

DO CENTRAL BANKS REACT TO HOUSE PRICES?*

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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.S., U.K.. and Japanese central bank reaction functions.

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 financial stability. 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 academic and policy debate:

1. Should central banks react to asset prices?
2. Do central banks respond to asset prices? And if so, what are the business cycle implications of a central bank reacting to asset 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 into the monetary policy rule of the U.S. Fed, the Bank of Japan and the Bank of England. The main contribution of the paper is 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 and we can contribute to the scarce empirical literature on estimated DSGE models for the U.K. and Japan. Second, using both real and simulated data, we show that GMM methods produce biased and dispersed estimates of monetary policy reaction functions augmented with house prices.

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 1983Q1-2008Q4 for the U.S. and the U.K. and between 1970Q1-1995Q4 for Japan.¹ The results show that house price movements did play a separate role in the central bank reaction function in the U.S., U.K. and Japan.

Many studies have estimated central banks' reaction functions augmented with stock prices, exchange rates or financial indices, but to the best of our knowledge none of them have considered house prices. Following the work of Clarida, Galí, and Gertler (2000), most of these papers estimate Taylor-type rules using GMM.² 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 being correlated with interest rate movements. Using an identification strategy that relies on the heteroskedasticity of stock market returns, they show that in the U.S. a 5% rise in the S&P index increases the likelihood of a 25 basis point tightening by about one half. 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. Also Fuhrer and Tootell (2008) stress the identification issues related to GMM and, using the actual forecast examined by the FOMC before each policy decision (the "Greenbook" forecasts), find little evidence that the Fed responds directly to stock values.

In this paper, we show that GMM methods produce unreliable estimates of the policy reaction. Therefore, 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 estimates

¹We 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.

²See, among many others, Bernanke and Gertler (1999), Clarida, Galí, and Gertler (1998), Cecchetti and Li (2008), Chadha, Sarno, and Valente (2003) and Jondeau, Bihan, and Galles (2004).

a full-fledged DSGE model where house price fluctuations affect firms' and households' balance sheets. Applying full information methods enables us to use the cross equation restrictions implied by the model to identify the parameters of interests. Moreover, using a DSGE model allows us to infer the business cycle implications of a central bank that reacts to house price inflation.

Contrary to previous literature, we focus on house prices rather than stock returns. Empirically, house and stock prices are highly correlated and swings in both kinds of assets have been highlighted as key factors behind business cycles.³ However, in contrast to most assets, real estate serves two important functions, which make the whole economy vulnerable to house price movements. Houses are durable goods that 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 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

³Once 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.

and Neri (2009), none of them introduces a housing sector.⁴ In contrast to these two papers, we are mostly interested in empirically testing whether central banks have reacted to house price movements.

On theoretical grounds, we follow 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.

The paper is organized as follows. Section 2 describes the model. In Section 3 we present the data, the estimation methodology and the results. In Section 4 we estimate the monetary policy rule followed by the three countries using GMM and use Monte Carlo simulations to show that GMM estimates of the Taylor rule produce unreliable estimators. Section 5 presents our conclusions.

2 The model

The model we estimate follows the work of Iacoviello (2005), which 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

⁴More work has been done in this direction since the first draft of this paper has circulated. For example, Christensen, Corrigan, Mendicino, and Nishiyama (2007) and Pariès and Notarpietro (2008) also estimate DSGE models with housing using Bayesian methods.

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 nondurable final goods and produce intermediate goods combining capital, real estate and the labor of both kinds of households. Households consume nondurable goods, 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 rigidities. 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. The model is described in more detail in the following subsections.

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:

$$\text{Max} E_0 \sum_{t=0}^{\infty} z_t (\beta^A)^t \left(\ln (c_{i,t}^A - \zeta C_{t-1}^A) + j_t \ln h_{i,t}^A - \frac{(l_{i,t}^A)^\eta}{\eta} \right), \text{ for } A = P, NP,$$

where c is consumption, h housing, l hours of work and ζ the degree of habit formation with respect to aggregate consumption of each group (C). The variables z and j represent exogenous shocks to aggregate demand and housing demand that follow AR(1) processes. As noticed in Iacoviello and Neri (2009), the housing preference shock might capture either a simple taste shock or some unmodelled features of housing demand. For instance, they find that their estimated housing shock depends negatively on initial fees and charges paid for a mortgage while depending positively on

the share of population in the 25-39 year-old range and the share of subprime mortgages in total mortgage origination.

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 equation:

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

where λ is a time varying wage markup, w nominal wages and L 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, π gross inflation rate, R nominal interest rate, b real debt (loans if b is negative),⁵ F lump-sum profits received by patient households from retailers and T net cash inflows from participating in state-contingent security markets.

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

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

⁵We assume loan contracts with a 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.

where m is the maximum loan-to-value ratio.

Given that $\beta^{NP} < \beta^P$, this constraint holds with equality in steady state.⁶ 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 (2009) 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:

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

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

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

⁶In steady state, $\beta^P - \beta^{NP} = (1 - \zeta) c^{NP} \chi^{NP}$, where χ^{NP} is the multiplier associated with the borrowing constraint. Since we assume $\beta^P - \beta^{NP} > 0$, χ^{NP} must be greater than zero in steady state which implies that the borrowing constraint holds with equality.

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

where a represents an AR(1) technology shock, X denotes the markup of the 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.⁷ Since by assumption $\gamma < \beta^P$, the borrowing constraint holds with equality in steady state. As in the case of impatient households, we assume the constraint to always be binding even 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.

2.3 Monetary policy

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

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

⁷We 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 (2009).

where variables with a circumflex (" $\hat{\cdot}$ ") represent log-deviations from the steady state and \hat{m} is an *iid* shock which captures a non-systematic component in the policy rule. As already described, the main purpose of the paper is to establish whether house prices play a separate role in monetary policy, namely whether $\Gamma_q \neq 0$.

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 fixed 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 AR(1) processes, while the two markup shocks and the monetary shock are iid. The variance of a ε_v shock is denoted by σ_v^2 .

3 Estimation results

We estimate the model for the U.S., U.K. and Japan using Markov chain Monte Carlo (MCMC) simulation methods. First, the model is loglinearized around its deterministic steady state and

solved numerically using the methods described in Sims (2002).⁸ Second, after estimating the posterior mode through numerical optimization methods, we generate a sample representative for the posterior using the random walk Metropolis algorithm.⁹

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.¹⁰ 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:Q1-2008:Q4. We choose this period since we can treat the period after 1983 as a single regime in both countries.¹¹ 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.¹²

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.¹³ The discount factors β^P , β^{NP} and γ are set at 0.9925, 0.97 and 0.98, respectively. The choice of the discount factor for patient households, β^P , implies that the annual real interest rate in steady state is three percent. The steady state rate of depreciation of capital, δ , is set equal to 0.03, which corresponds to an annual rate of depreciation of twelve percent.

⁸Appendix A reports the whole system of loglinearized equations.

⁹To 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.

¹⁰For 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).

¹¹In the case of the U.K., Queijo von Heideken (2007) 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.

¹²We detrend the series of hours worked in Japan using a kinked linear trend to take into account the effect of the *jitán*, a decrease in the number of statutory workdays per week which took place between 1988 and 1993.

¹³We 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.

The steady state price and wage markups are calibrated at twenty percent, while the coefficients in the production function μ and ν 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.

The priors for the remaining 23 parameters are set equal for the three countries since, in all the cases, we have relatively loose priors. We report the priors in Table 1. All shocks have a gamma distribution with mean 0.05 and standard deviation 0.05. 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 ζ is assumed to be beta distributed with mean 0.50 and standard deviation 0.20. The prior for the elasticity of labor supply η is normally distributed with mean 2 and standard deviation 0.75.

The Calvo parameters θ and θ_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 wages are adjusted every ten months.

There is a lot of uncertainty around the parameter ψ 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. We choose a gamma distribution with mean 2 and standard deviation 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 for the U.S.

The labor income share of the unconstrained agents, α , 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 the autoregressive parameter, ρ , to be beta distributed with mean 0.70 and standard deviation 0.10. The prior for the response coefficient of the interest rate to inflation, Γ_p , is gamma distributed with mean 1.80 and standard deviation 0.4, while the response to output, Γ_y , is gamma distributed with mean 0.125 and standard deviation 0.10.

Bayesian hypothesis tests are often criticized because of their dependence on prior distributions. Therefore, for the main parameter of interest, namely the response of the interest rate to house prices, Γ_q , we postulate a rather loose prior centered around our null hypothesis value: a normal distribution with mean 0 and standard deviation 0.5.

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 the 5 and 95 percentiles of the posterior distribution for the benchmark model and for the same model estimated with the restriction $\Gamma_q = 0$. In both cases, the nominal interest rate shows a standard smoothing component. The mean reaction to expected inflation is higher in the unrestricted model ($\Gamma_\pi = 2.22$) compared to the restricted one ($\Gamma_\pi = 2.09$) while the mean reaction to output is slightly higher under the assumption $\Gamma_q = 0$. In the model where the interest rate reacts to house prices, the posterior mean of Γ_q is 0.36.

The estimation of the structural parameters is robust to both specifications of the monetary policy and, in general, is consistent with previous literature. However, the habit persistence parameter, ζ , 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 will be 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 of 2.3 close to our prior. Price and wage stickiness are in line with the priors and previous studies. Prices adjust, on average, after six quarters while wages adjust after four quarters. Adjustment costs are estimated to be around 0.8.

Constrained agents have a labor income share, $(1 - \alpha)$, of around 40% in the restricted model and 20% in the unrestricted one. However, it is worth noting that this parameter is better identified in the latter case. In both cases, impatient households borrow on average up to 80% of their housing stock while entrepreneurs borrow up to 65%. This result is the opposite of the findings by Iacoviello (2005), who estimates loan-to-value ratios for entrepreneurs higher than for households, suggesting that entrepreneurs' real state can be used more easily as collateral.¹⁴

While all shocks are very persistent, it is important to mention that housing preference shocks are more volatile than the rest.

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, expected inflation and house price inflation than the Fed. The mean value of Γ_q is 0.16.

The estimates of the other structural parameters are robust to the choice of monetary policy rule and, in general, are similar to those in the U.S. However, there are some exceptions. Prices and, in particular, 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 an absence of wage

¹⁴In 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.

stickiness in the U.K. Last, housing shocks are large and very persistent.

3.2.3 Japan

The results for Japan are shown in Table 3. Overall, the estimates for the structural parameters for Japan are close to those for the U.K., while the estimated monetary policy rules are similar to the values founded in the U.S.

Like in the U.S., the mean reaction to expected inflation is slightly higher in the unrestricted model as compared to the restricted one and the mean reaction to house price inflation is equal to 0.26. As concerns the other structural parameters, 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, housing shocks are more volatile in Japan.

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. 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. The main result that emerges from this table is that the Federal Reserve, the Bank of England and the Bank of Japan 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 $3e^{-5}$, $5e^{-4}$ and 0.015, respectively, indicating clear evidence in favor of the unrestricted 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 1 through Figure 3.

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 significantly larger when monetary policy reacts to house prices. In the U.S. and 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 a fall in

consumption for impatient households. In this case, a substitution effect¹⁵ between housing and consumption dominates, causing a negative response of consumption to house prices. Interestingly, 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.

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 is dominant and total spending increases. Interestingly, the difference between the propagation mechanisms after a technology shock in the restricted and unrestricted model is more evident in the U.S.; the difference is mainly quantitative, not qualitative.

3.5 Variance decomposition

To analyze the importance of the different shocks in the data, we perform a variance decomposition analysis. In Tables 5, 6 and 7, we report the variance decomposition 1, 4 and 20 quarters ahead for the U.S., the U.K. and Japan. For the three countries, we report the results for the model with $\Gamma_q > 0$ since this is preferred by the data.

Table 5 reports the variance decomposition analysis for the U.S. House price movements are mostly driven by house preference shocks at all horizons. Remarkably, technology and preference shocks explain about 29% and 17% of house price fluctuations in the long run, showing an important feedback from the rest of the economy to the housing sector. Monetary policy shocks explain 14% of the variation in house prices in the short run, but this effect fades out at longer horizons. In the short run, output and consumption variations are mainly explained by technology, monetary and preference shocks. Inflation is mainly driven by markup shocks at all horizons. House price shocks

¹⁵A housing preference shock changes the marginal rate of substitution between consumption and housing.

play an important role in explaining interest rates both in the short run (36%) and in the long run (19%).

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 in the U.K. Supply shocks explain most of the variations of output, consumption and inflation in the medium/long run while monetary shocks play a role mainly in the short term. Again, housing preference shocks are important in explaining movements in the interest rate.

Table 7 shows the results for Japan. The results resemble partially what we find in the U.S. However, an important difference is the relative larger importance of technology shocks in Japan. Technology shocks have a stronger effect on house prices than in the U.S. and the U.K.; they explain one-third of the variation in house prices in the long run. These shocks are even more important in capturing the fluctuations of output in the long run and explain up to 85% of GDP variation after 20 quarters.

3.6 Model fit

To assess the empirical performance of our estimated model we report some selected second order moments. Table 8 reports the empirical moments as well as the 95 probability interval of the simulated moments generated from the model.¹⁶ Overall the model is able to capture the volatility in the data. Most of the volatilities in the data lie within the 95% probability interval generated by the model. The model is also able to replicate some of the comovements between the series. For example, the median correlation between house price and consumption is positive for the three countries as in the data.

¹⁶The posterior moments were computed for a sample of 500 simulations for 100 periods from 1,000 draws of the posterior. To avoid autocorrelation, the draws from the posterior were picked at fixed intervals.

3.7 Robustness

In order to check the robustness of our results, we reestimate the model using an alternative interest rate rule where the monetary authority reacts to contemporaneous rather than expected inflation. Table 9 shows the log marginal data density for the alternative model for the three countries. Posterior odds tests clearly confirm our result that the Fed and Bank of Japan reacted to house price inflation. In the case of the U.K., the results show very slight evidence in favor of the unrestricted model. 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.

4 GMM estimation

In this section we estimate the monetary policy rule followed by the three countries using GMM and compare the results with our MCMC estimates. Moreover, we estimate the same rule using simulated data to study the properties of the GMM estimators. Using Monte Carlo simulations we show that GMM estimates of the Taylor rule produce biased and dispersed estimators. This result highlights the importance of using full information model cross-equation restrictions to properly identify the parameters of the monetary policy function.

4.1 Estimating the data using GMM

Table 10 shows the results of the GMM estimation for the three countries and the numbers in parenthesis indicate the 95% confidence interval of the estimators. To estimate the parameters we use a continuous updating GMM procedure where the long-run covariance matrix is the Newey-West covariance matrix with bandwidth 4. The Hansen J -test validates the moment conditions we use at a 5% level in all three countries.

In choosing the instruments, we restrict our attention to variables included in the model developed in Section 2. This is necessary to later implement our simulation exercise. In other words, we do not consider variables often used in the literature, such as spreads or commodity prices, since we cannot simulate data on these variables with our model. Our choice of instruments is reported in Table 10.

For the U.S., the point estimate of the response of inflation is higher than the posterior mean in our benchmark MCMC estimation but the standard errors are very large (1.0 – 4.5). For ρ and Γ_y , the GMM estimates are 0.90 and 0.36 and thus are outside the 95% posterior probabilities band we found in our full information estimation. The result for Γ_q is the most interesting. The GMM estimator for the response to house price inflation is negative but not significant at a 5% level.

In the case of the U.K., the estimate of Γ_p is again higher than the posterior mean of the benchmark estimation but now the standard errors are very large (0.8 – 3.4). The interest rate smoothing parameter is similar to our MCMC estimate but less precise and the point estimates of Γ_y and Γ_q are not significant at a 5% confidence level.

Last, in the case of Japan, the point estimate of Γ_p falls outside the 90% probability bands of our Bayesian estimation but the standard errors are large (1.1 – 2.6). For Γ_q , the GMM point estimate is larger than before and outside the 90% probability bands.

Summing up, the GMM estimators present large standard errors for all parameter estimates and the point estimates for Γ_q are not significant at a 5% confidence level in the case of the U.S. and the U.K.

Overall, the DSGE model-based posteriors are more concentrated than the GMM estimates. As Lubik and Schorfheide (2007) point out, the model generates restrictions on the volatility and comovements of the variables to be consistent with the data which restrict the dispersion of the parameters. This restricts the parameter space, and the posterior distributions in our benchmark

case are more concentrated.

4.2 Estimating the simulated model using GMM

To assess the small sample performance of GMM in estimating Taylor rules, we simulate the model described in Section 2 and estimate the monetary policy reaction function using GMM.

We simulate two models, the unrestricted model with $\Gamma_q > 0$ and the restricted model with $\Gamma_q = 0$. To simulate these models we use the estimated means of the parameters for the U.S. reported in Table 1.

We simulate the model 10,000 times for 200 periods and we eliminate the first 100 periods to reduce the effects of initial conditions. We remove the estimates that did not converge to a solution and those which reached extreme values.¹⁷ We use the same set of instruments as the one used for the U.S. in the previous subsection.

Table 11 summarizes the distribution of the estimators. The median, 5 and 95% percentiles of the point estimates are reported as well as the percentage number of point estimates that were statistically significant at a 10% confidence level.

The main observation is that Γ_q is biased towards zero and insignificant in most of the simulations even though the true parameter is 0.36. Secondly, the estimates of Γ_p are also downward biased and inefficient.¹⁸

When we simulate the model with $\Gamma_q = 0$, in general we obtain the same results as when $\Gamma_q > 0$. However, the median of the point estimates for Γ_q is positive even though the true value is zero. This shows again that GMM estimates have difficulty identifying the true value of Γ_q . Moreover, it is interesting to note that in both simulations there is a high probability of obtaining negative

¹⁷In the case of $\Gamma_q > 0$, 26% of the simulations were removed while in the case of $\Gamma_q = 0$, 23% were removed.

¹⁸These results are robust to using an iterative GMM approach and to restricting ρ to be inside the $[0, 1]$ interval and $\Gamma_p > 0$.

estimates of Γ_q .¹⁹

Summarizing, we have shown that single equations methods are unable to identify the response of the monetary policy to house prices even though the true parameter is positive. Moreover, lack of identification alters the properties of standard limit theory and produces unreliable estimates. This is in line with research in different contexts showing that GMM estimators may be biased and dispersed in small samples²⁰ and with Jondeau, Bihan, and Galles (2004), who find that GMM estimators and maximum likelihood estimators yield substantially different parameter estimates of Taylor rules.

In our Bayesian approach, the presence of housing preference shocks help us to identify Γ_q . This can be seen from the IRFs after a housing preference shock, where the nominal interest rate increases twice as much after an increase in house prices when the central bank reacts to house prices as compared to when it does not.

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. 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 estimates a full-fledged DSGE model where house price fluctuations affect firms' and households' balance sheets. We show that GMM methods produce biased and dispersed estimates of the policy reaction function. This result highlights the importance of using full information model cross-equation restrictions to properly identify the parameters of the monetary policy function.

¹⁹A negative coefficient on asset prices is observed, for instance, in Bernanke and Gertler (1999). They apply GMM methods to estimate Taylor-type rules for the Federal Reserve and the Bank of Japan. Their estimated response coefficient on asset prices 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.

²⁰See, for instance, Fuhrer, Moore, and Schuh (1995) and Lindé (2005).

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 play a separate role in the monetary policy of the U.S., U.K. and Japan. This result is robust to different specifications of the estimated monetary policy rule.

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.

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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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:

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

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

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

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

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

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 estate, 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.

When we estimate the Taylor rules using GMM, we also use data on real GDP.

B.1 U.S.

For the U.S., we use data between 1983:Q1-2008:Q4. Data on real personal consumption expenditures (B002RA3), real gross private domestic investment (B006RA3), GDP price deflator (B191RG3) and real GDP (B191RA3) was taken from the Bureau of Economic Analysis of the U.S. Department of Commerce. Data on total hours (PRS85006033) and real hourly compensation (PRS85006153) in the non-farm sector was obtained from the Bureau of Labor Statistics. For house prices, we use the Conventional Mortgage Home Price Index (CMHPI) purchase-transactions only made available by Freddie Mac. The nominal interest rate is the Federal Funds Rate.

B.2 U.K.

The data for the U.K. also covers the period 1983Q1-2008Q4. Data on household final consumption expenditure (ABJR), total gross fixed capital formation (NPQT), GDP at market prices deflator (YBGB), total actual weekly hours of work (YBUS), wages and salaries (ROYJHN) and GDP (YBEZ) was taken from National Statistics U.K. For house prices, we use the price index 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, GDP deflator and GDP 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	SD	5%	Mean	95%	5%	Mean	95%
ζ	beta	0.5	0.20	0.03	0.13	0.26	0.07	0.22	0.38
θ	beta	0.7	0.15	0.80	0.83	0.87	0.80	0.83	0.87
θ_w	beta	0.7	0.15	0.64	0.73	0.82	0.64	0.72	0.81
ψ	gamma	2.0	1.00	0.62	0.81	1.02	0.68	0.86	1.06
m	beta	0.8	0.05	0.57	0.64	0.71	0.57	0.65	0.72
m^{NP}	beta	0.8	0.05	0.77	0.83	0.88	0.73	0.81	0.87
α	beta	0.64	0.10	0.42	0.59	0.77	0.67	0.81	0.91
η	normal	2.0	0.75	1.07	2.01	3.13	1.33	2.30	3.39
ρ	beta	0.7	0.1	0.63	0.69	0.75	0.64	0.71	0.77
Γ_p	gamma	1.8	0.4	1.66	2.09	2.61	1.68	2.22	2.88
Γ_y	gamma	0.125	0.1	0.03	0.06	0.11	0.003	0.02	0.04
Γ_q	normal	0	0.5	-	-	-	0.22	0.36	0.53
ρ_a	beta	0.85	0.1	0.954	0.969	0.986	0.960	0.971	0.987
ρ_j	beta	0.85	0.1	0.938	0.962	0.982	0.900	0.928	0.954
ρ_z	beta	0.85	0.1	0.874	0.898	0.919	0.883	0.907	0.929
ρ_s	beta	0.85	0.1	0.863	0.945	0.982	0.918	0.952	0.982
σ_a	gamma	0.05	0.05	0.0050	0.0056	0.0063	0.0051	0.0057	0.0065
σ_u	gamma	0.05	0.05	0.0017	0.0021	0.0024	0.0017	0.0020	0.0023
σ_j	gamma	0.05	0.05	0.0551	0.0930	0.1380	0.1045	0.1508	0.2031
σ_m	gamma	0.05	0.05	0.0015	0.0017	0.0019	0.0015	0.0018	0.0022
σ_z	gamma	0.05	0.05	0.0100	0.0122	0.0148	0.0095	0.0113	0.0134
σ_s	gamma	0.05	0.05	0.0234	0.0284	0.0339	0.0249	0.0296	0.0350
σ_λ	gamma	0.05	0.05	0.0039	0.0045	0.0052	0.0039	0.0045	0.0052

Table 2: U.K. Data

	Dist.	Prior		Posterior $\Gamma_q = 0$			Posterior $\Gamma_q > 0$		
		Mean	SD	5%	Mean	95%	5%	Mean	95%
ζ	beta	0.5	0.20	0.009	0.05	0.12	0.01	0.05	0.13
θ	beta	0.7	0.15	0.75	0.79	0.83	0.70	0.75	0.80
θ_w	beta	0.7	0.15	0.39	0.48	0.58	0.37	0.45	0.56
ψ	gamma	2.0	1.00	1.26	1.63	2.03	1.30	1.66	2.08
m	beta	0.8	0.05	0.45	0.52	0.59	0.48	0.55	0.62
m^{NP}	beta	0.8	0.05	0.64	0.72	0.79	0.67	0.74	0.81
α	beta	0.64	0.10	0.48	0.64	0.80	0.53	0.70	0.84
η	normal	2.0	0.75	1.46	2.05	2.80	1.63	2.22	2.99
ρ	beta	0.7	0.1	0.65	0.71	0.76	0.67	0.73	0.79
Γ_p	gamma	1.8	0.4	1.43	1.67	1.97	1.54	1.84	2.28
Γ_y	gamma	0.125	0.1	0.002	0.02	0.04	0.002	0.01	0.03
Γ_q	normal	0	0.5	-	-	-	0.10	0.16	0.24
ρ_a	beta	0.85	0.1	0.939	0.964	0.985	0.930	0.958	0.981
ρ_j	beta	0.85	0.1	0.9814	0.9912	0.998	0.974	0.988	0.996
ρ_z	beta	0.85	0.1	0.869	0.904	0.934	0.859	0.896	0.925
ρ_s	beta	0.85	0.1	0.923	0.962	0.993	0.928	0.972	0.995
σ_a	gamma	0.05	0.05	0.0076	0.0085	0.0096	0.0077	0.0086	0.0098
σ_u	gamma	0.05	0.05	0.0049	0.0055	0.0063	0.0051	0.0058	0.0068
σ_j	gamma	0.05	0.05	0.0473	0.0760	0.1163	0.0578	0.0947	0.1500
σ_m	gamma	0.05	0.05	0.0022	0.0025	0.0030	0.0020	0.0024	0.0028
σ_z	gamma	0.05	0.05	0.0118	0.0148	0.0184	0.0131	0.0160	0.0199
σ_s	gamma	0.05	0.05	0.0277	0.0337	0.0406	0.0285	0.0343	0.0413
σ_λ	gamma	0.05	0.05	0.0048	0.0056	0.0065	0.0049	0.0057	0.0066

Table 3: Japanese Data

	Dist.	Prior		Posterior $\Gamma_q = 0$			Posterior $\Gamma_q > 0$		
		Mean	SD	5%	Mean	95%	5%	Mean	95%
ζ	beta	0.5	0.20	0.01	0.03	0.06	0.01	0.02	0.06
θ	beta	0.7	0.15	0.66	0.70	0.75	0.67	0.72	0.76
θ_w	beta	0.7	0.15	0.23	0.32	0.42	0.27	0.37	0.48
Ψ	gamma	2.0	1.00	2.72	3.16	3.63	2.61	3.07	3.56
m	beta	0.8	0.05	0.58	0.63	0.69	0.58	0.64	0.70
m^{NP}	beta	0.8	0.05	0.69	0.74	0.79	0.67	0.73	0.78
α	beta	0.64	0.10	0.47	0.64	0.79	0.55	0.71	0.83
η	normal	2.0	0.75	2.08	2.96	3.92	1.93	2.77	3.75
ρ	beta	0.7	0.1	0.74	0.79	0.83	0.75	0.80	0.84
Γ_p	gamma	1.8	0.4	1.84	2.28	2.80	1.95	2.40	3.00
Γ_y	gamma	0.125	0.1	0.003	0.02	0.05	0.003	0.02	0.06
Γ_q	normal	0	0.5	-	-	-	0.13	0.26	0.41
ρ_a	beta	0.85	0.1	0.932	0.957	0.980	0.932	0.959	0.984
ρ_j	beta	0.85	0.1	0.935	0.959	0.979	0.925	0.950	0.972
ρ_z	beta	0.85	0.1	0.813	0.843	0.870	0.810	0.840	0.871
ρ_s	beta	0.85	0.1	0.907	0.935	0.962	0.906	0.936	0.966
σ_a	gamma	0.05	0.05	0.0109	0.0124	0.0140	0.0109	0.0122	0.0139
σ_u	gamma	0.05	0.05	0.0051	0.0059	0.0068	0.0049	0.0057	0.0067
σ_j	gamma	0.05	0.05	0.0979	0.1617	0.2374	0.1221	0.1879	0.2668
σ_m	gamma	0.05	0.05	0.0022	0.0026	0.0031	0.0022	0.0026	0.0032
σ_z	gamma	0.05	0.05	0.0108	0.0131	0.0158	0.0115	0.0136	0.0164
σ_s	gamma	0.05	0.05	0.0437	0.0514	0.0598	0.0420	0.0497	0.0585
σ_λ	gamma	0.05	0.05	0.0097	0.0114	0.0135	0.0093	0.0109	0.013

Table 4: Posterior Odds

Country	Log marginal data density		Posterior odds
	$\Gamma_q = 0$	$\Gamma_q > 0$	
U.S.	2505.7	2516.2	$3e^{-5}$
U.K.	2244.7	2252.2	$5e^{-4}$
Japan	2197.3	2201.5	0.015

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

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

	ϵ_a	ϵ_u	ϵ_j	ϵ_m	ϵ_z	ϵ_s	ϵ_w
	1 period ahead						
Real House Price	0.16	0.07	0.49	0.14	0.08	0	0.04
	[0.11,0.22]	[0.04,0.11]	[0.385,0.58]	[0.08,0.26]	[0.03,0.15]	[0,0.01]	[0.02,0.07]
Output	0.20	0.15	0.04	0.32	0.21	0.01	0.05
	[0.1,0.31]	[0.09,0.23]	[0,0.11]	[0.23,0.44]	[0.12,0.33]	[0,0.03]	[0.02,0.08]
Inflation	0.01	0.95	0	0.01	0.01	0	0.01
	[0.01,0.02]	[0.93,0.97]	[0,0]	[0,0.02]	[0.01,0.02]	[0,0]	[0.01,0.02]
Nominal Interest Rate	0.02	0.23	0.36	0.37	0	0.01	0
	[0,0.05]	[0.13,0.35]	[0.21,0.515]	[0.27,0.49]	[0,0.02]	[0.01,0.02]	[0,0.01]
Agg. Consumption	0.20	0.12	0	0.27	0.33	0	0.05
	[0.11,0.3]	[0.07,0.19]	[0,0.03]	[0.2,0.38]	[0.24,0.45]	[0,0.02]	[0.02,0.08]
	4 periods ahead						
Real House Price	0.21	0.09	0.43	0.05	0.13	0.01	0.06
	[0.16,0.28]	[0.06,0.14]	[0.34,0.52]	[0.03,0.1]	[0.07,0.21]	[0,0.01]	[0.03,0.1]
Output	0.35	0.25	0.03	0.15	0.1	0.01	0.09
	[0.23,0.45]	[0.18,0.34]	[0,0.07]	[0.1,0.235]	[0.05,0.17]	[0.01,0.03]	[0.05,0.14]
Inflation	0.05	0.80	0	0.03	0.06	0	0.05
	[0.03,0.09]	[0.72,0.86]	[0,0.01]	[0.02,0.06]	[0.03,0.09]	[0,0.01]	[0.03,0.07]
Nominal Interest Rate	0.03	0.40	0.26	0.17	0.06	0.02	0.05
	[0.02,0.04]	[0.29,0.5]	[0.15,0.4]	[0.12,0.24]	[0.03,0.145]	[0.01,0.03]	[0.02,0.08]
Agg. Consumption	0.35	0.22	0	0.13	0.18	0.01	0.09
	[0.24,0.46]	[0.16,0.3]	[0,0.02]	[0.08,0.2]	[0.12,0.26]	[0,0.03]	[0.05,0.14]
	20 periods ahead						
Real House Price	0.29	0.04	0.37	0.02	0.17	0.06	0.04
	[0.2,0.39]	[0.02,0.06]	[0.26,0.52]	[0.01,0.03]	[0.1,0.25]	[0.03,0.1]	[0.02,0.08]
Output	0.55	0.13	0.02	0.06	0.04	0.11	0.08
	[0.45,0.64]	[0.09,0.19]	[0,0.03]	[0.04,0.09]	[0.03,0.07]	[0.07,0.16]	[0.04,0.14]
Inflation	0.07	0.71	0.02	0.04	0.10	0	0.05
	[0.04,0.15]	[0.605,0.78]	[0.01,0.04]	[0.02,0.07]	[0.06,0.14]	[0,0.01]	[0.03,0.09]
Nominal Interest Rate	0.09	0.25	0.19	0.09	0.26	0.02	0.08
	[0.04,0.18]	[0.18,0.32]	[0.12,0.28]	[0.07,0.12]	[0.17,0.36]	[0.01,0.06]	[0.05,0.13]
Agg. Consumption	0.57	0.11	0	0.05	0.07	0.10	0.08
	[0.47,0.66]	[0.07,0.16]	[0,0.01]	[0.03,0.08]	[0.05,0.1]	[0.07,0.17]	[0.04,0.14]

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

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

	ϵ_a	ϵ_u	ϵ_j	ϵ_m	ϵ_z	ϵ_s	ϵ_w
	1 period ahead						
Real House Price	0.07	0.01	0.80	0.04	0.07	0	0
	[0.05,0.1]	[0.01,0.03]	[0.73,0.85]	[0.03,0.06]	[0.03,0.12]	[0,0.01]	[0,0.01]
Output	0.37	0.10	0.04	0.29	0.16	0	0.01
	[0.27,0.465]	[0.04,0.19]	[0.01,0.1]	[0.23,0.365]	[0.095,0.26]	[0,0.01]	[0,0.02]
Inflation	0.01	0.96	0	0.01	0.01	0	0.01
	[0.01,0.02]	[0.92,0.98]	[0,0]	[0.01,0.02]	[0,0.02]	[0,0]	[0,0.01]
Nominal Interest Rate	0	0.46	0.17	0.31	0.01	0	0.01
	[0,0.02]	[0.38,0.55]	[0.09,0.28]	[0.23,0.41]	[0,0.04]	[0,0.01]	[0.01,0.03]
Agg. Consumption	0.34	0.08	0	0.27	0.24	0.04	0.01
	[0.25,0.43]	[0.03,0.16]	[0,0.03]	[0.205,0.33]	[0.16,0.36]	[0.01,0.07]	[0,0.02]
	4 periods ahead						
Real House Price	0.09	0.02	0.78	0.01	0.09	0	0
	[0.06,0.12]	[0.01,0.04]	[0.7,0.83]	[0.01,0.02]	[0.05,0.14]	[0,0.01]	[0,0.01]
Output	0.53	0.21	0.04	0.12	0.07	0	0.02
	[0.4,0.63]	[0.12,0.33]	[0.02,0.08]	[0.09,0.16]	[0.04,0.11]	[0,0.01]	[0.01,0.03]
Inflation	0.04	0.83	0	0.04	0.06	0	0.02
	[0.02,0.07]	[0.75,0.9]	[0,0.01]	[0.02,0.07]	[0.03,0.1]	[0,0]	[0.01,0.03]
Nominal Interest Rate	0.06	0.48	0.14	0.11	0.15	0.01	0.04
	[0.03,0.12]	[0.33,0.61]	[0.08,0.21]	[0.08,0.16]	[0.07,0.27]	[0,0.02]	[0.03,0.06]
Agg. Consumption	0.50	0.19	0	0.11	0.12	0.04	0.02
	[0.39,0.6]	[0.11,0.31]	[0,0.02]	[0.08,0.15]	[0.08,0.17]	[0.02,0.08]	[0.01,0.03]
	20 periods ahead						
Real House Price	0.07	0.01	0.85	0	0.05	0.01	0
	[0.04,0.12]	[0,0.01]	[0.77,0.9]	[0,0.01]	[0.03,0.11]	[0.01,0.02]	[0,0]
Output	0.69	0.10	0.03	0.05	0.03	0.08	0.01
	[0.56,0.79]	[0.05,0.18]	[0.02,0.06]	[0.03,0.08]	[0.02,0.05]	[0.05,0.13]	[0.01,0.02]
Inflation	0.05	0.79	0.01	0.05	0.08	0	0.02
	[0.02,0.08]	[0.71,0.85]	[0,0.02]	[0.03,0.08]	[0.05,0.13]	[0,0.01]	[0.01,0.03]
Nominal Interest Rate	0.11	0.29	0.14	0.08	0.32	0.02	0.03
	[0.05,0.18]	[0.19,0.4]	[0.09,0.21]	[0.05,0.1]	[0.22,0.42]	[0,0.06]	[0.02,0.05]
Agg. Consumption	0.65	0.08	0	0.05	0.05	0.15	0.01
	[0.51,0.76]	[0.05,0.16]	[0,0.01]	[0.03,0.07]	[0.03,0.08]	[0.07,0.26]	[0.01,0.02]

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

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

	ϵ_a	ϵ_u	ϵ_j	ϵ_m	ϵ_z	ϵ_s	ϵ_w
	1 period ahead						
Real House Price	0.21	0.01	0.61	0.07	0.06	0.02	0.01
	[0.16,0.27]	[0.01,0.02]	[0.54,0.68]	[0.05,0.11]	[0.03,0.1]	[0.01,0.03]	[0.01,0.02]
Output	0.55	0.03	0.02	0.25	0.12	0	0.02
	[0.42,0.66]	[0.02,0.06]	[0,0.05]	[0.18,0.325]	[0.07,0.19]	[0,0.01]	[0.01,0.03]
Inflation	0.03	0.88	0	0.03	0.02	0	0.04
	[0.02,0.05]	[0.82,0.92]	[0,0]	[0.02,0.05]	[0.01,0.03]	[0,0]	[0.02,0.06]
Nominal Interest Rate	0.01	0.36	0.15	0.38	0.02	0	0.06
	[0,0.04]	[0.29,0.425]	[0.07,0.26]	[0.29,0.48]	[0.01,0.06]	[0,0.01]	[0.03,0.1]
Agg. Consumption	0.49	0.03	0	0.22	0.15	0.08	0.02
	[0.37,0.6]	[0.01,0.05]	[0,0.015]	[0.16,0.29]	[0.09,0.23]	[0.05,0.13]	[0.01,0.03]
	4 periods ahead						
Real House Price	0.27	0.02	0.55	0.02	0.08	0.02	0.02
	[0.21,0.35]	[0.01,0.04]	[0.47,0.63]	[0.01,0.04]	[0.05,0.13]	[0.01,0.03]	[0.01,0.03]
Output	0.73	0.07	0.02	0.1	0.04	0	0.03
	[0.62,0.81]	[0.04,0.12]	[0.01,0.04]	[0.07,0.14]	[0.02,0.07]	[0,0]	[0.02,0.06]
Inflation	0.09	0.68	0	0.09	0.06	0	0.07
	[0.05,0.14]	[0.595,0.76]	[0,0.01]	[0.06,0.13]	[0.04,0.09]	[0,0]	[0.05,0.1]
Nominal Interest Rate	0.13	0.31	0.11	0.13	0.16	0	0.14
	[0.06,0.21]	[0.22,0.41]	[0.06,0.18]	[0.09,0.18]	[0.1,0.26]	[0,0.01]	[0.1,0.2]
Agg. Consumption	0.66	0.06	0	0.09	0.05	0.09	0.03
	[0.56,0.75]	[0.03,0.11]	[0,0.01]	[0.06,0.12]	[0.03,0.09]	[0.06,0.14]	[0.02,0.06]
	20 periods ahead						
Real House Price	0.32	0.01	0.55	0.01	0.06	0.04	0.01
	[0.2,0.47]	[0,0.02]	[0.39,0.69]	[0.01,0.01]	[0.03,0.1]	[0.03,0.06]	[0.01,0.02]
Output	0.85	0.03	0.01	0.04	0.02	0.04	0.02
	[0.76,0.9]	[0.01,0.06]	[0.01,0.02]	[0.02,0.06]	[0.01,0.03]	[0.02,0.06]	[0.01,0.03]
Inflation	0.10	0.66	0	0.10	0.06	0	0.07
	[0.06,0.16]	[0.57,0.74]	[0,0.01]	[0.07,0.14]	[0.04,0.09]	[0,0]	[0.05,0.1]
Nominal Interest Rate	0.22	0.20	0.12	0.10	0.23	0	0.11
	[0.115,0.33]	[0.14,0.28]	[0.07,0.18]	[0.07,0.13]	[0.16,0.33]	[0,0.01]	[0.07,0.15]
Agg. Consumption	0.75	0.02	0	0.03	0.02	0.15	0.02
	[0.64,0.84]	[0.01,0.05]	[0,0.01]	[0.02,0.05]	[0.01,0.04]	[0.08,0.24]	[0.01,0.03]

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

Table 8: Selected Moments

	US ($\Gamma_q > 0$)			UK ($\Gamma_q > 0$)			Japan ($\Gamma_q > 0$)		
	Data	2.5%	97.5%	Data	2.5%	97.5%	Data	2.5%	97.5%
	Standard Deviation (%)								
Consumption	1.93	1.60	4.90	3.21	1.84	5.87	2.97	2.33	6.94
Hours	3.50	2.28	4.65	2.45	1.99	3.70	1.22	1.85	3.44
Inflation	0.24	0.31	0.55	0.62	0.77	1.23	0.92	0.75	1.18
Interest rate	0.54	0.26	0.57	0.54	0.45	0.92	0.65	0.40	0.77
House prices	6.92	2.40	7.33	20.31	5.11	19.71	8.92	3.94	11.55
Investment	10.25	6.17	18.59	6.84	5.02	19.95	12.24	4.11	13.14
Real wages	2.42	1.35	5.23	3.15	1.97	6.70	6.91	2.48	7.35
	Correlations								
C,q	0.49	-0.01	0.91	0.64	-0.52	0.86	0.33	-0.06	0.90
C,I	0.58	-0.11	0.85	0.84	-0.08	0.91	0.05	0.03	0.91
C,w	0.55	0.09	0.93	0.86	0.61	0.96	0.75	0.49	0.94
R,q	0.17	-0.73	0.27	0.38	-0.58	0.50	0.34	-0.68	0.28
q,I	-0.01	-0.08	0.88	0.60	-0.47	0.91	0.71	-0.14	0.90
q,w	0.72	-0.26	0.88	0.51	-0.56	0.85	-0.14	-0.19	0.86
π ,R	0.18	0.27	0.77	0.28	0.45	0.78	0.27	0.36	0.71

Note: For the model, the posterior 95 probability interval is reported for a total of 10,000 series.

Table 9: Robustness

Country	Log marginal data density		Posterior odds
	$\Gamma_q = 0$	$\Gamma_q > 0$	
U.S.	2478.2	2496.0	$2e^{-8}$
U.K.	2236.4	2237.3	0.40
Japan	2172.2	2180.4	$3e^{-4}$

Note: The table reports posterior odds of the hypothesis $\Gamma_q = 0$ versus $\Gamma_q > 0$ in a model where the monetary authority reacts to actual inflation.

Table 10: GMM estimation

Country	ρ	Γ_p	Γ_y	Γ_q
US	0.90* (.86,.95)	2.78* (1.0,4.5)	0.36* (.20,.52)	-0.20** (-.45,.06)
UK	0.67* (.48,.86)	2.11* (.84,3.4)	-0.22** (-.44,.01)	0.26** (-.03,.54)
Japan	0.55* (.29,.81)	1.84* (1.1,2.6)	-0.02 (-.12,.09)	0.51* (.19,.82)

Note: *Significant at a 5% level. **Significant at a 10% level. 95% confidence intervals in brackets.

For the U.S., we use as instruments two lags of real wages and nominal interest rates, four lags of output and lags 1-4, 6, 8 of inflation and house prices. For the U.K., we use the same instruments as for the U.S. except for using lags 1-2, 4, 6 for output and 1-4, 6 for house prices. Moreover, instead of using data on real wages we use two lags of hours worked. For Japan we use the same instruments as for the U.S. but we remove lags 6 and 8 for inflation and house prices and we do not use data on real wages.

Table 11: Simulated GMM estimation

Country	ρ	Γ_p	Γ_y	Γ_q
$\Gamma_q > 0$				
true value	0.71	2.22	0.02	0.36
simulated median	0.72	1.77	0.02	0.12
5-95% simulated interval	[-.15, .93]	[-.35, 7.6]	[-.13, .44]	[-.61, .91]
% of significant point estimates	91	80	44	52
$\Gamma_q = 0$				
true value	0.69	2.09	0.06	0
simulated median	0.72	1.90	0.07	0.07
5-95% simulated interval	[-.21, .93]	[.12, 7.0]	[-.10, .61]	[-.63, .86]
% of significant point estimates	90	85	47	48

Note: We use the same instruments as the ones reported for the U.S. in Table 10.

DO CENTRAL BANKS REACT TO HOUSE PRICES?

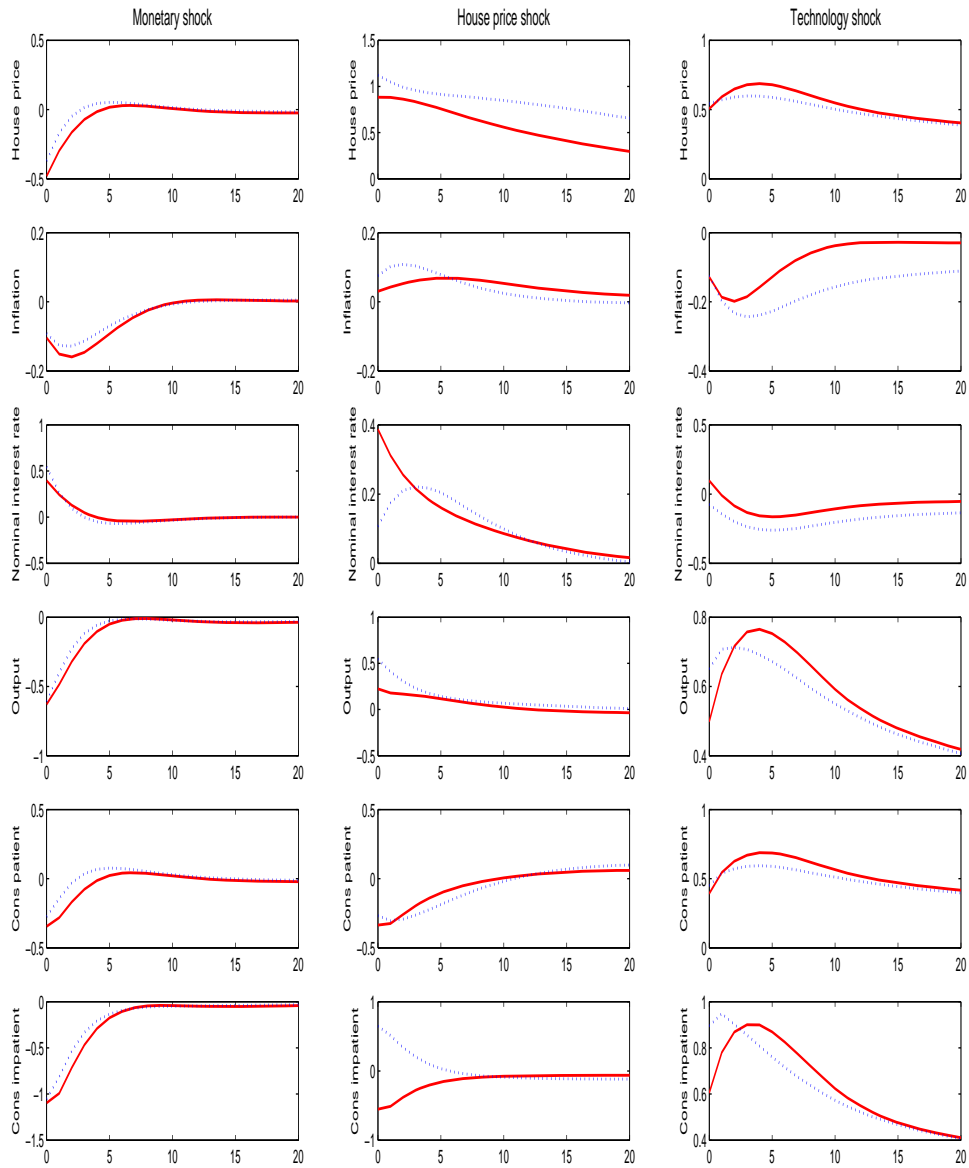


Figure 1: Posterior medians for impulse response functions in the U.S. Dotted line: Taylor rule with $\Gamma_q = 0$. Solid line: Taylor rule with $\Gamma_q > 0$. Responses are presented in percentage points. The shocks are set to one standard deviation.

DO CENTRAL BANKS REACT TO HOUSE PRICES?

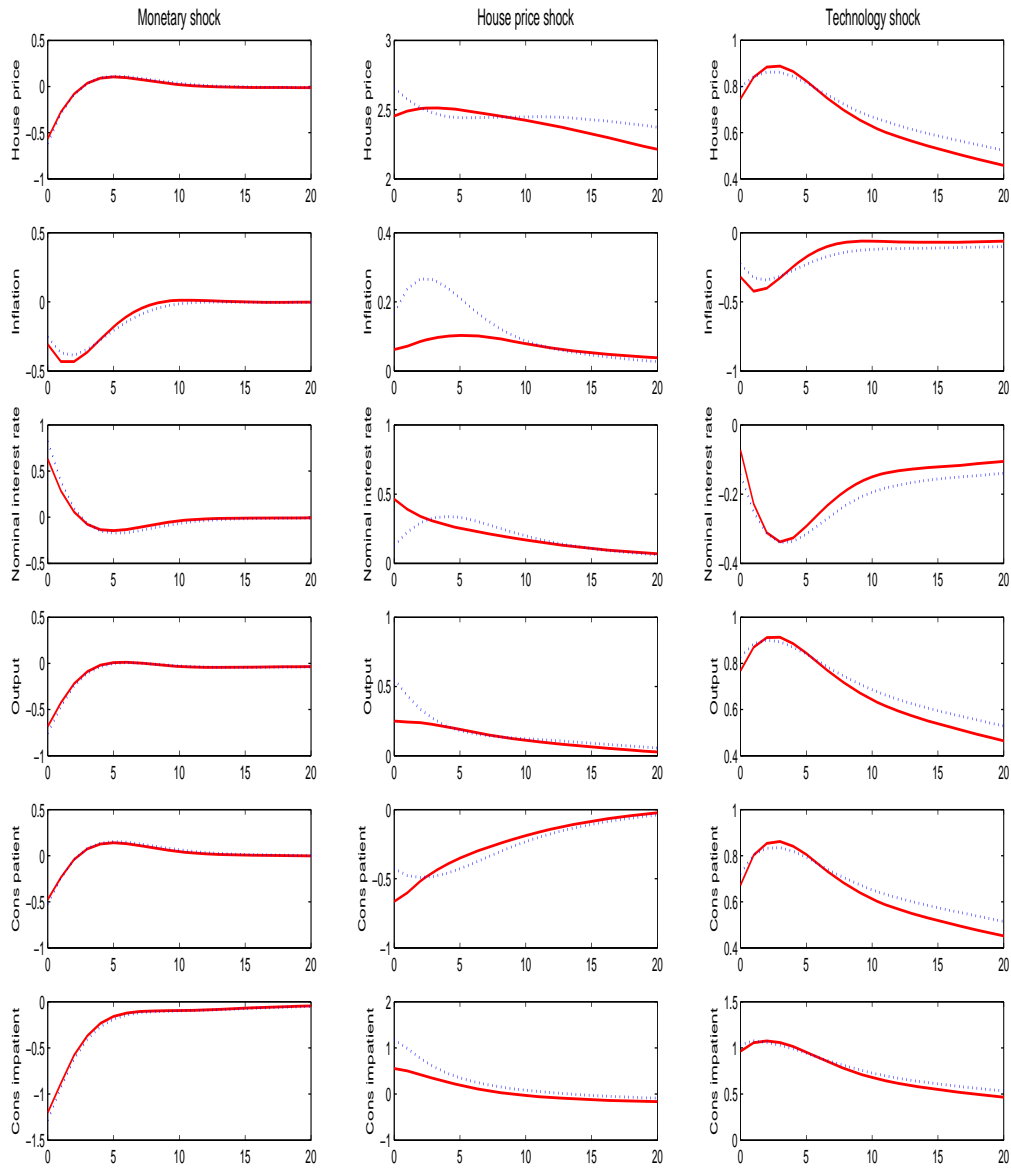


Figure 2: Posterior medians for impulse response functions in the U.K. Dotted line: Taylor rule with $\Gamma_q = 0$. Solid line: Taylor rule with $\Gamma_q > 0$. Responses are presented in percentage points. The shocks are set to one standard deviation.

DO CENTRAL BANKS REACT TO HOUSE PRICES?

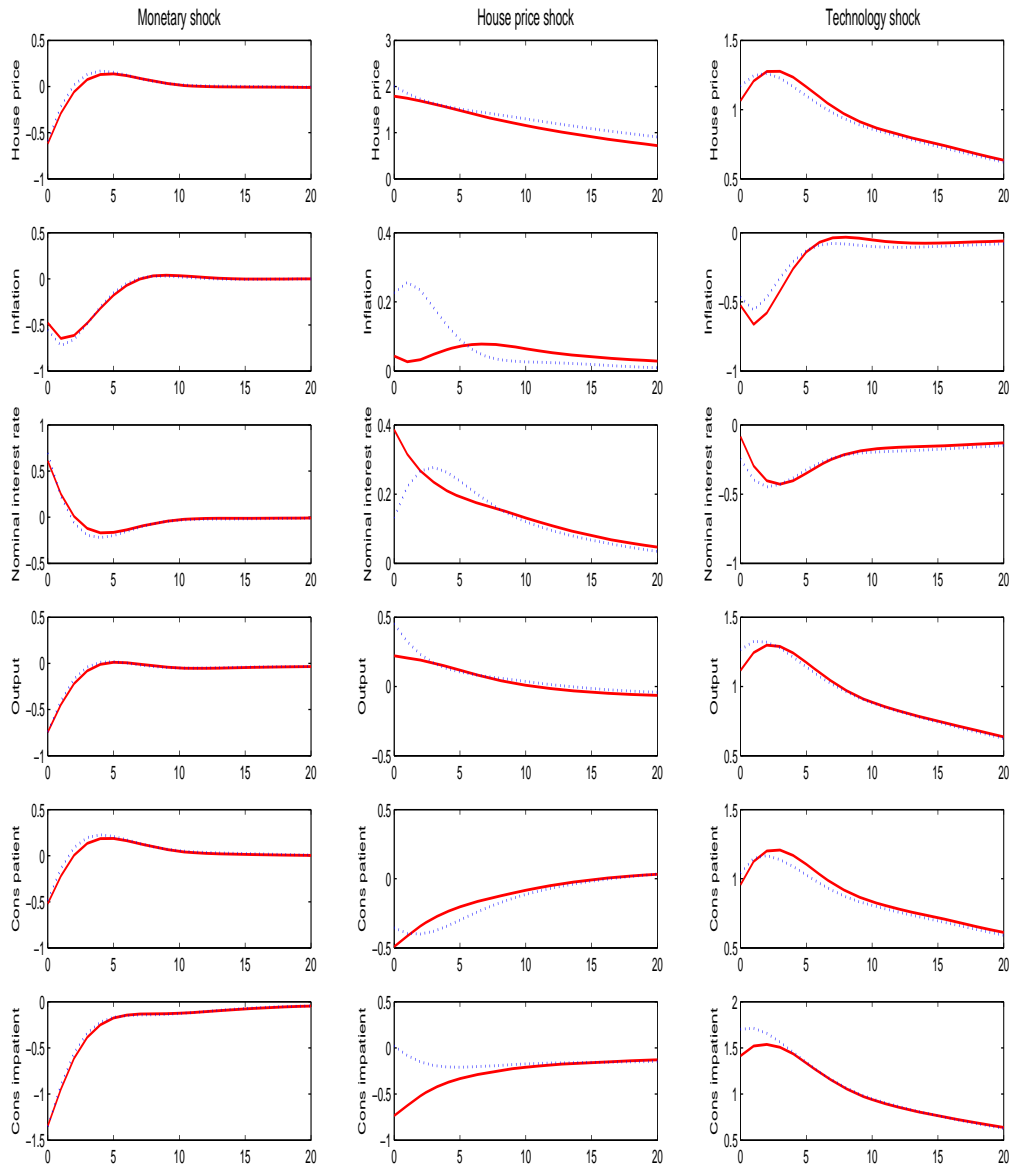


Figure 3: Posterior medians for impulse response functions in Japan Dotted line: Taylor rule with $\Gamma_q = 0$. Solid line: Taylor rule with $\Gamma_q > 0$. Responses are presented in percentage points. The shocks are set to one standard deviation.