.01]	[0,0.01]
Output	0.30	0.54	0.03	0.07	0.04	0.00	0.02
	[0.21,0.42]	[0.42,0.65]	[0.01,0.05]	[0.05,0.09]	[0.02,0.06]	[0,0.01]	[0.01,0.03]
Inflation	0.05	0.82	0.01	0.04	0.06	0.00	0.02
	[0.025,0.08]	[0.735,0.89]	[0,0.02]	[0.02,0.07]	[0.04,0.1]	[0,0.01]	[0.01,0.03]
Nominal Interest Rate	0.04	0.67	0.07	0.12	0.06	0.01	0.02
	[0.02,0.07]	[0.56,0.77]	[0.03,0.14]	[0.09,0.16]	[0.03,0.11]	[0,0.01]	[0.01,0.03]
Agg. Consumption	0.31	0.51	0.00	0.065	0.07	0.02	0.02
	[0.21,0.42]	[0.39,0.62]	[0,0.02]	[0.05,0.09]	[0.05,0.11]	[0.01,0.04]	[0.01,0.03]
	20 periods ahead						
Real House Price	0.06	0.02	0.85	0.00	0.05	0.01	0.00
	[0.04,0.11]	[0.01,0.04]	[0.77,0.9]	[0,0]	[0.02,0.09]	[0,0.02]	[0,0]
Output	0.52	0.31	0.03	0.04	0.02	0.06	0.01
	[0.38,0.65]	[0.21,0.44]	[0.02,0.05]	[0.03,0.06]	[0.02,0.04]	[0.03,0.1]	[0.01,0.02]
Inflation	0.06	0.76	0.01	0.04	0.10	0.00	0.02
	[0.03,0.11]	[0.69,0.83]	[0,0.03]	[0.02,0.06]	[0.06,0.14]	[0,0.01]	[0.01,0.03]
Nominal Interest Rate	0.09	0.47	0.09	0.08	0.21	0.01	0.02
	[0.05,0.15]	[0.36,0.59]	[0.05,0.15]	[0.06,0.11]	[0.14,0.3]	[0,0.04]	[0.01,0.03]
Agg. Consumption	0.52	0.29	0.00	0.04	0.04	0.09	0.01
	[0.38,0.65]	[0.19,0.41]	[0,0.01]	[0.02,0.05]	[0.03,0.06]	[0.04,0.175]	[0.01,0.02]

Notes: The table reports median and 95 percent probability intervals (in brackets)

**Table 7: Japan Variance decomposition** ( $\Gamma_q > 0$ )

	$\epsilon_a$	$\epsilon_u$	$\epsilon_j$	$\epsilon_m$	$\epsilon_z$	$\epsilon_s$	$\epsilon_w$
1 period ahead							
Real House Price	0.20	0.12	0.54	0.06	0.04	0.02	0.02
	[0.15,0.26]	[0.08,0.17]	[0.46,0.61]	[0.04,0.09]	[0.02,0.07]	[0.01,0.02]	[0.01,0.03]
Output	0.41	0.31	0.02	0.15	0.07	0.00	0.02
	[0.3,0.52]	[0.23,0.4]	[0.01,0.05]	[0.11,0.2]	[0.04,0.11]	[0,0]	[0.01,0.04]
Inflation	0.03	0.88	0.00	0.03	0.02	0.00	0.04
	[0.02,0.06]	[0.82,0.93]	[0,0]	[0.01,0.05]	[0.01,0.03]	[0,0]	[0.02,0.06]
Nominal Interest Rate	0.00	0.49	0.08	0.40	0.00	0.00	0.02
	[0,0.01]	[0.395,0.58]	[0.03,0.17]	[0.32,0.48]	[0,0.01]	[0,0]	[0.01,0.03]
Agg. Consumption	0.38	0.29	0.00	0.14	0.09	0.06	0.02
	[0.28,0.48]	[0.22,0.37]	[0,0.015]	[0.11,0.19]	[0.06,0.14]	[0.03,0.09]	[0.01,0.04]
4 periods ahead							
Real House Price	0.27	0.08	0.51	0.02	0.07	0.02	0.03
	[0.21,0.34]	[0.05,0.13]	[0.42,0.595]	[0.01,0.03]	[0.04,0.11]	[0.01,0.03]	[0.02,0.04]
Output	0.59	0.25	0.02	0.06	0.03	0.00	0.04
	[0.46,0.7]	[0.17,0.36]	[0.01,0.03]	[0.04,0.09]	[0.02,0.05]	[0,0]	[0.02,0.07]
Inflation	0.10	0.67	0.00	0.09	0.06	0.00	0.07
	[0.06,0.16]	[0.58,0.75]	[0,0.01]	[0.05,0.13]	[0.04,0.1]	[0,0]	[0.05,0.1]
Nominal Interest Rate	0.07	0.51	0.07	0.17	0.08	0.00	0.09
	[0.03,0.12]	[0.415,0.61]	[0.04,0.13]	[0.13,0.21]	[0.04,0.13]	[0,0.01]	[0.06,0.12]
Agg. Consumption	0.55	0.23	0.00	0.06	0.04	0.07	0.04
	[0.43,0.65]	[0.15,0.33]	[0,0.01]	[0.04,0.08]	[0.02,0.06]	[0.04,0.11]	[0.02,0.06]
20 periods ahead							
Real House Price	0.35	0.03	0.51	0.01	0.05	0.04	0.01
	[0.22,0.49]	[0.02,0.06]	[0.35,0.65]	[0.01,0.01]	[0.02,0.09]	[0.02,0.06]	[0.01,0.02]
Output	0.78	0.11	0.01	0.03	0.01	0.03	0.02
	[0.67,0.87]	[0.06,0.18]	[0.01,0.02]	[0.02,0.04]	[0.01,0.02]	[0.02,0.05]	[0.01,0.04]
Inflation	0.11	0.66	0.01	0.08	0.06	0.00	0.06
	[0.06,0.2]	[0.565,0.74]	[0.01,0.02]	[0.05,0.13]	[0.04,0.1]	[0,0]	[0.04,0.09]
Nominal Interest Rate	0.17	0.37	0.09	0.12	0.15	0.00	0.08
	[0.09,0.27]	[0.28,0.47]	[0.05,0.14]	[0.09,0.16]	[0.1,0.23]	[0,0.01]	[0.05,0.12]
Agg. Consumption	0.71	0.10	0.00	0.02	0.02	0.12	0.02
	[0.59,0.8]	[0.055,0.16]	[0,0.01]	[0.01,0.04]	[0.01,0.03]	[0.07,0.21]	[0.01,0.04]

Notes: The table reports median and 95 percent probability intervals (in brackets)

**Table 8: Counterfactual simulated standard deviation**

	US		UK		JPN	
	$\Gamma_q > 0$	$\Gamma_q = 0$	$\Gamma_q > 0$	$\Gamma_q = 0$	$\Gamma_q > 0$	$\Gamma_q = 0$
$\pi$	0.39	0.39	0.97	0.97	0.95	0.93
$Y$	2.11	2.14	3.04	3.12	3.90	4.01

Notes: Posterior median for a sample of 100 simulations for 75 periods  
using 1,000 draws of the model with  $\Gamma_q > 0$

**Table 9: Posterior mean for U.S. data**

	Expected Inflation				Contemporaneous Inflation		
	$\Gamma_q=0$ $\Gamma_{qq}=0$	Benchmark $\Gamma_q>0$	Lower prior $\Gamma_q>0$	Rule 2 $\Gamma_{qq}>0$	$\Gamma_q=0$ $\Gamma_{qq}=0$	Rule 3 $\Gamma_q>0$	Rule 4 $\Gamma_q>0$ $\Gamma_{qq}>0$
$\rho$	0.67	0.67	0.67	0.67	0.72	0.72	0.72
$\Gamma_p$	1.94	1.96	1.94	1.97	1.71	1.71	1.74
$\Gamma_y$	0.09	0.09	0.09	0.08	0.06	0.06	0.05
$\Gamma_q$	-	0.08	0.05	-	-	0.09	0.09
$\Gamma_{qq}$	-	-	-	0.008	-	-	0.005
Log marg data density	2452.6	2452.1	2451.0	2442.6	2434.2	2431.8	2424.9
Posterior odds	-	1.61	4.80	21315	-	11.23	11312

Notes: The table reports posterior odds of the hypothesis  $\Gamma_q = \Gamma_{qq} = 0$  versus the unrestricted model

**Table 10: Posterior mean for U.K. data**

	Expected Inflation				Contemporaneous Inflation		
	$\Gamma_q=0$ $\Gamma_{qq}=0$	Benchmark $\Gamma_q>0$	Lower prior $\Gamma_q>0$	Rule 2 $\Gamma_{qq}>0$	$\Gamma_q=0$ $\Gamma_{qq}=0$	Rule 3 $\Gamma_q>0$	Rule 4 $\Gamma_q>0$ $\Gamma_{qq}>0$
$\rho$	0.69	0.71	0.70	0.70	0.75	0.76	0.76
$\Gamma_p$	1.58	1.67	1.67	1.61	1.44	1.47	1.51
$\Gamma_y$	0.02	0.01	0.01	0.01	0.02	0.02	0.02
$\Gamma_q$	-	0.12	0.11	-	-	0.09	0.09
$\Gamma_{qq}$	-	-	-	0.003	-	-	0.002
Log marg data density	2075.1	2078.9	2076.3	2064.4	2062.4	2061.4	2057.6
Posterior odds	-	0.022	0.31	44223	-	2.80	119.7

Notes: The table reports posterior odds of the hypothesis  $\Gamma_q = \Gamma_{qq} = 0$  versus the unrestricted model

**Table 11: Posterior mean for Japanese data**

	Expected Inflation				Contemporaneous Inflation		
	$\Gamma_q=0$ $\Gamma_{qq}=0$	Benchmark $\Gamma_q>0$	Lower prior $\Gamma_q>0$	Rule 2 $\Gamma_{qq}>0$	$\Gamma_q=0$ $\Gamma_{qq}=0$	Rule 3 $\Gamma_q>0$	Rule 4 $\Gamma_q>0$ $\Gamma_{qq}>0$
$\rho$	0.77	0.77	0.77	0.77	0.80	0.81	0.81
$\Gamma_p$	1.94	1.99	1.92	1.97	1.56	1.62	1.64
$\Gamma_y$	0.02	0.02	0.02	0.02	0.02	0.02	0.02
$\Gamma_q$	-	0.19	0.14	-	-	0.29	0.30
$\Gamma_{qq}$	-	-	-	0.01	-	-	0.01
Log marg data density	2192.8	2200.3	2197.0	2188.0	2170.5	2179.0	2169.0
Posterior odds	-	0.006	0.015	119.1	-	0.0002	4.7

Notes: The table reports posterior odds of the hypothesis  $\Gamma_q = \Gamma_{qq} = 0$  versus the unrestricted model

DO CENTRAL BANKS REACT TO HOUSE PRICES?

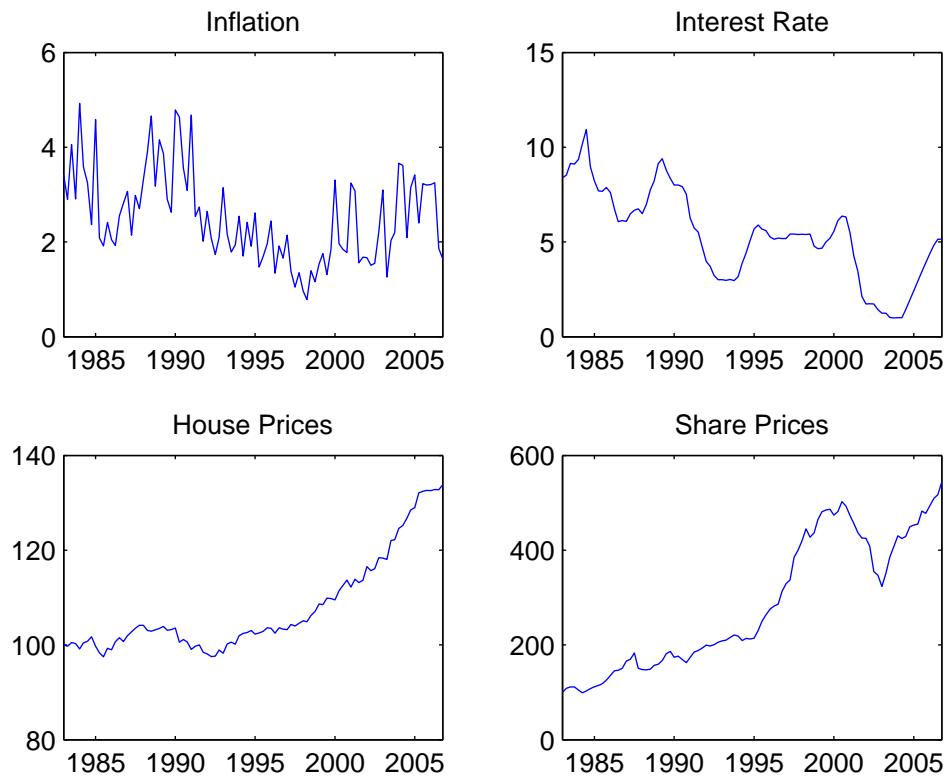


Figure 1: United States

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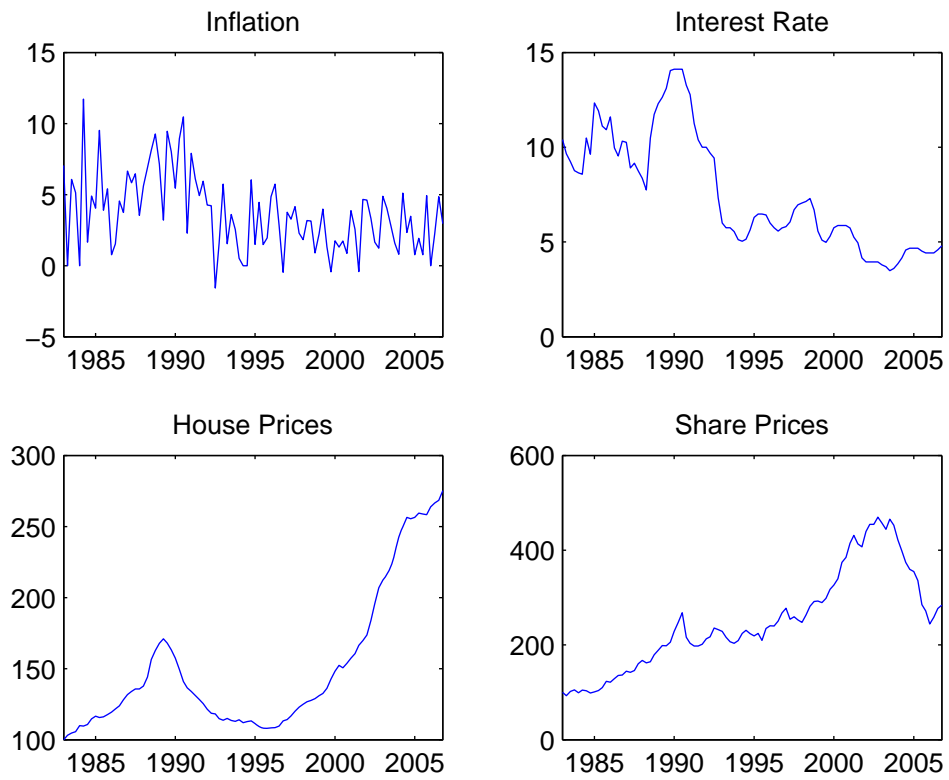


Figure 2: United Kingdom

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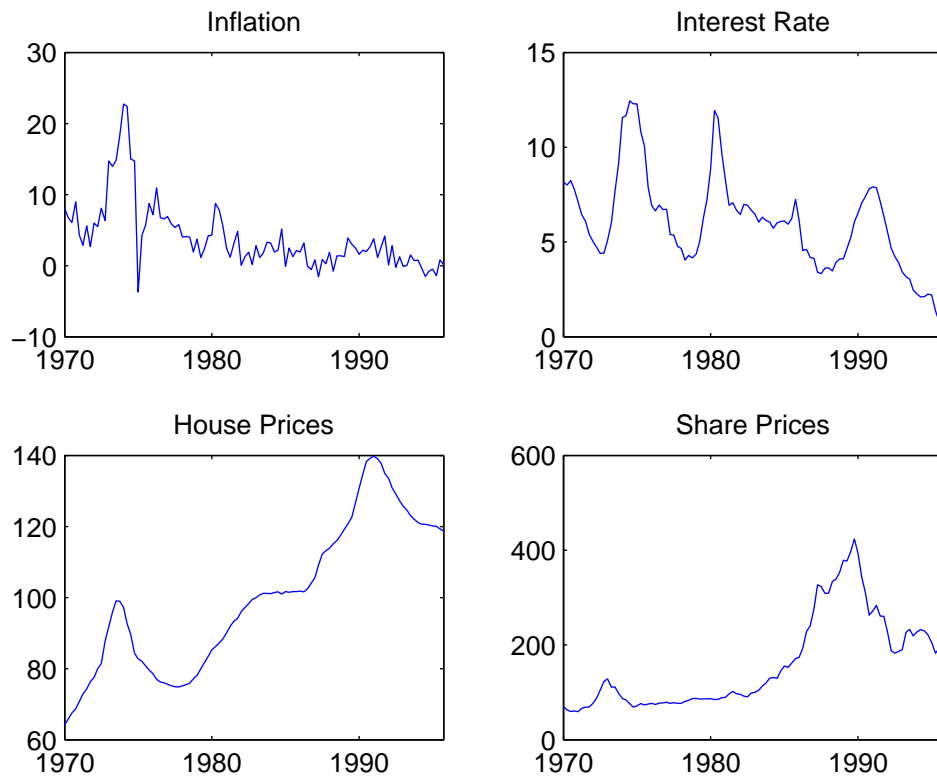


Figure 3: Japan

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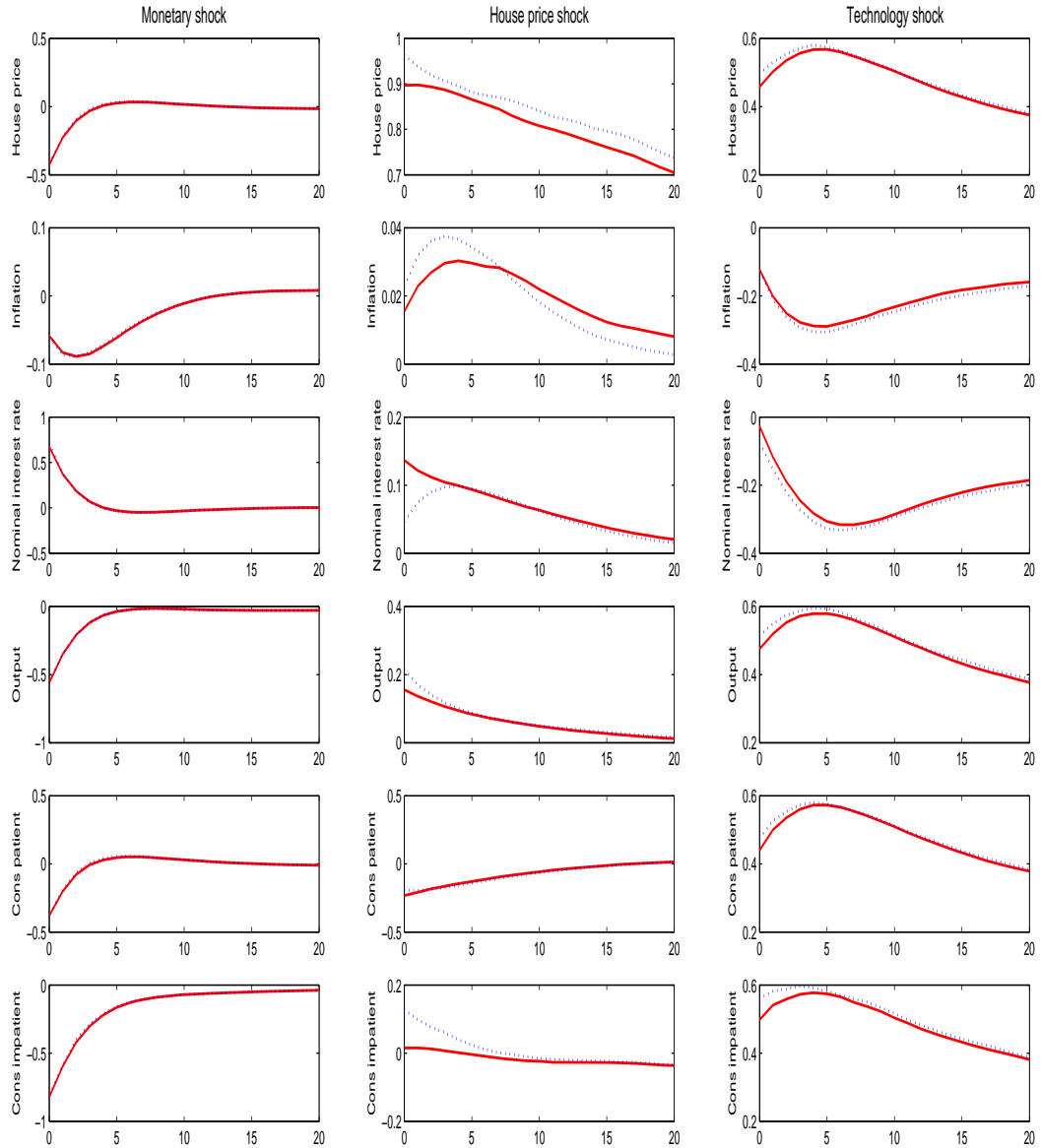


Figure 4: Posterior medians for impulse response functions in the U.S. Dotted line: Taylor rule with  $\Gamma_q = 0$ . Solid line: Taylor rule with  $\Gamma_q > 0$ .

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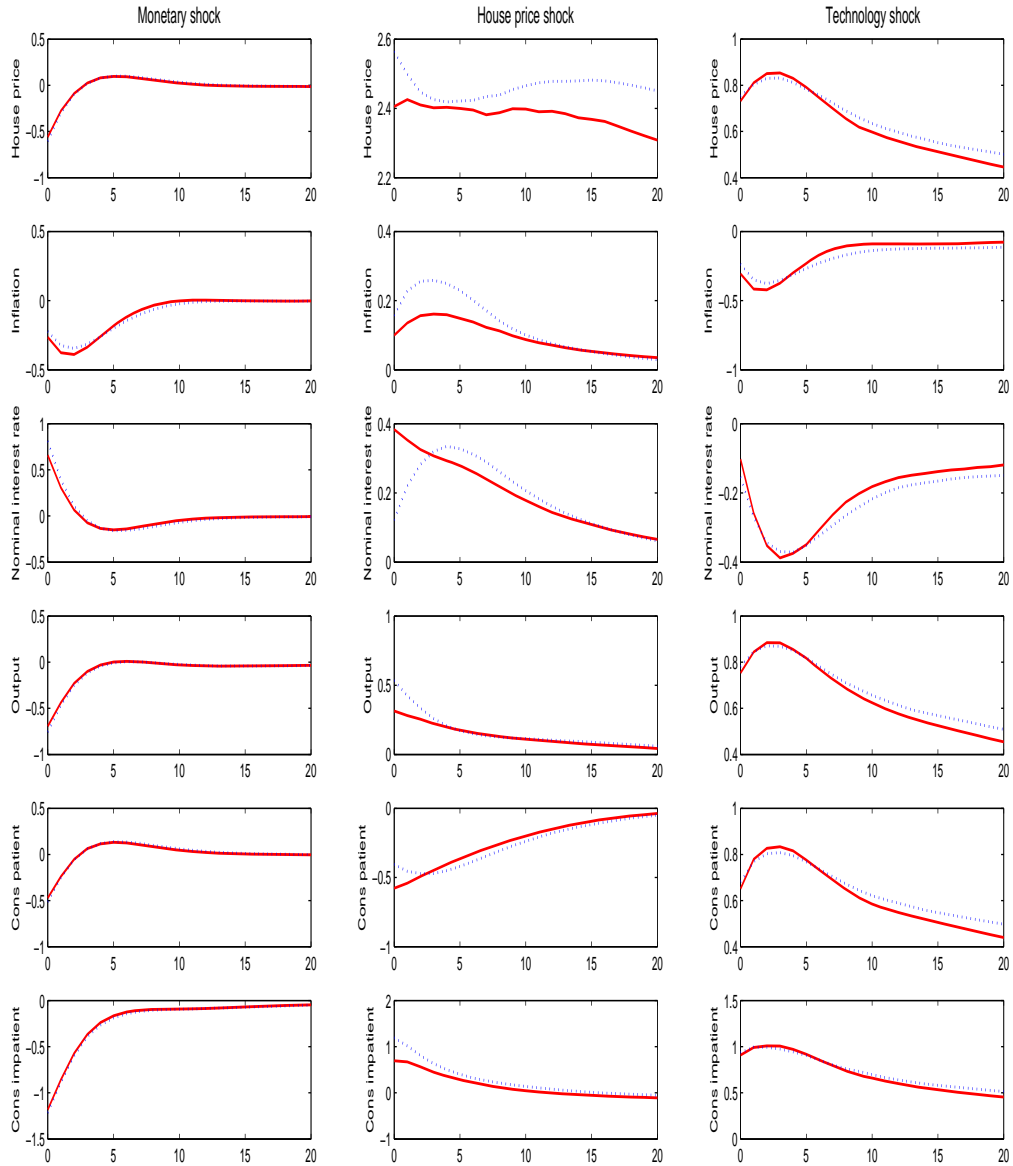


Figure 5: Posterior medians for impulse response functions in the U.K. Dotted line: Taylor rule with  $\Gamma_q = 0$ . Solid line: Taylor rule with  $\Gamma_q > 0$ .



# DO CENTRAL BANKS REACT TO HOUSE PRICES?

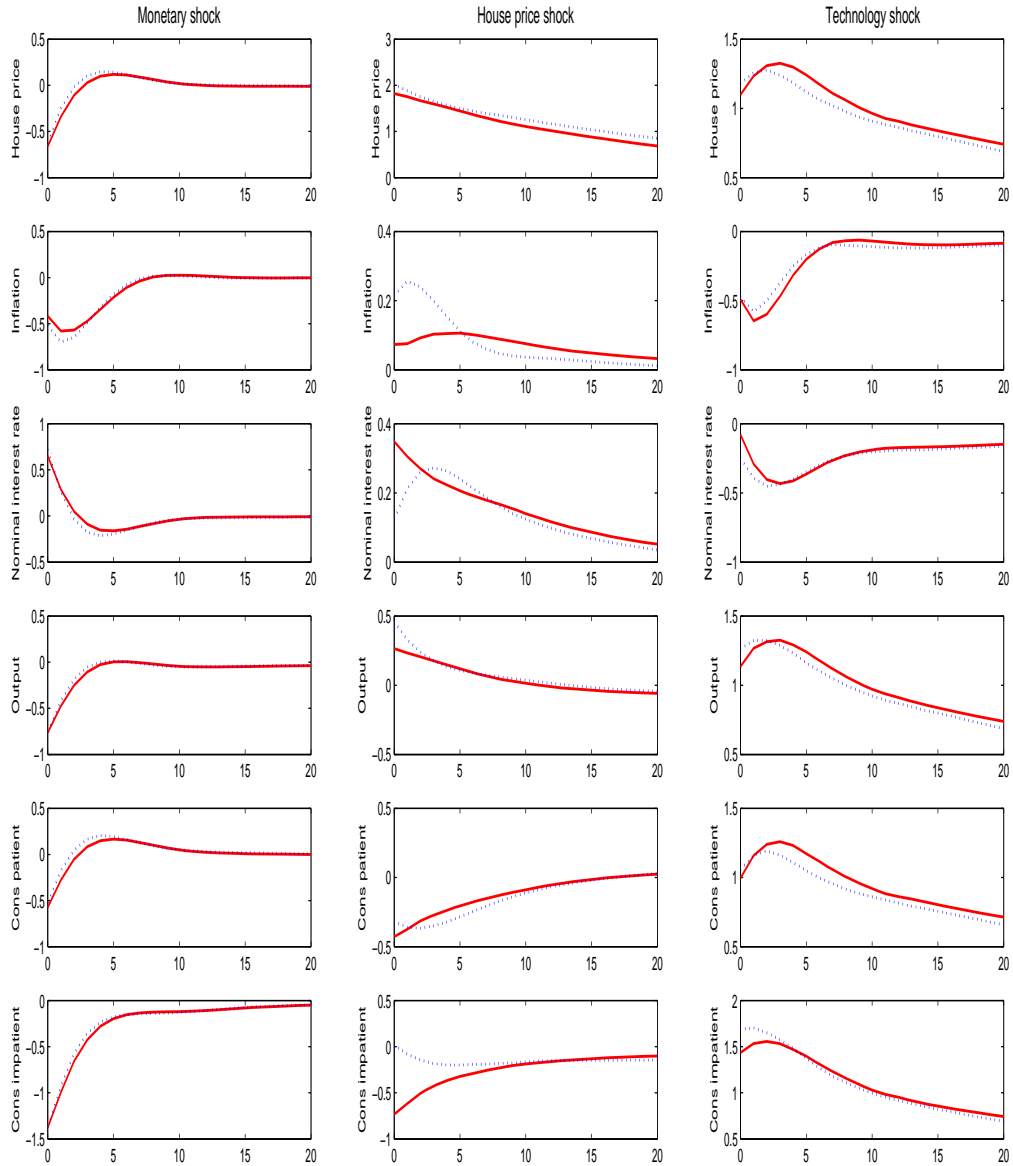


Figure 6: Posterior medians for impulse response functions in Japan. Dotted line: Taylor rule with  $\Gamma_q = 0$ . Solid line: Taylor rule with  $\Gamma_q > 0$ .

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