Essays on Monetary Policy and Asset Markets

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Abstract

This thesis consists of three essays on monetary policy and asset markets.

Monetary Policy Regimes and the Volatility of Long-Term Interest Rates

This paper addresses two important questions that have, so far, been studied separately in the literature. On the one hand, the paper aims at explaining the high volatility of long-term interest rates observed in the data, which is hard to replicate using standard macro models. Building a small-scale macroeconomic model and estimating it on U.S. (and U.K.) data, I show empirically that the policy responses of a central bank that is uncertain about the natural rate of unemployment can explain this volatility puzzle. On the other hand, the paper aims at shedding new light on the distinction between rules and discretion in monetary policy. My empirical results show that using yield curve data may facilitate the empirical discrimination between different monetary policy regimes.

Do Central Banks React to House Prices?

Recently, house prices have undergone major fluctuations in many industrialized economies, which has drawn the attention of policymakers and academics towards the developments in housing markets and their 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 price inflation. We study the responses of these central banks by estimating a structural model for each country where credit constrained agents borrow using real estate as collateral. The main result is that house price movements did play a separate role in the U.K. and Japanese central bank reaction functions in the last years, while they did not in the U.S.

How Important are Financial Frictions in the U.S. and the Euro Area?

This paper aims to evaluate if frictions in credit markets are important for business cycles in the U.S. and the Euro area. For this purpose, I modify the DSGE financial accelerator model developed by Bernanke, Gertler and Gilchrist (1999) by adding frictions such as price indexation to past inflation, sticky wages, consumption habits and variable capital utilization. When I estimate the model with Bayesian methods, I find that financial frictions are relevant in both areas. According to a

test based on posterior odds ratios, the data clearly favors the model with financial frictions both in the U.S. and the Euro area. Moreover, consistent with common perceptions, financial frictions are larger in the Euro area.

To my Parents

Acknowledgments

Doing a Ph.D. has been a constant sequence of ups and downs. And as this is a thesis about business cycles, one could say booms and busts. For those of you who are researchers, you know what I mean. For those of you who are not researchers but are my friends, I am sure you will recognize my booms and busts in the last years. I would like to thank all the people who accompanied me during all these fluctuations.

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Non Technical Summary

This thesis consists of three essays on monetary policy and asset markets. Current debates about monetary policy among policymakers and academics deal with questions such as transparency and credibility of the central bank, whether the central bank should respond to movements in the prices of assets such as shares or private houses, and the benefits of having an inflation target. The purpose of the essays in this thesis is to answer questions like these and to analyze the implications of alternative designs of policy.

Chapter 2 (Monetary Policy Regimes and the Volatility of Long-Term Interest Rates) considers data from the U.S. and the U.K. during the last forty years. I study the case of a central bank that cannot observe the *natural rate*, i.e., the underlying rate of unemployment that generates stable inflation. I show that when the central bank underestimates the natural rate, it sets a higher inflation than its own target to reduce unemployment. Since errors about the natural rate are very persistent, I show how this raises expectations of future inflation and future interest rates, and how it can explain a lot of the observed volatility in long-term interest rates. Moreover, movements in long-term rates are larger when the central bank cannot commit itself to follow a certain monetary policy in the future. In this case, the central bank loses control over inflation expectations, and inflation and interest rate volatility are higher than when the central bank can commit.

Chapter 3 (Do Central Banks React to House Prices?), is a joint essay with Daria Finocchiaro, which studies the conduct of monetary policy by three major central banks over the last few decades. We use economic theory as well as statistical methods to show that the Bank of Japan and the Bank of England have reacted to house price inflation increasing interest rates, while the U.S. Fed has not.

In *Chapter 4* (How Important are Financial Frictions in the U.S. and the Euro Area?), I show empirically that there are inefficiencies or frictions in U.S. and European credit markets. This reduces the supply of credit in the economy and amplifies business cycles. For instance, after a positive shock to the economy, entrepreneurs strengthen their financial position and their costs of obtaining funds decrease. This further stimulates investment, thereby amplifying the effects of the initial shock. Consistent with common perceptions, I also show that these financial frictions are larger in the Euro area.

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Chapter 1

Introduction

This thesis consists of three essays on monetary policy and asset markets. I study and develop models where money is not neutral: actions taken by a central bank can thus have a systematic impact on the economy. Current debates about monetary policy among policymakers and academics deal with questions such as transparency and credibility, whether the central bank should respond to movements in asset prices, and the benefits of having an inflation target. The purpose of the essays in this thesis is to answer some of these questions and to analyze the implications of alternative courses of action.

One common denominator is that all the three essays use Bayesian methods to asses the empirical relevance of the questions at issue. The advantage of Bayesian estimation relative to maximum likelihood (which is the posterior mode under a uniform prior density) is that the solution of any specific model implies many restrictions and boundary values for its parameters which are difficult to impose in maximum likelihood estimation. Besides, using Bayesian methods also enables the analyst to formally incorporate her beliefs about the parameters and to use the posterior output to compute any posterior function of the parameters: impulse responses, moments, etc. In the appendix to this chapter I describe the basics of Bayesian estimation methods.

In sum, this thesis aims at quantitatively addressing research questions of policy relevance. I now summarize the contents and results of each chapter in the order they appear in the thesis.

Chapter 2 (Monetary Policy Regimes and the Volatility of Long-Term Interest Rates) addresses two important questions that have, so far, been studied separately in the literature. On the one hand, the essay aims at explaining the high volatility

of long-term interest rates observed in the data, a phenomenon which is hard to replicate in standard macro models. I show that the policy responses of a central bank that is uncertain about the natural rate of unemployment can explain this volatility puzzle. On the other hand, the essay aims at shedding new light on the distinction between rules and discretion in monetary policy. My results show that yield curve data may facilitate the empirical discrimination between different monetary policy regimes.

The model in this essay is a forward-looking model where the private sector has full information, but the central bank cannot observe the shocks affecting the economy, in particular shocks to the natural rate of unemployment. This has important implications for inflation, implications which are amplified in the case of discretionary monetary policy. When a policymaker cannot commit, he loses control over inflation expectations, and inflation and interest rate volatility are higher than when he can commit. The intuition is that when the monetary authority underestimates the natural rate of unemployment, it sets a higher inflation than its own target in order to reduce the perceived unemployment gap. Since misperceptions about the natural rate of unemployment are persistent, this raises expectations of future inflation and future short-term interest rates. Once we view long-term interest rates through the lens of the expectation hypothesis, a discretionary regime can explain the volatility puzzle.

To investigate the quantitative implications of the model, I estimate it on U.S. data from 1960 to 2005 using Bayesian methods. I find that to explain the volatility of long-term interest rates observed in the U.S., we need a lack of commitment from the monetary authority. Thus, the results indicate that U.S. monetary policy in the last 45 years is best understood as originating from a discretionary regime.

Moreover, to analyze the role of institutions in monetary policy, the essay estimates the same model for two periods in the U.K., namely 1983-1997 and 1998-2005. In the latter period, the Bank of England became operationally independent. This exercise thus addresses the importance of central bank independence in the design of monetary policy. The U.K. evidence is different than the U.S. evidence. If anything, the post-independence monetary policy of the Bank of England has been closer to rules than discretion.

Chapter 3 (Do Central Banks React to House Prices?), a joint essay with Daria Finocchiaro, asks whether house prices entered directly in the monetary policy rule of the U.S. Fed, the Bank of Japan and the Bank of England. 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 developments in housing markets and their impact on economic activity and on financial stability. Since borrowing for housing constitutes the largest part of households' debt in most countries, the higher debts have made the overall macroeconomic situation more exposed to house price fluctuations.

The main contributions of the paper are two. 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 contribute to the scarce empirical literature on estimated dynamic stochastic general equilibrium (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. 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.

To deal with the endogeneity problem that would arise if we were to estimate Taylor rules with asset prices in a single-equation approach, 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.[1] The results show 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.

Chapter 4 (How Important are Financial Frictions in the U.S. and the Euro Area?) poses two basic questions. First, I want to determine if frictions in credit markets are quantitatively important for business cycles, even if realistic frictions in goods and labor markets are added to a model with frictions in financial markets. In the banking crisis experienced by many countries in the 1990s, financial market conditions appeared to have a direct effect on economic fluctuations. In this paper, however, I do not consider financial frictions as a source of shocks, but as a mechanism for the propagation of other shocks. The second question I investigate

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[1] 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.

is whether financial frictions have a similar magnitude in the U.S. as in the Euro area. Independent observations certainly suggest that financial markets are more developed and integrated in the U.S., and, consequently, more efficient.

The specification of the model follows Bernanke, Gertler, and Gilchrist (1999) (BGG) who incorporate financial market frictions in a general equilibrium model through a financial accelerator mechanism. The financial accelerator is a mechanism based on information asymmetries between lenders and entrepreneurs that creates inefficiencies in financial markets, which affect the supply of credit and amplify business cycles. Specifically, during booms (recessions), an increase (fall) in borrowers' net worth decreases (increases) their cost of obtaining external funds, which further stimulates (destimulates) investment, thereby amplifying the effects of the initial shock. Following recent work on DSGE models, I modify the BGG model to improve its empirical performance, by adding price indexation to past inflation, sticky wages, consumption habits and variable capital utilization.

In summary, this essay contributes to the existing literature in three respects. It empirically investigates the importance of frictions in credit markets for business cycles both in the U.S. and the Euro area. It uses Bayesian methods to estimates a DSGE model with a financial accelerator. And it can identify the structural parameters of the financial contract.

The results indicate that financial frictions are relevant: using posterior odds ratios as the evaluation criterion, I find that the data favors a model with financial frictions both in the U.S. and the Euro area. Moreover, consistent with common perceptions, financial frictions are larger in the Euro area.

Appendix

1.A   Bayesian Methods and Model Evaluation

In this thesis, I structurally estimate different DSGE models using Bayesian procedures. In each essay, I start by solving the model for an initial set of parameters. Then, the so-called Kalman Filter is used to calculate the likelihood function of the data (for given parameters). Combining prior distributions with the likelihood of the data gives the posterior kernel, which is proportional to the posterior density. Since the posterior distribution is unknown, I use Markov Chain Monte Carlo (MCMC) simulation methods to conduct inference about the parameters. As these methods

are recent, they may not be well-know by some readers. This Appendix therefore includes a brief elementary technical introduction (for a deeper treatment, see e.g., Gelman, Carlin, Stern, and Rubin (2004) and Geweke (1999)).

1.A.1   Prior Distribution

The prior distributions chosen in each chapter were selected depending on the supports and characteristics of the parameters. In the cases where evidence from microeconomic studies was available, such information was also incorporated in the priors.

1.A.2   Posterior Distribution

I first estimate the mode of the posterior distribution by maximizing the posterior density $p(\Omega \mid Y)$ with respect to the vector of parameters Ω and given the data Y. The objective is to maximize

$$\log p(\Omega \mid Y) = \log p(Y \mid \Omega) + \log p(\Omega) - \log p(Y),$$

where $p(Y \mid \Omega)$ is the sample density or likelihood function, $p(\Omega)$ is the prior density of the parameters and $p(Y)$ is the marginal likelihood of the data.

However, since $p(Y)$ does not depend on Ω, the posterior mode can be obtained maximizing (Hamilton (1994))[2]

$$\log p(\Omega, Y) = \log p(Y \mid \Omega) + \log p(\Omega). \tag{1.1}$$

MCMC simulation methods are used to obtain the posterior distribution. This is necessary since it is not possible to sample the parameters directly from the posterior distribution. The idea behind MCMC is to draw values of the parameters from an approximate distribution and then correct these draws to better approximate the posterior distribution. Starting from initial arbitrary values of the parameters, the samples are drawn sequentially, such that each draw will depend on the previous value. The approximate distribution of the parameters is improved at each step of the simulation until it converges to the posterior. The posterior output can then be used to compute any posterior function of the parameters: impulse responses,

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[2] In practice, the RHS of Equation (1.1) is maximized using the code csminwel.m from Sims' webpage.

statistical moments, etc.

To perform the simulations, I use the so-called Metropolis-Hasting algorithm, which uses an acceptance/rejection rule to converge to the posterior distribution. The algorithm samples a proposal vector of parameters from a jumping distribution $q(\Omega^{l+1} \mid \Omega^l)$ and accepts the draw with probability $\kappa = \min \left\{ \frac{p(\Omega^{l+1}|Y)/q(\Omega^{l+1}|\Omega^l)}{p(\Omega^l|Y)/q(\Omega^l|\Omega^{l+1})}, 1 \right\}$. If the new value of the parameters is rejected, then $\Omega^{l+1} = \Omega^l$. A random walk around the parameter space was used as the jumping function. In particular, I set $q(\Omega^{l+1} \mid \Omega^l) = N(\Omega^l, c^2\Sigma)$ where Σ is the inverse of the Hessian computed at the joint posterior mode, and c is a scale factor set to obtain efficient algorithms[3]. The purpose when choosing the scale factor was to tune the acceptance rate to around 25 percent as suggested by Gelman, Carlin, Stern, and Rubin (2004).

To check convergence, I run different chains starting from dispersed points. Convergence is monitored by comparing the parameter variation between and within simulated sequences until 'within' variation approximates 'between' variation. The idea is that only when the distribution of each sequence is close to that of all sequences mixed together, all draws can be considered as coming from the same posterior distribution.

To be more specific, consider the between- (B) and within-sequence (W) variance for each scalar estimand ψ given by:

$$B = \frac{N}{J-1} \sum_{j=1}^{J} (\overline{\psi}_{\cdot j} - \overline{\psi}_{\cdot\cdot})^2, \ \text{ where } \ \overline{\psi}_{\cdot j} = \frac{1}{N} \sum_{n=1}^{N} \psi_{nj} \ \text{ and } \ \overline{\psi}_{\cdot\cdot} = \frac{1}{J} \sum_{j=1}^{J} \overline{\psi}_{\cdot j} \ ,$$

and

$$W = \frac{1}{J} \sum_{j=1}^{J} s_j{}^2, \ \text{ where } \ s_j{}^2 = \frac{1}{N-1} \sum_{n=1}^{N} (\psi_{nj} - \overline{\psi}_{\cdot j})^2,$$

where J is the number of sequences and N the number of draws in each sequence. The marginal posterior variance of the parameter is a weighted average of W and B:

$$\widehat{var}(\psi|Y) = \frac{N-1}{N} W + \frac{1}{N} B.$$

One way of checking convergence is to calculate the potential scale reduction:

$$\widehat{R} = \sqrt{\frac{\widehat{var}(\psi|Y)}{W}},$$

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[3] Gelman, Carlin, Stern, and Rubin (2004) argue that within this class of jumping rules, the most efficient one has the scale coefficient $c \approx 2.4\sqrt{d}$, where d is the number of parameters to be estimated.

which declines to 1 as $N \to \infty$. If the potential scale reduction is high, one should proceed with further simulations to improve inference. This ratio is computed for all parameters.

Moreover, to avoid the effect of the starting points and given that eventually the distribution converges to the posterior, the first part of each sequence is ignored (typically, the first 10 percent of the draws).

1.A.3 Model Comparison

To compare the performance of different models, their marginal data density must be calculated. Let us label a particular model i by M_i. The marginal data density for model i is

$$p(Y \mid M_i) = \int p(Y \mid \Omega_i, M_i)p(\Omega_i \mid M_i)d\Omega_i,$$

where Ω_i is a vector of parameters of model i, $p(Y \mid \Omega_i, M_i)$ is the sample density of model i and $p(\Omega_i \mid M_i)$ is the prior density of the parameters for model i. The posterior probability for each model will be

$$p(M_i \mid Y) = \frac{p(Y \mid M_i)p(M_i)}{\displaystyle\sum_i p(Y \mid M_i)p(M_i)}.$$

Bayesian model selection is done pairwise, comparing the models in terms of the posterior odds ratio:

$$PO_{i,l} = \frac{p(M_i \mid Y)}{p(M_l \mid Y)} = \frac{p(Y \mid M_i)p(M_i)}{p(Y \mid M_l)p(M_l)},$$

where the prior odds $\frac{p(M_i)}{p(M_l)}$ are updated by the Bayes factor, $B_{il} = \frac{p(Y \mid M_i)}{p(Y \mid M_l)}$.

Following Geweke (1999), I use the modified harmonic mean to approximate the marginal likelihood. Gelfand and Dey (1994) show that for any pdf $f(\Omega)$ whose support Θ_m is contained in the parameter space, we have

$$E\left[\frac{f(\Omega_i)}{p(Y \mid \Omega_i, M_i)p(\Omega_i \mid M_i)} \mid Y, M_i\right]$$

$$= \int_{\Theta_m} \frac{f(\Omega_i)}{p(Y \mid \Omega_i, M_i)p(\Omega_i \mid M_i)}p(\Omega_i \mid Y, M_i)d\Omega_i = p(Y \mid M_i)^{-1}.$$

Based on this result, one can use the sample posterior mean of $\left[\frac{f(\Omega_i)}{p(Y \mid \Omega_i, M_i)p(\Omega_i \mid M_i)}\right]$ as

an approximation for the inverse of the marginal density. Following Geweke (1999), I choose f multivariate normal with mean $\overline{\Omega} = G^{-1} \sum_{g=1}^{G} \Omega_g$ (estimated posterior mean) and variance $\widehat{\Sigma} = G^{-1} \sum_{g=1}^{G} (\Omega_g - \overline{\Omega})(\Omega_g - \overline{\Omega})'$. Moreover, to ensure that the domain of f is contained in the parameter space, the distribution is truncated to the region $\Theta_p = \left\{ \Omega : (\Omega - \overline{\Omega})'\widehat{\Sigma}^{-1}(\Omega - \overline{\Omega}) \leq \chi^2_{1-p}(d) \right\}$, where d is the number of estimated parameters and all parameters subject to restrictions have been appropriately transformed.

Chapter 2

Monetary Policy Regimes and the Volatility of Long-Term Interest Rates[*]

1 Introduction

This paper addresses two important questions that have, so far, been studied separately in the literature. First, the paper aims at explaining the high volatility of long-term interest rates observed in the data, which is hard to replicate using standard macro models with a deterministic steady state. I show that the policy responses of a central bank that is uncertain about the natural rate of unemployment can help explain this volatility puzzle. Second, the paper aims at shedding some new light on the distinction between discretion and rules in monetary policy. Despite a great deal of theoretical work, there are few clear-cut empirical results regarding the real-word prevalence of alternative policy regimes. I show that including yield curve data may make it possible to empirically distinguish between different monetary policy regimes.

The model in the paper is a forward-looking model where the private sector has full information, but the central bank cannot observe the shocks affecting the

economy, in particular the natural rate of unemployment. Following the results in Orphanides and Williams (2002), I model policymakers' misperceptions of the natural rate of unemployment (the rate of unemployment consistent with stable inflation) as an autoregressive process. This has important implications for inflation, implications which are amplified in the case of discretionary monetary policy. When a policymaker cannot commit, he loses control over inflation expectations, and inflation and interest rate volatility are higher than when he can commit. The intuition is that when the monetary authority underestimates the natural rate of unemployment, it sets a higher inflation than its own target in order to reduce the perceived unemployment gap. Since misperceptions about the natural rate of unemployment are persistent, this raises expectations of future inflation and future short-term interest rates. Once we augment the model with the expectation hypothesis of interest rates, which establishes a relationship between long-term and short-term interest rates, a discretionary regime can also explain the volatility puzzle.

In contrast to other papers that combine a macro model with no-arbitrage models of the term structure,[1] I focus on a simple macro model and then explore the implications of different monetary regimes for long-term interest rates.[2] This allows me to analyze the unresolved issue on how monetary policy has been conducted in the last 45 years. Certainly, the goal of the paper is not to construct a very precise model of the yield curve, but to find some linkages between macroeconomic fundamentals, monetary policy, and the behavior of long-term rates. In particular, I want to calculate how much of the total volatility of long-term interest rates is explained by macro variables as opposed to financial risks. For this purpose, long-term interest rates are modelled by the expectation hypothesis.

To investigate the implications of the model, I estimate it using Bayesian methods. To the best of my knowledge, this is the first paper to rely on a structural estimation of a macromodel to distinguish between different monetary policy regimes or explain the volatility puzzle.

A large literature has documented a decline in business cycle volatility in the

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[1] See, for instance, Bekaert, Cho, and Moreno (2005), Hördahl, Tristani, and Vestin (2006) and Rudebusch and Wu (2004).

[2] Diebold, Rudebusch, and Arouba (2006) find that the effects of the yield curve on macro variables are less important than the effects of macro variables on the yield curve. They also find the short rate to be a sufficient statistic for interest rate effects in macro dynamics.

U.S. in the mid 1980s.[3] Based on this evidence, I divide the data into two periods: 1960-1978 and 1983-2005 (excluding the four years at the beginning of the Volcker period when the Fed targeted nonborrowed reserves and the volatility of interest rates of all maturities increased dramatically). Despite the lower volatility of the macro fundamentals, the second period shows higher long-run interest rate volatility than the first period. In my model, this is attributed to a slightly larger estimated persistence in policymakers' misperceptions which translates into more persistent inflation. Moreover, to explain the volatility of long-term interest rates in both periods, we need a lack of commitment from the monetary authority. Thus, the results indicate that U.S. monetary policy is best understood as originating from a discretionary regime.

To analyze the role of institutions in monetary policy, the paper also estimates the same model for two periods in the U.K., namely 1983-1997 and 1998-2005. In the latter period, the Bank of England became operationally independent. This exercise attempts to address the importance of central bank independence in the design of monetary policy. The U.K. evidence is different than the U.S. evidence. If anything, the post-independence monetary policy of the Bank of England has been closer to rules than discretion.

The rest of the paper is organized as follows. Section 2 reviews previous related literature. Section 3 describes the model. Sections 4 and 5 present the empirical evidence for the U.S. and the U.K., respectively. Section 6 concludes.

2   Literature Review

2.1   Long-Term Interest Rates

Three facts in the data on interest rates are hard to replicate in standard macro models. First, short- and long-term interest rates are strongly *positively correlated* (e.g., Cook and Hahn (1989))**.** As shown in Table 2.1, the correlations are positive

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[3] There has been a growing debate over whether the decline in volatility is a consequence of smaller economic disturbances ("good luck?") or better monetary policy. Among many others, Gordon (2005), Justiniano and Primiceri (2006), Sims and Zha (2006) and Stock and Watson (2002) mainly attribute this decline to smaller shocks in the economy, while Boivin and Giannoni (2006), Clarida, Gali, and Gertler (2000) and Cogley and Sargent (2005) also stress the importance of changes in monetary policy.

and above 0.75 for all subperiods and all maturities. Second, as stressed in Shiller (1979), long-term rates present *excess volatility*: the volatility of long-term rates is higher than predicted by expectation models of the term structure. Long-term interest rates should be expected to be much smoother than short-term rates, given that we can consider long rates as an average of expected short-term interest rates, plus a premium term. However, the data in Table 2.1 shows that long-term interest rates are about as volatile as short rates. Third, as shown by Gürkaynak, Sack, and Swanson (2005), long-term forward rates exhibit *excess sensitivity* to monetary policy announcements and macroeconomic news.[4] These three facts cannot easily be explained by standard macro models where the long-term properties of the model are given, say, by a deterministic steady state.

A number of papers have tried to model the behavior of long-term interest rates. Ellingsen and Söderström (2001) and Ellingsen and Söderström (2005) argue that a rise in the short-term interest rate perceived as a response to shocks to inflation or output will lead to higher inflation expectations and increases in long-term interest rates. On the other hand, a rise in the interest rate perceived to be triggered by a change in the preferences of the monetary policymaker towards lower inflation, will reduce inflation expectations and long-term interest rates. Ellingsen and Söderström obtain these results in models with high output and inflation inertia or a very persistent inflation target.[5] They empirically test some implications of their model and find that in general, long-term interest rates move in the same direction as short-term rates, except on days where market participants see movements in short rates as a change in policy preferences.

Using the same idea, other authors have explained the response of long-term interest rates to the central bank policy instrument using time-varying inflation targets. Shocks to the central bank inflation target change future expected inflation and thereby nominal long-term rates. In the extreme case of a random-walk inflation target, an increase in the central bank inflation objective will trigger an

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[4] A forward rate is the rate of return that an investor demands today to commit to lending money in the future.

[5] For instance, in Ellingsen and Söderström (2001), inflation is determined by an accelerationist Phillips curve: $\pi_{t+1} = \pi_t + \alpha y_t + \varepsilon_{t+1}$. This type of relation is not microfounded and implies highly persistent inflation, which in their model translates into responses of long-term interest rates. In Ellingsen and Söderström (2005), the results do not hold when the autoregressive coefficient of the inflation target process is less than 0.80.

equal size increase in long-term rates. Gürkaynak, Sack, and Swanson (2005) and Beechey (2006) develop calibrated models with a variable inflation target and imperfect information which generate long-term rate volatility since expected inflation is not anchored.[6] In both models, inflation and the short-term interest rate have a different steady state value after a shock.[7]

Similarly, Hördahl, Tristani, and Vestin (2005) explain the volatility of long-term interest rates using a second-order approximation of a standard DSGE model with a variable inflation target, where they calibrate the autocorrelation coefficient of the inflation target to be 0.99.

In all these papers, the high persistence of inflation and thus, the volatility of long-term rates, arises either from an accelerationist Phillips curve (where inflation is highly persistent by definition) or from very persistent inflation target shocks. In my model, on the other hand, inflation persistence is estimated rather than imposed and intrinsic to the model. Inflation persistence arises because of central bank misperceptions about the natural rate of unemployment, which are empirically very persistent. Moreover, in all the above mentioned papers, except Ellingsen and Söderström (2001), the volatility of long-term rates is explained by a shock to a policy objective, namely the inflation target. In my model, the policymaker's objectives are stable and long-term rates mainly move due to his misperception shocks.

Alexius and Welz (2005) resort to a time-varying natural real interest rate to explain the behavior of long-term yields. However, empirical evidence shows changes in long-term yields on U.S. Treasury bonds to mainly be due to changes in long-term inflationary expectations, implying that real forward interest rates are quite stable and the term premium is small. [8] Therefore, I abstract from variations in the real interest rate and explain long-term rate volatility through inflation expectations. Nevertheless, it would be interesting to bring together the nominal and real channel to explain the volatility puzzle.

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[6] Using a macro-finance model, Rudebusch and Wu (2004) also introduce time variation in the inflation target to generate responses of long rates to macro shocks.

[7] While Gürkaynak, Sack, and Swanson (2005) introduce an ad-hoc equation to specify the evolution of the inflation target, Beechey (2006) uses a random walk inflation target. In the first case, any shock affecting inflation will generate a new steady state level for inflation and interest rates while in the second case, only inflation target shocks will have this effect.

[8] See, for instance, Ireland (1996), Gürkaynak, Sack, and Swanson (2003), Rudebusch and Wu (2004) and Diebold, Rudebusch, and Arouba (2006).

Baxter (1989) tries to explain the high volatility of long- and short-term interest rates during the 1979-1982 period with a Bayesian learning model, where the response to shocks is largest in the initial stages of a new policy. However, she does not find any empirical support for her model.

In a robust control framework, where the policymaker adopts a min-max approach, Giordani and Söderlind (2004) show in a calibrated model that robustness leads to higher and more persistent reactions of inflation and the nominal interest rate after a shock. This feature of the robust solution implies that robustness makes long-term interest rates more volatile than in the standard rational expectation case. Their paper looks at one-year interest rates and assumes a discretionary monetary policy. In my paper, a discretionary regime is able to explain the high volatility of long-term rates even under certainty about the appropriate model.

2.2   Rules versus Discretion

A large theoretical literature analyzes the properties of monetary policy under discretion and commitment. In general, this literature considers the qualitative and not the quantitative implications of both regimes and, to my knowledge, no paper has explicitly analyzed the implication of these regimes for long-term interest rates. As pointed out by Baxter (1988) almost 20 years ago, it is important to use established statistical procedures for selecting among alternative models for policy-making. However, very little has been achieved on this empirical agenda and most current papers model monetary policy as a Taylor-type interest rate rule.

A first generation of theoretical papers studying the differences between commitment and discretion in monetary policy focuses on the time-consistency problem described in Kydland and Prescott (1977) and Barro and Gordon (1983). The main assumption of the so-called Barro-Gordon model is that a central bank lacking commitment will pursue an accommodative monetary policy, (unsuccessfully) trying to push unemployment below its natural rate. As a result, a discretionary regime gives rise to an *inflation bias*, where inflation is higher than the target.[9]

More recently, a second generation of papers, including Clarida, Gali, and Gertler (1999), Svensson (1997), and Woodford (1999) among others, stresses the fact that

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[9] In dynamic and/or stochastic models, average inflation is higher than the inflation target.

in forward-looking models, a discretionary regime generates a dynamic loss, even if the central bank targets the natural rate of unemployment.[10]   In these models, a discretionary monetary policy causes a *stabilization bias*, i.e., a suboptimal response to shocks given that the central bank cannot affect the private sector's expectations. In the commitment case, the monetary authority can effectively control private expectations about future inflation and thus, the behavior of the private sector today.

Empirical papers addressing the inflation bias problem of the Barro-Gordon model include Christiano and Fitzgerald (2003), Ireland (1999) and Ruge-Murcia (2003). The first two papers argue that their results support the Barro-Gordon model as an explanation for U.S. inflation since 1960. However, neither paper estimates the model or considers the counterfactual of monetary policy under commitment. On the other hand, Ruge-Murcia (2003) uses full information maximum likelihood to test the predictions of the Barro-Gordon model against an alternative model where the central bank gives different weights to upward and downward deviations of unemployment from its target. The problem is solved under a discretionary regime. Reduced-form estimates indicate that the Fed targeted the natural rate of unemployment, but gave more weight to positive than to negative unemployment deviations between 1960 and 1999.

Unlike these previous papers, I look at the problem from a different perspective and use data on long-term interest rates to distinguish between monetary policy regimes. Moreover, I assume that the monetary authority targets the natural rate of unemployment, which eliminates the Barro-Gordon type of inflation bias. In this sense, my model is closer to the second generation of papers described above. Given the volatility of long-term interest rates and their correlation with the short rate, my results show that a monetary regime under discretion is more likely to have prevailed in the U.S. since 1960.

Another related paper is Bikbov (2005). Like me, he stresses the importance of including term structure data to identify different monetary policy regimes. Bikbov models monetary policy as a forward-looking interest rate rule with monetary policy shocks. Allowing for switches in the parameters, he interprets periods with high

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[10]   McCallum and Nelson (2004) find the magnitude of these losses to be significant, and depending on the parameters, greater than the losses arising from the inflation bias.

variance in the monetary policy shock as discretionary regimes and periods with low variance as commitment regimes.[11] Bikbov's results indicate that since the 1970s, monetary policy in the U.S. has continuously alternated between "active" versus "passive" policy regimes[12] and between high versus low volatility monetary policy shocks. While Bikbov's results are suggestive, they are hard to interpret since he does not include optimal monetary policies of any kind in his analysis.

3   The Model

The model in this paper is a new Keynesian forward-looking model where firms have market power and get to adjust their prices with a fixed probability in each period (Calvo (1983)).[13]

The loglinearized version of the Phillips curve and the expectations based IS curve are given by

$$\pi_t = \beta E_t \pi_{t+1} - \theta \left(u_t - u_t^N \right) + \varepsilon_t \tag{2.1}$$

and

$$u_t = E_t u_{t+1} + \delta E_t \left(i_t - \pi_{t+1} \right) + \eta_t, \tag{2.2}$$

where π_t is the rate of inflation, u_t the unemployment rate, and u_t^N the natural rate of unemployment. The nominal interest rate, i_t, is the return on a short-term instrument from period t to $t+1$, η_t is an exogenous demand shock assumed to be *i.i.d.* $N \left(0, \sigma_\eta^2 \right)$, e.g. government expenditures, while ε_t can be considered as an *i.i.d.* $N \left(0, \sigma_\varepsilon^2 \right)$ markup shock. $E_t \left(\cdot \right)$ denotes the rational expectations operator given the private sector information in period t.

In the standard new Keynesian literature, equations (4.8) and (2.2) are expressed in terms of the output gap rather than the unemployment gap.[14] However, by reference to Okun's law, we can express the output gap as a monotonic function of the unemployment gap.[15]

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[11] He argues that more volatile monetary shocks can be seen as the Fed is more willing to deviate from the systematic rule.

[12] An "active" policy regime aggressively stabilizes inflation, while a "passive" one reacts less strongly to expected inflation.

[13] See, for instance, Clarida, Gali, and Gertler (1999) and Woodford (2003).

[14] This is due to the fact that employment variations only occur in the intensive margin and unemployment is always zero.

[15] Supply equations using unemployment gap instead of output gap have been used, for instance,

I assume that the natural rate of unemployment follows a first-order autoregressive process:

$$u_t^N = \gamma u_{t-1}^N + \chi_t, \tag{2.3}$$

where χ_t is *i.i.d.* $N\left(0, \sigma_\chi^2\right)$ and the unconditional mean of u_t^N is zero.[16]

A time-varying natural rate of unemployment is consistent with the substantial changes observed in U.S. unemployment in the last decades. Staiger, Stock, and Watson (1997) find that the natural rate has fluctuated during the last 30 years in the U.S., and decreased by one percentage point between the 1980s and the mid 1990s. Shocks to the natural rate of unemployment could, e.g., be associated with exogenous changes in productivity or labor force demographics that affect labor supply.

3.1   Information and the Natural Rate of Unemployment

I assume that the private sector has complete information about the current state of the economy, while the policymaker knows the structural relations of the economy (equations (4.8) and (2.2)) and the true parameter values, but conducts monetary policy under uncertainty about the shocks affecting the economy and, in particular, about u_t^N.[17] This type of information asymmetry has been used in Svensson and Woodford (2004), Aoki (2003) and Primiceri (2006). Svensson and Woodford (2004) argue that

> "(this) is the only case in which it is intellectually coherent to assume
> a common information set for all members of the private sector, so that
> the model's equations can be expressed in terms of aggregate equations ...
> while at the same time these model equations are treated as structural,
> and hence invariant under the alternative policies that are considered in
> the central bank's optimization problem ... But if all private agents are
> to have a common information set, they must then have full information
> about the relevant variables."

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in Blanchard and Gali (2006a), Blanchard and Gali (2006b), Primiceri (2006) and Reis (2003). One way of deriving the Okun's gap relation from first principles is to formulate a model of search and matching in the labor market.

[16] In practice, I work with demeaned data, so all the variables have an unconditional mean of zero in the model.

[17] Policymakers are uncertain about equation (2.3).

The importance of the natural rate of unemployment in choosing monetary policy follows from the effect on inflation of deviations of unemployment from its natural rate in equation (4.8). If the policymaker is unable to observe this gap, it may set interest rates higher or lower than optimal. As a result, misperceptions about the natural rate of unemployment can be costly in terms of stabilization performance. The private sector understands this fact when forming expectations about future inflation, and these inflationary expectations influence long-term interest rates.

Since this paper is a positive study seeking to explain the high volatility of long-term interest rates and to identify actual policy regimes, I abstract from any kind of optimal filtering by the monetary authorities.[18] I assume that the gap between the actual natural rate, u_t^N, and the central bank estimate of the natural rate at time t, $\widetilde{u}_t^N$, evolves according to

$$\left(u_t^N - \widetilde{u}_t^N\right) = \rho\left(u_{t-1}^N - \widetilde{u}_{t-1}^N\right) + \xi_t, \tag{2.4}$$

where ξ_t is assumed to be an *i.i.d.* $N\left(0, \sigma_\xi^2\right)$ misperception shock.

Orphanides and Williams (2002) empirically estimate a relationship like (2.4) and find that natural rate misperceptions are very persistent, independent of the filtering method. They calculate the gap as the difference between the retrospective estimates of the natural rate of unemployment (two-sided estimates) and the real time estimates (one-sided estimates) for six different estimation methods (four univariate filters and two multivariate unobserved-components models) which together give 36 alternative measures of natural rate misperceptions. They document a frequency distribution for ρ with median 0.96 and a fifty percent confidence interval $(0.95, 0.97)$, where the estimate of ρ using the Kalman filter is 0.95. They point out that equation (2.4) approximates several filtering methods and that the persistence of misperceptions is related to the nature of the filtering problem and does not necessarily imply that real-time estimates are inefficient.

In particular, equation (2.4) encompasses different filtering methods. In Appendix 2.A, I show (for a calibrated example) that when the central bank learns about

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[18] For instance, Svensson and Woodford (2003) and Svensson and Woodford (2004) derive the optimal weights on indicator variables in models with partial information. I discuss this case in Appendix 2.A.

the state of the natural rate of unemployment using a constant-gain learning rule[19] , or an optimal filter, the simulated value of ρ is around 0.95. In that appendix, I also show that the main results of the paper hold up if the central bank uses those types of updating rules.

Figure 2.1 shows the path of unemployment in the U.S. between 1965 and 2005. It also shows one- and two-sided estimates of the natural rate of unemployment obtained from a Hodrick-Prescott filter (smoothing parameter $1,600$) and band-pass filter (eight-year window), respectively. The estimated autoregressive parameter of the difference between the one- and two-sided filter is 0.97 in the former case and 0.94 in the latter.

3.2   Optimal Monetary Policy

To close the model, I study optimal monetary policy under discretion or commitment[20] , where the instrument of monetary policy is the nominal interest rate, i_t. In each period, policymakers set the optimal policy after forming their beliefs about the natural rate of unemployment according to equation (2.4).[21]

Under discretion, the central bank chooses the optimal nominal interest rate in each period, without any binding commitment to future actions. The private sector understands that the monetary authority cannot resist the temptation to exploit the short-run trade off between inflation and unemployment and hence, the central bank cannot influence private sector expectations. When maximizing, the monetary authority therefore takes future expectations as given.

Under commitment, the central bank has the ability to bind its future actions to follow an optimal state-contingent rule for the nominal interest rate, conditional upon the shocks arising in any period. In this case, the central bank can exploit its influence on private sector expectations for the entire future to stabilize the economy.

A well-known result in the literature is that the two regimes differ in their credibility properties. Under discretion, the rational expectations equilibrium is "time

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[19]   This kind of learning rule about the natural rate of unemployment has, for instance, been used in Primiceri (2006).

[20]   Even though the commitment solution is unrealistic in the absence of a commitment mechanism, it is a useful benchmark and closely related to other types of rules, or institutions, often used in the literature.

[21]   In Appendix 2.A, I show the case when policymakers update their beliefs about the natural rate of unemployment using a constant-gain learning rule or an optimal filter.

consistent": conditional on the state of the economy as described by a set of shocks, the central bank chooses the same policy in any period, even though it has the discretion to change it, implying an equilibrium state-contingent policy rule. Under commitment, the optimal state-contingent rule is credible by assumption, although the same policy rule would not be credible in a discretionary policy regime.

The central bank sets its policy instrument i_t, to minimize

$$\widetilde{E}_t \sum_{i=0}^{\infty} \beta^i \left[\pi_{t+i}^2 + \lambda \left(u_{t+i} - u_{t+i}^N \right)^2 \right],$$

subject to equations (2.1)-(2.2) describing the economy, and where $\widetilde{E}_t(\cdot)$ denotes the expectation operator given the central bank information set in period t.[22] In particular, $\widetilde{E}_t u_t^N = \widetilde{u}_t^N$ given that the central bank cannot observe u_t^N. This loss function penalizes deviations of inflation and unemployment from their targets, where the inflation target is normalized to zero.[23]

The first-order conditions of this problem under discretion imply[24]

$$\pi_t = \frac{\lambda}{\theta} \left(u_t - \widetilde{u}_t^N \right). \tag{2.5}$$

Using this result in equation (4.8) and performing repeated substitutions, the equilibrium outcome for inflation in the discretionary case is

$$\pi_t = \frac{\lambda\theta}{\lambda + \theta^2 - \beta\lambda\rho} \left(u_t^N - \widetilde{u}_t^N \right) + \frac{\lambda}{\lambda + \theta^2} \varepsilon_t.$$

This last equation shows that when the central bank estimate of the natural rate of unemployment differs from the real value, there is an inflation bias only in the sense that inflation will be different from its target. Note that the model does not have

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[22] Only in the case of optimal filters is $\widetilde{E}_t(\cdot)$ the rational expectation operator.

[23] The rationales for these costs are that inflation volatility is costly because it induces an inefficient allocation of resources, while unemployment volatility is costly for risk averse households. In practice, since I work with demeaned data, the inflation target is equal to the mean of inflation in each period.

[24] I assume that the central bank can achieve the first-order condition, but I do not specify how this is done. Conditional on a specific theory for how the central bank updates its information, we could derive an explicit mapping from observable variables to the interest rate. As mentioned above, Equation (2.4) can either approximates an optimal filter, or a constant-gain learning algorithm (but with different values for ρ). I take a more general stand and assume that the central bank (*i*) can attain its first-order condition, Equation (2.5), (*ii*) updates its information such that Equation (2.4) holds.

a conventional (Kydland and Prescott (1977), Barro and Gordon (1983)) inflation (level) bias.[25] The existence of such a bias is not essential for the argument in this paper. What is essential, however, is that the policymaker loses control over private expectations in a discretionary policy regime.

Doing some algebra, it is easily shown that inflation expectations evolve as

$$E_t \pi_{t+i} = \frac{\lambda \theta}{\lambda + \theta^2 - \beta \lambda \rho} \rho^i \left(u_t^N - \widetilde{u}_t^N \right).$$

As a result, when the natural rate of unemployment is higher (lower) than the central bank's estimate, there is a persistent rise (fall) in inflation.[26] The intuition is that when the monetary authority underestimates the natural rate of unemployment, it sets the interest rate so as to achieve a higher inflation than the target in order to reduce the perceived unemployment gap. Since misperceptions about the natural rate of unemployment are persistent, this raises expectations of future inflation (and thereby long-term interest rates).

For the commitment case, the first-order conditions of the central bank imply[27]

$$\pi_t = \frac{\lambda}{\theta} \left(u_t - \widetilde{u}_t^N \right) - \frac{\lambda}{\theta} \left(u_{t-1} - \widetilde{u}_{t-1}^N \right). \tag{2.6}$$

It can be shown that for given parameters, inflation reacts less to supply and misperception shocks in the commitment case than in the discretionary case. The reason is that the monetary authority can control future expectations under commitment and thus, the behavior of inflation today: if the private sector expects lower future inflation then inflation becomes lower already today.

For example, after a positive supply shock, the commitment solution implies periods of deflation after the initial positive impact on inflation. This is the case because lower inflation is achieved with the promise of having positive unemployment gaps in the future. In the full information case, the dynamic feature of the

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[25] Moreover, inflation is zero in steady state.

[26] Some authors have used this argument to explain the stagflation episode in the 1970s. See, for instance, Orphanides and Williams (2002), Primiceri (2006) and Reis (2003).

[27] I assume optimal monetary policy under commitment to be a *timeless perspective* policy. Moreover, I assume that the central bank does not revise its estimates of the natural rate of unemployment in the next period, and $\widetilde{E}_t u_t^N = \widetilde{E}_{t+1} u_t^N = \widetilde{u}_t^N$. In the data, the difference between $\widetilde{E}_t u_t^N$ and $\widetilde{E}_{t+1} u_t^N$ has a standard deviation of 0.16 in the case of the Hodrick-Prescott filter and 0.05 for the band-pass filter. However, since univariate filters are excessively sensitive to final observations, this difference could be expected to be even smaller using multivariate filters.

model introduces a *stabilization bias*, in that unemployment is overstabilized and inflation volatility is higher under discretion than under commitment. However, in my model, the volatility of unemployment turns out to be similar in both regimes. But the presence of the second term in equation (2.6) makes the inflation rate less autoregressive than in equation (2.5).

Svensson and Woodford (2004) show that equations (2.5) and (2.6) follow the principle of *certainty equivalence*, where the optimal response is the same as if the central bank had full information, except that it responds to an estimate of the state of the economy rather than to the actual values.

Orphanides and Williams (2002) show that when the policymaker adopts policy rules ignoring the misperceptions regarding the natural rate of unemployment, this is costly in terms of inflation and unemployment stabilization. In my model, misperceptions also translate into long-term interest rate volatility.

3.3   Expectation Hypothesis of the Yield Curve

To calculate long-term interest rates, I use the expectation hypothesis of interest rates, which establishes a relationship between long-term interest rates and short rates. The interest rate on a discount bond of maturity m at time t should be equal to the expected average of future short interest rates over the same period, plus a term premium:

$$i_t^m = \frac{1}{m} \left[i_t + i_{t+1|t} + i_{t+2|t} + ... + i_{t+m-1|t} \right] + \tau_t^m, \qquad (2.7)$$

where $i_{t+m|t} = E_t(i_{t+m})$ and term premium shocks are assumed *i.i.d.* $N(0, \sigma_m^2)$.[28]

Even though the empirical evidence on the relevance of the expectation hypothesis is mixed, it is often used in formal macroeconomic analysis. Fuhrer (1996) finds that changes in monetary policy regimes can account for most of the empirical failure of the expectation hypothesis. Given that I study two time periods when monetary policy may have been stable, the use of the expectation hypothesis may be a good approximation. Moreover, among the papers rejecting the expectation hypothesis, some fail to reject it at the long end of the yield curve, which is the main focus

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[28] According to the expectation hypothesis, the term premium varies with maturity (m) but not with time. That is, $\tau_t^m = \tau^m$.

in this paper.[29] Since I am not interested in constructing a very precise model of the yield curve, but in finding some macroeconomic fundamentals that potentially affect long-term interest rates, I assume that the expectation hypothesis holds if time-varying term premium shocks are added.

3.4 Solution Method

Given the asymmetry in the information set of the central bank and the private sector, optimal control methods, as those described in Söderlind (1999), cannot be applied here. However, equations (4.8)-(2.4) and the first-order condition of the monetary authority (equation (2.5) or (2.6)) form a system of difference equations that can be solved using the methods described in Sims (2002). Moreover, since i_t^m does not enter the first five equations of the model, the model is solved recursively as described in Appendix 2.B. Once the model is solved and expressed in state-space form, I can estimate it using the Kalman filter.

4 Empirical Evidence for the U.S.

The model is estimated using Bayesian methods. I use Markov Chain Monte Carlo (MCMC) simulation methods to obtain the posterior distribution of the parameters. The posterior output can then be used to compute any posterior function of the parameters: impulse responses, moments, etc., which is of great importance in this paper. For each model, two MCMC chains were simulated with 50,000 draws each and a burn-in period of 20%.

Five quarterly macro data series are used in the estimation: U.S. unemployment, inflation, short-term nominal interest rate and U.S. Treasury securities at five and ten years between 1960Q1-2005Q4.[30] All series were demeaned.

As mentioned earlier, I divide the data into two periods, from 1960Q1 to 1978Q4 and 1983Q1 to 2005Q4, excluding the Volcker nonborrowed reserves target period

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[29] See, for instance, Campbell and Shiller (1991) and Sarno, Thornton, and Valente (2007).

[30] The data on unemployment is seasonally adjusted data from the Bureau of Labor Statistics (BLS). The nominal interest rate is the quarterly Federal Funds Rate, and inflation is calculated as the change in the seasonally adjusted GDP deflator obtained from the Bureau of Economic Analysis (BEA). Long-term interest rates are quarterly market yields on U.S. Treasury securities at five and ten years constant maturity obtained from the Federal Reserve Board.

(when the volatility of interest rates at all maturities increased dramatically). Many studies have pointed out that these two periods have different characteristics in monetary policy and/or business cycles volatility.[31]   Figure 2.2 clearly shows a break in volatility in the early 1980s. Table 2.1 shows that the standard deviation of inflation and unemployment has indeed decreased in the second period. Even though inflation volatility is lower in the second period, interest rates at all maturities are more volatile.

As far as I know, no one has structurally estimated this kind of model, neither to distinguish between different monetary policy regimes nor to explain the volatility puzzle. An important element of the paper is that estimating the full structural model for each policy regime separately overcomes the problem of unstable nonpolicy parameters across different regimes.[32]   In other words, if one thinks that monetary policy has changed across the two subperiods and affected private sector behavior, this is not a major problem because I assume the parameters to be constant only within each subperiod.

The prior distributions of the parameters are presented in Table 2.2. All standard deviations have a gamma distribution with mode 0.10 and a standard error of 0.05, which implies a diffuse variance given the lack of knowledge about these parameters. The persistence in the natural rate of unemployment, γ, is beta distributed with mode 0.95 and a standard error of 0.02. In general, there is agreement among economists that the natural rate of unemployment is highly persistent, close to a unit root process. The weight on output gap in the central bank loss function, λ, is normally distributed with mode 1 and standard error 0.20.[33]   The slope coefficient in the Phillips curve, θ, is gamma distributed with mode 0.10 and standard error 0.02. This is approximately the value estimated by Orphanides and Williams (2002) and Rudebusch (2002) using survey data as proxies for inflation expectations.[34]

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[31]   See, among others, Clarida, Gali, and Gertler (2000), Stock and Watson (2002), Cogley and Sargent (2005), Gordon (2005) and Sims and Zha (2006).

[32]   Since the paper does not include any counterfactual analysis, it is immune to the Lucas critique.

[33]   The prior for λ is higher than the values commonly used in the literature. However, when I estimate the model with a flat prior for λ, the model prefers values of λ greater than one (or around one). This is robust to different priors for the shocks and estimating the model without long-term rates.

[34]   Since they use annual data on inflation, their results must be interpreted as four times θ. Moreover, Rudebusch uses the output gap instead of the unemployment gap, which should also be transformed in terms of the unemployment gap.

One prior that deserves special attention is the persistence in misperceptions, ρ, which is beta distributed with mode 0.95 and standard error 0.005. I set a very tight prior on this parameter to rule out cases where ρ is close to one, meaning that misperceptions never die out. Naturally, misperceptions can still be very persistent. Moreover, in Appendix 2.A I show that even very different filter methods deliver values of ρ larger than 0.90. In particular, a value of ρ equal to 0.95 implies that the half-life of a shock (the time it takes for the shock to dissipate by 50%) is three years and one quarter.[35]   As previously mentioned, the high persistence in misperceptions is documented in Orphanides and Williams (2002). Alternatively, I could have fixed this parameter, but allowing for some flexibility seems a better solution.

As is common practice, I fix the value of the discount factor, β, at 0.99, which corresponds to an annual steady state real rate of four percent. Finally, the value of the slope parameter in the IS-curve, δ, was pre-set at 0.5, corresponding to a degree of risk aversion equal to one, and an output gap approximately two times the unemployment gap.

4.1   Estimation Results

Before going into the main topics of the paper, I discuss the general properties of my estimation results. Tables 2.2 and 2.3 report the mean and the 5th and 95th percentile of the posterior distribution of the parameters under alternative monetary policy regimes.[36]

A first thing to notice is that most of the estimates are robust to the monetary policy regime. However, the posterior mean of the standard deviation of misperception shocks, σ_ξ, and the weight on the unemployment gap in the central bank loss function, λ, are higher in the commitment case. Higher values of these parameters imply a larger impact of misperceptions and thus, higher volatility in the data (especially long-term rates). This is important because, as discussed below, the commitment regime has difficulties in replicating the volatility of long-term rates observed in the data. In the same way, the variances of term premium shocks are larger in the commitment case.

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[35] The half-life of an AR(1) process is $-\log(2)/\log(\rho)$.

[36] Convergence to a stationary distribution was monitored computing the potential scale reduction for all parameters, as described in Gelman, Carlin, Stern, and Rubin (2004), and plotting the path of the different parameters along the chain.

It is worth mentioning that under discretion, the weights on inflation and unemployment are similar to each other and stable across the two subperiods. This implies that the Fed gave equal importance to both variables during the whole postwar period.

In accordance with most estimates in the literature, both the natural rate of unemployment and misperceptions about this variable exhibit a high degree of persistence in both regimes. The slope coefficient in the Phillips curve, θ, is stable across time and also similar to other estimates in the literature, although considerably lower in the commitment case.

One slightly puzzling result is that the variance of supply shocks across regimes is larger in the second period. This result is in contrast to the common perception that certain supply shocks, e.g. oil shocks, were larger in the 1970s. The estimates also show that the variance of shocks to the natural rate of unemployment has been lower in the second period. One explanation for this time pattern is the productivity slowdown. Last, the estimates of σ_η, the variability of demand shocks, are also lower in the second period. This result is in line with Gordon (2005) who provides some evidence for smaller demand shocks after 1984 due to a reduced volatility of Federal government spending, residential housing and inventory change.[37]

4.2   Macroeconomic Variables and Monetary Policy Regimes

Figures 2.3 and 2.4 show the posterior predictive distribution of the standard deviation of unemployment, inflation and the short-term interest rate.[38] A first look at the graphs indicates that in the first period, both regimes replicate the observed volatility in the data reasonably well.

In the second period, however, both regimes have problems replicating the volatility of unemployment and inflation, while a discretionary regime matches the volatility of the short-term interest rate much better. The model's inability to match the volatility of inflation in the second period is related to the high estimates of the variance of supply shocks, which seem at odds with the data.

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[37] Gordon attributes these changes respectively to "the reduced share of military spending in GDP, banking and financial market reforms, and information technology".

[38] The posterior density was computed using a kernel smoothing method, for a sample of 200 simulations for 75 periods from 500 draws of the posterior. To avoid autocorrelation, the draws from the posterior were picked in fixed intervals.

Overall, and in line with the common view in the literature, it is not possible to distinguish between alternative monetary policy regimes by only looking at the volatility of the macro variables.

4.3 Long-Term Rates and Monetary Policy Regimes

4.3.1 Variance Decomposition

Both monetary policy regimes can explain a large part of the volatility of long-term interest rates, since the term premium shock, the residual in equation (2.7), will capture a great deal of the variation not explained by the macro model.[39] However, the relative sources of interest rate volatility differ across monetary regimes.

The variance decomposition of inflation, the short interest rate and long-term interest rates at different horizons are shown in Tables 2.4 and 2.5. Misperception shocks that feed into monetary policy account for a great deal of the variation in long-term rates in a model under discretion. After a period of ten years, misperception shocks explain 87% of the variation in long-term rates in the first sub-sample and 96% in the second.

In the commitment regime, the variation in ten-year interest rates is instead predominantly explained by term premium shocks. After ten years, term premium shocks explain 45% of the variation in long-term rates in the first sub-sample and 88% in the second. Hence, if we want to attribute some of the variation in long-term rates to macroeconomic fundamentals, rather than to residual variation in time-varying term premiums, a monetary policy regime under discretion provides a better explanation for the volatility puzzle. Moreover, this implies that the expectation hypothesis of interest rates allows us to account for most of the observed long-term interest rate volatility when the central bank acts under discretion.

4.3.2 Switching off Term Premium Shocks

To further investigate how much of the total volatility of long-term interest rates is explained by macro variables, as opposed to financial risks, I once more simulate the model, but switch off the term-premium shocks. This allows me to isolate the

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[39] Notice that the model is estimated with quarterly data, implying that to annualize the standard deviation of the term premiums, they should be multiplied by four.

effect of macro variables in explaining the volatility of long-term rates. Figure 2.5 shows the posterior predictive distribution of the standard deviation of the ten-year long-term interest rate implied by the model, both with and without time-varying term premiums. The left-hand panel in the figure shows that the model under discretion is much closer to explaining the volatility of the long-term interest rate and can replicate a large part of the volatility observed in the data, especially during the second period.[40]   The main features of the model driving this result are policymakers' autocorrelated misperceptions about the natural rate of unemployment and a discretionary monetary policy. Together, these translate into a very persistent inflation response.

It is important to mention that even in the case with term premium shocks, the model underpredicts the volatility in the data. The reason for that is that a large share of the variance is unlikely to be explained without a level factor, which captures parallel movements in the level of the whole yield curve.[41]   Empirically, the level factor of the yield curve has been associated with long-run expected inflation. One way of introducing a level factor in the model would be to introduce a random walk inflation target or sporadic shifts in the long-run policy target for inflation (shifting endpoints).[42]   Kozicki and Tinsley (2001) reject the random walk hypothesis and link endpoint shifts to agent learning about shifts in long-term policy goals.

Figure 2.5 also shows that U.S. interest rates were more volatile in the second period than in the first. In the model, there is also an increase in bonds volatility; there is a shift to the right in the posterior predictive distribution of long rates in the second period. This is due to a slightly larger estimate of the persistence in misperceptions. Interestingly, when I calculate the difference between one- and two-sided estimates of the natural rate of unemployment using the same univariate filters as those described in Section 3.1, I also find an increase in the autocorrelation coefficient in the second period.

Moreover, the model is also able to explain bond *returns* volatility. Table 2.6

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[40]   However, other factors absent in the model, such as a time-varying inflation target or real interest rate, could also potentially add some extra volatility to my results.

[41]   To address this problem, I also estimate the model using linearly detrended data. The results are in general the same as before. However, a better alternative would be to detrend the data using estimates of the level factor obtained from the finance literature.

[42]   In the case when endpoint shifts occur in each period, the endpoint is similar to a unit root process.

reports the simulated volatility in bond returns implied by the model when term premiums are switched off, and where the volatility of bond returns is defined as the standard deviation of the quarter-to-quarter change in long-term interest rates.[43] Once more, a monetary regime under discretion appears to more closely replicate the data. The table also shows an increase in bond returns volatility in the second period, both in the model and in the data. As mentioned before, in the model this is caused by a slightly higher persistence in policymakers' misperceptions.

4.3.3   Correlations with Short-term Interest Rate

As shown in Table 2.1, short- and long-term interest rates are positively correlated. Figures 2.6 and 2.7 show posterior predictive distributions of the correlation coefficient between the short-term interest rate and the other variables in the model. As in the case of volatility, the model under discretion fits the data better. In particular, the discretionary regime can replicate the high positive correlation between short- and long-term interest rates observed in the data, while the commitment regime fails miserably in this regard.

The model can also explain another puzzling observation. In the real world, long-term interest rates typically move in the same direction as the short rate. However, during certain episodes, they move in the opposite direction. In the model, this can happen when the economy is simultaneously hit by a negative demand shock and a positive misperception shock. In that particular case, nominal long-term rates move up because of the positive misperception shock, since this will have a positive effect on future inflation. On the other hand, the movement in the short rate is determined by the relative size of the two shocks. When demand shocks are sufficiently large to offset misperception shocks, the short rate goes down to prevent a higher unemployment rate. This mechanism can clearly be seen from the impulse response functions plotted in Figure 2.8.

4.3.4   Monetary Policy Regimes

Finally, let us explicitly consider the second issue motivating the paper, namely the debate about monetary policy regimes. The model I estimate uses long-term inter-

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[43] The return on a bond of maturity m is $\ln(\frac{P_t^m}{P_{t-1}^m}) \simeq -m\left(i_t^m - i_{t-1}^m\right)$, where $P_t^m = \exp(-i_t^m m)$ is the price of the zero coupon bond.

est rate data to empirically distinguish between different monetary policy regimes. Given the results already discussed in this section, it should be clear that a monetary regime under discretion is more likely to have prevailed in the U.S. In the data, we observe long rates to be highly volatile and correlated with the short rate. The results generated by the model seem to preclude a regime where the central bank can commit to future actions and stabilize inflation expectations. It seems that market participants believed and behaved as if the monetary policy followed by the Fed were discretionary during the whole sample. Moreover, the different chairmen of the Fed do not seem to have influenced those beliefs. In this way, long-term interest rates can help us understand how monetary policy has been conducted in the last 45 years.

This result is formally confirmed if we use posterior odds ratios to compare the two policy regimes.[44] Table 2.7 shows that the posterior odds ratios clearly favor the discretionary regime in both periods.[45] Similarly to my previous observations, this result is starker in the second period.

A discretionary monetary policy implies a more volatile process for inflation and the short-term interest rate than a commitment regime. In the model, this translates into larger movements in long-term interest rates which are strongly correlated with movements in the short rate. A central bank that can credibly commit does not need to move its instrument so much to control inflation, since it can effectively control the path of inflation by managing inflation expectations. In that sense, policymakers' misperceptions about the natural rate of unemployment are less important in the commitment regime.

4.3.5   Model Assessment

In the previous subsections, I have shown that the variability of long-term interest rates is due to a combination of lack of knowledge about the natural rate of unemployment and monetary policy regimes. Next, I investigate the marginal contribution of these factors to explain long-term rate volatility. I graphically do so

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[44] The posterior odds ratio is the ratio of the marginal data densities between two models (given that I set the prior odds equal to one). To calculate the marginal likelihood, I use the modified harmonic mean.

[45] The posterior odds ratio also favors the discretionary regime as compared to a model with a Taylor-type interest rate rule.

for the case when risk premium shocks are shut off. Figure 2.9 shows the standard deviation of 10-year interest rates in the U.S. between 1983 and 2005 to be 2.26. The figure also shows the posterior predictive distribution for the discretionary and commitment case (as in Figure 2.5), and the simulated standard deviation in the case when the monetary authority can directly observe u_t^N: when misperception shocks are shut off.[46] The two lines to the left show that the simulated volatility in a model where the central bank can observe u_t^N is very low and far from the data, independently of the monetary policy regime. Once we allow for imperfect information about the natural rate of unemployment, the model under discretion outperfoms the commitment case and is able to explain most of the observed volatility in the data.

Subsequently, I ask how important is the value of ρ for explaining movements in long-term rates. Figure 2.10 shows that only high values of ρ can add volatility to long-term interest rates. Using the posterior mean of the other parameters for the period 1983-2005, the figure simulates the volatility of 10 year rates for different values of ρ under discretion.[47] In accordance with Table 2.3, values of ρ of around 0.98 are able to explain the observed volatility in the data. Furthermore, very little volatility can be explained when misperception shocks are not very persistent: when ρ is below 0.85, the model is not able to add volatility to long-term rates. In the commitment case, even for values of $\rho = 1$, the model generates a maximum of 165 basis point of volatility.

5   The Case of the U.K.

A large literature has studied the relation between monetary institutions and credibility.[48] In particular, many papers stress the fact that independent central banks with price stability as their main objective will increase credibility and stabilize inflation without much effect on output or unemployment.[49]

In May 1997, the Bank of England was officially granted operational independence. Since then, the bank is committed to "promoting and maintaining monetary

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[46] I simulate the standard deviation of 10-year interest rates under discretion and commitment using the estimated posterior mean and setting the variance of misperception shocks equal to zero.

[47] For a sample of 1000 simulations for 75 periods.

[48] See Persson and Tabellini (2000) for a review.

[49] Alesina and Summers (1993), among others, find that a more independent central bank reduces the level and variability of inflation, but has not impact on real activity.

and financial stability as its contribution to a healthy economy"[50] . Given the specific inflation target objective of the bank, one may think that monetary policy can be approximated by a commitment regime to achieve this goal.[51]

A first look at the data shows that after the Bank of England became independent, U.K. data is indeed less volatile both when it comes to inflation and unemployment. Table 2.8 shows that the volatility of short and long rates in the U.K. during the independence period has been lower than in earlier periods. The table also includes data for the U.S. over the same two periods. Clearly, the volatility in long-term rates fell proportionally more in the U.K. than in the U.S. To investigate whether this downward shift in volatility can be attributed to a change of monetary regime, I estimate the model under discretion and commitment for U.K. data during the periods 1983-1997 and 1998-2005.[52]

5.1   Estimation Results for the U.K.

In the estimation, I use the same priors as for the U.S. Table 2.9 reports the estimated mean of the parameters for the U.K. The results are in general similar to those in the U.S. reported in Section 4: high persistence of the natural rate of unemployment and the misperceptions of the central bank, a weight on the unemployment gap in the central bank loss function greater than one, and a response of inflation to the unemployment gap close to 0.08.

5.2   Implications of Different Monetary Policy Regimes

Results not reported here show that both regimes replicate the observed volatility in the macro data reasonably well in both periods. One interesting issue is that after 1997, the correlation between inflation and the short-term interest rate becomes negative in the U.K. (see Table 2.8). Figure 2.11 shows that this can only be replicated by the commitment regime.[53]   However, the discretionary regime does

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[50]   Quotation from Bank of England's home page.

[51]   Sholtes (2002) documents that inflation expectations have fallen and that U.K. monetary policy credibility is stronger since the Bank of England gained independence.

[52]   The data was obtained from the OECD database on unemployment, short-term interest rate (three-months Treasury bill), GDP deflator and ten-year government bond yields. All series were demeaned.

[53]   For the U.S., none of the regimes replicates the negative correlation between inflation and the short-term rate observed in the data.

better in replicating the correlation of the short-term and the long-term rate.

Figure 2.12 reports the posterior predictive distribution of the standard deviation of the ten-year long-bond rate implied by the model, with and without time-varying term premiums, before and after 1998. The figure shows that the discretionary regime does better in replicating the volatility of long-term rates before 1998, even if we add term-premium shocks. However, after 1998, the commitment regime is closer to replicating the observed volatility. Moreover, a variance-decomposition analysis for the U.K. after 1998 shows that term premium shocks have a large role in explaining the volatility of long-term rates in both regimes.[54] Rephrasing, term-premium shocks are now an important component of long-term rate volatility in the U.K., independently of the monetary policy regime. This indicates that we only need to add a small amount of variable term premiums to the model, for the commitment regime to do well in replicating the volatility of long-term rates.[55]

Last, Table 2.10 formally shows that the posterior odds ratio decisively prefers the discretionary regime before 1998. However, after 1998, we cannot longer reject the commitment regime in favor of the discretionary regime; in fact, there is slight evidence in favor of the former.[56] If anything, the evidence suggests that once the Bank of England gained independence, its monetary policy regime became closer to rules than discretion.

6   Conclusion

This paper attempts to explain the behavior of long-term U.S. interest rates in the last 45 years from a macroeconomic perspective. Most papers in the literature rely on a time-varying inflation target to explain the volatility of long-term rates. I propose an alternative explanation and show that the high volatility observed in long-term yields and their correlation with the short rate may be due to a combination of quite persistent misperceptions about the natural rate of unemployment and discretionary monetary policy. In a discretionary regime, the policymaker loses

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[54]   After a period of ten years, term premium shocks explain one fourth of the variation in long-term rates in the discretionary regime and three fourths in the commitment case.

[55]   Alternatively, some kind of monetary policy shock could be introduced to explain long-term volatility. For instance, we can think of control errors as introducing higher volatility.

[56]   In the case of the U.S. during the same period, and despite the lower volatility of long-term interest rates, the posterior odds ratio still favors the discretionary regime after 1998.

control over inflation expectations and actual inflation. Persistent misperceptions that feed into policy make inflationary expectations quite volatile, which has an effect on the volatility of long-term rates and their correlation with the short rate. For this reason, incorporating yield-curve data in the analysis makes it possible to empirically distinguish between different monetary policy regimes.

To further analyze the role of different institutions in monetary policy, the paper estimates the same model with U.K. data during 1983-1997 and 1998-2005, the latter being a period during which the Bank of England was operationally independent. Evidence suggests that during the independence period, the policy pursued by the Bank of England can equally well be classified as a commitment regime or a discretionary regime.

If there are benefits from stabilizing inflation expectations and bonds volatility, the paper has some normative implications. In particular, providing a commitment technology for the monetary authority can reduce the costs of a discretionary regime. Persson and Tabellini (2000) survey the institutional reforms suggested in the literature to enhance the credibility of policymakers, such as the appointment of an independent (conservative) central bank, rigid monetary rules with escape clauses, and explicit inflation targets and contracts to stabilize inflation expectations. Moreover, reaction functions for the central bank that do not respond to the natural rate of unemployment will avoid the problem of policymakers' misperceptions.[57]

One natural extension to this paper would be to investigate the robustness of my results while allowing for time-varying inflation targets, and see how these two mechanisms interact with each other. As previously mentioned, it would also be interesting to study the case when shifts in long-term policy goals occur sporadically.

Although all these extensions are interesting and relevant issues for the conduct of monetary policy, they are beyond the scope of the present paper and thus left to future research.

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[57] Orphanides and Williams (2002) suggest, for instance, that the monetary authority could react to unemployment growth instead of the unemployment gap.

Appendix

2.A   Central Bank Updating Rules

This appendix investigates the behavior of the model when the central bank updates its estimate about the natural rate of unemployment using a constant-gain learning rule or an optimal filter.

2.A.1   Constant-Gain Learning Rules

This is the same learning mechanism for the natural rate as the one used in Primiceri (2006), for instance. Primiceri assumes that policymakers form their estimates about the natural rate using univariate methods: the monetary authority updates its beliefs of the natural rate only looking at the behavior of unemployment. This is consistent with results in Staiger, Stock, and Watson (2001). They show that the natural rate estimated on macro data and the univariate trend in unemployment track each other very closely.

Assuming that, on average, unemployment is equal to its natural rate, the algorithm for updating $\widetilde{u}_t^N$ is

$$\widetilde{u}_t^N = \widetilde{u}_{t-1}^N + \psi R_t^{-1} \left(u_{t-1} - \widetilde{u}_{t-1}^N \right), \tag{2.A1}$$

$$R_t = R_{t-1} + \psi \left(1 - R_{t-1} \right) \tag{2.A2}$$

where ψ is the gain parameter and R_t is the variance of the regressor in equation (2.A1). For this particular problem, this is equivalent to the adaptive expectations formula, since the regressor in the first equation is one. Evans and Honkapohja (2001) show that in general, constant-gain learning rules do not converge to rational expectations. In this model, this will have the effect of producing very little volatility in unemployment.

To solve the model, I calibrate the parameters of a model with commitment and discretion using the estimated posterior means between 1960-1978 reported in Ta-

ble 2.2. For the constant gain parameter, ψ, I set it equal to 0.50.[58] Using these calibrated values, implied values for ρ can be simulated in equation (2.4), which are shown in the last row of Table 2.11. As in my model, misperceptions about the natural rate of unemployment are very persistent. The table also shows the simulated standard deviation and correlation of the variables in the model. Moreover, the table shows that in the case of constant-gain learning, the discretionary regime better replicates both the volatility and the correlation of long-term interest rates. This is in line with the main results in the paper. However, both regimes have problems replicating the behavior of unemployment.

2.A.2   Optimal Filter

Next, I follow the work of Svensson and Woodford (2003) who derive the optimal weights on indicators in models with symmetric partial information.[59] The structure of the model is similar to that in Section 3, but now the central bank uses an optimal filter to infer u_t^N and the other shocks affecting the economy.[60] To generate a more well-defined signal extraction problem for the bank, I assume that the supply shock in equation (1) follows a first-order autoregressive process

$$\varepsilon_t = \omega \varepsilon_{t-1} + \varphi_t,$$

where φ_t is assumed to be *i.i.d.* $N\left(0, \sigma_\varphi^2\right).$

Once again, I calibrate the model for the commitment and discretionary case using the estimated posterior means between 1960-1978 reported in Table 2.2. I set ω equal to 0.85 and σ_φ equal to 0.16. These values imply an unconditional standard deviation for ε of 0.30, which is approximately the estimated mean value reported in Table 2.2.

Table 2.11 shows that when the central bank updates its estimates optimally, the discretionary regime better replicates the volatility of long-term interest rates.

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[58]   This is a higher value than the one generally used in the literature. In another calibration exercise, I set $\psi = 0.03$ which is the same value as that used in Primiceri (2006), and adjust the variance of the shocks to match the observed volatility in inflation and the short-term interest rate. In that case, the discretionary regime does even better matching the volatility of long-term rates.

[59]   The case of asymmetric partial information is more complicated and does not add much for the purpose of this exercise.

[60]   For a detailed description of the solution, see Svensson and Woodford (2003).

This example shows that the main results of my paper still hold in the extreme case of optimal filtering.

Last, the last row in Table 2.11 reports the simulated implied values for ρ in equation (2.4). As shown by Orphanides and Williams (2002), misperceptions about the natural rate of unemployment are very persistent even when the monetary authority uses an optimal filter.

2.B State-Space Representation of the Model

This appendix shows the state-space representation of the model to be estimated with the Kalman filter. I solve the model recursively. First, I solve for equations (4.8)-(2.4) and the corresponding first-order condition, equation (2.5) or (2.6). Second, I use this solution to solve for long-term interest rates using equation (2.7).

2.B.1 Macro Variables

To solve the model numerically, I follow the method described in Sims (2002). Let us define a 7x1 vector of variables

$$Y_t = \left(\ \widetilde{u}_t^N, u_t^N, u_t, \pi_t, i_t, E_t u_{t+1}, E_t \pi_{t+1} \ \right)',$$

a 4x1 vector of exogenous shocks

$$Z_t = (\eta_t, \varepsilon_t, \chi_t, \xi_t)',$$

and a 2x1 vector of expectational errors

$$X_t = (e_t^\pi, e_t^u)'.$$

We can then write the structural model in compact form as:

$$\Gamma_0 Y_t = \Gamma_1^i Y_{t-1} + \Psi Z_t + \Pi X_t, \quad i = D, C$$

where

$$\Gamma_0 = \begin{pmatrix} 0 & \theta & -\theta & -1 & 0 & 0 & \beta \\ 0 & 0 & 1 & 0 & -\delta & -1 & \delta \\ -\frac{\lambda}{\theta} & 0 & \frac{\lambda}{\theta} & -1 & 0 & 0 & 0 \\ 1 & -1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 \end{pmatrix},$$

$$\Gamma_1^D = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ \rho & -\rho & 0 & 0 & 0 & 0 & 0 \\ 0 & \gamma & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 \end{pmatrix}$$

in the discretionary case and

$$\Gamma_1^C = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -\frac{\lambda}{\theta} & 0 & \frac{\lambda}{\theta} & 0 & 0 & 0 & 0 \\ \rho & -\rho & 0 & 0 & 0 & 0 & 0 \\ 0 & \gamma & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 \end{pmatrix}$$

in the commitment case,

$$\Psi = \begin{pmatrix} 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix} \quad \text{and} \quad \Pi = \begin{pmatrix} 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 1 & 0 \\ 0 & 1 \end{pmatrix}.$$

Using Sims matlab code gensys.m, the system can be expressed in standard state-space form

$$Y_t = MY_{t-1} + QZ_t. \tag{2.B1}$$

2.B.2 Long-term Interest Rates

Using the previous solution and equation (2.7), we can solve for long-term interest rates as:

$$i_t^m = \frac{1}{m}\left(M_5 Y_{t-1} + Q_5 Z_t\right) + \frac{M_5}{m}\left(I + M + ... + M^{m-2}\right)\left(MY_{t-1} + QZ_t\right) + \tau_t^m, \quad (2.B2)$$

where $M_5 = M(5,:)$ is the fifth row of matrix M and $Q_5 = Q(5,:)$ is the fifth row of matrix Q. Equations (2.B1) and (2.B2) form the state-space representation of the whole system.

Table 2.1: U.S. Data

	1960-2005	1960-1978	1983-2005
Standard deviation			
Inflation	2.43	2.66	0.97
Unemployment	1.45	1.36	1.27
Short-term interest rate	3.32	2.33	2.54
5-year bonds	2.65	1.57	2.38
10-year bonds	2.55	1.56	2.26
Correlation with short-term rate			
Inflation	0.67	0.82	0.45
5-year bonds	0.91	0.82	0.92
10-year bonds	0.87	0.76	0.87

Note: Annualized data

Table 2.2: Distribution of the Parameters for the U.S. between 1960-1978

Parameter	Prior			Posterior					
				Discretion			Commitment		
	Density	Mode	St. Error	5%	Mean	95%	5%	Mean	95%
σ_ε std. dev. supply shock	Gamma	0.10	0.05	0.284	0.325	0.372	0.264	0.305	0.351
σ_χ std. dev. natural rate of unemployment	Gamma	0.10	0.05	0.270	0.309	0.351	0.267	0.309	0.355
σ_η std. dev. demand shock	Gamma	0.10	0.05	0.150	0.173	0.200	0.155	0.180	0.208
σ_ξ std. dev. misperceptions	Gamma	0.10	0.05	0.066	0.092	0.124	0.206	0.252	0.302
ρ autocor. coef. misperceptions	Beta	0.95	0.005	0.959	0.964	0.970	0.974	0.977	0.981
γ autocor. coef. natural rate of unemployment	Beta	0.95	0.02	0.974	0.982	0.989	0.967	0.976	0.984
λ weight on unemployment gap in loss function	Normal	1.00	0.20	0.716	1.015	1.331	1.342	1.611	1.884
θ response of π to unemployment gap	Gamma	0.10	0.02	0.065	0.091	0.121	0.018	0.023	0.029
σ_5 std. dev. 5-year term premium shock	Gamma	0.10	0.05	0.020	0.038	0.059	0.041	0.059	0.078
σ_{10} std. dev. 10-year term premium shock	Gamma	0.10	0.05	0.085	0.103	0.122	0.112	0.136	0.163

Table 2.3: Distribution of the Parameters for the U.S. between 1983-2005

Parameter	Prior			Posterior					
				Discretion			Commitment		
	Density	Mode	St. Error	5%	Mean	95%	5%	Mean	95%
σ_ε std. dev. supply shock	Gamma	0.10	0.05	0.438	0.491	0.551	0.456	0.512	0.576
σ_χ std. dev. natural rate of unemployment	Gamma	0.10	0.05	0.166	0.187	0.212	0.126	0.146	0.169
σ_η std. dev. demand shock	Gamma	0.10	0.05	0.115	0.131	0.149	0.008	0.016	0.025
σ_ξ std. dev. misperceptions	Gamma	0.10	0.05	0.063	0.081	0.102	0.172	0.201	0.234
ρ autocor. coef. misperceptions	Beta	0.95	0.005	0.973	0.976	0.980	0.975	0.979	0.982
γ autocor. coef. natural rate of unemployment	Beta	0.95	0.02	0.968	0.977	0.986	0.949	0.959	0.969
λ weight on unemployment gap in loss function	Normal	1.00	0.20	0.875	1.141	1.411	1.479	1.732	1.992
θ response of π to unemployment gap	Gamma	0.10	0.02	0.062	0.083	0.107	0.027	0.032	0.039
σ_5 std. dev. 5-year term premium shock	Gamma	0.10	0.05	0.013	0.025	0.039	0.233	0.265	0.301
σ_{10} std. dev. 10-year term premium shock	Gamma	0.10	0.05	0.077	0.090	0.105	0.303	0.345	0.391

Table 2.4: U.S. Variance Decomposition Under Discretion

Shock	1960-1978				1983-2005			
	Inflation	Int. Rate	5 year bonds	10 year bonds	Inflation	Int. Rate	5 year bonds	10 year bonds
After 1 year								
Demand	0	0.60	0	0	0	0.40	0	0
Supply	0.54	0.02	0	0	0.69	0.03	0	0
Natural Rate of Unem.	0	0	0.01	0.01	0	0	0	0
Misperceptions	0.46	0.38	0.96	0.67	0.31	0.57	0.99	0.84
5 year term premium	-	-	0.04	-	-	-	0.01	-
10 year term premium	-	-	-	0.33	-	-	-	0.16
After 10 years								
Demand	0	0.29	0	0	0	0.12	0	0
Supply	0.24	0.01	0	0	0.31	0.01	0	0
Natural Rate of Unem.	0	0.01	0.01	0.01	0	0	0	0
Misperceptions	0.76	0.69	0.98	0.87	0.69	0.87	1	0.96
5-year term premium	-	-	0.01	-	-	-	0	-
10-year term premium	-	-	-	0.11	-	-	-	0.04

Note: Calculated using the posterior mean of the parameters estimated in a model with optimal monetary policy under discretion.

Table 2.5: U.S. Variance Decomposition Under Commitment

Shock	1960-1978				1983-2005			
	Inflation	Int. Rate	5 year bonds	10 year bonds	Inflation	Int. Rate	5 year bonds	10 year bonds
After 1 year								
Demand	0	0.76	0	0	0	0.02	0	0
Supply	0.61	0	0	0	0.82	0.01	0	0
Natural Rate of Unem.	0	0	0.02	0.01	0	0.01	0	0
Misperceptions	0.39	0.24	0.82	0.30	0.18	0.96	0.19	0.05
5-year term premium	-	-	0.16	-	-	-	0.80	-
10-year term premium	-	-	-	0.68	-	-	-	0.94
After 10 years								
Demand	0	0.49	0	0	0	0.01	0	0
Supply	0.32	0	0.01	0.01	0.59	0.02	0.01	0.01
Natural Rate of Unem.	0	0.02	0.04	0.04	0	0.01	0.01	0
Misperceptions	0.68	0.49	0.89	0.51	0.41	0.96	0.38	0.11
5-year term premium	-	-	0.06	-	-	-	0.60	-
10-year term premium	-	-	-	0.45	-	-	-	0.88

Note: Calculated using the posterior mean of the parameters estimated in a model with optimal monetary policy under commitment.

Table 2.6: Simulated Bond *Returns* Volatility for the U.S.

	1960-1978			1983-2005		
	Data	Discretion	Commitment	Data	Discretion	Commitment
5-year returns	0.39	0.44	0.32	0.54	0.54	0.29
10-year returns	0.28	0.32	0.21	0.47	0.43	0.19

Note: Bond returns volatility is calculated as $Std\left(i_t^m - i_{t-1}^m\right)$, performing 1,000 simulations for 75 periods using the posterior mean of the parameters. Annualized data.

Table 2.7: Model Comparison for the U.S.

| | Log marginal likelihood | | Posterior |
	Discretion	Commitment	Odds Ratio
1960-1978	-33.95	-107.28	10^{32}
1983-2005	-13.29	-159.66	10^{63}

Note: The marginal likelihood is approximated by the modified harmonic mean.

Posterior odds of the hypothesis discretion versus commitment.

Table 2.8: U.K. and U.S. Data before and after 1998

| | U.K. | | U.S. | |
	1983-1997	1998-2005	1983-1997	1998-2005
Standard deviation				
Inflation	2.96	1.32	0.98	0.83
Unemployment	1.94	0.53	1.21	0.73
Short-term interest rate	2.93	1.17	2.13	1.94
10-year bonds	1.51	0.44	1.92	0.76
Correlation with short-term rate				
Inflation	0.51	-0.15	0.58	-0.21
10-year bonds	0.83	0.71	0.85	0.82

Note: Annualized data

Table 2.9: Distribution of the Parameters for the U.K.

Parameter	Prior			Posterior Mean			
				1983-1997		1998-2005	
	Density	Mode	St. Error	Dis.	Com.	Dis.	Com.
σ_ε std. dev. supply shock	Gamma	0.10	0.05	0.549	0.569	0.314	0.359
σ_χ std. dev. natural rate of unemployment	Gamma	0.10	0.05	0.325	0.301	0.119	0.123
σ_η std. dev. demand shock	Gamma	0.10	0.05	0.121	0.070	0.085	0.033
σ_ξ std. dev. misperceptions	Gamma	0.10	0.05	0.171	0.311	0.064	0.103
ρ autocor. coef. misperceptions	Beta	0.95	0.005	0.954	0.968	0.950	0.953
γ autocor. coef. natural rate of unemployment	Beta	0.95	0.02	0.967	0.946	0.940	0.915
λ weight on unemployment gap in loss function	Normal	1.00	0.20	1.269	1.519	1.182	1.190
θ response of π to unemployment gap	Gamma	0.10	0.02	0.077	0.043	0.085	0.096
σ_{10} std. dev. 10 year term premium shock	Gamma	0.10	0.05	0.129	0.236	0.059	0.080

Table 2.10: Model Comparison for the U.K.

	Log marginal likelihood		Posterior
	Discretion	Commitment	Odds Ratio
1983-1997	-129.50	-169.75	10^{17}
1998-2005	-9.56	-7.93	0.20

Note: The marginal likelihood is approximated by the modified harmonic mean.

Posterior odds of the hypothesis discretion versus commitment.

Table 2.11: Simulated Results under Different Updating Rules

| | U.S. Data | Simulated | | | |
| | | Constant-Gain Learning | | Optimal Filter | |
	1960-1978	Discretion	Commitment	Discretion	Commitment
Standard Deviation					
Inflation	2.66	3.18	1.50	2.03	3.19
Unemployment	1.36	0.47	0.41	0.40	0.86
Short-term interest rate	2.33	2.84	1.68	2.17	2.58
5-year interest rate[1]	1.57	1.26	0.56	1.38	1.09
10-year interest rate[1]	1.56	0.69	0.45	0.93	0.49
Correlation with Short-Term Rate[1]					
Inflation	0.82	0.78	0.26	0.99	0.99
5-year interest rate	0.82	0.87	0.50	0.80	0.69
10-year interest rate	0.76	0.79	0.20	0.69	0.64
simulated ρ	-	0.91	0.94	0.95	0.96

Note: Performing 1,000 simulations for 75 periods. [1]Calculated for the case of constant term premiums.
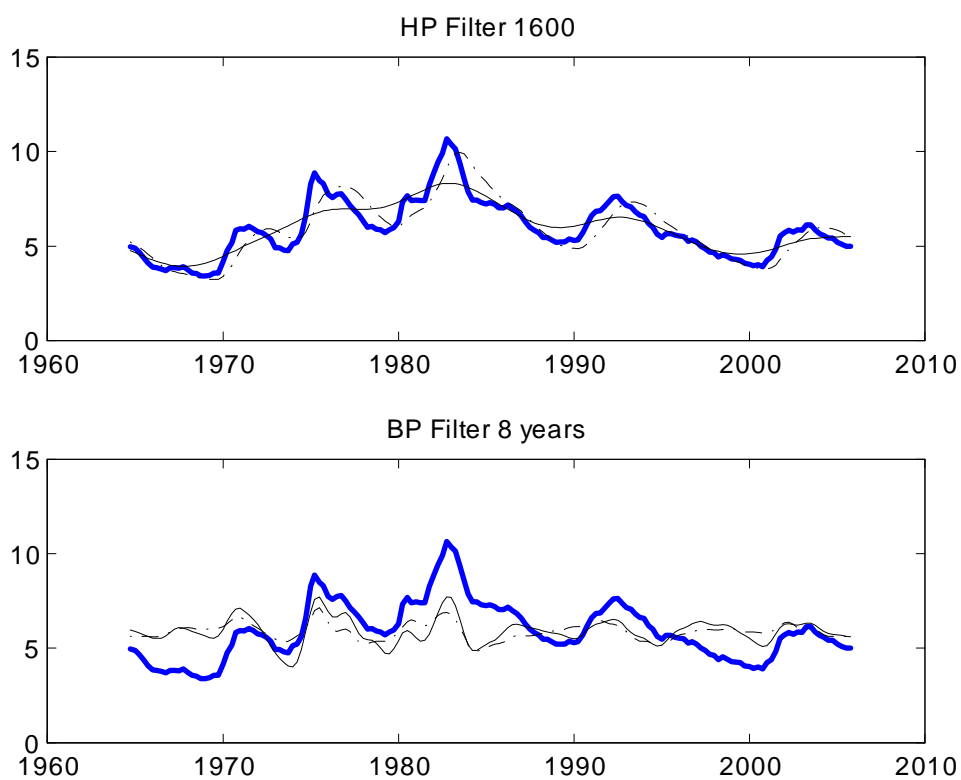
Figure 2.1: U.S. unemployment. Thick line: real data. Thin line: 2-sided filtered data. Dashed line: 1-sided filtered data. Panel A: Hodrick-Prescott filter with smoother parameter 1, 600. Panel B: band-pass filter with an 8-year window.
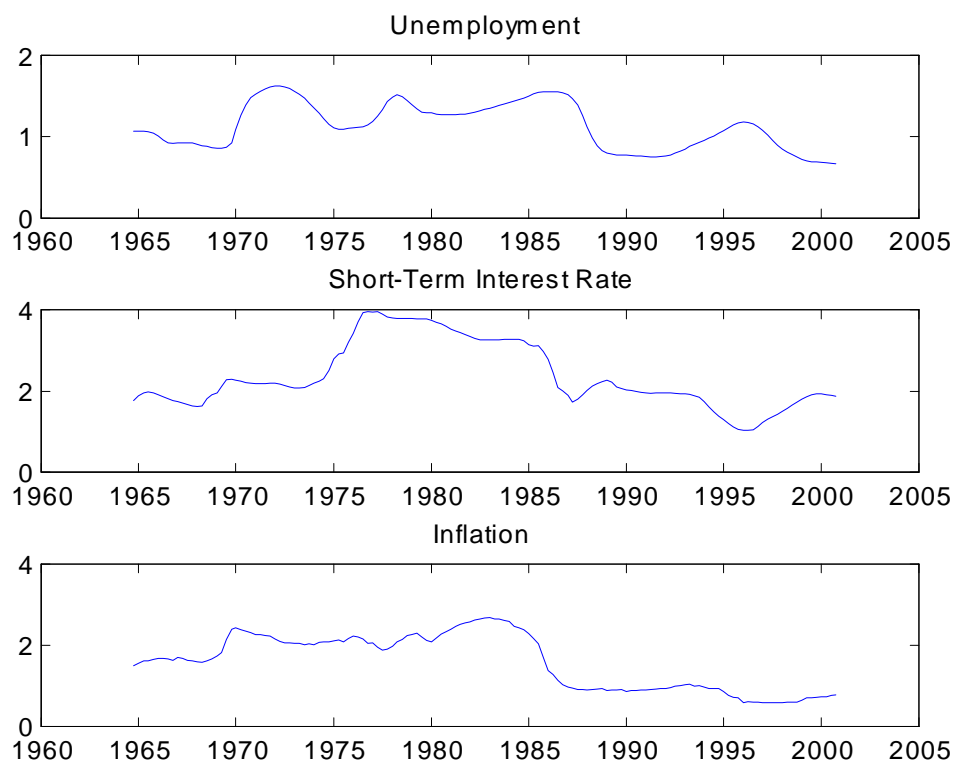
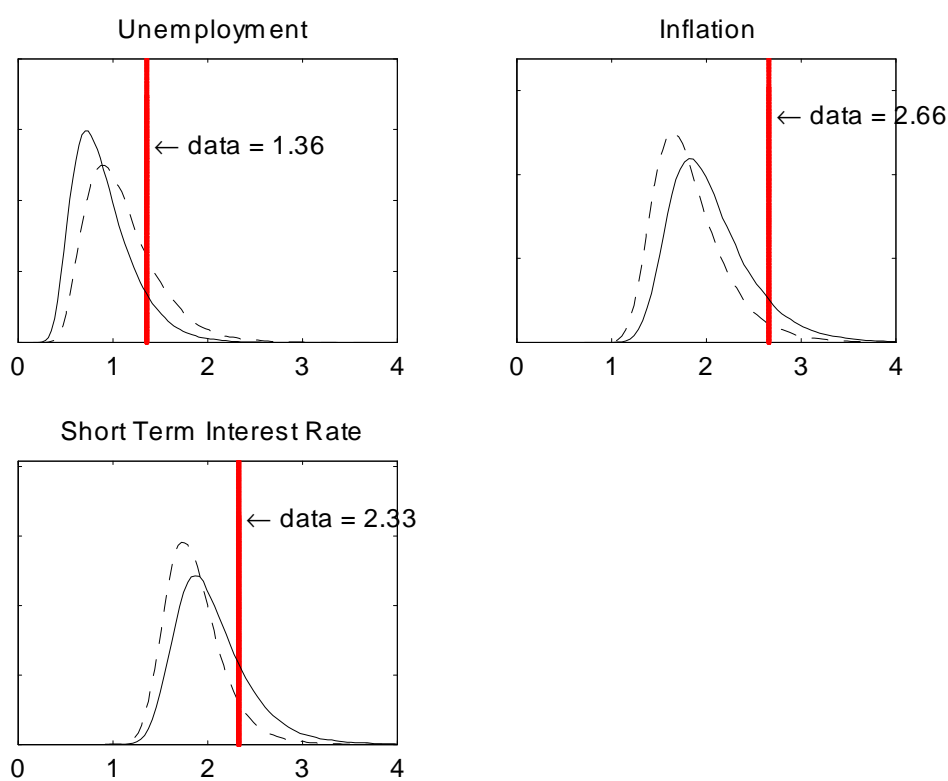Figure 2.2: 10 years rolling standard deviation (centered)

Figure 2.3: Posterior predictive distribution of the standard deviation for U.S. data between 1960-1978. Solid line distribution: optimal monetary policy under discretion. Dashed line distribution: optimal monetary policy under commitment. Bar: actual data.
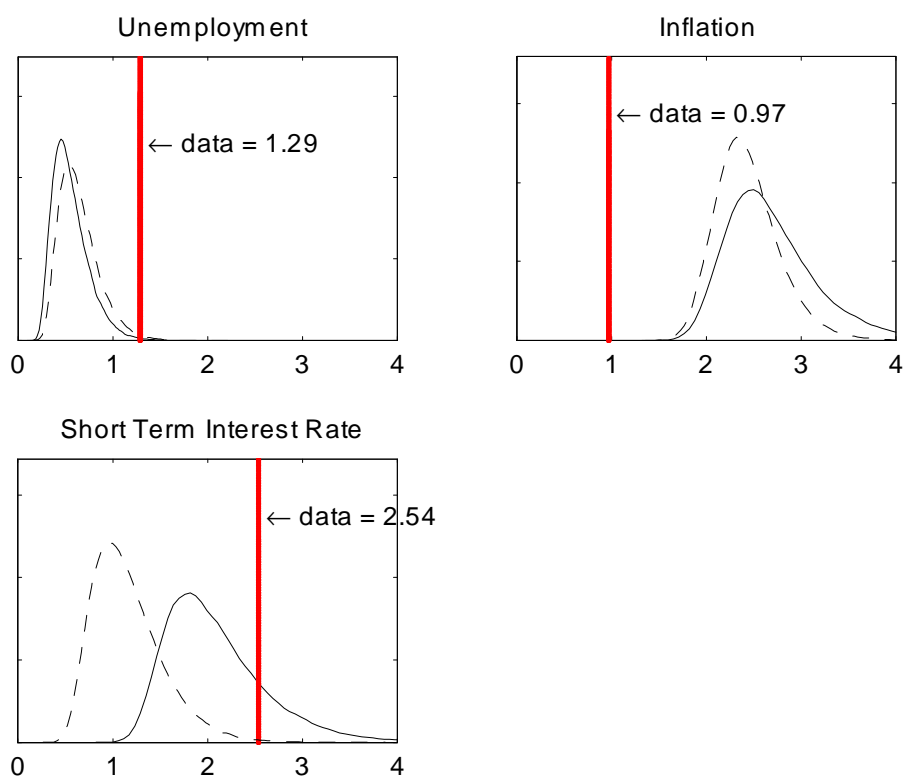
Figure 2.4: Posterior predictive distribution of the standard deviation for U.S. data between 1983-2005. Solid line distribution: optimal monetary policy under discretion. Dashed line distribution: optimal monetary policy under commitment. Bar: actual data.
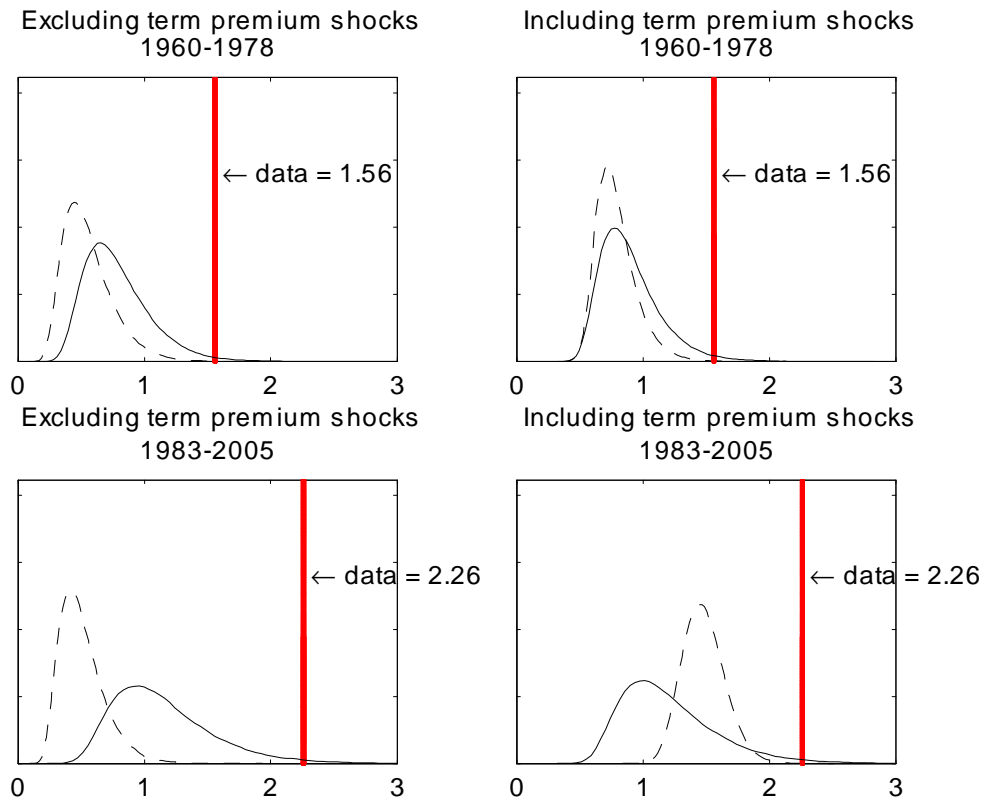
Figure 2.5: Posterior predictive distribution of the standard deviation for U.S. 10-year interest rates. Solid line distribution: optimal monetary policy under discretion. Dashed line distribution: optimal monetary policy under commitment. Bar: actual data.
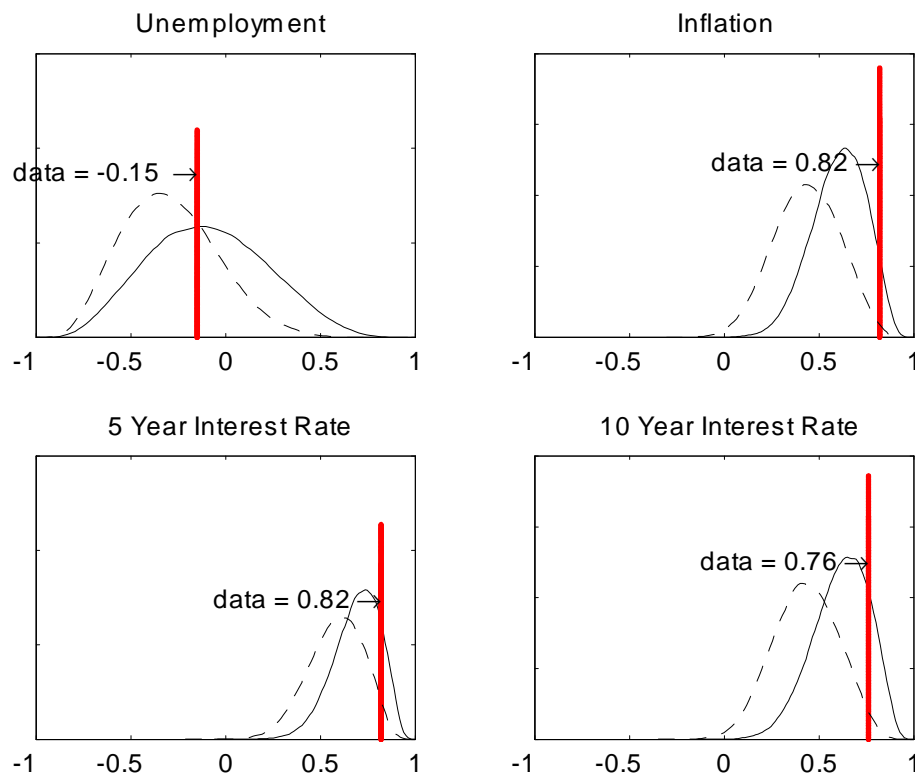
Figure 2.6: Posterior predictive correlation with the short-term interest rate for U.S. data between 1960-1978 (including term premium shocks). Solid line distribution: optimal monetary policy under discretion. Dashed line distribution: optimal monetary policy under commitment. Bar: actual data
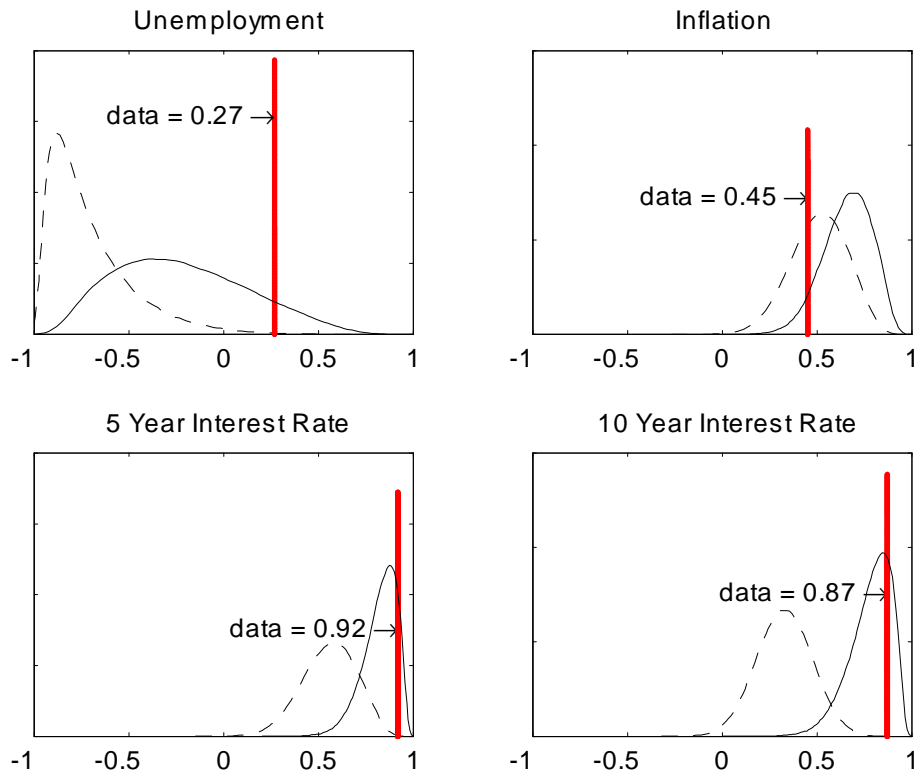
Figure 2.7: Posterior predictive correlation with the short-term interest rate for U.S. data between 1983-2005 (including term premium shocks). Solid line distribution: optimal monetary policy under discretion. Dashed line distribution: optimal monetary policy under commitment. Bar: actual data
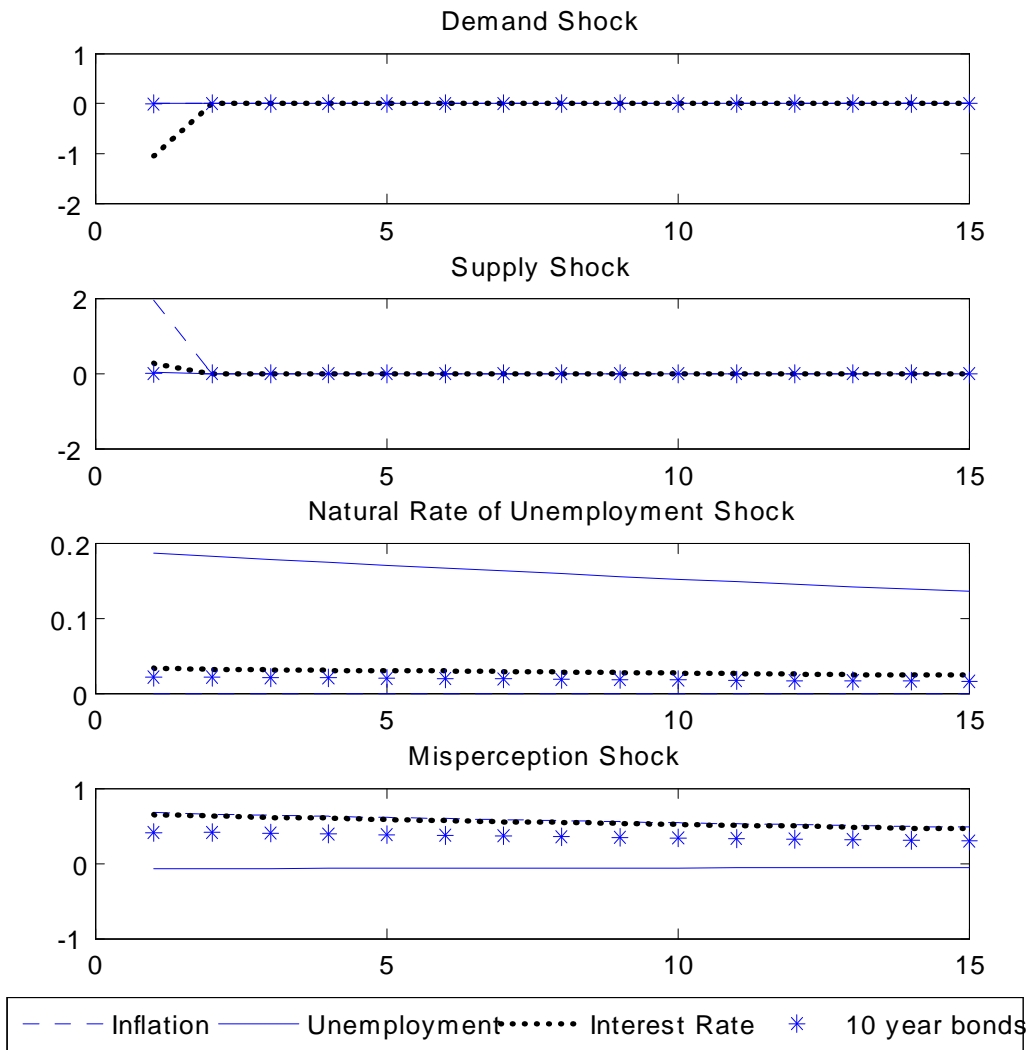
Figure 2.8: Impulse response functions using the posterior mean of the model under discretion estimated with U.S. data from 1983-2005.

10 Year Interest Rate

← Model wo misperception shocks
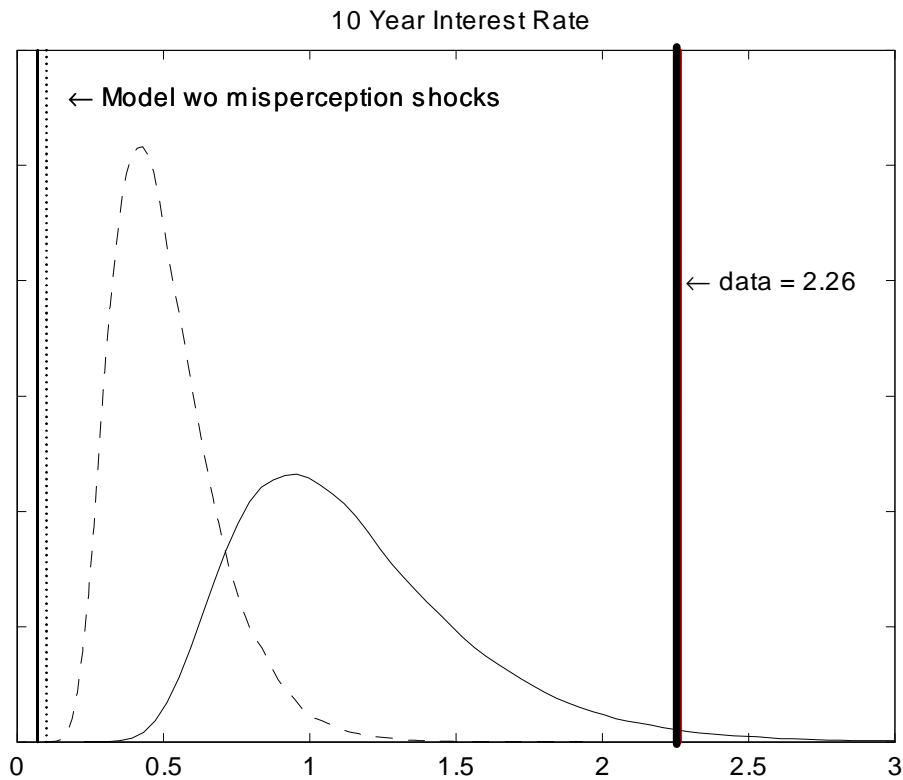
← data = 2.26

0   0.5   1   1.5   2   2.5   3

Figure 2.9: Simulated standard deviation for U.S. 10 year interest rates between 1983-2005. Bar: actual data. Solid line distribution: optimal monetary policy under discretion (exc. term premium shocks). Dashed line distribution: optimal monetary policy under commitment (exc. term premium shocks). Solid line: optimal monetary policy under discretion shutting off misperception shocks. Dashed line: optimal monetary policy under commitment shutting off misperception shocks.
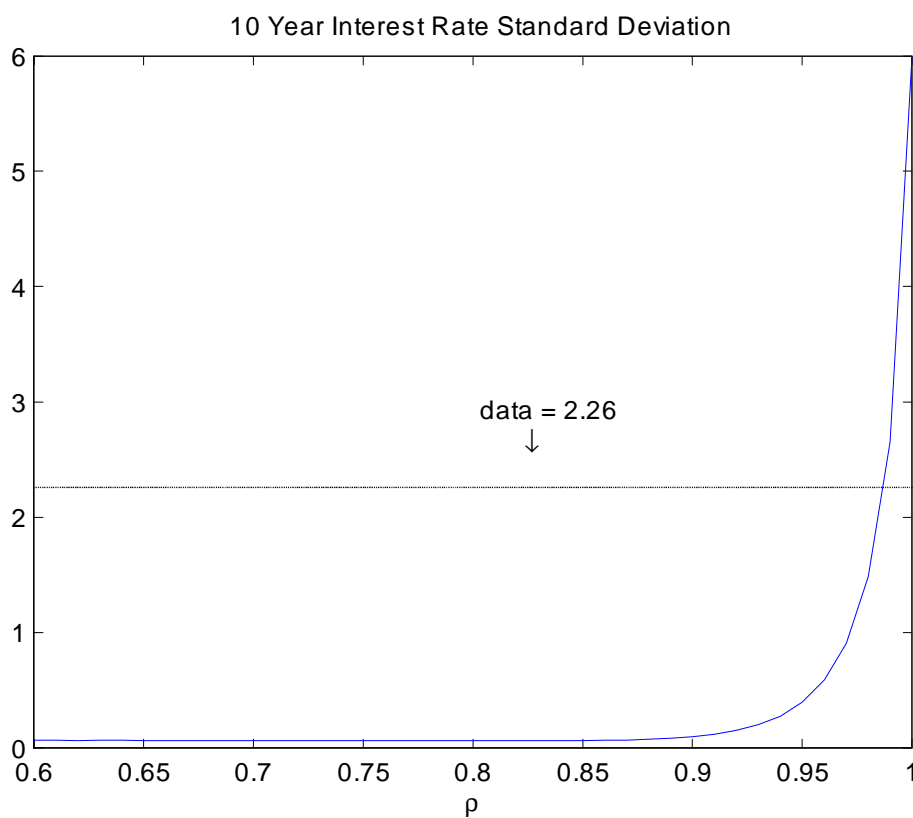
Figure 2.10: Simulated standard deviation of 10 year interest rates using the U.S. estimated mean between 1983 and 2005 under discretionary monetary policy and varying the values of ρ.
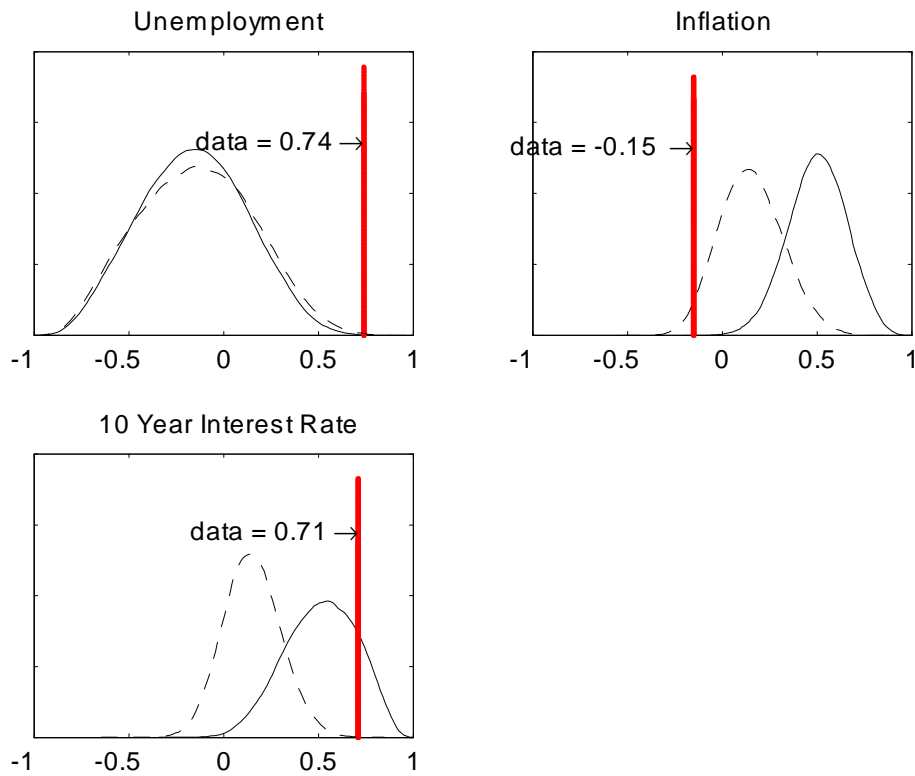
Figure 2.11: Posterior predictive correlation with the short-term interest rate for U.K. data between 1998-2005 (including term premium shocks). Solid line distribution: optimal monetary policy under discretion. Dashed line distribution: optimal monetary policy under commitment. Bar: actual data

Excluding term premium shocks
1983-1997

Including term premium shocks
1983-1997

← data = 1.51

← data = 1.51

Excluding term premium shocks
1998-2005

Including term premium shocks
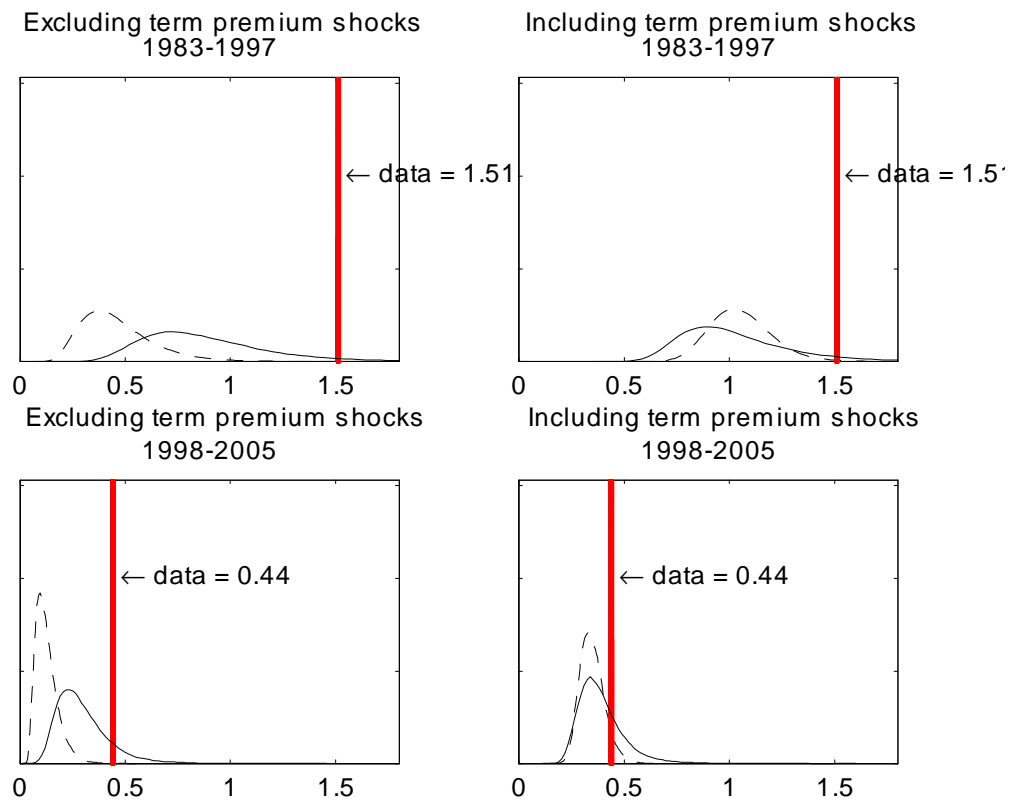1998-2005

← data = 0.44

← data = 0.44

Figure 2.12: Posterior predictive distribution of the standard deviation for U.K. 10 year interest rates. Solid line distribution: optimal monetary policy under discretion. Dashed line distribution: optimal monetary policy under commitment. Bar: actual data.

Chapter 3

Do Central Banks React to House Prices? [*]

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 have risen more than 30% in the U.S. since 1995 (Figure 3.1). In the U.K., house prices peaked in 1989, lost almost 40% of their value by 1995, and have continuously increased since then (Figure 3.2).[1] The experience of Japan is also dramatic. Property prices increased almost 40% in the five years before 1991 and have fallen since then (Figure 3.3). 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?

  [1] The financial liberalization of mortgage lending institutions in the 1980s contributed to the increase in housing prices during this period.

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 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.[2] The results show that house price movements did not a 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 Wadhwani (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 Wadhwani (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

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[2] 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.

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.

Policymakers also hold contrasting views on this issue. For instance, Charles Goodhart, a former member of the Bank of England's Monetary Policy Committee, argues that central banks should track a broader price index which includes the prices of assets, such as houses and equities. However, Filardo (2000) concludes that adopting Goodhart's recommendation would not improve U.S. economic performance since asset prices might contain unreliable information about future inflation.

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 attempting to stabilize the stock market after that date reacting with a positive coefficient. 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. Contrary to the previous literature, we focus on house prices rather than stock returns. Empirically, house and stock prices are highly correlated (Figures 3.1-3.3) and swings in both kinds of assets have been highlighted as key factors behind business cycles.[3] 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,[4] 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.[5]

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. 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.

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

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[3] 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.

[4] See e.g. Carroll, Otsuka, and Slacalek (2006) among others.

[5] See e.g. Stock and Watson (2003) and Filardo (2000).

Iacoviello and Neri (2007), all use Bayesian methods to estimate 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.[6] 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 an 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 de-

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[6] Iacoviello estimates the key structural parameters by minimizing the distance between the impulse responses implied by the model and those generated by an unrestricted vector autoregression in the U.S.

flation). 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 combing 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, denoted with prime (" ′ "), and impatient, denoted with double prime (" ″ "). Each group has a continuum of agents indexed by $i \in (0,1)$. Impatient households discount the future more heavily than patient ones $(\beta'' < \beta')$. Both groups maximize a lifetime utility function given by:

$$MaxE_0 \sum_{t=0}^{\infty} z_t \left(\beta'\right)^t \left(\ln \left(c'_{i,t} - \zeta C'_{t-1}\right) + j_t \ln h'_{i,t} - \frac{\left(l'_{i,t}\right)^{\eta}}{\eta} \right),$$

$$MaxE_0 \sum_{t=0}^{\infty} z_t \left(\beta''\right)^t \left(\ln \left(c''_{i,t} - \zeta C''_{t-1}\right) + j_t \ln h''_{i,t} - \frac{\left(l''_{i,t}\right)^{\eta}}{\eta} \right),$$

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).[7] The variables z and j represent shocks to aggregate demand and housing demand, which both

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[7] Real balances do not enter households' utility function since we assume a cashless limiting economy as in Woodford (2003).

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:

$$l'_{i,t} = \left(\frac{w'_{i,t}}{w'_t}\right)^{\frac{\lambda_t}{1-\lambda_t}} L'_t,$$

$$l''_{i,t} = \left(\frac{w''_{i,t}}{w''_t}\right)^{\frac{\lambda_t}{1-\lambda_t}} L''_t,$$

where λ is a time varying wage markup and w are nominal wages. 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 constraints:

$$c'_{i,t} + q_t \Delta h'_{i,t} + \frac{R_{t-1}}{\pi_t} b'_{i,t-1} = b'_{i,t} + \frac{w'_{i,t}}{P_t} l'_{i,t} + F_{i,t} + T'_{i,t},$$

$$c''_{i,t} + q_t \Delta h''_{i,t} + \frac{R_{t-1}}{\pi_t} b''_{i,t-1} = b''_{i,t} + \frac{w''_{i,t}}{P_t} l''_{i,t} + T''_{i,t},$$

where q denotes real house prices, b real debt,[8] F lump-sum transfers received by patient households from retailers and T net cash inflows from participating in state-contingent security markets.[9]

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

$$b''_{i,t} \leq m'' E_t \left(q_{t+1} h''_{i,t} \frac{\pi_{t+1}}{R_t}\right).$$

Given that $\beta'' < \beta'$, this constraint holds with equality in steady state.[10] As

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[8] We assume that households can save only in one period bonds. 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.

[9] As described in the next subsection, we assume monopolistic competition in the retail sector. The resulting profits are rebated lump-sum to patient households (F).

[10] In steady state, $\beta' - \beta'' = (1 - \zeta) c'' \chi''$, where χ'' is the multiplier associated with the borrowing

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.

The first-order conditions for the households' problems are standard and their loglinearized versions are reported in Appendix 3.A.

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 constraints:

$$Y_t = a_t K_{t-1}^{\mu} h_{t-1}^{\nu} L_t'^{\alpha(1-\mu-\nu)} L_t''^{(1-\alpha)(1-\mu-\nu)},$$

$$\frac{Y_t}{X_t} + b_t = c_t + q_t \Delta h_t + \frac{R_{t-1}}{\pi_{t-1}} b_{t-1} + \frac{w_t'}{P_t} L_t' + \frac{w_t''}{P_t} L_t'' + \widetilde{I}_t,$$

$$K_t = (1 - \delta) K_{t-1} + s_t \widetilde{I}_t - \xi_{Kt},$$

$$\widetilde{I}_t = \frac{I_t + \xi_{Kt}}{s_t},$$

$$\xi_{K,t} = \psi \left(\frac{I_t}{K_{t-1}} - \delta \right)^2 \frac{K_{t-1}}{2\delta},$$

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

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constraint. Since we assume $\beta' - \beta'' > 0$, χ'' must be greater than zero in steady state which implies that the borrowing constraint holds with equality.

where:

$$L'_t = \left[\int_0^1 \left(l'_{i,t} \right)^{\frac{1}{\lambda_t}} di \right]^{\lambda_t},$$

$$L''_t = \left[\int_0^1 \left(l''_{i,t} \right)^{\frac{1}{\lambda_t}} di \right]^{\lambda_t},$$

the variable a represents an AR(1) technology shock, X denotes the markup of final over intermediate good $\left(X \equiv \frac{P}{P^w} \right)$, ξ_K represents adjustment costs for capital installation,[11] and s is an investment-specific technological shock which follows an AR(1) process. Since by assumption $\gamma < \beta'$, the borrowing constraint holds with equality in steady state.[12] As in the case of impatient households, we assume the constraint to always be binding, also outside of 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^w_t 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:

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

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. The loglinearized first-order conditions for entrepreneurs and retailers are reported in Appendix 3.A.

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[11] We also tried a different 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).

[12] As in the case of impatient households, in steady state $\beta' - \gamma = c\chi$, where χ 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:

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

where variables with a circumflex (" ˆ ") 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:

$$H = h_t + h_t' + h_t''$$

$$Y_t = C_t + C_t' + C_t'' + \frac{I_t}{s_t} + \frac{\varepsilon_{K_t}}{s_t}$$

$$b_t + b_t' + b_t'' = 0.$$

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:

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

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

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

The variances of the ε_v shocks are denoted by σ_v^2.

The model is loglinearized around its deterministic steady state and solved nu-

merically using the methods described in Sims (2002). In Appendix 3.A, we report the whole system of equations.

3   Estimation Results

We estimate the model for the U.S., U.K. and Japan using Bayesian methods. Combining prior distributions with the likelihood function of the data, we obtain the posterior kernel which is proportional to the posterior density. Since the posterior distribution is unknown, we use Markov Chain Monte Carlo (MCMC) simulation methods to conduct inference about the structural parameters.[13]

The data used for the estimation corresponds to the seven variables in the model: real consumption, real investment, hours worked, real wages, real house prices, inflation and nominal interest rates.[14]   A detailed description of the data can be found in Appendix 3.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.[15]   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.[16]

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[13] 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.

[14] 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).

[15] 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.

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

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.[17] The discount factors β', β'' and γ are set at 0.9925, 0.97 and 0.98, respectively.[18] The choice of the discount factor for patient households, β', 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. 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.[19]

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 3.1. 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 ζ 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 η is normally distributed with mean 2 and standard error 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

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[17] 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.

[18] These are the same values as those chosen in Iacoviello and Neri (2007) which guarantee that the borrowing constraints bind.

[19] 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'').

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'' 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.[20]

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 an autoregressive parameter ρ, beta distributed with mean 0.70 and standard deviation 0.10. The prior for the response coefficient of the interest rate to inflation Γ_π, is gamma distributed with mean 1.70 and standard deviation 0.20, while the response to output Γ_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 Γ_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.

3.2 General Estimation Results and Posterior Distributions

3.2.1 Results for the U.S.

We start by reporting the results for the U.S. Table 3.1 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 Γ_q is 0.08. However, looking at the posterior estimates of Γ_q may be misleading since the results may be influenced by the choice of our prior. In the next subsection, we report posterior

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[20] Iacoviello and Neri (2007) calibrate m'' to 0.85.

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 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 discussed later, after a negative price markup shock, the hike in inflation deflates the real value of the debt for borrowers, thereby diminishing the initial fall 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%[21] 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.[22] This result is opposite to 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.[23]

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.[24]

3.2.2 Results for the U.K.

Table 3.2 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

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[21] This result is in line with macro estimates of the fraction of disposable income that goes to rule-of-thumb consumers.

[22] In interpreting this result, we should take into account that, as mentioned above, our house price data does not include commercial housing. This might distort our estimates of the loan-to-value ratio for entrepreneurs.

[23] Also the house price series used by Iacoviello (2005), i.e., the Freddie Mac's conventional mortgage home price index, does not include commercial housing.

[24] For instance, we could think that housing preference shocks follow an AR(2) process instead.

inflation and more strongly to house price inflation than the Fed. The mean value of Γ_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 Results for Japan

The results for Japan are shown in Table 3.3. 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 Γ_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 3.4 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 strong evidence in favor of the unrestricted model.[25]

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 Γ_q in the unrestricted model is different from zero is related to the choice of our prior. Once we take this into account, the 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 3.4 through Figure 3.15.[26]

After a tightening of monetary policy (Figures 3.4, 3.8 and 3.12), aggregate demand, house prices and inflation fall. As mention 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

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[25] 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 Γ_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.

[26] Responses are presented in percentage points. The shocks are set to one standard deviation.

of housing is fixed in the model. A positive house price shock (Figures 3.5, 3.9 and 3.13) 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 for impatient households. In this case, a substitution effect[27] 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 fall in asset prices after a price markup shock (Figures 3.6, 3.10 and 3.14) cuts down the borrowing capacity of borrowers. On the other hand, the increase in inflation transfers wealth from lenders to borrowers. It turns out that the first effect dominates and total spending decreases. Interestingly, for the three countries, the propagation mechanism after a markup shock is not affected by a central bank that responds to house prices.

The same happens in the case of technology shocks (Figures 3.7, 3.11 and 3.15). A positive shock to productivity raises house prices, thus increasing the spending capacity of borrowers. The fall in consumer prices, on the other hand, transfers wealth towards lenders, but borrowers still choose to raise their consumption.

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[27] A housing preference shock changes the marginal rate of substitution between consumption and housing.

3.5   Variance Decomposition

To analyze the importance of the different shocks in the data, we perform variance decomposition analysis. In Tables 3.5, 3.6 and 3.7, 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 3.5 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 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 3.6. 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 3.7 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 3.8 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 Γ_q.[28] Tables 3.9-3.11 show the posterior distribution of the monetary policy parameters under the alternative models for the three countries.

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[28] 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 $E_t\pi_{t+1}$.

Lower prior

First, we reestimate the model using a lower prior mean for Γ_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 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 Γ_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:

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

This specification assumes that central banks react to house price levels rather than house price inflation. We set a prior distribution for Γ_{qq} equal to that for Γ_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:

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

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 ρ, 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:

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

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 Γ_{qq} equal to the one for Γ_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 univariate 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 a 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.[29] 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 bonds. As a result, we might overestimate the response of the economy to monetary policy in a country like

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[29] One related question is to what extent house price inflation is driven by fundamental or non-fundamental changes. In our paper, all movements in house prices are caused by fundamental shocks.

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.

Appendix

3.A   Steady State and Log-linearized Model

3.A.1   Steady state

Assuming zero inflation in steady state, the steady state of the model is given by:

$$1 = \beta R$$

$$\frac{I}{Y} = \frac{\delta \mu \gamma}{X \left(1 - (1 - \delta)\gamma\right)}$$

$$\frac{C}{Y} = \frac{1}{X}\left(\mu + \nu - m\frac{\gamma \nu (1 - \beta')}{(1 - \gamma_e)} - \frac{\mu \gamma \delta}{1 - (1 - \delta)\gamma}\right)$$

$$\frac{C''}{Y} = \frac{1 - \gamma_h}{(1 - \beta')m''j(1 - \zeta) + 1 - \gamma_h}s''$$

$$\frac{b}{Y} = m\beta'\frac{\nu\gamma}{(1 - \gamma_e)}\frac{1}{X}$$

$$\frac{b''}{Y} = \frac{\beta(1 - \zeta)jm''}{(1 - \beta')m''(1 - \zeta)j + 1 - \beta'' - m''(\beta' - \beta'')}s''$$

$$\frac{qh}{Y} = \frac{\nu\gamma}{(1 - \gamma_e)}\frac{1}{X}.$$

$$\frac{qh'}{Y} = (1 - \zeta)jm''\left(\frac{j(1 - \zeta)}{(1 - \beta')m''j(1 - \zeta) + 1 - \gamma_h}s''\right)$$
$$+ (1 - \zeta)jm\left(\frac{\nu\gamma}{(1 - \gamma_e)}\frac{1}{X}\right) + \frac{s'(1 - \zeta)j}{(1 - \beta')}$$

$$\frac{qh''}{Y} = \frac{j(1 - \zeta)}{(1 - \beta')m''j(1 - \zeta) + 1 - \gamma_h}s'',$$

where:

$$s' = \frac{\alpha(1 - \mu - \nu) + X - 1}{X}$$

$$s'' = \frac{(1 - \alpha)(1 - \mu - \nu)}{X}$$

$$\gamma_h = \beta'' + m''(\beta' - \beta'')$$

$$\gamma_e = (1 - m)\gamma + m\beta'.$$

3.A.2   Log-linearized Model

The model is loglinearized around its deterministic steady state where variables with a circumflex (" ˆ ") represent log-deviations from the steady state. The first order conditions for patient and impatient households' choice of consumption, real state and wages are[30] :

$$\hat{z}_t - \hat{c}'_t + \zeta\hat{c}'_{t-1} = E_t\left(\hat{r}_t - \hat{\pi}_{t+1} + \hat{z}_{t+1} - \hat{c}'_{t+1} + \zeta\hat{c}'_t\right)$$

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

$$\hat{w}'^r_t = \frac{1}{1 + \beta'}\hat{w}'^r_{t-1} + \frac{\beta'}{1 + \beta'}E_t\hat{w}'^r_{t+1} - \hat{\pi}_t + \frac{\beta'}{1 + \beta'}E_t\hat{\pi}_{t+1} + \frac{1}{1 + \beta'}\hat{\pi}_{t-1}$$

$$+ \frac{1}{1 + \beta'}\frac{(1 - \theta_w\beta')(1 - \theta_w)}{\theta_w\left(1 - (\eta - 1)\frac{\lambda}{1-\lambda}\right)}\left[(1 - \zeta)^{-1}\left(\hat{c}'_t - \zeta\hat{c}'_{t-1}\right) + (\eta - 1)\hat{l}'_t - \hat{w}'^r_t\right] + \hat{\lambda}_t$$

$$\hat{q}_t = \gamma_h E_t q_{t+1} + (1 - \gamma_h)\left(\hat{\jmath}_t + \hat{z}_t - \hat{h}''_t\right) - (1 - m''\beta')\left(\hat{z}_t - \omega E_t\left(\hat{z}_{t+1}\right)\right)$$

$$- m''\beta'\left(\hat{r}_t - E_t\hat{\pi}_{t+1}\right) + (1 - m''\beta')\left(\frac{\hat{c}''_t - \zeta\hat{c}''_{t-1}}{(1 - \zeta)} - \omega\frac{E_t\left(\hat{c}''_{t+1} - \zeta\hat{c}''_t\right)}{(1 - \zeta)}\right)$$

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[30] Here we express wages in real terms, $\hat{w}^r_t$.

$$\hat{w}_t^{\prime\prime\prime r} = \frac{1}{1+\beta^{\prime\prime}}\hat{w}_{t-1}^{\prime\prime\prime r} + \frac{\beta^{\prime\prime}}{1+\beta^{\prime\prime}}E_t\hat{w}_{t+1}^{\prime\prime\prime r} - \hat{\pi}_t + \frac{\beta^{\prime\prime}}{1+\beta^{\prime\prime}}E_t\hat{\pi}_{t+1} + \frac{1}{1+\beta^{\prime\prime}}\hat{\pi}_{t-1}$$

$$+\frac{1}{1+\beta^{\prime\prime}}\frac{(1-\theta_w\beta^{\prime\prime})(1-\theta_w)}{\theta_w\left(1-(\eta-1)\frac{\lambda}{1-\lambda}\right)}\left[(1-\zeta)^{-1}\left(\hat{c}_t^{\prime\prime}-\zeta\hat{c}_{t-1}^{\prime\prime}\right)+(\eta-1)\hat{l}_t^{\prime\prime}-\hat{w}_t^{\prime\prime\prime r}\right]$$

$$+\frac{(1-\theta_w\beta^{\prime\prime})(1+\beta^{\prime})}{(1-\theta_w\beta^{\prime})(1+\beta^{\prime\prime})}\hat{\lambda}_t.$$

The budget and borrowing constraints for impatient households are:

$$\frac{b^{\prime\prime}}{Y}\hat{b}_t^{\prime\prime} + s^{\prime\prime}(\hat{y}_t - \hat{x}_t) = \frac{C^{\prime\prime}}{Y}\hat{c}_t^{\prime\prime} + \frac{qh^{\prime\prime}}{Y}\Delta\hat{h}_t^{\prime\prime} + \frac{Rb^{\prime\prime}}{Y}\left(\hat{b}_{t-1}^{\prime\prime} - \hat{\pi}_t + \hat{r}_t\right)$$

$$\hat{b}_t^{\prime\prime} = E_t\left(\hat{q}_{t+1} + \hat{h}_t^{\prime\prime} + \hat{\pi}_{t+1} - \hat{r}_t\right).$$

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

$$\hat{\imath}_t - \hat{k}_{t-1} = \gamma E_t\left(\hat{\imath}_{t+1} - \hat{k}_t\right) + \frac{1-(1-\delta)\gamma}{\psi}E_t\left(\hat{y}_{t+1} - \hat{x}_{t+1} - \hat{k}_t\right)$$

$$+\frac{\hat{c}_t - E_t\hat{c}_{t+1}}{\psi} + \frac{\hat{s}_t - (1-\delta)\gamma E_t\hat{s}_{t+1}}{\psi} - \frac{\hat{z}_t - E_t\hat{z}_{t+1}}{\psi}$$

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

$$\hat{l}_t^{\prime} = \hat{y}_t - \hat{x}_t - \hat{w}_t^{\prime r}$$

$$\hat{l}_t^{\prime\prime} = \hat{y}_t - \hat{x}_t - \hat{w}_t^{\prime\prime\prime r}.$$

The budget and borrowing constraints for entrepreneurs are:

$$(\hat{y}_t - \hat{x}_t)(1-s^{\prime}-s^{\prime\prime}) + \frac{b}{Y}\hat{b}_t = \frac{C}{Y}\hat{c}_t + \frac{qh}{Y}\Delta\hat{h}_t + \frac{Rb}{Y}\left(\hat{b}_{t-1} - \hat{\pi}_t + \hat{r}_{t-1}\right) + \frac{I}{Y}(\hat{\imath}_t - \hat{s}_t)$$

$$\hat{b}_t = E_t\left(\hat{q}_{t+1} + \hat{h}_t + \hat{\pi}_{t+1} - \hat{r}_t\right).$$

The production technology and capital accumulation are given by:

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

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

Retailers choose prices so that:

$$\hat{\pi}_t = \frac{1}{1+\beta'}\hat{\pi}_{t-1} + \frac{\beta'}{1+\beta'}\hat{\pi}_{t+1} - \frac{1}{1+\beta'}\frac{(1-\theta\beta')(1-\theta)}{\theta}\hat{x}_t + \hat{u}_t.$$

Monetary policy is given by:

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

The market clearing condition is:

$$\hat{y}_t = \frac{C}{Y}\hat{c}_t + \frac{C'}{Y}\hat{c}_t' + \frac{C''}{Y}\hat{c}_t'' + \frac{I}{Y}\hat{\imath}_t.$$

The structural shocks are:

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

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

$$\hat{\jmath}_t = \rho_z \hat{\jmath}_{t-1} + \varepsilon_{jt}$$

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

where:

$$\iota = (1-\beta')\frac{h}{h'}$$

$$\iota'' = (1-\beta')\frac{h''}{h'}$$

$$\omega = \frac{(\beta''-m''\beta'')}{1-m''\beta'}$$

3.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.

3.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. 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.

3.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.

3.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.

Table 3.1: U.S. Data

	Prior			Posterior $\Gamma_q = 0$			Posterior $\Gamma_q > 0$		
	Dist.	Mean	SE	5%	Mean	95%	5%	Mean	95%
ζ	beta	0.5	0.2	0.01	0.04	0.09	0.01	0.04	0.09
θ	beta	0.7	0.15	0.83	0.86	0.89	0.83	0.86	0.89
θ_w	beta	0.7	0.15	0.60	0.70	0.81	0.60	0.70	0.82
ψ	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''	beta	0.8	0.05	0.63	0.70	0.77	0.63	0.70	0.77
α	beta	0.64	0.1	0.57	0.71	0.83	0.59	0.72	0.84
η	normal	2	0.75	2.20	3.16	4.19	2.14	3.12	4.16
ρ	beta	0.7	0.1	0.61	0.67	0.73	0.61	0.67	0.73
Γ_p	gamma	1.7	0.2	1.69	1.94	2.22	1.70	1.96	2.25
Γ_y	gamma	0.125	0.1	0.06	0.09	0.12	0.06	0.09	0.12
Γ_q	gamma	0.15	0.1	-	-	-	0.02	0.08	0.16
ρ_a	beta	0.85	0.1	0.970	0.972	0.976	0.969	0.972	0.976
ρ_j	beta	0.85	0.1	0.954	0.979	0.995	0.948	0.975	0.994
ρ_z	beta	0.85	0.1	0.848	0.876	0.914	0.846	0.873	0.913
ρ_s	beta	0.85	0.1	0.811	0.845	0.879	0.811	0.846	0.882
σ_a	i-gamma	0.01	0.2	0.0046	0.0052	0.0059	0.0046	0.0052	0.0059
σ_u	i-gamma	0.01	0.2	0.0013	0.0015	0.0017	0.0013	0.0015	0.0017
σ_j	i-gamma	0.01	0.2	0.0226	0.0488	0.0853	0.0246	0.0543	0.0951
σ_m	i-gamma	0.01	0.2	0.0017	0.0020	0.0024	0.0017	0.0021	0.0025
σ_z	i-gamma	0.01	0.2	0.0073	0.0088	0.0107	0.0074	0.0089	0.0107
σ_s	i-gamma	0.01	0.2	0.0223	0.0264	0.0308	0.0224	0.0266	0.0312
σ_λ	i-gamma	0.01	0.2	0.0015	0.0017	0.0020	0.0015	0.0017	0.0020

Table 3.2: U.K. Data

| | Prior | | | Posterior $\Gamma_q= 0$ | | | Posterior $\Gamma_q > 0$ | | |
	Dist.	Mean	SE	5%	Mean	95%	5%	Mean	95%
ζ	beta	0.5	0.2	0.01	0.06	0.14	0.01	0.06	0.14
θ	beta	0.7	0.15	0.75	0.79	0.84	0.71	0.77	0.81
θ_w	beta	0.7	0.15	0.42	0.51	0.61	0.41	0.50	0.60
ψ	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''	beta	0.8	0.05	0.64	0.71	0.78	0.66	0.73	0.80
α	beta	0.64	0.1	0.50	0.67	0.82	0.54	0.70	0.84
η	normal	2	0.75	1.64	2.33	3.17	1.77	2.47	3.31
ρ	beta	0.7	0.1	0.63	0.69	0.75	0.65	0.71	0.76
Γ_p	gamma	1.7	0.2	1.40	1.58	1.81	1.46	1.67	1.93
Γ_y	gamma	0.125	0.1	0.002	0.02	0.03	0.002	0.01	0.03
Γ_q	gamma	0.15	0.1	-	-	-	0.06	0.12	0.18
ρ_a	beta	0.85	0.1	0.935	0.962	0.981	0.928	0.956	0.978
ρ_j	beta	0.85	0.1	0.986	0.994	0.999	0.980	0.991	0.998
ρ_z	beta	0.85	0.1	0.871	0.906	0.935	0.867	0.900	0.930
ρ_s	beta	0.85	0.1	0.905	0.951	0.989	0.913	0.958	0.992
σ_a	i-gamma	0.01	0.2	0.0074	0.0083	0.0094	0.0074	0.0084	0.0095
σ_u	i-gamma	0.01	0.2	0.0047	0.0054	0.0062	0.0049	0.0056	0.0065
σ_j	i-gamma	0.01	0.2	0.0413	0.0626	0.0948	0.0456	0.0758	0.1202
σ_m	i-gamma	0.01	0.2	0.0021	0.0025	0.0029	0.0020	0.0024	0.0028
σ_z	i-gamma	0.01	0.2	0.0115	0.0142	0.0176	0.0124	0.0153	0.0187
σ_s	i-gamma	0.01	0.2	0.0256	0.0314	0.038	0.0263	0.0321	0.0387
σ_λ	i-gamma	0.01	0.2	0.0042	0.0049	0.0057	0.0043	0.0049	0.0057

Table 3.3: Japanese Data

	Prior			Posterior $\Gamma_q = 0$			Posterior $\Gamma_q > 0$		
	Dist.	Mean	SE	5%	Mean	95%	5%	Mean	95%
ζ	beta	0.5	0.2	0.01	0.02	0.05	0.01	0.02	0.06
θ	beta	0.7	0.15	0.67	0.71	0.76	0.68	0.73	0.78
θ_w	beta	0.7	0.15	0.26	0.35	0.46	0.29	0.40	0.53
Ψ	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''	beta	0.8	0.05	0.68	0.73	0.78	0.66	0.72	0.78
α	beta	0.64	0.1	0.52	0.68	0.82	0.58	0.72	0.84
η	normal	2	0.75	2.00	2.88	3.84	1.88	2.76	3.75
ρ	beta	0.7	0.1	0.72	0.77	0.80	0.73	0.77	0.81
Γ_p	gamma	1.70	0.2	1.68	1.94	2.23	1.72	1.99	2.27
Γ_y	gamma	0.125	0.1	0.003	0.02	0.04	0.003	0.02	0.04
Γ_q	gamma	0.15	0.1	-	-	-	0.09	0.19	0.29
ρ_a	beta	0.85	0.1	0.941	0.964	0.985	0.942	0.966	0.989
ρ_j	beta	0.85	0.1	0.931	0.957	0.980	0.920	0.948	0.973
ρ_z	beta	0.85	0.1	0.812	0.843	0.871	0.811	0.845	0.883
ρ_s	beta	0.85	0.1	0.909	0.937	0.964	0.908	0.938	0.967
σ_a	i-gamma	0.01	0.2	0.0110	0.0123	0.0139	0.0109	0.0123	0.0139
σ_u	i-gamma	0.01	0.2	0.0049	0.0057	0.0066	0.0048	0.0056	0.0064
σ_j	i-gamma	0.01	0.2	0.0946	0.1665	0.2510	0.1168	0.1924	0.2807
σ_m	i-gamma	0.01	0.2	0.0022	0.0026	0.0031	0.0022	0.0026	0.0031
σ_z	i-gamma	0.01	0.2	0.0101	0.0121	0.0145	0.0107	0.0127	0.0152
σ_s	i-gamma	0.01	0.2	0.0428	0.0507	0.0591	0.0413	0.049	0.0575
σ_λ	i-gamma	0.01	0.2	0.0093	0.0109	0.0128	0.0090	0.0105	0.0123

Table 3.4: 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 3.5: 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	0.12	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]
Nom. Int. 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. Cons.	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]
Nom. Int. 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. Cons.	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]
Nom. Int. 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. Cons.	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: Median and 95 percent probability intervals (in brackets)

Table 3.6: 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	0.13	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]
Nom. Int. 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. Cons.	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]
Nom. Int. 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. Cons.	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]
Nom. Int. 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. Cons.	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: Median and 95 percent probability intervals (in brackets)

Table 3.7: 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	0.20	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]
Nom. Int. 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. Cons.	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]
Nom. Int. 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. Cons.	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]
Nom. Int. 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. Cons.	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: Median and 95 percent probability intervals (in brackets)

Table 3.8: Counterfactual simulated standard deviation

	US $\Gamma_q > 0$	US $\Gamma_q = 0$	UK $\Gamma_q > 0$	UK $\Gamma_q = 0$	JPN $\Gamma_q > 0$	JPN $\Gamma_q = 0$
π	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

for 1,000 draws of the model with $\Gamma_q > 0$

Table 3.9: Posterior mean for U.S. data

	Expected Inflation Benchmark $\Gamma_q = 0$ $\Gamma_{qq} = 0$	Expected Inflation Benchmark $\Gamma_q > 0$	Expected Inflation Lower prior $\Gamma_q > 0$	Expected Inflation Rule 2 $\Gamma_{qq} > 0$	Contemporaneous Inflation $\Gamma_q = 0$ $\Gamma_{qq} = 0$	Contemporaneous Inflation Rule 3 $\Gamma_q > 0$	Contemporaneous Inflation Rule 4 $\Gamma_q > 0$ $\Gamma_{qq} > 0$
ρ	0.67	0.67	0.67	0.67	0.72	0.72	0.72
Γ_p	1.94	1.96	1.94	1.97	1.71	1.71	1.74
Γ_y	0.09	0.09	0.09	0.08	0.06	0.06	0.05
Γ_q	-	0.08	0.05	-	-	0.09	0.09
Γ_{qq}	-	-	-	0.008	-	-	0.005
Log marg data	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 3.10: Posterior mean for U.K. data**

| | Expected Inflation | | | | Contemporaneous Inflation | | |
| | | Benchmark | Lower prior | Rule 2 | | Rule 3 | Rule 4 |
	$\Gamma_q=0$ $\Gamma_{qq}=0$	$\Gamma_q>0$	$\Gamma_q>0$	$\Gamma_{qq}>0$	$\Gamma_q=0$ $\Gamma_{qq}=0$	$\Gamma_q>0$	$\Gamma_q>0$ $\Gamma_{qq}>0$
ρ	0.69	0.71	0.70	0.70	0.75	0.76	0.76
Γ_p	1.58	1.67	1.67	1.61	1.44	1.47	1.51
Γ_y	0.02	0.01	0.01	0.01	0.02	0.02	0.02
Γ_q	-	0.12	0.11	-	-	0.09	0.09
Γ_{qq}	-	-	-	0.003	-	-	0.002
Log marg data	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 3.11: Posterior mean for Japanese data

| | Expected Inflation | | | | Contemporaneous Inflation | | |
| | | Benchmark | Lower prior | Rule 2 | | Rule 3 | Rule 4 |
	$\Gamma_q=0$ $\Gamma_{qq}=0$	$\Gamma_q>0$	$\Gamma_q>0$	$\Gamma_{qq}>0$	$\Gamma_q=0$ $\Gamma_{qq}=0$	$\Gamma_q>0$	$\Gamma_q>0$ $\Gamma_{qq}>0$
ρ	0.77	0.77	0.77	0.77	0.80	0.81	0.81
Γ_p	1.94	1.99	1.92	1.97	1.56	1.62	1.64
Γ_y	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Γ_q	-	0.19	0.14	-	-	0.29	0.30
Γ_{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
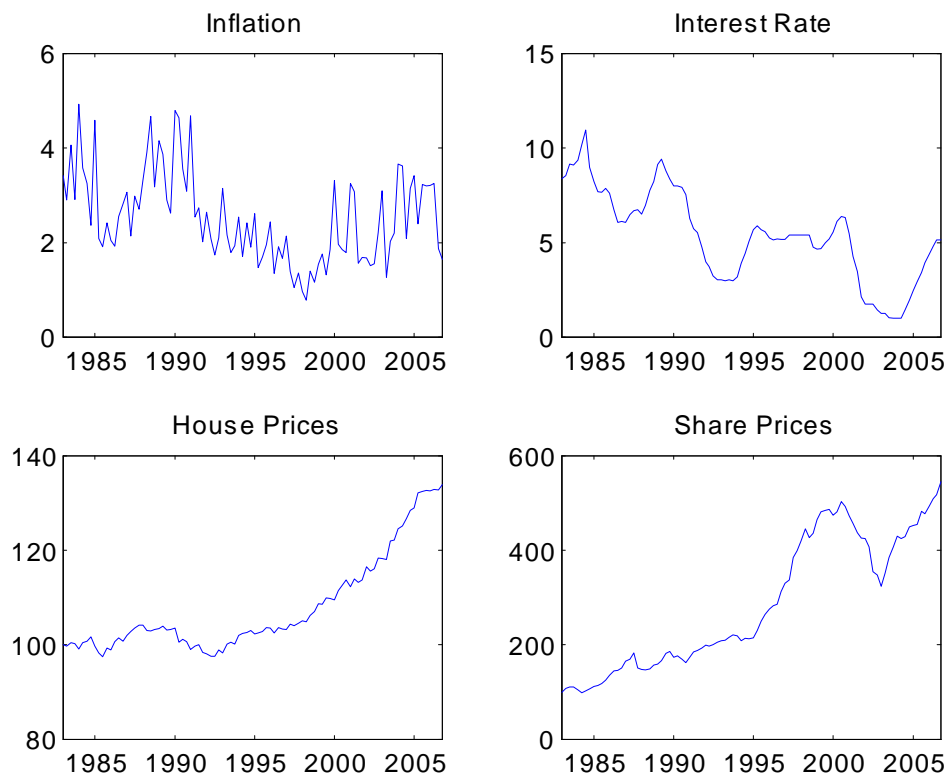
Figure 3.1: United States
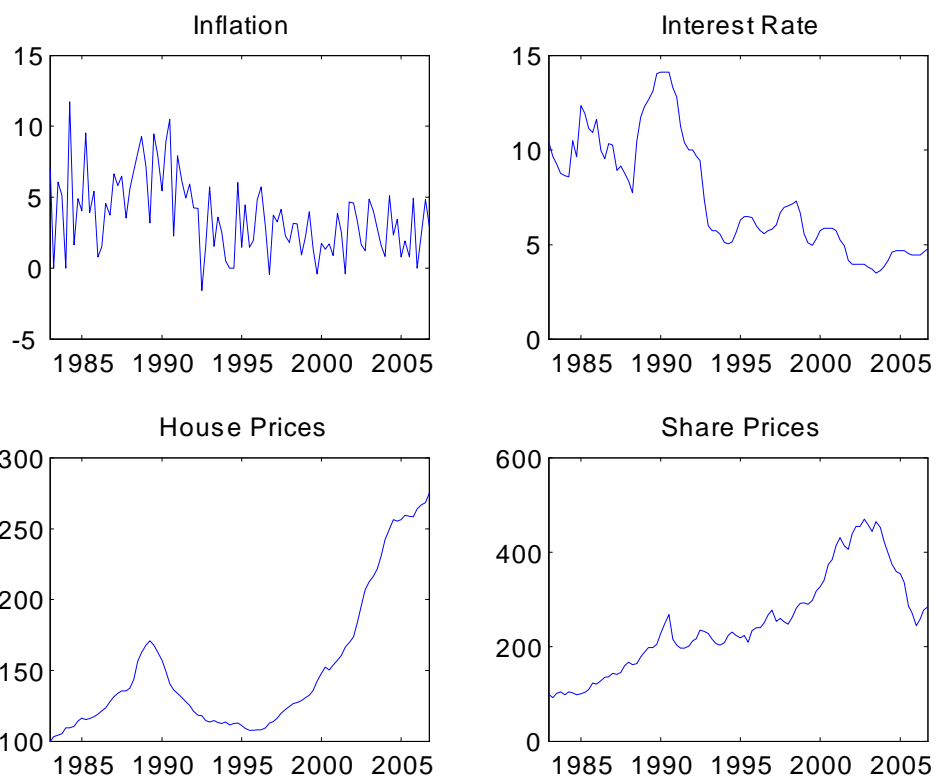
Figure 3.2: United Kingdom
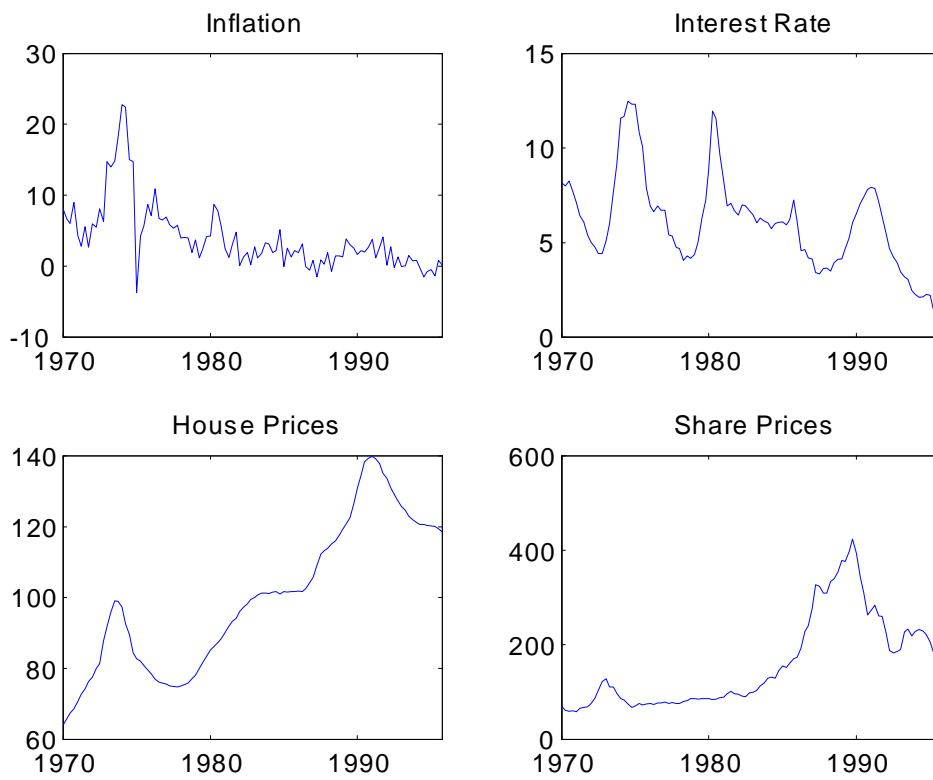
Figure 3.3: Japan
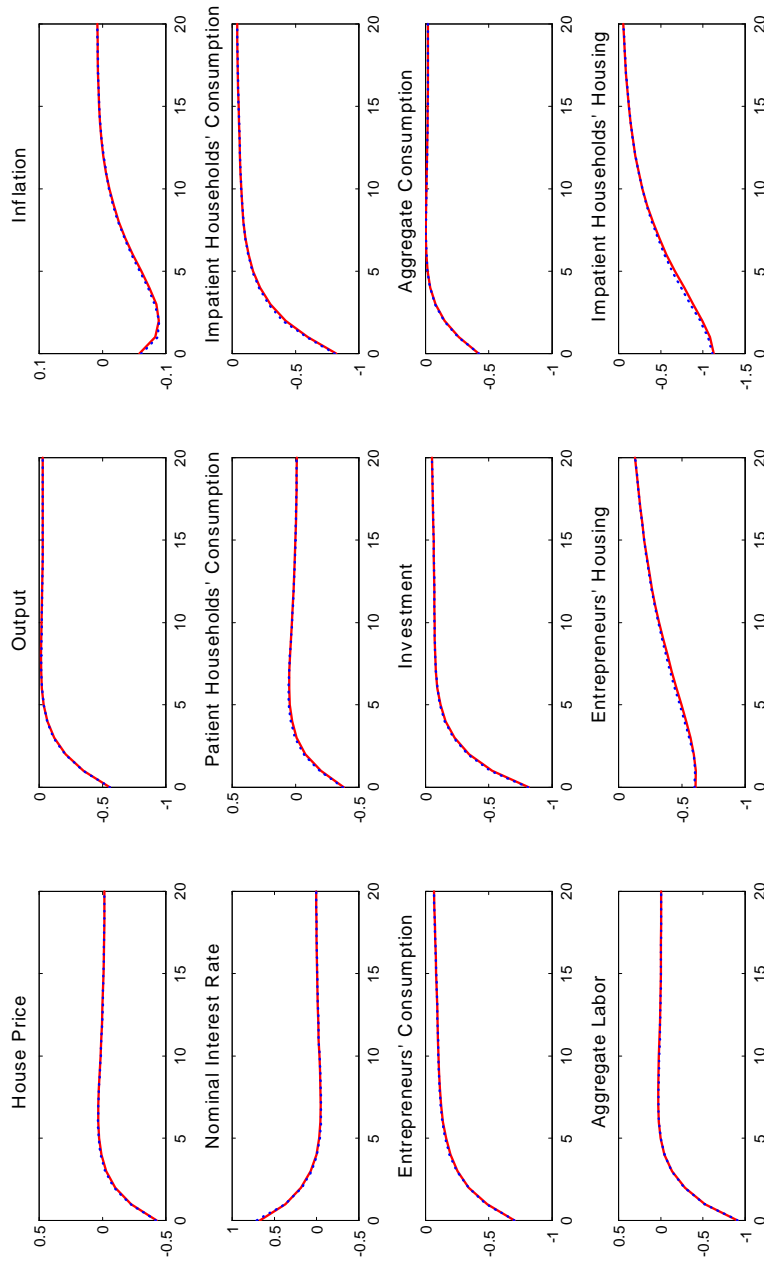
Figure 3.4: Posterior medians for impulse response functions after a monetary policy shock in the U.S. Dotted line: Taylor rule with $\Gamma_q = 0$. Solid line: Taylor rule with $\Gamma_q > 0$.
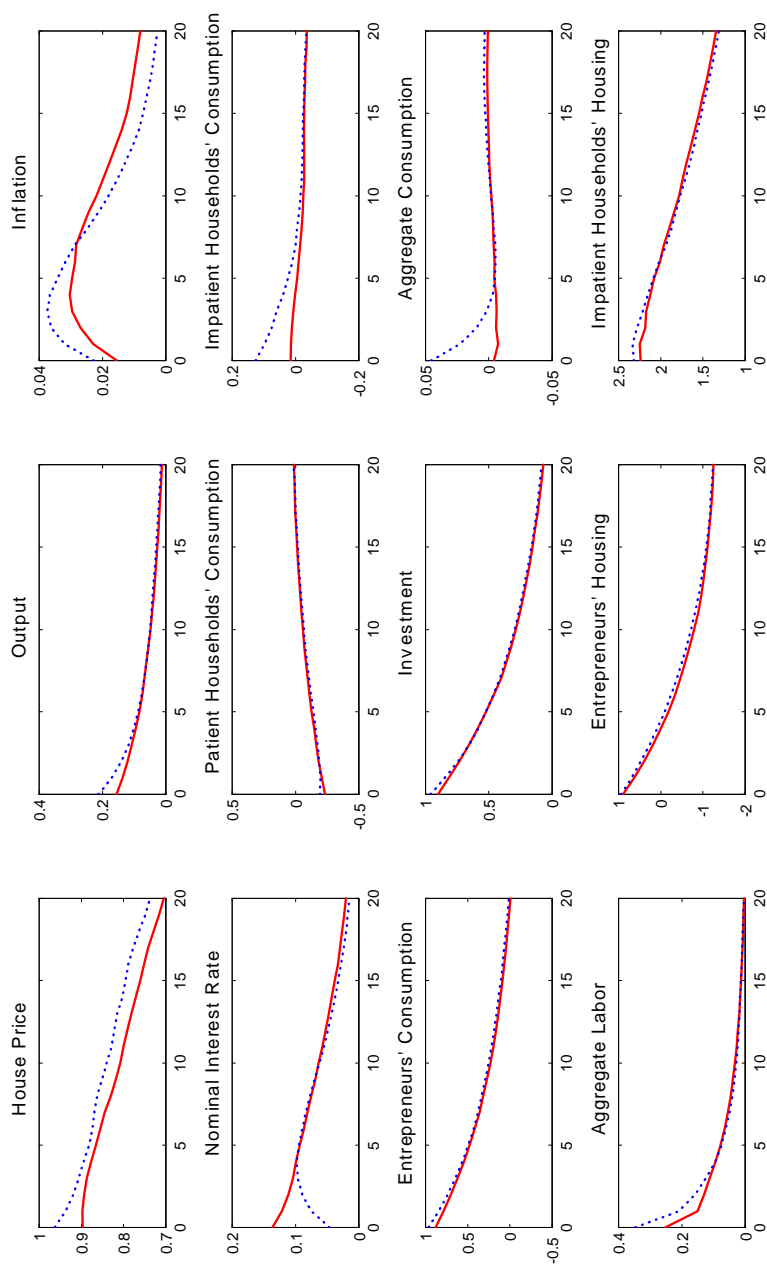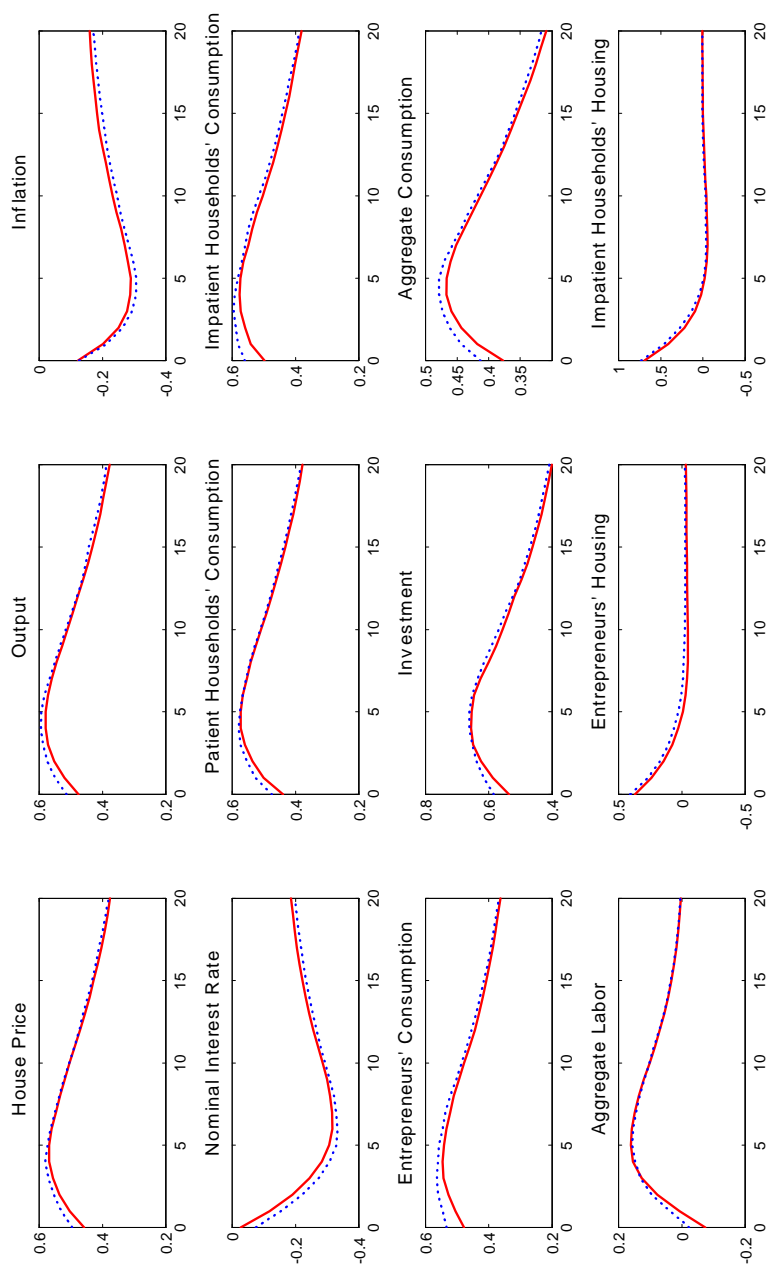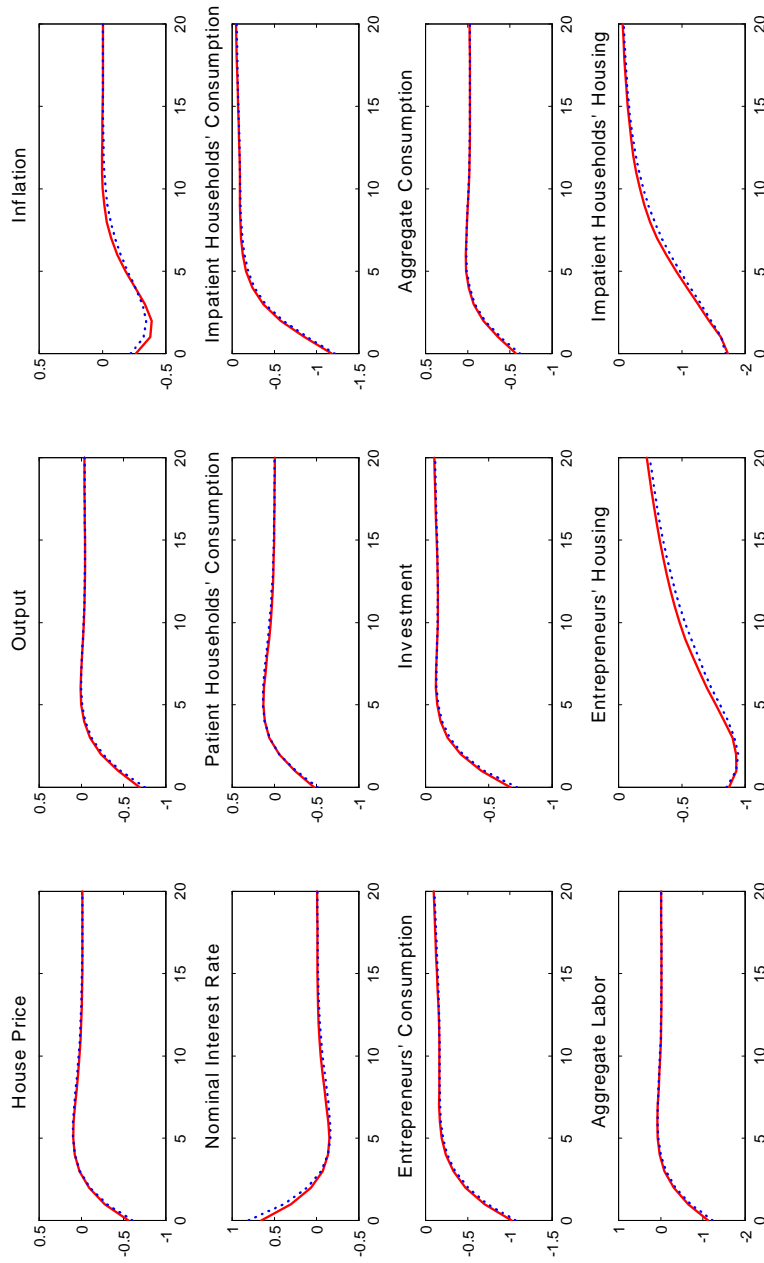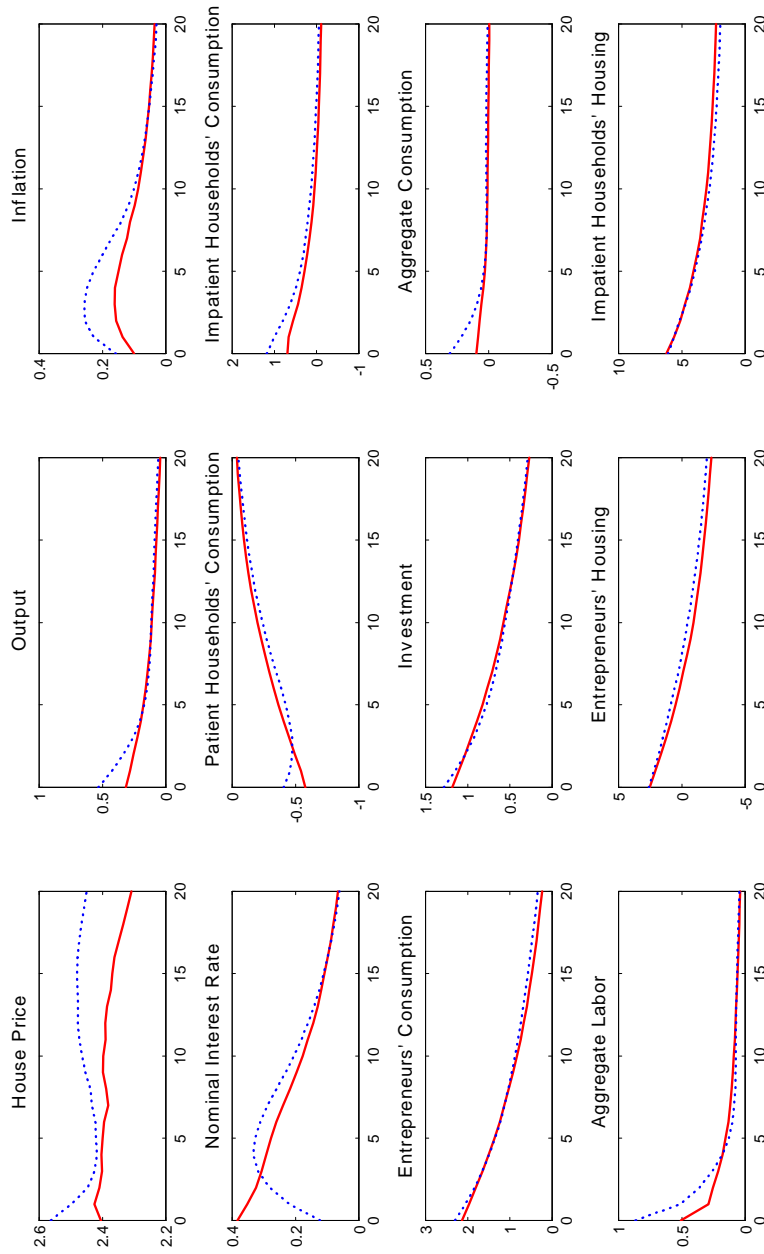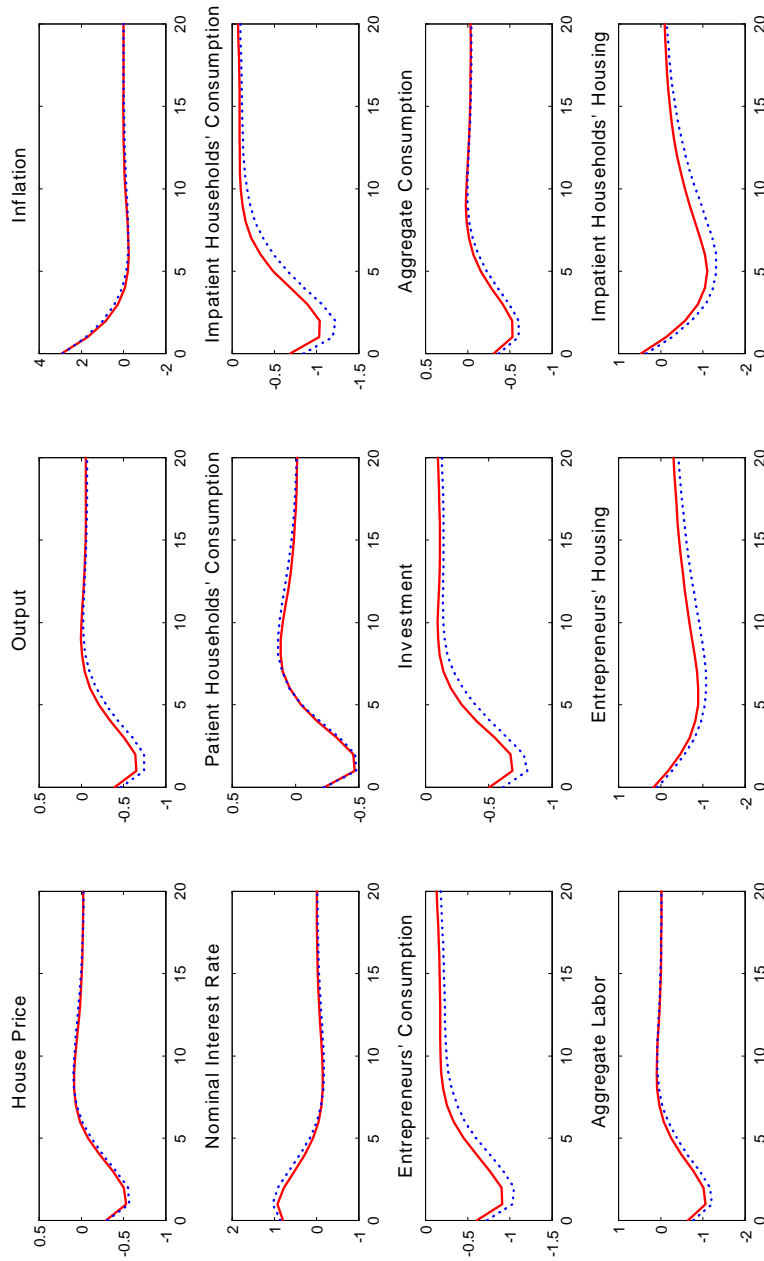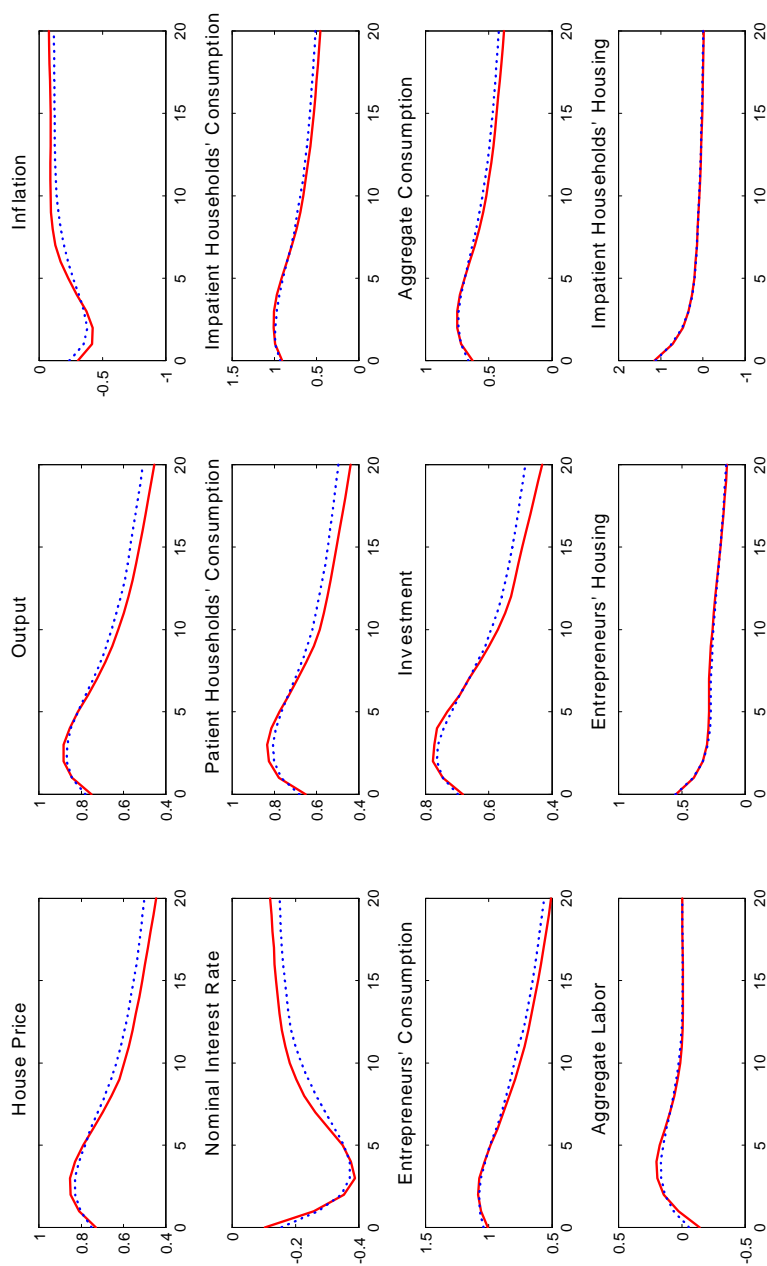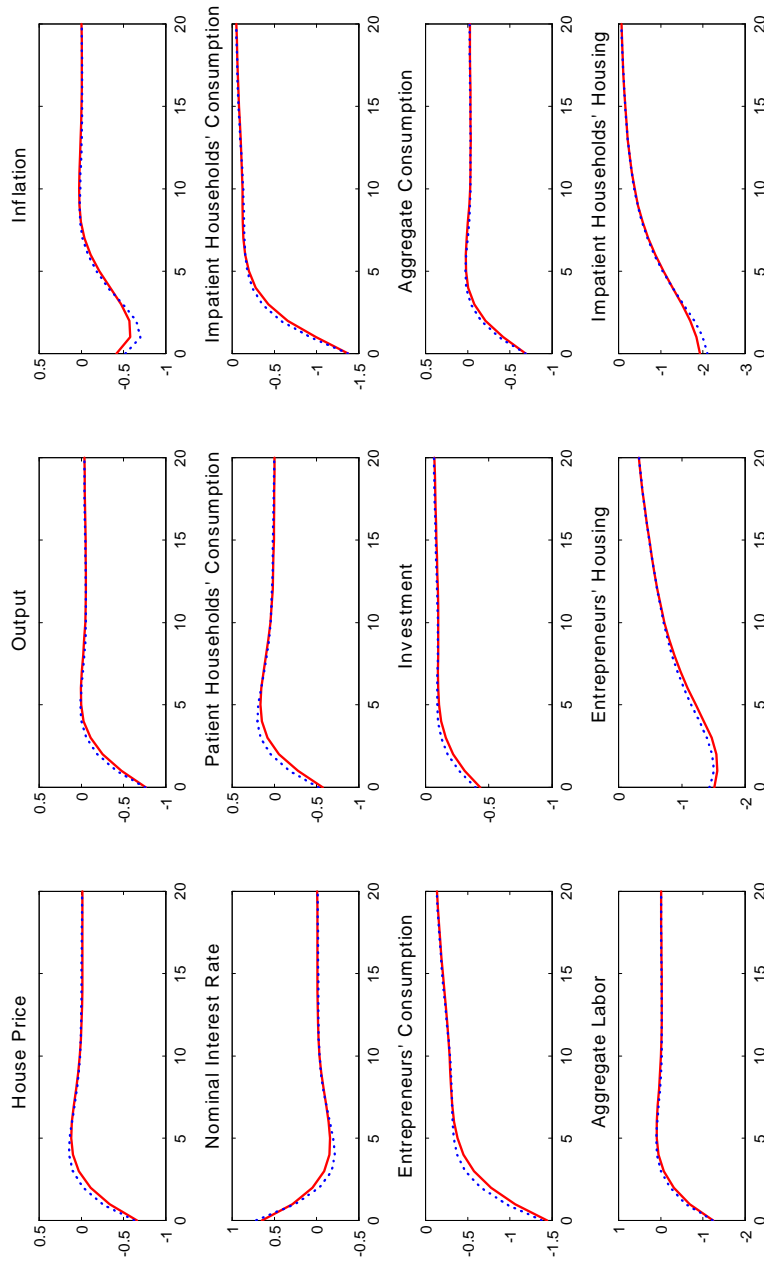
Figure 3.5: Posterior medians for impulse response functions after a house price shock in the U.S. Dotted line: Taylor rule with $\Gamma_q = 0$. Solid line: Taylor rule with $\Gamma_q > 0$.
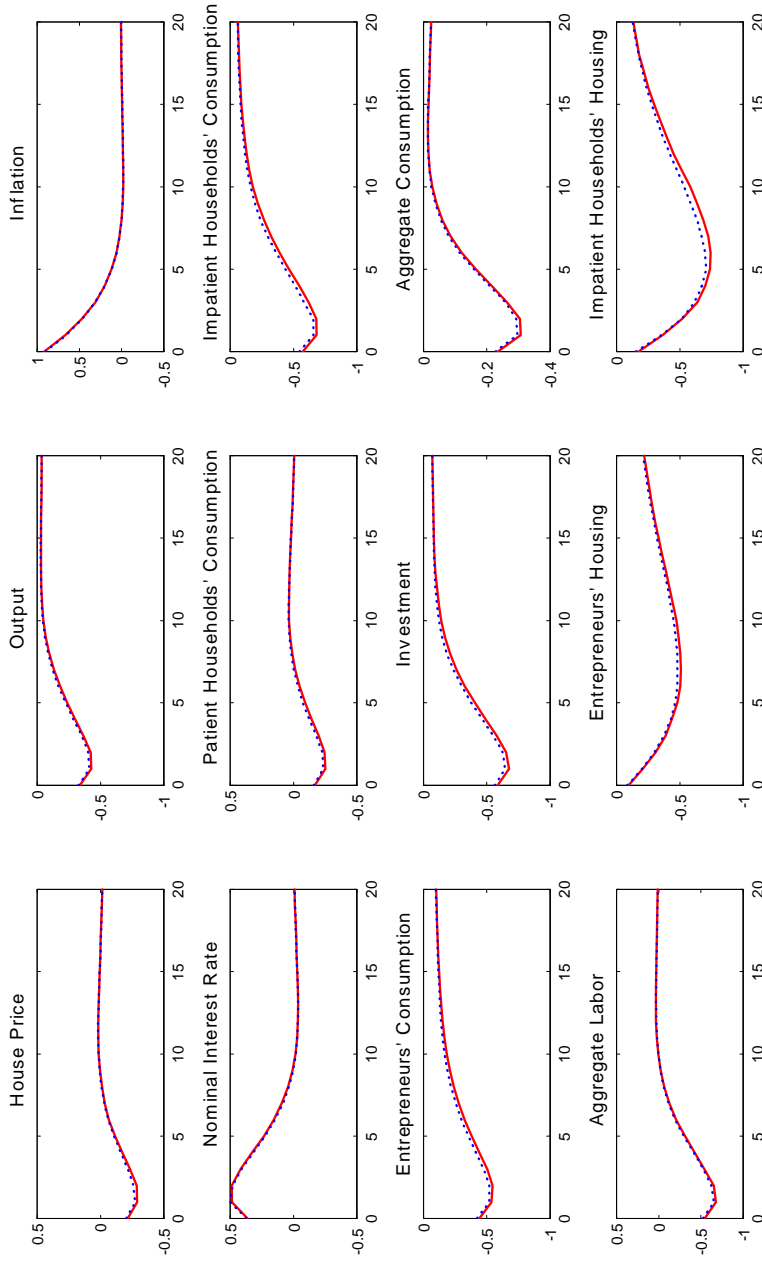
Figure 3.6: Posterior medians for impulse response functions after a price markup shock in the U.S. Dotted line: Taylor rule with $\Gamma_q = 0$. Solid line: Taylor rule with $\Gamma_q > 0$.

Figure 3.7: Posterior medians for impulse response functions after a technology shock in the U.S. Dotted line: Taylor rule with $\Gamma_q = 0$. Solid line: Taylor rule with $\Gamma_q > 0$.

Figure 3.8: Posterior medians for impulse response functions after a monetary policy shock in the U.K. Dotted line: Taylor rule with $\Gamma_q = 0$. Solid line: Taylor rule with $\Gamma_q > 0$.
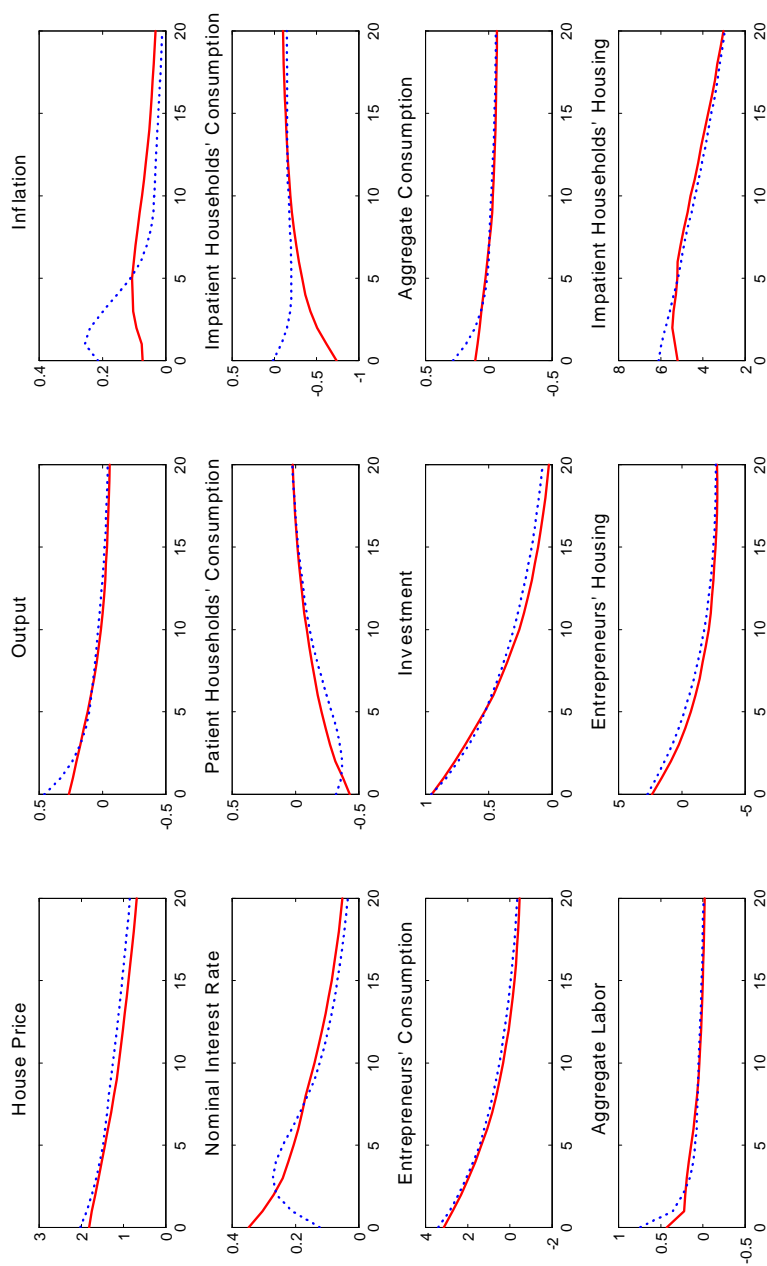
Figure 3.9: Posterior medians for impulse response functions after a house price shock in the U.K. Dotted line: Taylor rule with $\Gamma_q = 0$. Solid line: Taylor rule with $\Gamma_q > 0$.
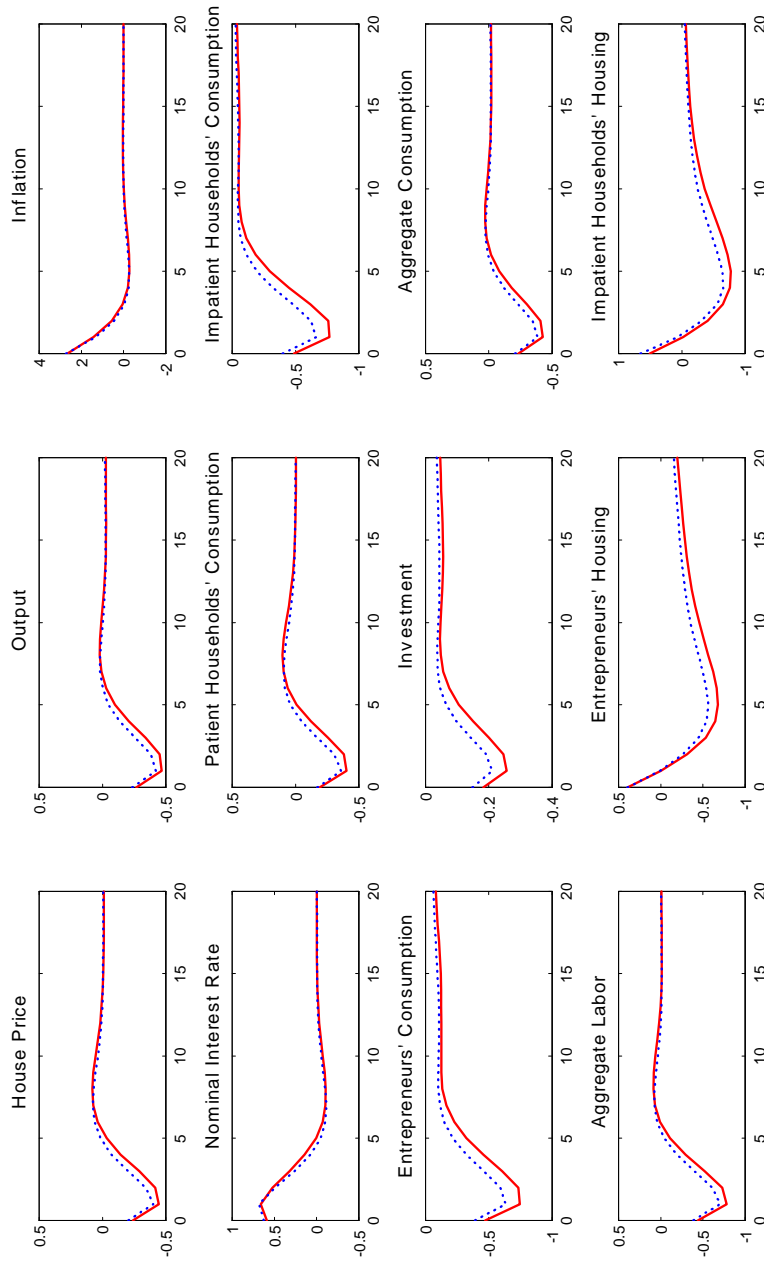
Figure 3.10: Posterior medians for impulse response functions after a price markup shock in the U.K. Dotted line: Taylor rule with $\Gamma_q = 0$. Solid line: Taylor rule with $\Gamma_q > 0$.
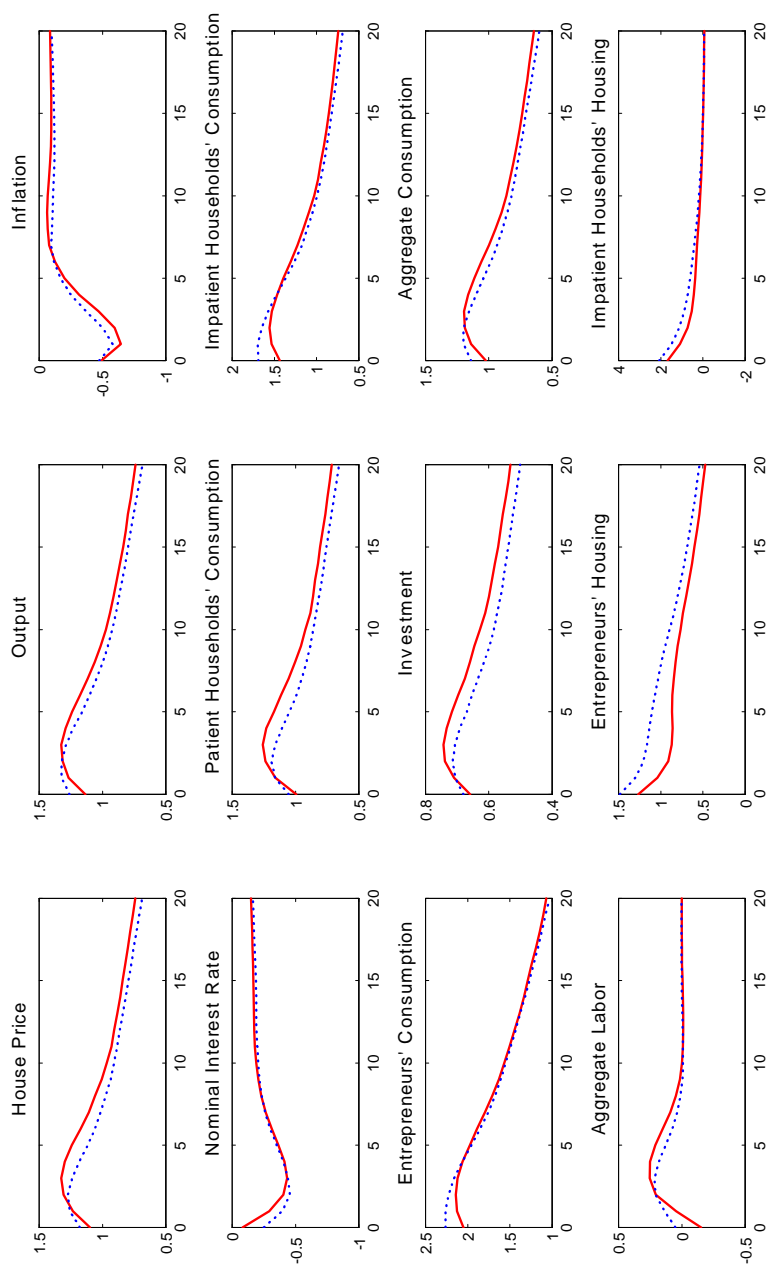
Figure 3.11: Posterior medians for impulse response functions after a technology shock in the U.K. Dotted line: Taylor rule with $\Gamma_q = 0$. Solid line: Taylor rule with $\Gamma_q > 0$.

Figure 3.12: Posterior medians for impulse response functions after a monetary policy shock in Japan. Dotted line: Taylor rule with $\Gamma_q = 0$. Solid line: Taylor rule with $\Gamma_q > 0$.

Figure 3.13: Posterior medians for impulse response functions after a house price shock in Japan. Dotted line: Taylor rule with $\Gamma_q = 0$. Solid line: Taylor rule with $\Gamma_q > 0$.

Figure 3.14: Posterior medians for impulse response functions after a price markup shock in Japan. Dotted line: Taylor rule with $\Gamma_q = 0$. Solid line: Taylor rule with $\Gamma_q > 0$.

Figure 3.15: Posterior medians for impulse response functions after a technology shock in Japan. Dotted line: Taylor rule with $\Gamma_q = 0$. Solid line: Taylor rule with $\Gamma_q > 0$.

Chapter 4

How Important are Financial Frictions in the U.S. and the Euro Area? *

The works of Bernanke and Gertler (1989) and Carlstrom and Fuerst (1997), where endogenous procyclical movements in entrepreneurial net worth magnify investment and output fluctuations, constitute the corner stone of most recent theoretical papers with financial frictions.[1] Bernanke, Gertler, and Gilchrist (1996) develop the so-called financial accelerator, a mechanism based on information asymmetries between lenders and entrepreneurs that creates inefficiencies in financial markets, which affect the supply of credit and amplify business cycles. Specifically, during booms (recessions), an increase (fall) in borrowers' net worth decreases (increases) their cost of obtaining external funds, which further stimulates (destimulates) investment, thereby amplifying the effects of the initial shock.[2] The financial accelerator approach has become wide-spread in the literature and many studies have introduced

[1] There exists a large literature emphasizing the role of financial frictions in business cycles, see Kiyotaki and Moore (1997) and Greenwald and Stiglitz (1993).

[2] However, the effects of the financial accelerator on output may depend on the policy rule and the type of shock.

similar frictions in DSGE models (Bernanke, Gertler, and Gilchrist (1999), henceforth BGG; Christiano, Motto, and Rostagno (2003)). The same idea has been used in closed-economy growth models (Aghion, Bacchetta, and Banerjee (2004), Aghion, Howitt, and Mayer-Foulkes (2003)) as well as in open-economy business cycle models (Gertler, Gilchrist, and Natalucci (2003), Gilchrist, Hairault, and Kempf (2002)).

Despite the ample theoretical work based on the financial accelerator, little has been done when it comes to the econometric estimation of these models. I only know of three papers estimating closed-economy general equilibrium models with a financial accelerator.[3] Christiano, Motto, and Rostagno (2003) estimate a DSGE model with a financial accelerator, but they fix the parameters related to the financial frictions and use the same calibration as in BGG. They ask which shocks had a more important role in the Great Depression and if a different monetary policy could have moderated the crisis. Christensen and Dib (2007) estimate the standard BGG model for the U.S. using maximum likelihood and find evidence in favor of the financial accelerator model.[4] Meier and Muller (2006) use minimum distance estimation based on impulse responses to estimate a model with a financial accelerator in the U.S., and find that financial frictions do not play a very important role in the model.[5] In addition, Levin, Natalucci, and Zakrajsek (2004) use microdata to estimate the structural parameters of a canonical debt contract model with informational frictions. Using data for 900 U.S. firms over the period 1997Q1 to 2003Q3, they reject the null hypothesis of frictionless financial markets.

Given the paucity of empirical work on the financial accelerator, the purpose of this paper is to answer two basic questions. First, I want to determine if frictions in credit markets are important for business cycles, even if realistic frictions in goods and labor markets are added to a model with frictions in financial markets. After the banking crisis experienced by many countries in the 1990s, financial market conditions have turned out to be a relevant factor for economic fluctuations. In this

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[3] More work has been done on this direction since the first draft of this paper. De Graeve (2006) studies the properties of the external finance premium using the BGG framework. Furthermore, Neri (2004) estimates the model of Carlstrom and Fuerst (1997) where agency costs arise on investment.

[4] They estimate the model in BGG where the structural parameters that underpin the financial contract are reduced to the elasticity of the external finance premium with respect to the change in the leverage position of entrepreneurs. In that sense, they are not able to identify monitoring costs or other structural parameters regarding financial frictions.

[5] However, they only focus on the propagation of monetary policy shocks.

paper, however, I do not consider financial frictions as a source of shocks, but as a mechanism for the propagation of other shocks in the economy. The second question I investigate is whether financial frictions have a similar magnitude in the U.S. and the Euro area. This resonates with the common perception that financial markets are more developed in the U.S. and, consequently, more efficient. This is a relevant question for better understanding the relative performance of the two areas in recent years.

To answer these two questions, I modify the standard BGG model and estimate it for U.S. and European data using Bayesian methods. I extend the BGG model by adding price indexation to past inflation, sticky wages, consumption habits and variable capital utilization. One benefit of using Bayesian methods is that we can include prior information about the parameters, especially information about structural parameters from microeconomic studies. Another benefit is related to the fact that some parameters have a specific economic interpretation and a bounded domain, which can be incorporated in the priors.

The paper contributes to the existing literature in three respects. It empirically investigates the importance of frictions in credit markets for business cycles both in the U.S. and the Euro area. It uses Bayesian methods to estimates a DSGE model with a financial accelerator. And unlike Christensen and Dib (2007) and Meier and Muller (2006), it can identify the structural parameters of the financial contract.

The results indicate that financial frictions are relevant in both areas. Using posterior odds ratios as the evaluation criterion, I find that the data favors a model with financial frictions both in the U.S. and the Euro area. Moreover, consistent with common perceptions, financial frictions are larger in the Euro area.

The rest of the paper is organized as follows. In Section 2, I describe the model. Section 3 presents the estimation methodology while Section 4 presents the results. In Section 5, I discuss the results. Section 6 concludes.

1   The Model

The specification of the model follows the work of BGG who incorporate financial market frictions through a financial accelerator mechanism in a general equilibrium model. The basic idea of the financial accelerator is that there exits a negative

relationship between the external financial premium (the difference between the cost of funds raised externally and the opportunity cost of funds) and the net worth of potential borrowers. The intuition is that firms with higher leverage (lower net worth to capital ratio) will have a greater probability of defaulting and will therefore have to pay a higher premium. Since net worth is procyclical (because of the procyclicality of profits and asset prices), the external finance premium becomes countercyclical and amplifies business cycles through an accelerator effect on investment, production and spending.

Following the recent literature in DSGE models, I modify the original BGG model to improve its empirical performance by introducing a number of alternative real and nominal frictions commonly considered in the literature. More specifically, I allow for external habit formation in consumption, variable capital utilization and Calvo prices and wages with full indexation to previous period inflation.[6] Christiano, Eichenbaum, and Evans (2005) show variable capital utilization and wage stickiness to be fundamental frictions for explaining inflation inertia and persistent, hump-shaped responses in output after policy shocks. The other frictions in the model help account for the response of other variables such as consumption and investment. Given these additional frictions in other markets, I ask whether financial frictions are still empirically important.

Christiano, Motto, and Rostagno (2003) also extend the BGG model but with several differences. First, they include a banking sector.[7] Second, in their paper, the return on deposits received by households is in nominal terms which allows for a 'debt deflation' effect. Third, capital is produced with different technology functions: I follow BGG by assuming the existence of adjustment costs in the production of capital, while Christiano, Motto and Rostagno assume there to exist costs for changing the investment flow.[8] Fourth, in my model, variable capital utilization

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[6] It is important to introduce these frictions since when testing for financial frictions, the results might be capturing dynamics in the data caused by other frictions. For instance, for given parameters, the response of prices will be smoother in a model with a financial accelerator. However, introducing variable capital utilization also helps offset the fluctuations in labor productivity and affects the marginal cost, which is reflected in a more gradual response of prices.

[7] Even if I include financial intermediaries in my model, Christiano, Motto, and Rostagno (2003) consider a larger banking sector which manages different kinds of deposits and loans, and requires capital and labor services.

[8] However, Groth and Khan (2007) find that it is difficult to motivate investment adjustment costs from a disaggregated empirical perspective.

arises because of higher depreciation rates, while in their model high capital utilization gives rise to higher cost in terms of goods. Last, I introduce external habit formation in consumption, while they use internal habits.

There are seven types of agents in the model: households, retailers, wholesale sector, capital producers, entrepreneurs, financial intermediaries and government. The following subsections describe the behavior of these agents.

1.1 Households

Consider a continuum of individuals, indexed by j, whose total mass is normalized to unity. In each period, each of these households maximizes its expected lifetime utility choosing a final consumption good, c_t^j, nominal bonds issued by the government, nb_{t+1}^j, and real deposits held at financial intermediates, d_{t+1}^j, which pay a real gross free risk rate r_t.[9] Moreover, each household supplies differentiated labor services to the wholesale sector, l_t^j. Following Christiano, Eichenbaum, and Evans (2005), I assume that households buy securities with payoffs contingent on whether they can reoptimize their wages. This ensures that, in equilibrium, households are homogenous in consumption and asset holdings. Households discount the future at a rate β.

The representative household's period utility and budget constraint are

$$U_t = \nu_t \left[\frac{1}{1-\sigma} \left(c_t^j - h c_{t-1} \right)^{1-\sigma} - \frac{\xi_t}{2} \left(l_t^j \right)^2 \right]$$

and

$$\frac{nb_{t+1}^j}{p_t} + d_{t+1}^j + c_t^j = \frac{w_t^j}{p_t} l_t^j + r_{t-1} d_t^j + r_{t-1}^n \frac{nb_t^j}{p_t} - t_t + div_t + X_t,$$

where w_t^j is the nominal wage of household j, p_t is the nominal level of prices, t_t are lump-sum taxes, div_t are dividends received from ownership of firms and X_t are net cash inflows from participating in state-contingent security markets. ν_t and ξ_t are shocks to consumer preferences for intertemporal consumption and leisure, respectively, which follow $AR(1)$ processes with mean equal to one.

The introduction of external habit formation in consumption mainly helps account for the gradual and hump-shaped response of consumption observed in the

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[9] In Appendix A, I show how the lender is able to obtain a free risk rate.

data after a monetary policy shock.

Households also act as monopolistically competitive suppliers of differentiated labor services to the wholesale sector, where the labor aggregator has the Dixit-Stiglitz form

$$
L_t = \left[\int_0^1 \left(l_t^j \right)^{1/(\tau_t+1)} dj \right]^{(\tau_t+1)},
$$

and τ_t is a wage (net) mark up *iid* shock with mean τ (the steady state wage mark up). Firms minimize the cost of hiring a fixed amount of total labor given the different price of labor. The optimal demand for labor is

$$
l_t^j = \left(\frac{w_t}{w_t^j} \right)^{(\tau_t+1)/\tau_t} L_t.
$$

Integrating this equation and imposing the Dixit-Stiglitz aggregator for labor, we can express the aggregate wage index as

$$
w_t = \left[\int_0^1 \left(w_t^j \right)^{-1/\tau_t} dj \right]^{-\tau_t}.
$$

I assume that households can reset their wages with probability $(1 - \vartheta)$ at each period. Whenever the household is not allowed to reset its wage contract, wages are set at $w_t^j = \pi_{t-1} w_{t-1}^j$, where π_{t-1} is gross inflation in the last period. According to Christiano, Eichenbaum, and Evans (2005), wage stickiness plays a crucial role in the performance of the model. The first-order condition with respect to wages is

$$
\begin{aligned}
& E_t \sum_{k=0}^{\infty} (\beta\vartheta)^k \, \nu_{t+k} \left(c_{t+k}^j - h c_{t-1+k} \right)^{-\sigma} \left(\frac{\widehat{w}_t^j}{p_{t+k}} l_{t+k}^j \left[\frac{1}{\tau_{t+k}} \right] \right) \\
= \; & E_t \sum_{k=0}^{\infty} (\beta\vartheta)^k \, \nu_{t+k} \xi_{t+k} \left(l_{t+k}^j \right)^2 \left[\frac{(\tau_{t+k}+1)}{\tau_{t+k}} \right].
\end{aligned}
$$

1.2   Final Good Sector

Firms in the final good sector produce a consumption good, y_t, in a perfectly competitive market, combining a range of intermediate goods, y_t^s, $s \in (0,1)$. The production function transforming intermediate goods into final output is the usual Dixit-Stiglitz

aggregator given by

$$y_t = \left[\int_0^1 (y_t^s)^{1/(\lambda_t+1)} \, ds \right]^{(\lambda_t+1)},$$

where $\lambda_t \geq 0$ is a (net) mark up *iid* shock with mean λ. Firms take prices as given and choose y_t^s to minimize costs:

$$\min_{y_t^s} \int_0^1 p_t^s y_t^s ds$$

subject to the Dixit-Stiglitz aggregator. The first-order conditions of this problem imply

$$y_t^s = \left(\frac{p_t}{p_t^s} \right)^{(\lambda_t+1)/\lambda_t} y_t.$$

Integrating this equation and imposing the constraint, we can express the aggregate price index as

$$p_t = \left[\int_0^1 (p_t^s)^{-1/\lambda_t} \, ds \right]^{-\lambda_t}.$$

1.3 Wholesale Sector

The existing range of intermediate inputs are produced by a continuum of monopolistically competitive firms indexed by $s \in [0,1]$. Each firm hires the services of capital, k_t^s, and labor, L_t^s, to face the demand curve for its product. It rents capital from an entrepreneurial sector, which owns the capital stock.

Firms produce according to Cobb-Douglas production function:

$$y_t^s = a_t \left(k_t^s \right)^\alpha \left(L_t^s \right)^{1-\alpha},$$

where a_t is a productivity shock which follows a first-order autoregressive process with mean one. Each intermediate goods firm chooses capital and labor to minimize its total costs, taking factor prices as given. The minimization problem can be written as

$$\min_{L_t^s, k_t^s} \frac{w_t}{p_t} L_t^s + z_t k_t^s,$$

subject to the production function, where z_t is the real rental price of capital.

Moreover, wholesale firms have market power and can choose prices to maximize expected profits with probability $1 - \theta$ in each period (Calvo, 1983). As in the case of wages, firms that cannot choose prices index their prices according to the last period's inflation rate: $p_t^s = \pi_{t-1} p_{t-1}^s$.

For those firms that can choose prices, $\widehat{p}_t$, the first-order condition is

$$
\begin{aligned}
& E_t \sum_{k=0}^{\infty} (\beta\theta)^k \, m_{t,t+k} y_{t+k} (1/\lambda_{t+k}) \left[\frac{\widehat{p}_t}{p_{t-1}\pi_{t+k}} \right]^{-1/\lambda_{t+k}} \\
= \; & E_t \sum_{k=0}^{\infty} (\beta\theta)^k \, m_{t,t+k} y_{t+k} (\lambda_{t+k}+1)/\lambda_{t+k} s_{t+k} \left[\frac{\widehat{p}_t}{p_{t-1}\pi_{t+k}} \right]^{-(\lambda_{t+k}+1)/\lambda_{t+k}},
\end{aligned}
$$

where $\beta^k m_{t,t+k} = \beta^k \frac{u_c(t+k)}{u_c(t)}$ is the stochastic discount factor between periods t and $t + k$ and s_t is the real marginal cost. Profits are distributed to households.

1.4   Capital Producers

The physical stock of capital, $\widetilde{k}_t$ (where the t subscript indicates when capital is actually used), is produced by a continuum of competitive firms indexed by j. At the end of each period, these firms produce new capital goods combining investment i_t^j and the existing capital stock. Capital producers buy the undepreciated capital stock at the end of each period and after producing the new capital, they sell it back to the entrepreneurs at a relative price q_t.[10] I assume there are increasing marginal adjustment costs in the production of capital: investment expenditures, i_t^j, deliver $\Phi\left(\frac{i_t^j}{\widetilde{k}_t^j}\right)\widetilde{k}_t^j$ new capital goods. This generates a weaker response of investment to any shock and a relative price of capital different from one.

I assume that investment decisions are made one period in advance, while the price of capital adjusts immediately after a shock. This assumption helps account for a gradual response of investment to shocks affecting the real interest rate, a strong feature observed in the data. Capital producers solve the following problem:

$$
\max_{i_{t+1}^j} E_t \left[q_{t+1} \Phi\left(\frac{i_{t+1}^j}{\widetilde{k}_{t+1}^j} \right) \widetilde{k}_{t+1}^j - i_{t+1}^j \right],
$$

where near the steady state $\Phi > 0$, $\Phi'(.) > 0$, $\Phi''(.) < 0$. I also assume that in

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[10]   We can assume that capital-producing firms are owned by entrepreneurs. After entrepreneurs rebuy the old stock of capital, used capital depreciates.

steady state, the relative price of capital is one. In the empirical part, I estimate φ, the elasticity of the price of capital with respect to the investment-capital ratio in the steady state: $\varphi = \Phi'' \left(\frac{i}{k} \right) \left(\frac{i}{k} \right).$

The law of motion of the aggregate capital stock is

$$\widetilde{k}_{t+1} = \Phi \left(\frac{i_t}{\widetilde{k}_t} \right) \widetilde{k}_t + (1 - \delta(u_t))\widetilde{k}_t,$$

where u_t is the rate of capital utilization,[11] $\delta(u_t) \in (0,1)$ is a convex depreciation function with $\delta'(.) > 0$, and $\delta''(.) > 0$ around the steady state. I choose the function $\delta(u_t)$ such that $\delta(0) = 0$, $\delta(\infty) = 1$ and in steady state, $\delta(1) = \delta.$[12]

1.5 Entrepreneurs and Financial Intermediaries

Entrepreneurs own the physical stock of capital, $\widetilde{k}_t$, and provide capital services, k_t. They finance capital purchases both with their own net worth and debt. Capital services are related to the physical stock of capital by

$$k_t = u_t \widetilde{k}_t.$$

Entrepreneurs are risk neutral and have finite horizons: $\gamma < 1$ is their probability of survival to the next period. This assumption rules out the possibility of entrepreneurs accumulating enough wealth to be fully self-financed: part of their capital must be financed through bank loans with a standard debt contract.

At the end of period t, entrepreneurs decide how much to borrow. Then, at the beginning of period $t + 1$, after observing all the shocks, they choose how intensely to use their capital.

1.5.1 Optimal Contract

As in BGG, the return on capital depends on both aggregate and idiosyncratic shocks. The ex-post return on capital for entrepreneur i is $\omega_{t+1}^i r_{t+1}^k$, where ω^i is

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[11] u_t can take any value ≥ 0, where values greater than one mean that there exists over utilization of capital.

[12] One example of this kind of function can be $\delta(u_t) = 1 - \frac{1+p}{p+\exp^{\varepsilon u_t}}$ with $p, \varepsilon > 0$. In this case, $\delta(0) = 0$, $\delta(\infty) = 1$, $\delta(1) = 1 - \frac{1+p}{p+\exp^{\varepsilon}} = \delta$. However, I focus on a more general case of functional forms and I estimate the steady state elasticity of marginal depreciation with respect to the utilization rate: δ'' / δ'.

an *i.i.d.* lognormal random variable with pdf $F(\omega)$ and mean one.[13]   The riskiness
of entrepreneurs is determined by the variance of the idiosyncratic shock, σ_ω. The
average return of capital in the economy is

$$r_{t+1}^k = \frac{u_{t+1}z_{t+1} + (1 - \delta(u_{t+1}))q_{t+1}}{q_t}.$$

Entrepreneurs finance their capital stock at the end of period t with their own
net worth at the end of the period, n_{t+1}^i, and banks loans, b_{t+1}^i:[14]

$$q_t \widetilde{k}_{t+1}^i = n_{t+1}^i + b_{t+1}^i.$$

The entrepreneur borrows from a financial intermediary that obtains its funds from
households, with an opportunity cost equal to the riskless gross rate of return, r_t.
In equilibrium, the intermediary holds a pooled, and perfectly safe, portfolio and
the entrepreneurs absorb any aggregate risk.

BGG follow a "costly state verification" approach like in Townsend (1979), where
lenders must pay a fixed auditing cost to observe an individual borrower's realized
return. They assume monitoring costs to be a proportion μ of the realized gross
payoff to the firms' capital, i.e., monitoring costs equal $\mu \omega_{t+1}^i r_{t+1}^k q_t \widetilde{k}_{t+1}^i$.[15]   When
$\mu = 0$, we are in the special case of frictionless financial markets.

The optimal contract will be incentive compatible, characterized by a schedule
of state contingent threshold values of the idiosyncratic shock ϖ_{t+1}^i, such that for
values of the idiosyncratic shock greater than the threshold, the entrepreneur is able
to repay the lender, and for values below the threshold, the entrepreneur declares
default and the lender obtains $(1 - \mu)\,\omega_{t+1}^i r_{t+1}^k q_t \widetilde{k}_{t+1}^i$. Only one-period contracts
between borrowers and entrepreneurs are feasible.

Under these assumptions, the optimal contract is chosen to maximize expected
entrepreneurial utility, conditional on the expected return of the lender, for each
possible realization of r_{t+1}^k, being equal to the riskless rate, r_t. In Appendix 4.A,
I show that two first-order conditions must hold in the optimal contract between

---

[13]   As in Christiano, Motto, and Rostagno (2003), I assume that after entrepreneurs have pur-
chased capital, they draw an idiosyncratic shock which changes $\widetilde{k}_{t+1}^i$ to $\omega_{t+1}^i \widetilde{k}_{t+1}^i$.

[14] The relevant price of capital at the end of period t is q_t.

[15] The relevant price here is q_t since capital price gains are included in r_{t+1}^k.

entrepreneurs and banks, namely:

$$E_t \left\{ \left(1 - \Gamma(\varpi_{t+1}^i)\right) \frac{r_{t+1}^k}{r_t} + \lambda(\varpi_{t+1}^i) \left[\left(\Gamma(\varpi_{t+1}^i) - \mu G(\varpi_{t+1}^i)\right) \frac{r_{t+1}^k}{r_t} - 1 \right] \right\} = 0$$

and

$$\left[\Gamma(\varpi_{t+1}^i) - \mu G(\varpi_{t+1}^i)\right] r_{t+1}^k q_t \widetilde{k}_{t+1}^i = r_t \left[q_t \widetilde{k}_{t+1}^i - n_{t+1}^i \right],$$

where expected monitoring costs are $\mu G(\varpi_{t+1}^i) = \mu \int\limits_0^{\varpi_{t+1}^i} \omega dF(\omega)$, the expected gross share of profits going to the lender $\Gamma(\varpi_{t+1}^i) = \left(1 - F(\varpi_{t+1}^i)\right)\varpi_{t+1}^i + G(\varpi_{t+1}^i)$, and $\lambda(\varpi_{t+1}^i) = \frac{\Gamma'(\varpi_{t+1}^i)}{\Gamma'(\varpi_{t+1}^i) - \mu G'(\varpi_{t+1}^i)}$.

From the first first-order condition, we see that when financial markets are frictionless, $\mu = 0$, $\lambda(\varpi_{t+1}^i) = 1$ and $E_t r_{t+1}^k = r_t$: the ex-ante return on capital equals the risk free rate when there are no monitoring costs. The second first-order condition is related to the fact that the financial intermediary receives an expected return equal to the opportunity cost of its funds. In this case, the lender's expected return can simply be expressed as a function of the average cutoff value of the firm's idiosyncratic shock, ϖ_{t+1}.

Since the entrepreneur is risk neutral, he only cares about the mean return on his wealth. He guarantees the lender a return that is free of any systematic risk: conditional on r_{t+1}^k, he offers a state-contingent contract that guarantees the lender a expected return equal to the riskless rate.

From these two equations, aggregation is straightforward and it can be shown that capital expenditures by each entrepreneur i are proportional to his net worth. Aggregate entrepreneurial net worth (in consumption units) at the end of period t, n_{t+1} is given by

$$n_{t+1} = \gamma \left\{ r_t^k q_{t-1} \widetilde{k}_t - \left[r_{t-1} \left(q_{t-1} \widetilde{k}_t - n_t \right) + \mu \int\limits_0^{\varpi_t} \omega dF(\omega) r_t^k q_{t-1} \widetilde{k}_t \right] \right\} + w^e,$$

where γ is the fraction of entrepreneurs surviving to the next period,[16] and w^e are net transfers to entrepreneurs. In each period, a fraction $(1-\gamma)$ of new entrepreneurs enters the market receiving some transfers and the wealth of the fraction that did not survive is given to the government.

---

[16] So, on average, entrepreneurs live $1/(1-\gamma)$ periods.

1.5.2   Optimal Capital Utilization Decision

After observing the shocks at the beginning of period $t + 1$, entrepreneurs decide how intensively to use their capital. Higher capital utilization is costly because of higher depreciation rates.[17] This is an important assumption because it allows for variable capital utilization, a relevant feature in the data. Entrepreneurs choose capital utilization, u_{t+1} to solve

$$\max_{u_{t+1}} \left[\frac{u_{t+1} z_{t+1} + (1 - \delta(u_{t+1})) q_{t+1}}{q_{t+1}} \right].$$

1.6   Monetary and Fiscal Policy

The monetary authority conducts monetary policy by controlling the gross nominal interest rate, r_t^n. For convenience, I assume a cashless economy, but the monetary authority can set the interest rate directly in the inter-bank market. The loglinearized monetary policy rule is

$$\widehat{r}_t^n = \rho^r \widehat{r}_{t-1}^n + (1 - \rho^r) \left[\gamma^\pi E \widehat{\pi}_{t+1} + \gamma^y \widehat{y}_t / 4 \right] + \widehat{\varepsilon}_t^r,$$

where letters with a hat represent log deviations from the steady state, $\widehat{\varepsilon}_t^r$ is an *iid* monetary policy shock with mean zero and $\widehat{\pi}_{t+1}$ is the inflation rate in $t + 1$.

Government consumption expenditures, g_t, follow a first-order autoregressive process. The government finances its expenditures by lump-sum taxes, t_t, and nominal bonds, nb_{t+1}.[18]

1.7   Competitive Equilibrium

In a competitive equilibrium, all the above optimality conditions are satisfied. In addition, markets clear. The aggregate resource constraint is

$$y_t = c_t + i_t + g_t + \mu \int\limits_0^{\overline{\omega}_t} \omega dF(\omega) r_t^k q_{t-1} \widetilde{k}_t.$$

---

[17] This approach has been used by Baxter and Farr (2005), among others.

[18] I assume that the government adjusts the fiscal effects of monetary policy with lump-sum taxes.

Final goods are allocated to consumption, investment, government expenditure and monitoring costs.[19] Furthermore, credit markets clear and $b_t = d_t$.

1.8 Solution Method

To solve the model, I loglinearize the equilibrium conditions around their steady state values. In Appendix 4.B, I write the loglinearized model. Then, I use the method described in Sims (2002) and his matlab code gensys.m to solve the linearized model.

2 Methodology for Estimation and Model Evaluation

The model has a total of 30 free parameters. Seven of these are calibrated to their steady state values, as they cannot be identified from the detrended data. The steady state rate of depreciation of capital δ is set equal to 0.025, which corresponds to an annual rate of depreciation of ten percent. The discount factor β is set at 0.99, which corresponds to an annual real rate of four percent in steady state. The steady state share of government spending was set equal to 19.5 percent.[20] The parameter of the Cobb-Douglas production function, α, was set equal to 0.33, while the steady state price mark up, λ, was set at 20 percent. These values imply steady state consumption and investment ratios of 60.9 and 19.6 percent in models without financial frictions.[21] Moreover, the steady state wage mark up, τ, was set equal to five percent, and the steady state probability of default, $F(\varpi)$, equal to three percent per year, the same value as BGG.[22]

The remaining 23 parameters are estimated using Bayesian procedures. To check convergence, I run different chains starting from different and dispersed points. Each set of estimates is based on two different chains starting from the mode of the posterior plus-minus two standard deviations, with a total of $100,000$ draws in each

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[19] The last term is the loss in monitoring costs associated with defaulting entrepreneurs.

[20] Since this number does not include transfers, we can assume the same value for the U.S. and the Euro area.

[21] In models with a financial accelerator, these ratios will also depend on the risk premium.

[22] De Fiore and Uhlig (2005) report that average default rates are similar in the U.S. and the Euro area, i.e. between 3 and 4.5 percent.

simulation and a burn-in period of $50,000$.[23]   Convergence was monitored calculating the potential scale reduction, $\widehat{R}$, as described in Gelman, Carlin, Stern, and Rubin (2004), which declines to 1 as convergence is achieved.[24]   This ratio was computed for all parameters.

2.1   Data

The data used for the estimation corresponds to seven variables of the model: real output, real consumption, real investment, hours worked, nominal interest rate, inflation and real wages. I do not include any financial variables in the estimation. To compare the model with and without financial frictions, the former will have a natural advantage if these variables are included since the BGG model performs poorly in terms of financial variables when $\mu = 0$.

For the U.S., the data covers the period 1980Q1-2004Q1[25] , while for the Euro area, it covers the period 1980Q1-2002Q4[26] . In both cases, I use quarterly detrended

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[23] I use an adaptive algorithm where after the first round of simulations, I set the covariance matrix in the jumping distribution equal to that estimated in the first round.

[24] For most examples, values below 1.1 are acceptable.

[25] U.S. data was taken from the Bureau of Economic Analysis of the U.S. Department of Commerce (BEA), the IMF database and the Bureau of Labor Statistics (BLS). Real output is measured by real GDP converted into per capita terms divided by the population aged above sixteen (P16). Real consumption is real personal consumption expenditures divided by P16. Real investment is real gross private domestic investment also in per capita terms. Hours worked are measured by the product of average weekly hours in the private sector times the population aged above twenty. The nominal interest rate is the Federal Funds Rate, and inflation is calculated as the difference of the GDP deflator. Real wages are measured by the average hourly earnings of production workers in real terms. All series were detrended with a linear trend and in the case of the interest rate, I used the same trend as inflation.

[26] European data was taken from the AWM database of the ECB. One problem with a "synthetic" data set for the Euro area is how to aggregate and the fact that there is not a unique monetary policy at the beginning of the sample. However, this is the best dataset I can obtain. Real output is measured by real GDP converted into per capita terms divided by the labor force. Real consumption is real consumption divided by the labor force. Real investment is real gross investment also in per capita terms. To calculate hours worked, I use data on total employment, and transform it into hours worked using the same criterion as Smets and Wouters (2003). They assume that in any period, only a constant fraction of firms, ξ_e, is able to adjust employment to its desired total labor input. This results in the following equation for employment:

$$\widehat{e}_t = \beta \widehat{e}_{t+1} + \frac{(1 - \xi_e)(1 - \beta \xi_e)}{\xi_e}(\widehat{l}_t - \widehat{e}_t),$$

where $\widehat{e}_t$ is total employment. In contrast to them, I do not estimate ξ_e, but following their results and the results in Adolfson, Laséen, Lindé, and Villani (2007), I fix it equal to 0.70. The nominal interest rate is the quarterly short-term interest rate, and inflation is calculated as the difference of the GDP deflator. Real wages are measured by the wage rate deflated by the GDP deflator. All series were detrended with a linear trend and in the case of the interest rate, I used the same

data.

2.2 Prior Distribution

All prior distributions of the parameters were selected from the normal, beta, gamma and uniform distributions, depending on the supports and characteristics of the parameters. The prior distributions are the same for the U.S. and the Euro area and are shown in Table 4.1.

Many of the priors are standard and follow the literature (Smets and Wouters (2007), Adolfson, Laséen, Lindé, and Villani (2007)). The relative risk aversion coefficient, σ, has a normal distribution with mode one; the habit persistence parameter, h, has a beta distribution with mode 0.70. The parameters determining prices and wages follow a beta distribution. The modes of the Calvo parameters θ and ϑ, the probability of not adjusting prices and wages, were set equal to 0.70, so that, on average, prices and wages adjust every ten months.

Some of the parameters are particular to the way I capture some frictions in the model. This is true for the elasticity of the capital price to the investment-capital ratio, φ. BGG set this parameter equal to –0.25 while King and Wolman (1996) use a value of –2 based on estimations of Chirinko (1993). Since there is not enough information about this parameter, I use a uniform prior distribution between –1 and 0. The prior for δ''/δ' is a gamma distribution with a mode equal to one, following the calibration of Baxter and Farr (2005).

Other non-standard parameters in the model are those related to the financial frictions. Following BGG, the prior for monitoring costs, μ, was assumed to be beta distributed with mode equal to 0.12. The fraction of entrepreneurs surviving to the next period, γ, has a beta distribution with a mode of 0.975 which implies that, on average, entrepreneurs (and their firms) live for ten years. Finally, the prior for the steady state external risk premium (the difference between the cost of funds raised externally and the opportunity cost of funds), $r^k - r$, was set gamma distributed with a mode 0.005, which corresponds to an annual 2% risk premium as in BGG.

The priors for the long-run weights on inflation and output in the central bank reaction function are based on a standard Taylor rule, where γ^π and γ^y are nor-

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trend as inflation.

mally distributed with mode 1.5 and 0.5, respectively. The interest rate smoothing parameter, ρ_r, follows a beta distribution with mode 0.85.

Regarding the shocks affecting the economy, the autoregressive coefficients have a beta distribution with mode 0.85, while the standard deviations for the shocks follow a gamma distribution with mode 0.01 for the monetary, technology and government shocks, and 0.10 for the other shocks.

2.3 Model Comparison

To pairwise compare the performance of the different models, I calculate the posterior odds ratio. Since I set the prior odds equal to one, the posterior odds ratio is the ratio of the marginal data densities between models i and j. I use the modified harmonic mean to approximate the marginal likelihood.

3 Results

3.1 U.S.

3.1.1 Frictions in the U.S.

In Table 4.2, I report the log marginal data density and posterior odds ratio for the two versions of the model: with and without credit frictions. The posterior odds ratio of the model with financial frictions against the model without financial frictions is 10^{21} to one, which is decisive evidence against the model without a financial accelerator.[27] This extends the findings by Christensen and Dib (2007) who estimate the standard BGG model with maximum likelihood and provide evidence in favor of a financial accelerator.

In addition to the prior distributions, Table 4.1 also reports the mean and the 5th and 95th percentile of the posterior distribution for U.S. data. The table shows that

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[27] In results not shown here, I start out by estimating the standard BGG model and then add sequentially four frictions not present in that model: price indexation to past inflation, sticky wages, external habit formation in consumption and variable capital utilization. In all the cases, the posterior odds test favors the financial accelerator model. Moreover, the size of monitoring costs decreases once we introduce other frictions to the standard BGG model. In the standard BGG case, monitoring costs are almost twice as large as the ones presented below. The intuition is that higher monitoring costs are necessary in the standard BGG model to capture the dynamics of the data. Once other frictions are introduced, however, the data does not require such large financial frictions.

the estimated mean of monitoring costs is twelve percent. This result is in line with the results of Levin, Natalucci, and Zakrajsek (2004). Using microdata for 900 U.S. firms over the period 1997Q1 to 2003Q3, they estimate that time-varying monitoring cost moved between eight and sixteen percent between 1997 and 1999. When they smooth through a spike in 1998Q4, the average monitoring costs during this period are close to twelve percent of the realized gross payoff to the firms' capital. After the fall of the stock market in 2000, monitoring costs went up to reach values as high as forty percent, and then once more declined in 2003.

3.1.2 Parameter Estimates for the U.S.

Table 4.1 also reports the potential scale reduction statistic, which shows that all the posterior estimates converge to a stationary distribution.[28] The only parameter which presents some doubts is the variance of the wage mark up shocks, σ^τ. However, relatively small changes in the value of this parameter do not affect the properties of the model since it is multiplied by a very small number in the solution. Furthermore, Figures 4.1 and 4.2 plot the prior and posterior distribution of the parameters. The figures show that the data is informative to identify all the parameters, except for δ''/δ'. In this one case, the use of a prior is similar to calibration. Nevertheless, small changes in this parameter do not affect the properties of the model when the impulse response functions are plotted.

The estimated posterior mean of the risk premium in steady state, $rk - r$, implies an annual premium of 2.4 percent, which is in line with the value used by BGG and Christiano, Motto, and Rostagno (2003), and the one reported in De Fiore and Uhlig (2005). Together with other parameters, this value implies that the investment-output ratio and consumption-output ratio in steady state are 17 and 63 percent, respectively. Moreover, the fraction of GDP used in bankruptcy costs is around 0.4 percent, and the mean for the fraction of entrepreneurs who survive, γ, is 0.99, implying an average duration of entrepreneurial activities of 27 years.[29]

Table 4.1 indicates that the four autoregressive shocks affecting the economy are

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[28] Moreover, in results not presented here, I show that the path of the different parameters along the chain and the value of the posterior likelihood function confirm this result.

[29] These values imply an elasticity of the external finance premium with respect to the leverage ratio of 0.04, which is lower than the value estimated by Christensen and Dib (2007) but close to the 0.05 used in BGG. The implied standard deviation of the idiosyncratic shock, σ_ω, is 0.13.

very persistent as compared to the priors.

The coefficients describing consumer preferences do not differ substantially from the priors. The mean of risk aversion is 1.1 rather than one as the prior, and the habit persistence parameter has a posterior mean of 0.60 as compared to the prior mean of 0.70.

The posterior mean of θ implies that prices on average adjust once every fourteen months, similarly to the result in Smets and Wouters (2007). In the case of wages, the average duration of contracts is estimated at only four months and is lower than the estimated value in other studies. Both the elasticity of capital price with respect to the investment capital ratio, φ, and the variable depreciation parameter, δ''/δ', have a similar posterior mean as the prior: –0.47 and 1.02, respectively.

Concerning the coefficients in the central bank Taylor rule, all coefficients differ from their priors. The coefficient on future inflation, γ^π, is higher while the coefficient on output, γ^y, and the interest rate smoothing parameter, ρ_r, are lower. Moreover, the response to inflation and output is lower than that estimated in Clarida, Gali, and Gertler (2000) using GMM methods.

When the model is estimated without monitoring costs (no financial accelerator), the results are robust for most of the parameters, except for two: the elasticity of the price of capital, φ, and the entrepreneurs' rate of survival, γ. Both these parameters are higher in the model with financial frictions. A possible explanation is that investment reacts more to shocks in a model with a financial accelerator, which requires higher adjustment costs to match the dynamics of investment in the data. This implies that monitoring costs are not relevant because the model cannot explain investment behavior without them, but because monitoring costs help explain other variables. Moreover, to ensure that self-financing never occurs, estimates of the probability of survival are lower in a frictionless credit market model. In addition, monetary policy reacts slightly more strongly to output in the case with financial frictions which dampens the amplification of output fluctuations caused by the financial accelerator.

3.2 Euro Area

3.2.1 Frictions in the Euro Area

Table 4.2 shows that the posterior odds ratio for the hypothesis of financial frictions versus no financial frictions in the Euro area is 10^{17} to one, which clearly favors a model with monitoring costs. Table 4.3 shows that the posterior mean of monitoring costs in the Euro area is 18 percent, fifty percent higher than the cost estimated for the U.S., and outside the 90 percent confidence bands for the U.S. As in the U.S., the data thus prefers a model with credit market imperfections, but these imperfections seem to be larger in the Euro area.[30]

3.2.2 Parameter Estimates for the Euro Area

Table 4.3 also reports the mean and the 5th and 95th percentile of the posterior distribution of the model with and without financial frictions in the Euro area. The value of the potential scale reduction indicates some convergence problems for the parameters governing variable capital depreciation and preference shocks. Figures 4.3 and 4.4 visually confirm this result. However, small changes in the value of these parameters do not affect the properties of the model when the impulse response functions are plotted.

The posterior distribution of the parameters using European data is in general very similar to that of the U.S. This indicates that the shocks driving the economy and the transmission mechanisms in the two areas are not too different. However, some parameters display more distinct differences.

The fact that monitoring costs are larger in the Euro area drives up the external risk premium: in the Euro area, the posterior mean of the annual risk premium is 3.6 percent in steady state. This value is slightly higher that the one reported in De Fiore and Uhlig (2005) for Euro data: they report a risk premium on loans between 1.6 and 2.7 percent. The estimated risk premium implies that in steady state, the investment and consumption ratio to output are 15.6 and 64.3 percent,

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[30] As for the U.S., I start estimating the standard BGG model and then add, one at a time, price indexation to past inflation, sticky wages, consumption habits and variable capital utilization. In all the cases, the data clearly favors a model with monitoring costs, which reach values as high as 52 percent in the model with price indexation and sticky wages. Moreover, for each model, the estimated mean of monitoring costs is higher than in the U.S.

respectively, and that the fraction of GDP used in bankruptcy cost is 0.6 percent.

Concerning the size of the shocks, monetary shocks are smaller in the Euro area: the posterior mean value for the standard deviation of monetary shocks is 145 basis points (annual) in the U.S., but only 92 basis points in the Euro area. This difference in monetary policy shocks between the U.S. and the Euro area has also been documented by, among others, Angeloni, Kashyap, Mojon, and Terlizzese (2003) and Smets and Wouters (2005). Another difference is that preference shocks are larger in the Euro area, while wage mark up shocks are smaller. When it comes to persistence, technology shocks are slightly more persistent in the Euro area, while government spending shocks are less persistent.

The mean of risk aversion in the Euro area is 1.2, which is higher than in the U.S. On the other hand, the parameter of consumption habit formation is smaller in the Euro area, and around 0.50.

Concerning price stickiness, prices on average adjust every six quarters. This implies that prices are more sticky in the Euro area, consistent with Peersman and Smets (2001) who find that the impact on prices after a monetary shock is faster in the U.S. Moreover, wage behavior is very similar to the U.S.: wages change every four months on average.

The elasticity of the price of capital with respect to the investment capital ratio, φ, is larger in Europe, with a mean value of -0.97. Given larger monitoring costs in the Euro area, the model requires higher adjustment costs in investment to dampen the response of investment after a shock. In the model, these two effects offset each other and investment responds similarly in the U.S. and the Euro area after most of the shocks.

The coefficients in the monetary rule are similar in both areas, and different from the prior, thereby suggesting that both areas have responded in a similar way to expected inflation and output in the last twenty years. As in the case of the U.S., the response of the interest rate to output is stronger in the model with financial frictions.

3.3   Robustness

Since the assessment of the importance of financial frictions relies on a clear identification of monitoring costs, I check the robustness of my results changing the prior

for μ. As discussed in Canova and Sala (2006), the posterior of parameters presenting identification problems becomes more diffuse once we use more diffuse priors. Hence, they suggest using a sequence of prior distributions with larger variances to detect potential identification problems. Figure 4.5 plots the prior and posterior distribution of μ in both areas. The first row corresponds to a beta prior for μ with mean 0.12 and standard deviation 0.05. The second row corresponds to a beta prior with mean 0.12 and standard deviation 0.10. The figure shows than once we increase the prior variance of μ, the posterior does not become more diffuse. This confirms my result that monitoring costs are well identified and, as shown in the figure, monitoring costs are larger in the Euro area, independently of the prior I choose.

4   Discussion

The results show that frictions in financial markets are important in the U.S. and the Euro area. Moreover, these frictions are larger in the Euro area. This is in line with independent observations suggesting that financial markets are more developed and integrated in the U.S., and that the institutional and legal framework in the two areas differ. For example, Danthine, Giavazzi, Vives, and von Thadden (1999) argue that the legal differences among European countries, and the lack of a 'European corporate law', constitute an additional factor of market segmentation. These authors claim that the European financial framework is not harmonized when it comes to law, taxation, and supervisory and regulatory institutions. Evidently, such discrepancies translate into a less efficient credit market.

Moreover, the U.S. has a more fragmented banking sector than the Euro area and a larger number of publicly listed firms 'per capita', which may also imply a more transparent and competitive market.

A number of studies have documented these kinds of differences in financial markets on the two sides of the Atlantic. For instance, Cecchetti (1999) shows the Thomson rating to be lower in the U.S., meaning a more efficient banking system. Moreover, while the return on assets is higher in the U.S., loan losses are lower. In the model, loan losses are an increasing function of monitoring costs and though, consistent with higher monitoring costs in the Euro area.

De Fiore and Uhlig (2005) find that investment of the corporate sector relies much more heavily on bank finance in the Euro area than in the U.S.: bank to bond finance ratios are 7.3 and 0.74, respectively. If we also consider that the cost of acquiring information is higher for banks, these two facts imply higher monitoring cost in the Euro area, consistent with the results in my paper. However, in contrast to my paper, De Fiore and Uhlig report that risk premiums on loans are higher in the U.S.

The financial market structure can play an important role in the transmission mechanism of shocks and the decisions of firms. The fact that the Euro area presents more frictions in credit markets than the U.S. might generate different dynamics of investment. For example, with the rest of the parameters being equal, a model with larger monitoring costs has a more powerful financial accelerator and hence greater response in investment to a monetary policy shock.

Figures 4.6 and 4.7 plot the impulse response function to a one standard deviation monetary shock of the benchmark model, with and without monitoring costs, in each of the two areas. In the absence of monitoring costs, both inflation and investment react much less to the shock.[31] To facilitate the comparison, Figure 4.8 shows the impulse response functions to a monetary policy shock of equal size in both economies, evaluated at the posterior mean. Even though monitoring costs are larger in the Euro area, the response of investment is similar in both economies. In the model, this is due to higher investment adjustment costs in the Euro area, which offset the larger credit frictions.[32] In that sense, frictions in credit markets are not a good explanation for the 'output composition puzzle' described in Angeloni, Kashyap, Mojon, and Terlizzese (2003). These authors find that while the response patterns to a monetary policy shock are similar in the U.S. and the Euro area, there is a noticeable difference in the composition of output changes. In the U.S., consumption is the predominant driver of output changes after a monetary shock, while in the Euro area it is investment. Figure 4.8 shows that even though financial frictions in the Euro area are higher, this does not imply a different response of output, investment or consumption after a monetary policy shock. This result is

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[31] However, since some posterior estimates differ in the two models, the response of output is similar, contrary to the standard BGG model predictions.

[32] De Walque, Smets, and Wouters (2005) also find that adjustment costs in capital accumulation are larger in the Euro area.

closely related to Meier and Muller (2006) who find that after a monetary policy shock, a model with financial frictions does not necessarily better fit the data.

To check that this result is not caused by other parameters in the model, I perform a counterfactual analysis. In Figure 4.9, I plot the impulse response function to a monetary policy shock of the estimated model for the U.S. (evaluated at the mean of the posterior). I then repeat the same exercise only changing the value of three parameters: monitoring costs, steady state risk premium and investment adjustment costs. I set these three parameters equal to their mean estimates for the Euro area. The figure shows that larger monitoring costs in the Euro area are offset by larger adjustment costs, such that on impact, investment reacts less, which also causes a smaller fall in output. However, the existence of higher monitoring costs implies a higher response of the costs of funds in the Euro area.

Figure 4.10 shows the same counterfactual exercise in the case of a productivity shock. The figure shows that higher financial frictions are once more offset by higher capital adjustment costs and investment reacts less, even though the financial accelerator effect is stronger. A positive productivity shock increases the marginal productivity of capital and thus the rental price of capital, the return on capital, the demand for capital and the price of capital. This has a positive effect on net worth and with higher financial frictions, these effects are larger through the positive effect on net worth. For instance, the higher price of capital under higher financial frictions increases the rental price of capital. Moreover, a positive productivity shock decreases the marginal costs given the increase in the marginal productivity of labor and capital. The initial fall in marginal costs is lower when financial frictions are larger since the increase in the rental price of capital is also larger. This difference in marginal costs causes a lower decrease in inflation on impact and in the next periods. This shows that the behavior of inflation and nominal interest rates after a productivity shock can favor a model with higher financial frictions and adjustment costs, even though the path of investment and output is not very different in the two scenarios.

Last, Figure 4.11 shows the impulse response function to a preference shock in the same counterfactual scenario. Now, the model with higher monitoring costs and capital adjustment costs has a much lower response of investment, but a similar path for inflation and the nominal interest rate.

The counterfactual exercises documented in Figures 4.9-4.11 show that financial frictions and capital adjustment costs are not observationally equivalent. Financial frictions do not only affect the response of investment and output after a shock, but also the path of other observable variables. It is only by considering the response of macro variables to a large number of shocks, that we can disentangle the effects of financial frictions and capital adjustment costs.

5   Conclusions

I study an extended version of the BGG model augmented with other frictions, such as price indexation to past inflation, sticky wages, consumption habits and variable capital utilization. This model allows us to quantify credit market frictions in an economically meaningful way. The model is estimated using Bayesian techniques for both the U.S. and the Euro area.

The results indicate that financial frictions are relevant in both areas, but quantitatively more important in the Euro area. This suggests that the financial market structure can play an important role in the transmission mechanism of shocks and the decisions of firms. The fact that the Euro area has more credit market frictions might lead one to believe that it has different dynamics in investment than the U.S. In actual fact, however, the response of investment is similar in both economies after most shocks. In the model, this is due to higher investment adjustment costs in the Euro area, which offset the larger credit frictions. Higher financial frictions in the Euro area do generate different responses of prices, the nominal interest rate and the external risk premium, though. I show that only considering the response of the variables to a large number of shocks makes it possible to disentangle these two effects.

Future research should investigate the robustness of these results to alternative ways of specifying financial frictions. The financial accelerator mechanism is certainly a popular device to account for informational frictions in financial markets, but not the only one. Moreover, it would be interesting to investigate if financial frictions have varied over time. Justiniano and Primiceri (2006) suggest that a decline in the volatility of investment specific technology shocks, which can be interpreted as investment financial frictions, account for most of the "Great Moderation".

As mentioned before, the paper only analyzes whether financial frictions are important as a source of propagation of shocks. A natural extension of the model should allow for financial frictions as a source of shocks: shocks originating from the financial side of the economy. This can be an important component when comparing business cycle dynamics in the U.S. and in the Euro area.

Last, it would be interesting to make use of financial data in the analysis. This would provide better information on the parameters governing financial frictions. Since the BGG model performs poorly in terms of credit spread dynamics when $\mu = 0$, one could reestimate only the model with the financial accelerator and investigate the robustness of the magnitude of the financial frictions in the two areas. This might help us better understand the relative economic performance of the two areas in recent years.

Appendix

4.A   Optimal Contract

As in BGG, the return on capital depends both on aggregate and idiosyncratic shocks. The ex-post return on capital in state s of the economy is $\omega^i_{t+1} r^k_{s,t+1}$, where ω^i is an *i.i.d.* lognormal random variable with pdf $F(\omega)$ and mean one.

Entrepreneurs finance their capital stock at the end of period t with their own net worth at the end of the period and bank loans:

$$q_t \widetilde{k}^i_{t+1} = n^i_{t+1} + b^i_{t+1},$$

where q_t is the relative price of capital at the end of the period. As in BGG, the entrepreneur borrows from a financial intermediary that obtains its funds from households, with an opportunity cost equal to the riskless gross rate of return, r_t. Following a "costly state verification" problem of the type analyzed by Townsend (1979), lenders must pay a fixed "auditing cost" to observe an individual borrower's realized return. BGG assume monitoring costs to be a proportion μ of the realized gross payoff to the firms' capital, i.e., the monitoring cost equals $\mu \omega^i_{t+1} r^k_{s,t+1} q_t \widetilde{k}^i_{t+1}$.

The optimal contract will be characterized by a schedule of state contingent

threshold values of the idiosyncratic shock $\varpi^i_{s,t+1}$, such that for values of the idiosyncratic shock greater than the threshold, the entrepreneur repays the lender, and for values below, the entrepreneur declares default and the lender gets $(1 - \mu)\,\varpi^i_{t+1}r^k_{s,t+1}q_t\widetilde{k}^i_{t+1}$. Because the entrepreneur is risk neutral, he is willing to guarantee the lender a return free of any aggregate risk.

Under these assumptions, the optimal contract is chosen to maximize expected entrepreneurial utility conditional on the return of the lender, for each possible realization of r^k_{t+1}, being equal in expected value to the riskless rate, r_t. The problem to solve is:

$$\max_{\left\{\varpi^i_{s,t+1}\right\}_s,\widetilde{k}^i_{t+1}} \sum_s \Pi_s \left(1 - \Gamma(\varpi^i_{s,t+1})\right) r^k_{s,t+1}q_t\widetilde{k}^i_{t+1}$$

subject to

$$\left[\Gamma(\varpi^i_{s,t+1}) - \mu G(\varpi^i_{s,t+1})\right] r^k_{s,t+1}q_t\widetilde{k}^i_{t+1} = r_t \left[q_t\widetilde{k}^i_{t+1} - n^i_{t+1}\right] \qquad \forall s,$$

where Π_s is the probability of reaching state s, $\mu G(\varpi^i_{s,t+1}) = \mu \int_0^{\varpi^i_{s,t+1}} \omega dF(\omega)$ is the expected monitoring costs and $\Gamma(\varpi^i_{s,t+1}) = \left(1 - F(\varpi^i_{s,t+1})\right)\varpi^i_{s,t+1} + G(\varpi^i_{s,t+1})$ is the expected gross share of profits going to the lender, given state s of the economy. Associating a multiplier $\Pi_s\lambda_s$ for each constraint, the FOC are:

$$\Gamma'(\varpi^i_{s,t+1})r^k_{s,t+1}q_t\widetilde{k}^i_{t+1} + \lambda_s \left[\left[\Gamma'(\varpi^i_{s,t+1}) - \mu G'(\varpi^i_{s,t+1})\right] r^k_{s,t+1}q_t\widetilde{k}^i_{t+1}\right] = 0,$$

$$\sum_s \Pi_s \left(1 - \Gamma(\varpi^i_{s,t+1})\right) r^k_{s,t+1}q_t + \sum_s \Pi_s\lambda_s \left[\left(\Gamma(\varpi^i_{s,t+1}) - \mu G(\varpi^i_{s,t+1})\right) r^k_{s,t+1} - r_t\right] = 0,$$

and

$$\left[\Gamma(\varpi^i_{s,t+1}) - \mu G(\varpi^i_{s,t+1})\right] r^k_{s,t+1}q_t\widetilde{k}^i_{t+1} = r_t \left[q_t\widetilde{k}^i_{t+1} - n^i_{t+1}\right] \qquad \forall s.$$

Rearranging, we get

$$\lambda_s(\varpi^i_{s,t+1}) = \frac{\Gamma'(\varpi^i_{s,t+1})}{\Gamma'(\varpi^i_{s,t+1}) - \mu G'(\varpi^i_{s,t+1})} \qquad \forall s,$$

$$E_t \left\{\left(1 - \Gamma(\varpi^i_{t+1})\right) r^k_{t+1} + \lambda(\varpi^i_{t+1}) \left[\left(\Gamma(\varpi^i_{t+1}) - \mu G(\varpi^i_{t+1})\right) r^k_{t+1} - r_t\right]\right\} = 0$$

and

$$\left[\Gamma(\varpi^i_{s,t+1}) - \mu G(\varpi^i_{s,t+1})\right] r^k_{s,t+1}q_t\widetilde{k}^i_{t+1} = r_t \left[q_t\widetilde{k}^i_{t+1} - n^i_{t+1}\right] \qquad \forall s.$$

Since all entrepreneurs have the same distribution of the idiosyncratic risk, $\varpi^i_{s,t+1} = \varpi_{s,t+1}$ and $\lambda_s(\varpi^i_{s,t+1}) = \lambda_s(\varpi_{s,t+1})$. From the third FOC, this implies that $\frac{n^i_{t+1}}{k^i_{t+1}}$ will also be the same across entrepreneurs.

From the second FOC, we see that when $\mu = 0, \lambda(\varpi_{t+1}) = 1$ and $E_t r^k_{t+1} = r_t$. The third FOC is related to the fact that bank profits are zero ex post. In this case, the lender's expected return can simply be expressed as a function of the average cutoff value of the firm's idiosyncratic shock, ϖ_{t+1}.

BGG show the capital to wealth ratio to be an increasing function of the ex ante premium on external funds.

4.B   The log-linearized model

To solve the model, I loglinearize the equilibrium conditions around their steady state values. The model can then be written in terms of three blocks of linear equations where letters with a hat represent log deviations from the steady state at time t, and letters without a subscript represent the steady state values of the variables.

4.B.1   Equilibrium conditions

The loglinearized versions of aggregate demand and supply are

$$\widehat{y}_t = \frac{c}{y}\widehat{c}_t + \delta\frac{\widetilde{k}}{y}\widehat{i}_t + \frac{g}{y}\widehat{g}_t + \frac{\mu G(\varpi)r^k\widetilde{k}}{y}(\widehat{r}^k_t + \widehat{q}_{t-1} + \widehat{\widetilde{k}}_t) + \frac{\mu r^k G'(\varpi)\widetilde{k}\varpi}{y}\widehat{\varpi}_t \qquad (4.1)$$

and

$$\widehat{y}_t = \widehat{a}_t + \alpha\widehat{k}_t + (1-\alpha)\widehat{L}_t, \qquad (4.2)$$

where δ is the steady state capital depreciation.

Next, I write the consumption Euler equation, equation (4.3); the arbitrage condition for nominal bonds, equation (4.4); and the law of motion of real wages,

equation $(4.5)^{33}$:

$$\widehat{c}_t = \frac{(1-h)}{\sigma(1+h)}\left(\widehat{\nu}_t - E_t\widehat{\nu}_{t+1}\right) + \frac{h}{(1+h)}\widehat{c}_{t-1} - \frac{(1-h)}{\sigma(1+h)}\widehat{r}_t + \frac{E_t\widehat{c}_{t+1}}{(1+h)}, \qquad (4.3)$$

$$\widehat{r}^n_t = \widehat{r}_t + E_t\widehat{\pi}_{t+1}, \qquad (4.4)$$

$$E_t\left\{ \begin{array}{c} \eta_0\widehat{w}^r_{t-1} + \eta_1\widehat{w}^r_t + \eta_2\widehat{w}^r_{t+1} + \eta_3\widehat{\pi}_{t-1} + \eta_4\widehat{\pi}_t + \eta_5\widehat{\pi}_{t+1} + \\ \eta_6\widehat{L}_t + \eta_7\left(\widehat{c}_t - h\widehat{c}_{t-1}\right) + \eta_8\widehat{\xi}_t + \eta_9\widehat{\tau}_t \end{array} \right\} = 0, \qquad (4.5)$$

where $b_w = \left[(\tau+1)+\tau\right]/\left[(1-\vartheta)(1-\beta\vartheta)\right]$ and

$$\eta = \begin{pmatrix} b_w\vartheta \\ -b_w\left(1+\beta\vartheta^2\right)+(\tau+1) \\ \beta\vartheta b_w \\ b_w\vartheta \\ -\vartheta b_w\left(1+\beta\right) \\ b_w\beta\vartheta \\ \tau \\ \tau\sigma\left(1-h\right)^{-1} \\ \tau \\ \tau\frac{\tau}{\tau+1} \end{pmatrix} = \begin{pmatrix} \eta_0 \\ \eta_1 \\ \eta_2 \\ \eta_3 \\ \eta_4 \\ \eta_5 \\ \eta_6 \\ \eta_7 \\ \eta_8 \\ \eta_9 \end{pmatrix}.$$

These three equations are derived from the households' first-order conditions. τ is the net wage mark up in steady state; $\widehat{\nu}_t$ is the preference shock, and $\widehat{\xi}_t$ is the labor supply shock.

The demands for labor and capital in the wholesale sector, where factor prices are equal to marginal productivity plus real marginal cost, $\widehat{s}_t$, are given by

$$\widehat{y}_t - \widehat{L}_t + \widehat{s}_t = \widehat{w}^r_t \qquad (4.6)$$

and

$$\widehat{s}_t + \widehat{y}_t - \widehat{k}_t = \widehat{z}_t. \qquad (4.7)$$

A Phillips curve can be derived from the wholesale sector optimization problem for prices, where $(1-\theta)$ is the probability of adjusting prices and λ is the net price

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[33] This is the same notation as in Christiano, Eichenbaum, and Evans (2005) but a net wage mark up has been introduced.

mark up in steady state:

$$\widehat{\pi}_t = \frac{\widehat{\pi}_{t-1}}{(1+\beta)} + \frac{\beta}{(1+\beta)} E_t \widehat{\pi}_{t+1} + \frac{(1-\theta)(1-\beta\theta)}{(1+\beta)\theta} \widehat{s}_t + \frac{(1-\theta)(1-\beta\theta)}{(1+\beta)\theta} \frac{\lambda}{(\lambda+1)} \widehat{\lambda}_t. \tag{4.8}$$

Capital producers' optimality condition is

$$E_t \widehat{q}_{t+1} + \varphi \left[\widehat{i}_{t+1} - \widehat{\widetilde{k}}_{t+1} \right] = 0. \tag{4.9}$$

This equation links asset prices and investment, where $\varphi = \Phi''\left(\frac{i}{\tilde{k}}\right)\left(\frac{i}{\tilde{k}}\right)$ is the elasticity of the price of capital with respect to the investment-capital ratio.

The equilibrium conditions of the entrepreneurs are

$$E_t \widehat{r}^k_{t+1} - \widehat{r}_t = E_t \widehat{\varpi}_{t+1} \varpi \frac{r^k}{r} (1 - \Gamma(\varpi)) \left[\frac{\Gamma''(\varpi)}{\lambda(\varpi)\Gamma'(\varpi)} - \frac{\Gamma''(\varpi)}{\Gamma'(\varpi)} + \frac{\mu G''(\varpi)}{\Gamma'(\varpi)} \right], \tag{4.10}$$

$$[(1 - F(\varpi)) - \mu G'(\varpi)] \frac{\widetilde{k}}{n} \frac{r^k}{r} \varpi \widehat{\varpi}_{t+1} + \left[\frac{\widetilde{k} - n}{n} \right] (\widehat{r}^k_{t+1} - \widehat{r}_t) = \widehat{\widetilde{k}}_{t+1} + \widehat{q}_t - \widehat{n}_{t+1}, \tag{4.11}$$

$$\widehat{k}_t = \widehat{u}_t + \widehat{\widetilde{k}}_t, \tag{4.12}$$

and

$$\widehat{z}_{t+1} = \frac{\delta''(1)}{\delta'(1)} \widehat{u}_{t+1} + \widehat{q}_{t+1}. \tag{4.13}$$

Equations (4.10) and (4.11) are the first-order conditions of the optimal lending contract.[34] Equation (4.12) relates capital services to the capital stock, while equation (4.13) is the optimality condition for capital utilization.

The loglinearized return on capital is

$$\widehat{r}^k_{t+1} = \frac{z}{r^k} \widehat{z}_{t+1} + \frac{(1-\delta)}{r^k} \widehat{q}_{t+1} - \widehat{q}_t. \tag{4.14}$$

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[34] In the model without financial frictions, $\mu = 0$, and these equations and the law of motion of net worth are:

$$E_t \widehat{r}^k_{t+1} = \widehat{r}_t,$$

$$[(1 - F(\varpi))] \frac{\widetilde{K}}{N} \varpi \widehat{\varpi}_{t+1} + \left[\frac{\widetilde{K} - N}{N} \right] (\widehat{r}^k_{t+1} - \widehat{r}_t) = \widehat{\widetilde{k}}_{t+1} + \widehat{q}_t - \widehat{n}_{t+1},$$

and

$$\widehat{n}_{t+1} = \gamma R \left\{ \left(\frac{\widetilde{K}}{N} \right) \widehat{r}^k_t - \left(\frac{\widetilde{K} - N}{N} \right) \widehat{r}_{t-1} + \widehat{n}_t \right\}.$$

The first equation shows that without monitoring costs, the ex-ante risk premium is zero.

Equations (4.15) and (4.16) are the law of motion of net worth and capital, respectively:

$$\widehat{n}_{t+1} = \gamma \left\{ \begin{array}{c} \left(\frac{\widetilde{k} - \mu G(\varpi)\widetilde{k}}{n} \right) r^k \widehat{r}_t^k + \left(\frac{r^k \widetilde{k} - \widetilde{k}r - \mu G(\varpi)r^k \widetilde{k}}{n} \right) \widehat{q}_{t-1} + \left(\frac{r^k - r - \mu G(\varpi)r^k}{n} \right) \widetilde{k}\widehat{\widetilde{k}}_t \\ - \left(\frac{\widetilde{k} - n}{n} \right) r\widehat{r}_{t-1} + r\widehat{n}_t - \left(\frac{\mu r^k G_w \widetilde{k}}{n} \right) \varpi\widehat{\varpi}_t \end{array} \right\}$$

(4.15)

and

$$\widehat{\widetilde{k}}_{t+1} = \delta\widehat{\imath}_t + (1-\delta)\widehat{\widetilde{k}}_t - \delta'(1)\widehat{u}_t.$$

(4.16)

4.B.2   Monetary policy rule

The loglinearized monetary policy rule is

$$\widehat{r}_t^n = \rho^r \widehat{r}_{t-1}^n + (1-\rho^r)(\gamma^\pi E\widehat{\pi}_{t+1}) + (1-\rho^r)(\gamma^y \widehat{y}_t)/4 + \widehat{\varepsilon}_t^r.$$

(4.17)

4.B.3   Shock Process

There exist seven shocks in the model:

$$\widehat{\varepsilon}_t^r = \varepsilon_t^r,$$

(4.18)

$$\widehat{\lambda}_t = \varepsilon_t^\lambda,$$

(4.19)

$$\widehat{\tau}_t = \varepsilon_t^\tau,$$

(4.20)

$$\widehat{\xi}_t = \rho^\xi \widehat{\xi}_{t-1} + \varepsilon_t^\xi,$$

(4.21)

$$\widehat{\nu}_t = \rho^\nu \widehat{\nu}_{t-1} + \varepsilon_t^\nu,$$

(4.22)

$$\widehat{g}_t = \rho^g \widehat{g}_{t-1} + \varepsilon_t^g,$$

(4.23)

and

$$\widehat{a}_t = \rho^a \widehat{a}_{t-1} + \varepsilon_t^a,$$

(4.24)

where ε_t^i are white noise shocks affecting the economy.

Equations (4.18)-(4.20) are the monetary policy, price mark up and wage mark up shocks. I specify these shocks as white noise shocks. The rest of the shocks in the model, to labor supply, preferences, government spending and technology, follow a

first-order autoregressive process. I choose this specification for the shocks to avoid identification problems.

Table 4.1-A: Prior and Posterior Distribution of the Parameters for the U.S.

Parameter	Prior			Financial Accelerator				no Financial Accelerator			
	Type	Mode	St. Er.	5%	Mean	95%	$\widehat{R}$	5%	Mean	95%	$\widehat{R}$
σ_r monetary shock	Gam	0.01	0.005	0.003	0.004	0.004	1.002	0.003	0.004	0.005	1.000
σ_a technology shock	Gam	0.01	0.005	0.006	0.007	0.008	1.002	0.005	0.006	0.007	1.001
σ_g gov. spending shock	Gam	0.01	0.005	0.015	0.017	0.019	1.000	0.017	0.019	0.021	1.000
σ_ν preferences shock	Gam	0.10	0.05	0.089	0.126	0.165	1.024	0.085	0.145	0.228	1.003
σ_ξ labor supply shock	Gam	0.10	0.05	0.026	0.031	0.037	1.014	0.034	0.040	0.048	1.000
σ_λ price mark up shock	Gam	0.10	0.05	0.271	0.329	0.397	1.021	0.215	0.260	0.312	1.005
σ_τ wage mark up shock	Gam	0.10	0.05	1.877	2.143	2.414	1.295	2.164	2.438	2.740	1.000
ρ^r instrument rule	Beta	0.85	0.10	0.354	0.430	0.500	1.014	0.313	0.395	0.470	1.000
ρ^a technology shock	Beta	0.85	0.10	0.953	0.976	0.993	1.000	0.896	0.923	0.945	1.002
ρ^g gov. spend. shock	Beta	0.85	0.10	0.868	0.920	0.963	1.010	0.945	0.966	0.983	1.009
ρ^ν preferences shock	Beta	0.85	0.10	0.991	0.993	0.996	1.008	0.990	0.994	0.997	1.008
ρ^ξ labor supply shock	Beta	0.85	0.10	0.985	0.992	0.998	1.002	0.981	0.989	0.996	1.001

Table 4.1-B: Prior and Posterior Distribution of the Parameters for the U.S.

Parameter	Prior			Financial Accelerator				no Financial Accelerator			
	Type	Mode	St. Er.	5%	Mean	95%	$\widehat{R}$	5%	Mean	95%	$\widehat{R}$
γ^π response to inflation	Norm	1.50	0.05	1.542	1.614	1.687	1.001	1.564	1.637	1.708	1.000
γ^y response to output	Norm	0.50	0.05	0.157	0.240	0.322	1.001	0.109	0.198	0.285	1.001
σ risk aversion	Norm	1.00	0.10	0.984	1.110	1.227	1.034	0.944	1.100	1.259	1.000
θ Calvo prices	Beta	0.70	0.05	0.758	0.782	0.804	1.013	0.734	0.759	0.783	1.004
φ elasticity of K price wrt I/K	Unif	-0.5*	0.29	-0.578	-0.475	-0.386	1.001	-0.278	-0.220	-0.168	1.000
γ entrepreneurs' rate of survival	Beta	.975	0.01	0.985	0.991	0.995	1.000	0.952	0.971	0.985	1.000
μ monitoring costs	Beta	0.12	0.05	0.083	0.119	0.158	1.000	-	-	-	-
$r^k - r$ risk premium in SS	Gam	0.005	0.002	0.004	0.006	0.008	1.000	-	-	-	-
ϑ Calvo wages	Beta	0.70	0.05	0.174	0.208	0.243	1.171	0.157	0.186	0.215	1.000
h habit formation	Beta	0.70	0.05	0.548	0.604	0.659	1.004	0.601	0.661	0.718	1.001
δ''/δ' variable depreciation	Gam	1.00	0.05	0.939	1.020	1.106	1.098	0.924	1.005	1.090	1.003

Note: * Mean

Table 4.2: Model Comparison

	Log marginal data density		Posterior odds
	FA	no FA	
U.S.	1880.2	1829.8	10^{21}
Euro Area	1921.0	1881.1	10^{17}

Note: Posterior odds of the hypothesis FA versus no FA

Table 4.3-A: Prior and Posterior Distribution of the Parameters for the Euro Area

Parameter	Prior			Financial Accelerator				no Financial Accelerator			
	Type	Mode	St. Er.	5%	Mean	95%	$\widehat{R}$	5%	Mean	95%	$\widehat{R}$
σ_r monetary shock	Gam	0.01	0.005	0.002	0.002	0.003	1.035	0.002	0.003	0.003	1.000
σ_a technology shock	Gam	0.01	0.005	0.007	0.008	0.009	1.000	0.007	0.008	0.009	1.000
σ_g gov. spending shock	Gam	0.01	0.005	0.015	0.017	0.019	1.001	0.014	0.016	0.018	1.000
σ_ν preferences shock	Gam	0.10	0.05	0.082	0.155	0.218	1.793	0.053	0.104	0.181	1.000
σ_ξ labor supply shock	Gam	0.10	0.05	0.027	0.032	0.037	1.001	0.027	0.033	0.041	1.011
σ_λ price mark up shock	Gam	0.10	0.05	0.272	0.320	0.376	1.019	0.204	0.252	0.307	1.002
σ_τ wage mark up shock	Gam	0.10	0.05	1.514	1.807	2.061	1.138	2.077	2.369	2.681	1.005
ρ^r instrument rule	Beta	0.85	0.10	0.428	0.499	0.564	1.038	0.309	0.395	0.479	1.000
ρ^a technology shock	Beta	0.85	0.10	0.965	0.985	0.996	1.006	0.748	0.842	0.949	1.022
ρ^g gov. spend. shock	Beta	0.85	0.10	0.739	0.841	0.948	1.011	0.934	0.965	0.987	1.002
ρ^ν preferences shock	Beta	0.85	0.10	0.993	0.996	0.998	1.572	0.990	0.994	0.997	1.000
ρ^ξ labor supply shock	Beta	0.85	0.10	0.99	0.995	0.999	1.000	0.988	0.994	0.998	1.001

Table 4.3-B: Prior and Posterior Distribution of the Parameters for the Euro Area

Parameter	Prior			Financial Accelerator				no Financial Accelerator			
	Type	Mode	St. Er.	5%	Mean	95%	$\widehat{R}$	5%	Mean	95%	$\widehat{R}$
γ^π response to inflation	Norm	1.50	0.05	1.482	1.556	1.631	1.013	1.477	1.568	1.651	1.002
γ^y response to output	Norm	0.50	0.05	0.146	0.227	0.307	1.015	0.057	0.152	0.245	1.003
σ risk aversion	Norm	1.00	0.10	1.052	1.211	1.373	1.155	0.943	1.093	1.247	1.000
θ Calvo prices	Beta	0.70	0.05	0.812	0.832	0.852	1.007	0.822	0.843	0.862	1.003
φ elasticity of K price wrt I/K	Unif	-0.5*	0.29	-0.999	-0.973	-0.92	1.000	-0.458	-0.347	-0.264	1.007
γ entrepreneurs' rate of survival	Beta	.975	0.01	0.991	0.994	0.997	1.007	0.954	0.971	0.985	1.000
μ monitoring costs	Beta	0.12	0.05	0.117	0.182	0.245	1.005	-	-	-	-
$r^k - r$ risk premium in SS	Gam	0.005	0.002	0.006	0.009	0.012	1.005	-	-	-	-
ϑ Calvo wages	Beta	0.70	0.05	0.236	0.274	0.311	1.058	0.210	0.245	0.279	1.004
h habit formation	Beta	0.70	0.05	0.458	0.516	0.574	1.068	0.501	0.569	0.635	1.004
δ''/δ' variable depreciation	Gam	1.00	0.05	0.913	0.997	1.087	1.301	0.936	1.013	1.095	1.009

Note: * Mean
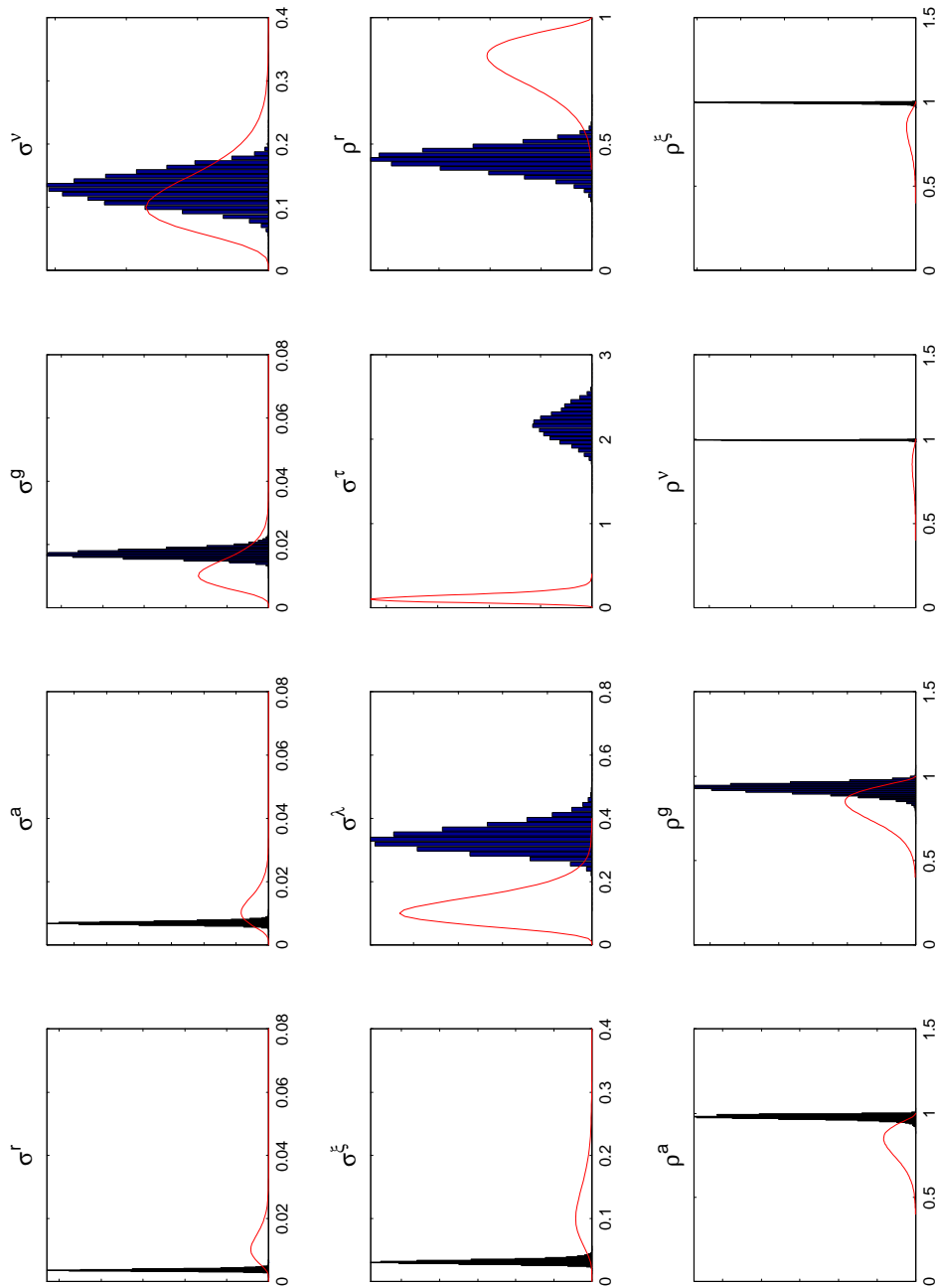
Figure 4.1: Prior and posterior distribution of the model with financial frictions for U.S. data
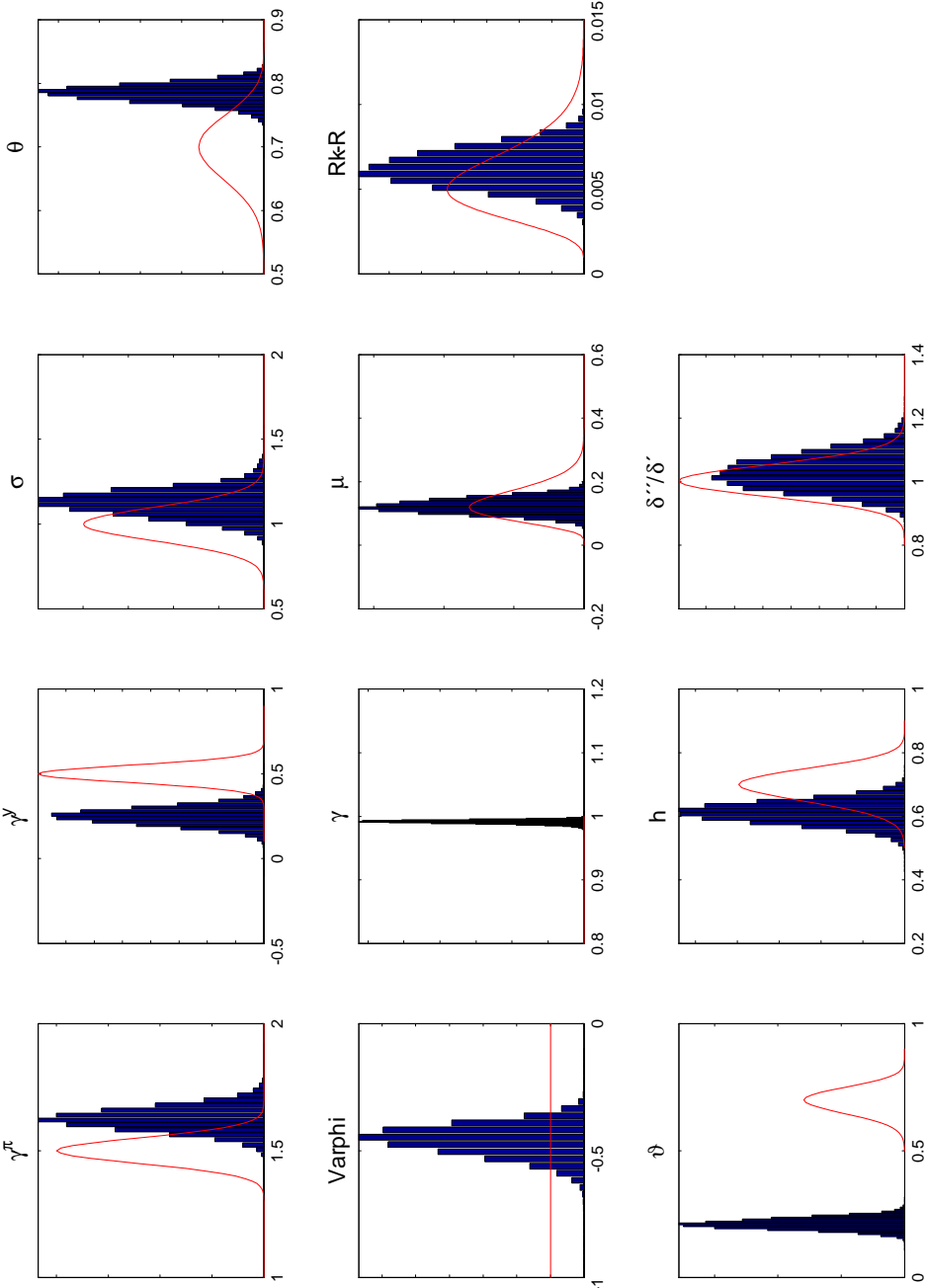
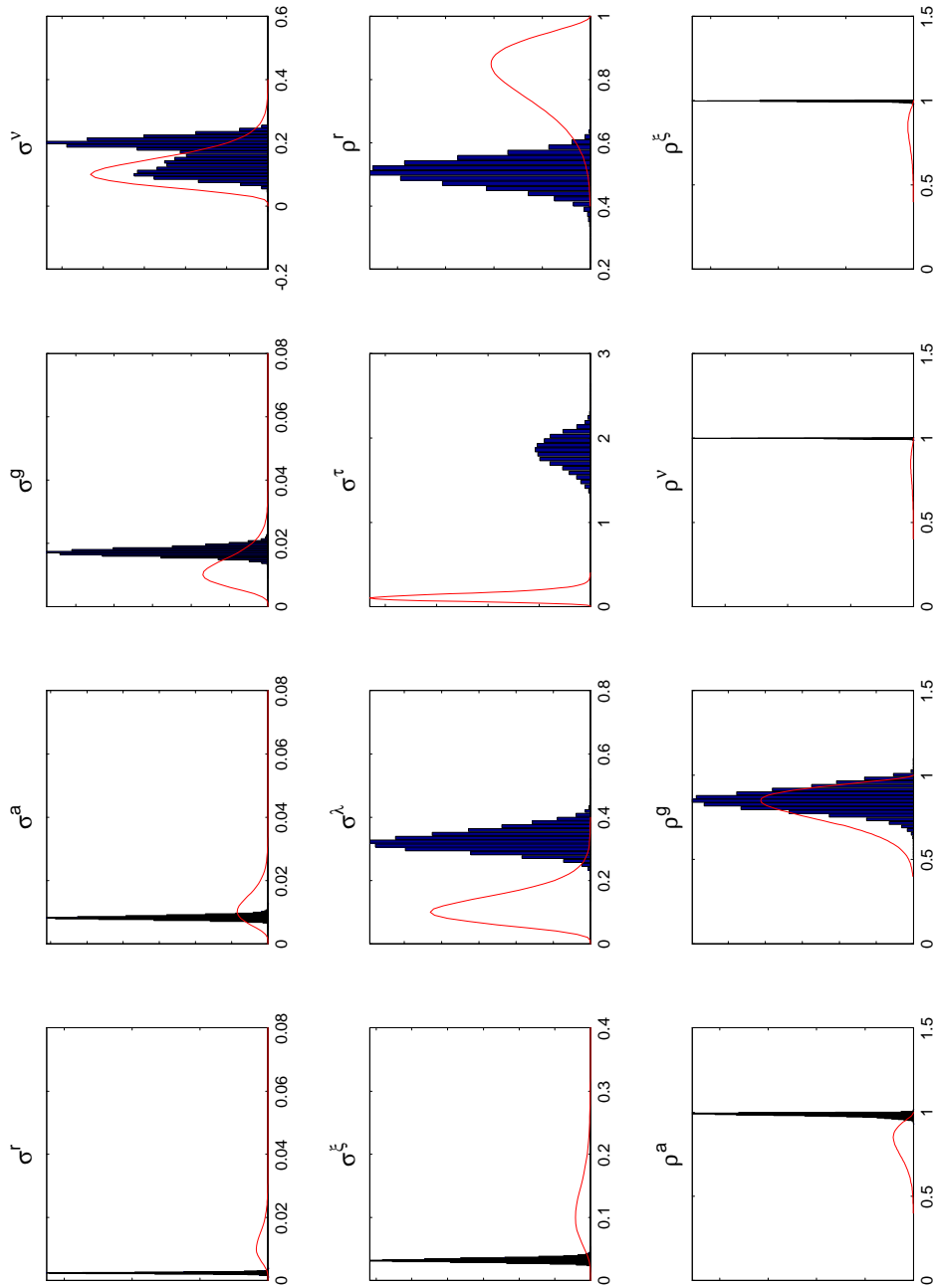Figure 4.2: Prior and posterior distribution of the model with financial frictions for U.S. data

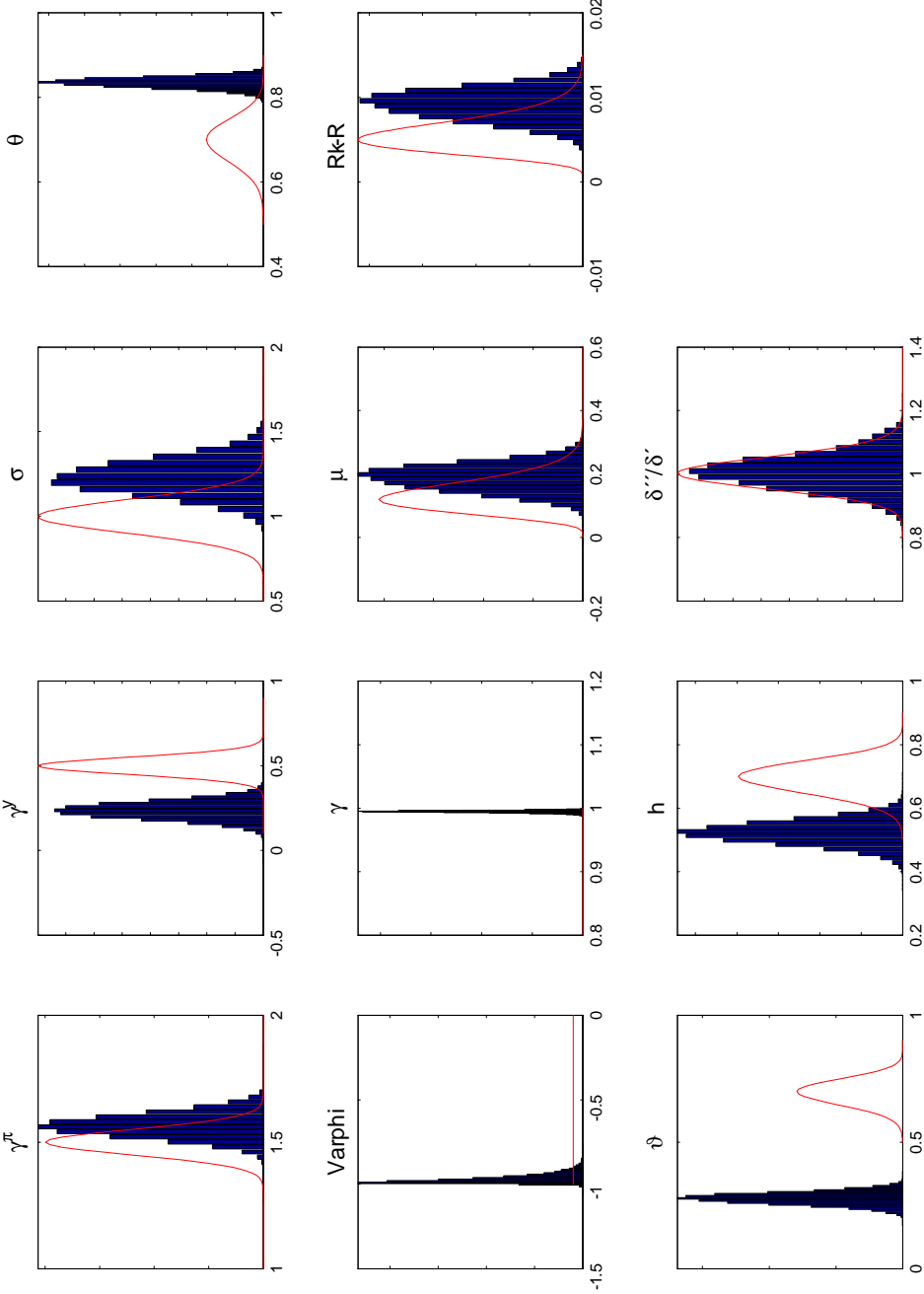Figure 4.3: Prior and posterior distribution of the model with financial frictions for Euro data

Figure 4.4: Prior and posterior distribution of the model with financial frictions for Euro data
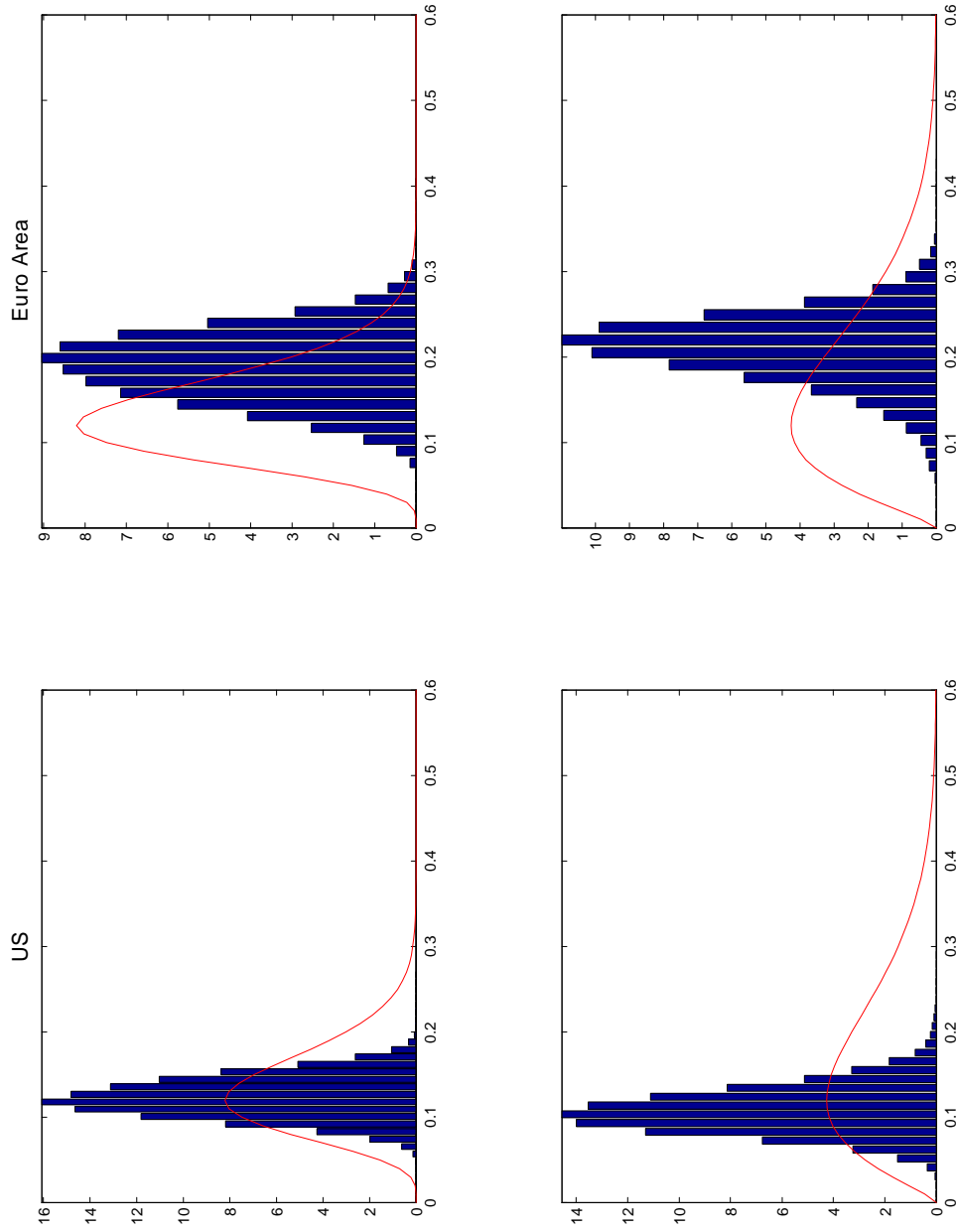
Figure 4.5: Prior and posterior distribution of μ. The first row corresponds to a beta prior with mean 0.12 and standard deviation 0.05. The second row corresponds to a beta prior with mean 0.12 and standard deviation 0.10.
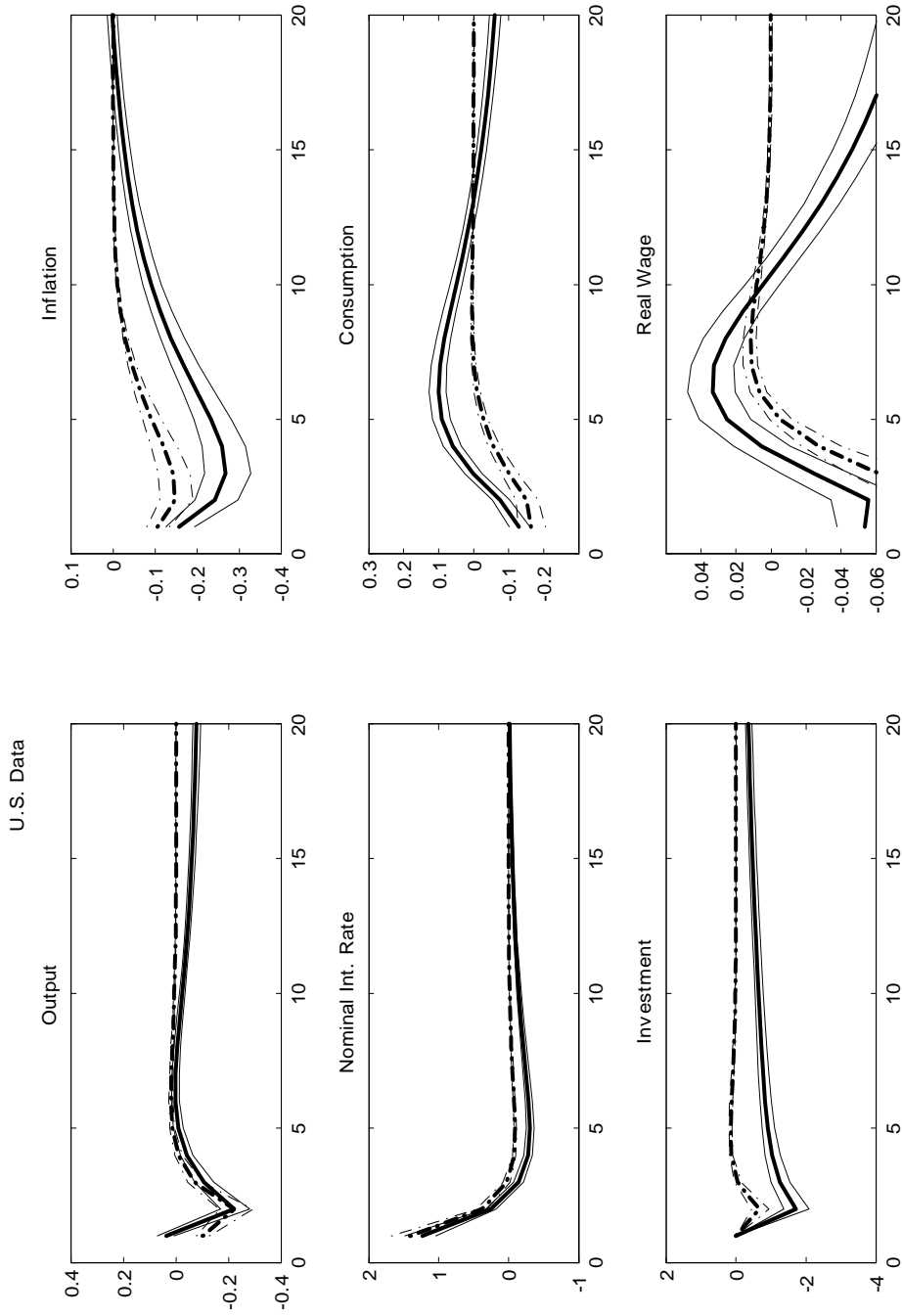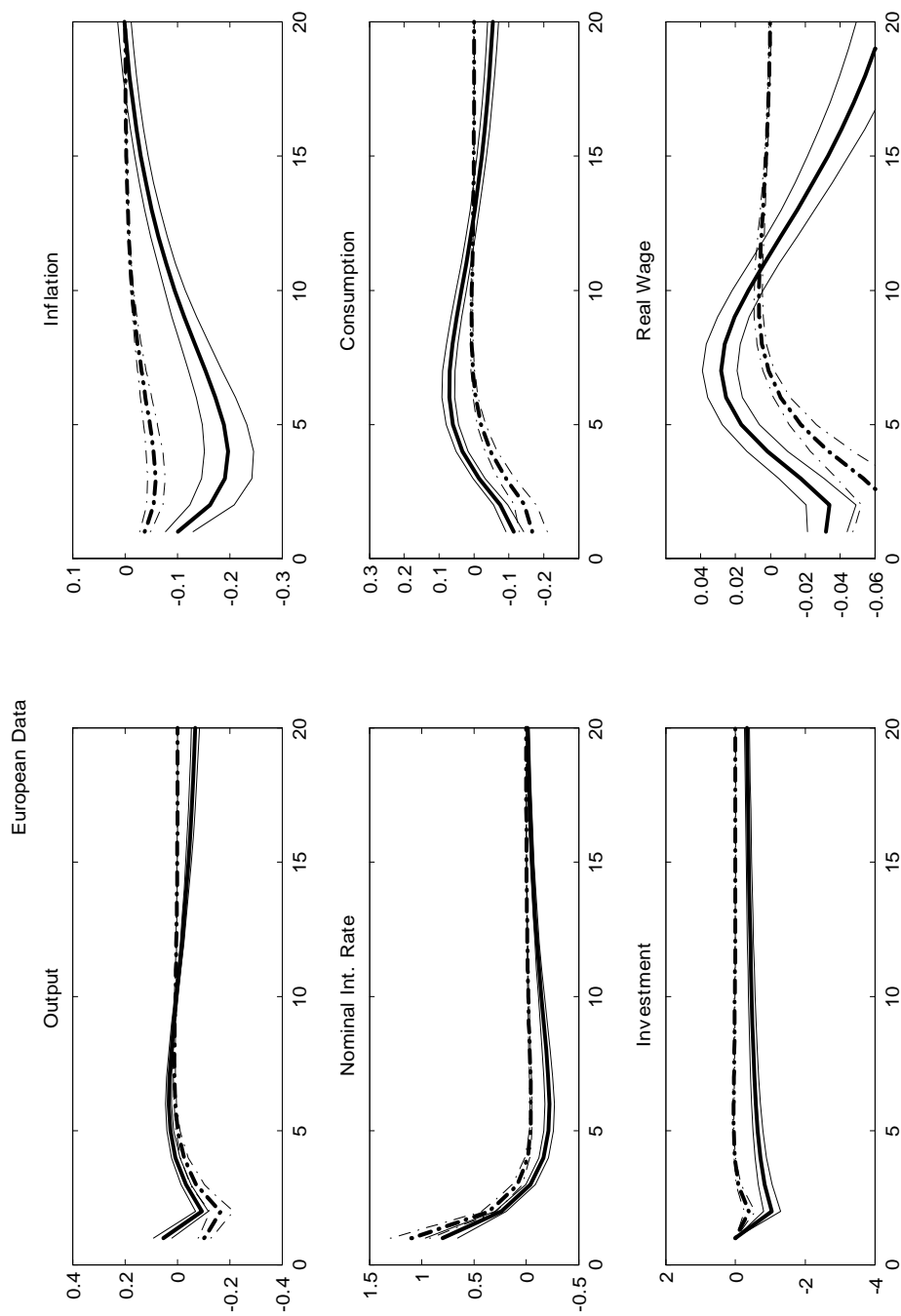
Figure 4.6: Impulse Response Function to a one standard deviation monetary policy shock (mean, 5 and 95 percentiles). Solid line: financial accelerator model. Dashed line: model without financial accelerator. Values expressed as percentage deviation from steady state values, and in the case of inflation and the nominal interest rate as annual percentage points.
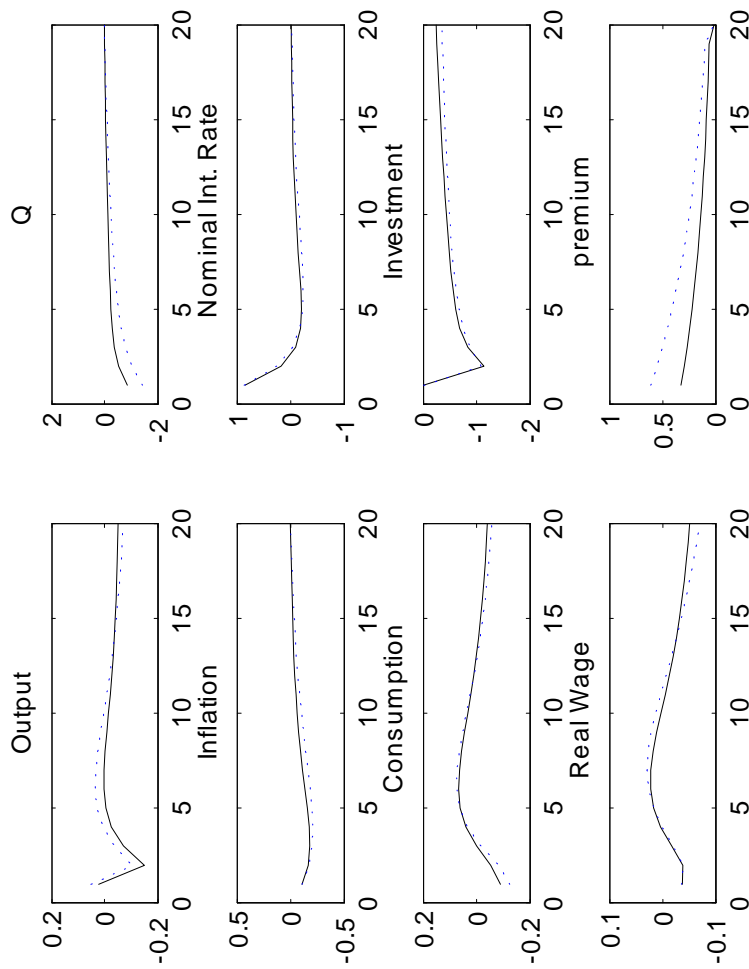
Figure 4.7: Impulse Response Function to a one standard deviation monetary policy shock (mean, 5 and 95 percentiles). Solid line: financial accelerator model. Dashed line: model without financial accelerator. Values expressed as percentage deviation from steady state values, and in the case of inflation and the nominal interest rate as annual percentage points.

Figure 4.8: Impulse Response functions to a one percent shock to the nominal interest rate (annual) for the model with monitoring costs. Solid line: U.S. data. Doted line: European data. Values expressed as percentage deviation from steady state values, and in the case of inflation, the nominal interest rate and premium as annual percentage points.
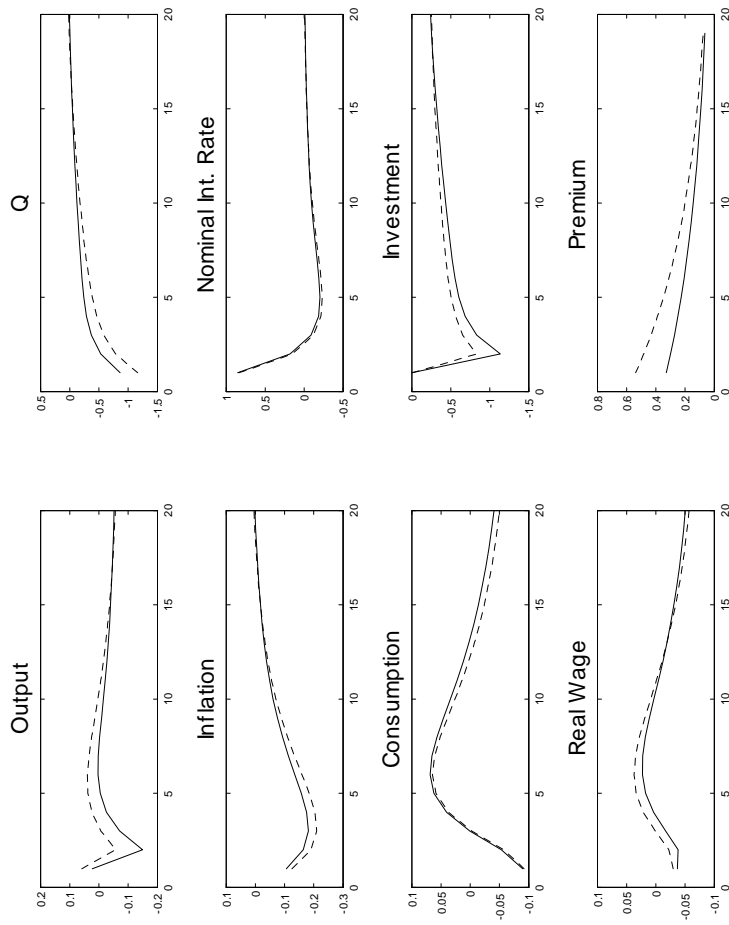
Figure 4.9: Counterfactual: Impulse Response functions to a one percent shock to the nominal interest rate (annual) for the model with monitoring costs. Solid line: U.S. data. Dashed line: U.S. data using credit market frictions and investment adjustment costs as in the Euro area. Values expressed as percentage deviation from steady state values, and in the case of inflation. the nominal interest rate and premium as annual percentage points.
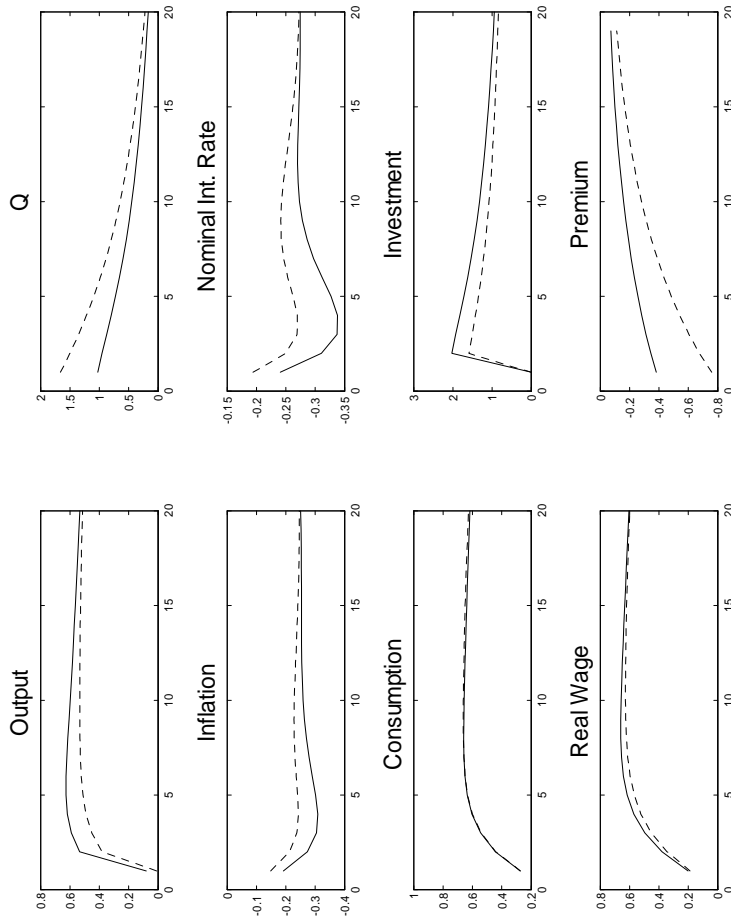
Figure 4.10: Counterfactual: Impulse Response functions to a one standard deviation shock to productivity for the model with monitoring costs. Solid line: U.S. data. Dashed line: U.S. data using credit market frictions and investment adjustment costs as in the Euro area. Values expressed as percentage deviation from steady state values, and in the case of inflation, the nominal interest rate and premium as annual percentage points.
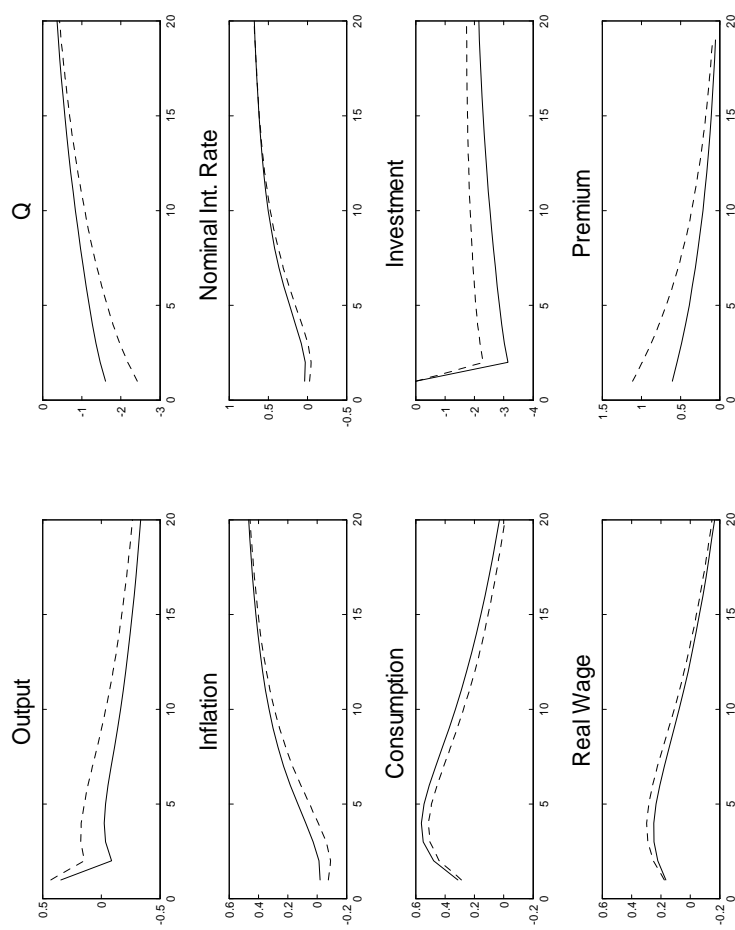
Figure 4.11: Counterfactual: Impulse Response functions to a one standard deviation preference shock for the model with monitoring costs. Solid line: U.S. data. Dashed line: U.S. data using credit market frictions and investment adjustment costs as in the Euro area. Values expressed as percentage deviation from steady state values, and in the case of inflation, the nominal interest rate and premium as annual percentage points.

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