Asymmetric Effects of Monetary Policy

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Abstract

In this paper, we first use a structural vector autoregression model to examine whether the US economy responds asymmetrically to expansionary and contractionary monetary policies. The empirical results show that monetary policy has significant asymmetric effects on output and investment. To provide an explanation of such asymmetries, we consider a nonlinear dynamic stochastic general equilibrium (DSGE) model in which collateral constraints are occasionally binding over the business cycle. The nonlinear DSGE model is able to match the empirical findings that macroeconomic aggregates react asymmetrically to positive and negative monetary policies.

Keywords: monetary policy; asymmetric effects; occasionally binding constraint.

JEL classification:

1 Introduction

Whether the effects of monetary policy are asymmetric has important implications for the effectiveness of monetary policy and the transmission mechanism of monetary policy. For example, if a contractionary policy has a stronger effect on the economic activity than does an expansionary policy, the policymaker should be aware that the transmission mechanism of monetary policy could be different for contractionary and expansionary policies; moreover, the same size of monetary contractions and expansions could result in different magnitudes of policy effects. A large literature has investigated the asymmetric monetary policy effect on economic aggregates (such as consumption, investment, output, employment) and asset prices (such as stock prices, house prices).

A strand of these works studies the asymmetric effects of a positive (expansionary) and a negative (contractionary) shock of monetary policy respectively and tends to find that monetary contractions have a significantly greater effect on the economic activity than equally sized expansionary policy.[1] The other strand studies whether the effects of monetary shocks under different states of the economy are asymmetric, where the regimes are usually assumed to shift as a Markov process.[2] Many works find evidences that a monetary policy shock has a more significant effect during recessions than in booms.[3]

Several possible mechanisms have been proposed to explain the existence of asymmetric

[1] See DeLong and Summers (1988), Cover (1992), Thoma (1994), Rhee and Rich (1995), Karras (1996a,b), Kim et al. (1998), Karras and Stokes (1999), Wong (2000) and Fehr and Tyran (2001).

[2] See Azariadis and Smith (1998), Garcia and Schaller (2002), Chen (2007), and Chen et al. (2013).

[3] Using various specifications and methods, a few studies find no evidence of asymmetric effects of monetary policy shocks. See, for example, Weise (1999) and Ravn and Sola (2004).

responses to monetary policy shocks.[4] A fast growing literature in the last two decades has stressed the role of financial frictions faced by households and firms in generating asymmetric responses of monetary policy. Financial frictions, which may be rooted in the asymmetric information or limited commitment, lead lenders to not only charge a higher premium but also impose a credit constraint on borrowers. Thus, a contractionary monetary policy has a stronger effect on economic aggregates because credit constraints are more likely to be binding when liquidity is scarce due to a monetary tightening.[5]

In recent years, many quantitative macroeconomic models incorporating financial frictions were proposed to exploit the amplification and propagation mechanism of borrowing constraints to exogenous shocks.[6] Even though many of these models are able to match various aspects of business regularities and the patterns of impulse responses to exogenous shocks, however, they are unable to match the data in terms of generating asymmetric effects on economic aggregates for exogenous shocks.

The main reason is that these models tend to implicitly assume that the credit constraints faced by borrowers not only bind in the steady state, but also bind all the time. Specifically, this

[4] The other mechanisms include a convex supply curve and a change in economic outlook Morgan (1993). For example, if prices are downward sticky, the aggregate supply curve will be a convex function, which implies that output will be more sensitive to the policy during recessions than booms. As for the economic outlook, pessimism during recession hinders the effectiveness of expansionary policies, while optimism during booms keeps the economic expansion going even when tightened monetary policy is implemented.

[5] Corresponding to the empirical literature, an alternative sense of asymmetry is that monetary shocks have larger effects in recessions than in boom because agents have lower net worth and thus are more likely to be credit-constrained.

[6] See, e.g., Carlstrom and Fuerst (1997), Bernanke et al. (1999), Iacoviello (2004), Iacoviello (2005), Iacoviello and Neri (2010), Bianchi (2011), Rubio (2011), Liu et al. (2013), Iacoviello (2015), Notarpietro and Siviero (2015), Chakraborty (2016), Kydland et al. (2016) and Suh and Walker (2016).

is equivalent to assuming that exogenous shocks are small enough so that the disturbances occur only in the neighborhood of the steady state. As a result, the decision rules of agents behave linearly and the economy respond symmetrically to either a negative or a positive shock. This assumption, however, is clearly implausible because a consecutive positive shock or a big good shock may raise the net worth of households and firms and thus their borrowing constraints no longer bind. Thus, for some periods, financial frictions play no role so that consumption and investment behaviors of households and firms may switch to resemble those under a perfect credit market. Relaxing the assumption that borrowing constraints are always binding not only removes an implausible assumption, but also allows us to exploit the asymmetric effect of exogenous shocks on economic aggregates that have been widely observed in empirical works.

In this paper we consider a nonlinear general equilibrium model in which collateral constraints are occasionally binding over the business cycles to study the asymmetric effect of monetary policies on the economic activity. Under this framework, the source of asymmetries arises from financial frictions and also occasionally binding collateral constraints. The decision rules of households and firms will be nonlinear with respect to whether or not the borrowing constraint is binding. We examine how monetary shocks affect the borrowing constraints, and how the responses of economic aggregates behave differently to contractionary and expansionary monetary shocks.

Before presenting the model, we provide empirical evidence of asymmetric effects of monetary policy using a two-step approach. We first use a structural vector autoregression (VAR) model to identify monetary policy shocks. Then, we separate the shocks into two categories: contractionary monetary policy shocks and expansionary monetary policy shocks, and examine whether the economy responds asymmetrically to expansionary and contractionary monetary policies. In particular, motivated by the findings in Bernanke and Mihov (1998), we choose the federal funds rate as a proxy of monetary policy. That is, a negative (positive) interest rate innovation represents an easy (tightening) monetary policy. Our empirical results provide evidence in support of asymmetric effects and the asymmetries are present in major macroeconomic aggregates including output, investment and consumption.

The idea of occasionally binding constraints we adopt here emerged only recently in a number of works. For example, Mendoza (2010) introduces an occasionally binding constraint through which the debt-deflation mechanism works to explain the stylized facts of sudden stops. The model is solved by reformulating it in recursive form and applying a nonlinear global solution method. Brunnermeier and Sannikov (2014) solve the full dynamics of the model with endogenous friction and risks using a continuous-time methodology. Nevertheless, the solution methods of these models involve a wider state space and thus the computations are very cumbersome. To mitigate the curse of dimensionality, recent studies combine the piecewise-linear algorithm with an alternative algorithm as a solution method for models with occasionally binding constraints. Among these studies, Guerrieri and Iacoviello (2015) provide a toolkit, OccBin, that handles the occasionally binding constraints as different regimes of the same model, allowing the model to be easily solved. Guerrieri and Iacoviello (2016) further apply OccBin to investigate the asymmetric effects of housing wealth changes on economic activity. They claim that through collateral constraints, house prices play a more important role during severe recessions than during booms. Recently, this method has been applied in some studies.[7]

[7]See, for example, Altomonte et al. (2015), Anzoategui et al. (2016), Ajello (2016), Cui (2016), Kollmann et al. (2016), and Lim and McNelis (2016).

Using the OccBin toolkit, this paper extends the model developed by Iacoviello (2005) to allow for the existence of occasionally binding constraints. In particular, we focus on the asymmetric effect of monetary policy on the macroeconomy through the collateral constraints that bind occasionally. When facing a tight monetary policy, the expected future value of the collateral assets decreases, and the borrowing constraints are more likely to bind. The funds that individuals and investors are able to obtain become less available and thus aggregate variables, including investment, output, and consumption, fall. On the other hand, when an easy monetary policy is conducted, the cost of borrowing is lowered, and the entrepreneurs invest and produce more. Accordingly, households will consume more. Under this situation, most importantly, the collateral constraints tend to become slack. When this happens, the propagation mechanism fails to work and the effect of monetary expansion is not as profound as that of monetary contraction. That is, an expansionary monetary policy makes a smaller contribution to economic growth when collateral constraints do not always bind.

The rest of the paper is organized as follows.[OLE4] Section 2 describes the data and the results of the structural VAR model. Section 3 presents the DSGE model with two collateral constraints. Section 4 discusses the results and shows the impulse responses of monetary shocks. Section 5 concludes.

2 Empirical Framework and Results

In this section, we first show how we identify structural monetary policy shocks from a structural VAR model. Next, contractionary monetary policy shocks (positive interest rate shocks) and expansionary monetary policy shocks (negative interest rate shocks) are constructed accordingly. We then present the empirical model used to examine the link between interest rate shocks and major macroeconomic aggregate variables. Finally, we provide the data and the empirical results.

2.1 Monetary Policy Shocks

To estimate monetary policy shocks, we consider the following structural VAR model of monetary policy:

$$y_t = D_0 y_t + D_1 y_t + \cdots + D_k y_{t-k} + e_t, \tag{1}$$

where $y_t = [OP_t, P_t, GDP_t, R_t]'$ is a vector containing oil prices, aggregate prices, output, and interest rates. All the variables except the interest rate are in logarithms. e_t denotes the structural shocks with a mean of zero and a diagonal variance covariance matrix $\Lambda = E(e_t e_t')$, where the diagonal entries are the variances of structural shocks.

The corresponding reduced-form VAR can be estimated by

$$y_t = \Phi_1 y_{t-1} + \Phi_2 y_{t-2} + \cdot + \Phi_k y_{t-k} + \epsilon_t, \tag{2}$$

where ϵ_t denotes the regression residuals. As equation (1) can be rewritten as

$$y_t = (I - D_0)^{-1} D_1 y_{t-1} + (I - D_0)^{-1} D_2 y_{t-2} + \cdots + (I - D_0)^{-1} D_k y_{t-k} + (I - D_0)^{-1} e_t,$$

the structural shocks and the reduced-form residuals are related by

$$(I - D_0)^{-1} e_t = \epsilon_t,$$

and the relationship between the coefficients in equations (1) and (2) is

$$\Phi_j = (I - D_0)^{-1} D_j, \forall j = 1, 2, ..., k.$$

The identification is achieved by imposing restrictions on $I - D_0$ such that

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ a_{21} & 1 & 0 & 0 \\ a_{31} & a_{32} & 1 & 0 \\ a_{41} & a_{42} & a_{43} & 1 \end{bmatrix} \begin{bmatrix} OP_t \\ P_t \\ GDP_t \\ R_t \end{bmatrix} = D_1 y_{t-1} + D_2 y_{t-2} + \cdot + D_k y_{t-k} + \begin{bmatrix} e_t^{OP} \\ e_t^{P} \\ e_t^{GDP} \\ e_t^{R} \end{bmatrix},$$

where $e_t^{OP}, e_t^{P}, e_t^{GDP}$, and e_t^{R} are the structural shocks, i.e., oil price shocks, aggregate price shocks, output shocks, and monetary policy shocks, respectively.

As shown in Sims (1992), Bernanke and Mihov (1998), and Kim (2003), commodity prices (e.g., oil prices) are included in the structural VAR model to capture additional information available to the Federal Reserve about the future course of inflation. We follow Blanchard and Gali (2009) in identifying oil price shocks by assuming that unexpected variations in the nominal price of oil are exogenous relative to the contemporaneous values of the remaining macroeconomic variables included in the VAR. The second equation says that oil prices pass through into changes in the aggregate price level, and the third equation assumes that both oil price shocks and aggregate price shocks have an influence on the output level. In the last equation, we assume that the interest rate is affected by various real and nominal shocks, which suggests that the Federal Reserve is modeled as setting the interest rate to react to various shocks (see, e.g., Stock and Watson, 2001).

2.2 Asymmetric Effects of Monetary Policy Shocks

After identifying the structural shocks to interest rates, e_t^{R}, we construct the contractionary monetary policy shock as $e_t^{R+} \equiv \max[0, e_t^{R}]$ and the expansionary monetary policy shock as

$e_t^{R-} \equiv \min[0, e_t^R]$ because a positive (negative) value of e_t^R implies tightness (looseness) of monetary policy. We then consider the following autoregressive distributed lag (ADL) model to investigate whether asymmetric effects of monetary policy on the macroeconomy exist:

$$\Delta X_t = \alpha + \sum_{j=1}^{j=4} \rho_j \Delta X_{t-j} + \beta^+ e_t^{R+} + \beta^- e_t^{R-} + u_t, \tag{3}$$

where X_t denotes macroeconomic variables, such as GDP, investment, consumption, house prices, and loans. The regressand $\Delta X_t = (\log X_t - \log X_{t-1}) \times 100$ denotes the percentage change in the corresponding variables. Accordingly, if $\beta^+ \neq \beta^-$, it suggests that there is evidence of asymmetric effects of monetary policy, and vice versa.

2.3 Data

Quarterly US data are used to examine the asymmetric effects of monetary policy. To identify monetary policy shocks, oil prices, aggregate prices, real output, and short-run interest rates are included in the VAR system. Oil prices are measured by West Texas Intermediate (WTI) spot crude oil prices. We use the GDP deflator and real GDP to measure aggregate prices and real output, respectively. The short-run interest rate is measured by the federal funds rate. The sample period is from 1980:Q1 to 2016:Q3 because Bernanke and Mihov (1998) provide evidence that the federal funds rate provides a good measure of monetary policy after the 1980s.

The macroeconomic variables (X_t) of the ADL regression model in equation (3) are real output, real investment, real consumption, real house prices, and real loans. We use private nonresidential investment and personal consumption to measure investment and consumption, respectively. The house prices we considered are based on the CoreLogic Home Price Index (single-family home). Loans are measured by the real estate loans (revolving home equity loans, all commercial banks) to correspond with the loan variable in our theoretical model, which is the mortgage loan. All real variables are deflated using the GDP deflator. The data are available from the Federal Reserve Economic Data (FRED), except the house price index, which is obtained from CoreLogic. Figure 1 plots the data in logarithmic form, and Figure 2 shows the first difference.

2.4 Empirical Results

The optimal lag length chosen for the VAR model is two, based on the Bayesian Information criterion (BIC). The identified structural shocks to the interest rates, e_t^R, are plotted in Figure 3. To assess whether the structural shocks to the federal funds rates provide a good measure of monetary policy shocks, we further present the impulse responses of oil prices, the GDP deflator, real GDP, and the federal funds rate to a one-standard deviation shock to monetary policy, e_t^R, in Figure 4. The 95% confidence intervals are constructed by bootstrapping with 1000 replications. By using such a quantitative measure of the dynamic effects of policy changes on the economy, we can examine if the responses are in line with economic theory.

We observe that an unexpected positive interest rate shock causes a decrease in both aggregate prices and output, which is consistent with the predictions of standard economic models and conventional wisdom. The decrease in output reaches a peak at 10 quarters, whereas the reduction in the price level is more persistent. The above results are in line with those reported by Bernanke and Mihov (1998). Therefore, the evidence shows that the structural interest rate shock identified in our structural VAR model is a reasonable measure of monetary policy shocks.

After decomposing the interest rate shock e_t^R into positive and negative shocks (e_t^{R+} and

e_t^{R-}), we estimate the ADL regression model in equation (3). Table 1 reports the results, with the dependent variables being real output, real investment, real consumption, real house prices, and real loans.

First, as columns (1) and (2) of Table 1 show, it is evident that the coefficients for the positive interest rate shock are significantly negative: a 1% increase in the interest rate shock leads to a 0.5% decrease in output and a 0.63% fall in investment. However, the coefficients estimated for the negative shock are positive but statistically insignificant. That is, the results show that monetary policy has asymmetric effects on macroeconomic aggregates, including output and investment. To test further whether the asymmetry is statically significant, we use the Wald statistic to test whether β^+ equals β^-. It is obvious that the hypothesis $\beta^+ = \beta^-$ can be rejected with a Wald statistic $\chi^2 = 5.4578$ and p-value equaling 0.0195 for output in column (1), and $\chi^2 = 2.8387$ and p-value equaling 0.0920 for investment in column (2). These results suggest that the difference between these two magnitudes is statistically significant. That is, we find strong evidence that there are asymmetric effects of monetary policy on output and investment.

Next, we turn to the estimation results for consumption and loans. It can be observed from column (3) of Table 1 that neither positive nor negative interest rate shocks have significant impacts on consumption. Although the estimates are not statistically significant, it is worth noting that the coefficients for both positive and negative shocks are negative and show some sort of asymmetry. Specifically, a 1% increase in the interest rate causes a 0.15% decrease in consumption, whereas a 1% fall in the interest rate causes only a 0.051% growth in consumption. Nevertheless, the Wald test statistic indicates that we are not able to reject the null hypothesis of symmetry. As for the impact of the interest rate on loans, the estimation reaches a similar conclusion, as shown in column (3) of Table 1. That is, contractionary and expansionary monetary policies have asymmetric effects but these are not statistically significant. In particular, a tight policy has a more profound impact than does an easy policy.

Finally, we investigate the impact of interest rate shocks on house prices. Column (4) of Table 1 shows that the coefficients for positive and negative interest rate shocks are negative. In contrast to the estimation results for consumption and loans, the effect of a contractionary monetary policy on house prices is smaller than the impact from an expansionary policy. As shown in the table, a 1% increase in the interest rate leads to a 0.03% decrease in house prices, whereas a 1% fall in the interest rate causes a 0.04% increase in house prices. We can see that the influence of the interest rate on house prices, regardless of whether it is positive or negative, is far smaller than its impact on other variables, including output and investment. However, the estimates are not statistically significant and the evidence of asymmetry is not significant either.

3 The DSGE Model

As we have found that contractionary monetary policy and expansionary monetary policy have different impacts on output and investment, in this section, we construct a DSGE model that allows for the existence of occasionally binding constraints to explain such asymmetric effects of monetary policy on the macroeconomy. Following Iacoviello (2005), the economy is populated by three groups of agents: patient households, impatient households, and entrepreneurs, all of whom are infinitely lived and of measure one. Households work and consume both consumption goods and housing. The difference between patient and impatient households is that the former save, whereas the latter borrow. Entrepreneurs hire household labor, invest, produce homogeneous goods, and use real estate as collateral to obtain loans. In addition, there are retailers as a source of nominal rigidity and a central bank conducting monetary policy.

Patient Households

Patient households choose levels of consumption c'_t, housing h'_t, labor supply L'_t, and money M'_t/P_t to maximize their expected lifetime utility, given by

$$E_0 \sum_{t=0}^{\infty} \beta^t \left(\ln c'_t + j_t \ln h'_t - (L'_t)^\eta/\eta + \chi \ln(M'_t/P_t)\right),$$

where M'_t/P_t are money balances divided by the price level and j_t is the random disturbance to the marginal utility of housing. Households are subject to the following budget constraint:

$$c'_t + q_t \Delta h'_t + \frac{R_{t-1} b'_{t-1}}{\pi_t} = b'_t + w'_t L'_t + F_t + T'_t - \frac{\Delta M'_t}{P_t} - \xi_{h',t},$$

where $q_t \equiv Q - t/P_t$ and $w'_t \equiv W'_t/P_t$ denote the real house price and real wage, respectively. Patient households lend in real terms $-b'_t$ and earn a nominal interest rate R_t, which is the return on loans between time $t-1$ and t. In addition, $\pi_t \equiv P_t/P_{t-1}$ represents the gross inflation rate and $F_t = (1 - 1/X_t)Y_t$ is the lump-sum benefits received from the retailers. The last three terms are net transfers from the central bank, which are financed by printing money, and the housing adjustment cost, $\xi_{h',t} = \phi_e(\Delta h'_t/h'_{t-1})^2 q_t h'_{t-1}/2$.

Impatient Households

With a smaller discount factor $\beta'' < \beta$, impatient households choose levels of consumption c''_t, housing h''_t, labor supply L''_t, and money M''_t/P_t to maximize their expected lifetime utility, given by

$$E_0 \sum_{t=0}^{\infty} \beta''^t \left(\ln c''_t + j_t \ln h''_t - (L''_t)^\eta/\eta + \chi \ln(M''_t/P_t)\right),$$

subject to the following budget constraint and collateral constraint:

$$
\begin{aligned}
c_t'' + q_t \Delta h_t'' + \frac{R_{t-1} b_{t-1}''}{\pi_t} &= b_t'' + w_t'' L_t'' + T_t'' - \frac{\Delta M_t''}{P_t} - \xi_{h'',t}, \\
b_t'' &\leq m'' E_t \left(\frac{q_{t+1} h_t'' \pi_{t+1}}{R_t} \right),
\end{aligned}
\tag{4}
$$

where $\xi_{h'',t} = \phi_e (\Delta h_t'' / h_{t-1}'')^2 q_t h_{t-1}''/2$ is the housing adjustment cost and m'' can be interpreted as a loan-to-value (LTV) ratio.

Entrepreneurs

Entrepreneurs produce intermediate goods Y_t and maximize a lifetime utility function given by

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

where γ denotes the discount factor, with $\gamma < \beta$. The maximization problem, subject to technology constraints, the flow of funds constraint, the capital law of motion, and the collateral constraint, is as follows:

$$
\begin{aligned}
Y_t &= A_t K_{t-1}^{\mu} h_{t-1}^{\nu} L_t'^{\alpha(1-\mu-\nu)} L_t''^{(1-\alpha)(1-\mu-\nu)}, \\
\frac{Y_t}{X_t} + b_t &= c_t + q_t \Delta h_t + I_t + w_t' L_t' + w_t'' L_t'' + \frac{R_{t-1} b_{t-1}}{\pi_t} + \xi_{e,t} + \xi_{K,t}, \\
K_t &= (1-\delta) K_{t-1} + I_t, \\
b_t &\leq m E_t \left(\frac{q_{t+1} h_t \pi_{t+1}}{R_t} \right).
\end{aligned}
\tag{5}
$$

The term A_t is a technology shock. Inputs used to produce intermediate good Y_t include capital K_t, real estate h_t, and labor L_t'. The parameters μ and ν measure the output elasticities of capital and real estate, respectively. Entrepreneurs sell intermediate good to retailers at the wholesale price P_t^w, and pay the gross nominal interest rate R_t for loans obtained from patient households.

The terms $\xi_{e,t} = \phi_e(\Delta h_t/h_{t-1})^2 q_t h_{t-1}/2$ and $\xi_{K,t} = \psi(I_t/K_{t-1} - \delta)^2 K_{t-1}/(2\delta)$ are the adjustment costs of changing the stock of real estate and capital, respectively. Finally, δ is the capital depreciation rate and m is the LTV limitation imposed on entrepreneurs.

Retailers

There is a continuum of retailers of mass unity, indexed by z. Retailer z buys intermediate goods Y_t from entrepreneurs at P_t^w in a competitive market and then differentiates the goods at no cost into $Y_t(z)$. The final output Y_t^f is a constant elasticity of substitution (CES) composite given by

$$Y_t^f = \left[\int_0^1 Y_t(z)^{\frac{\varepsilon-1}{\varepsilon}} dz \right]^{\frac{\varepsilon}{\varepsilon-1}}.$$

The individual demand curve is obtained from cost minimization by users of the final output, which can be shown as

$$Y_t(z) = \left(\frac{P_t(z)}{P_t} \right)^{-\varepsilon} Y_t^f,$$

where $P_t(z)$ is the price of $Y_t(z)$ and therefore the composite price index is given by

$$P_t = \left[\int_0^1 P_t(z)^{\varepsilon-1} dz \right]^{\frac{1}{\varepsilon-1}}.$$

Retailers use one unit of intermediate goods to produce one unit of retail output, and each of them chooses a sale price $P_t(z)$, taking P_t^w and the demand curve as given. In particular, a retailer can freely adjust its price with probability $1 - \theta$ in every period. Therefore, the retailer chooses the optimal reset price $P_t^*(z)$ to solve

$$E_t \sum_{i=0}^{\infty} \theta^i \Lambda_{t,t+i} \left[\frac{P_t^*(z)}{P_{t+i}} - \frac{X}{X_{t+i}} \right] Y_{t+i}^*(z) = 0,$$

where $\Lambda_{t,t+i} = \beta^i (c_t'/c_{t+i}')$ is the patient household stochastic discount factor. X_t is the markup and $X = \varepsilon/(\varepsilon - 1)$ is its steady state value. The term $Y_{t+i}^*(z) = (P_t^*(z)/P_{t+i})^{-\varepsilon} Y_{t+i}$ is the corresponding demand. Now with the constant probability θ, the evolution of the aggregate price level is

$$P_t = \left[(1-\theta)(P_t^*)^{1-\varepsilon} + \theta P_{t-1}^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}}.$$

Central Bank

The monetary policy is set by a central bank according to a conventional Taylor rule with interest rate smoothing, given by

$$R_t = (R_{t-1})^{r_R}\left((\pi_{t-1})^{r_\pi}(Y_{t-1}/Y)^{r_Y}\overline{rr}\right)^{1-r_R} e_t^R, \tag{6}$$

where $\overline{rr}$ and Y are the steady state real interest rate and output, respectively. e_t^R is an exogenous shock process with mean zero and variance σ_e^2. The parameter r_R captures the smoothing of the interest rate and r_π and r_Y measure the response to past inflation and output, respectively. We follow Iacoviello (2005) in choosing the values of the model parameters, which are summarized in Table 2.

4 Asymmetric Responses to Monetary Policy Shocks

It is clear that the constraints (4) and (5) are not always binding. As a result of the occasionally binding nature of the borrowing constraints, we use the toolkit OccBin developed by Guerrieri and Iacoviello (2015) to deal with this nonlinearity problem. This toolkit applies a first-order perturbation approach to a piecewise-linear approximation to solve dynamic models with occasionally binding constraints. Depending on whether a constraint binds, a model has two regimes. Under one regime, the constraint binds; under the other, the constraint is slack. As our model has two collateral constraints, there are four possible regimes: (i) the borrowing constraint faced by impatient households binds, and the one imposed on entrepreneurs does not; (ii) the borrowing constraint faced by impatient households is slack, and the one imposed on entrepreneurs is binding; (iii) both constraints bind; and (iv) both constraints are slack. OccBin then employs a guess-and-verify method to generate time-varying decision rules.

Figures 5 and 6 plot the impulse response of chosen variables to positive and negative interest rate shocks, governed by the random shock e_t^R in equation (6). The blue line represents the case where there is a monetary expansion, i.e., a fall in the interest rate, and the red dashed line shows the case where there is a monetary contraction, i.e., a rise in the interest rate. Note that the x-axis indicates the time horizon in quarters and the y-axis denotes the percentage deviation from the initial steady state.

The asymmetric properties of the nonlinear DSGE model are consistent with the empirical results discussed in Section 2. First, from Figure 5, we can observe that output and investment rise in response to the easy monetary policy, i.e., a fall in the interest rate. However, when monetary policy is tight and the interest rate increases, it is obvious that the decrease in output and investment is more aggressive than the responses to the expansionary monetary policy. Taking the impulse response of investment as an example, we can see that a 1% fall in the interest rate leads to a growth of approximately 0.73% in investment, whereas the same size of positive shock to the interest rate results in a decline of more than 1.31%.

The intuition behind these results is that, under the assumptions that $\beta' < \beta$ and $\gamma < \beta$, the two borrowing constraints bind at the steady state, and the loans available to borrowers tend to expand only when the interest rate becomes low. When the monetary authority tightens the money policy with a higher interest rate, the collateral constraints remain binding and the loanable fund to borrowers becomes smaller, given the same present value of mortgages. That is, the budget constraint of borrowers such as the entrepreneurs is tightened and firms have no choice but to reduce their investment in productive inputs, including capital, labor, and housing, thus eventually producing less. In the contrary scenario, when the policy maker expands the money supply and lowers the interest rate, two things happen. First, borrowers are able to obtain more loans with the same mortgage. On the other hand, the collateral constraints are more inclined to be relaxed and become slack. Facing a looser constraint, entrepreneurs raise investment but may not borrow to the limit, so that the responses of the variables to a negative interest rate shock are weaker than the responses to a positive interest rate shock. Therefore, the mechanism of the occasionally binding constraint explains why the changes in macroeconomic variables are larger, and the reductions are more profound, when a contractionary monetary policy is adopted.

There is also an asymmetric response to monetary policy by consumption, but the asymmetry is less strong than is the case for output and investment. The reason for this lesser asymmetry may be consumption smoothing and this may relate to the observation, made in our empirical section, that we cannot reject the null hypothesis of symmetry (see column (3) of Table 1). Further, the asymmetry in house prices is not as significant as that found for other variables. According to Figure 5, there is a very small asymmetry, and the magnitude of which is much less than the asymmetry observed for the other dependent variables. A 1% decrease in the interest rate leads to a rise of approximately 0.41% in house prices, and a 1% increase in the interest rate causes a fall in house prices of around 0.43%. This impulse response corresponds to the empirical implications that: first, the effect of an interest rate change on house prices is less than the impact on output, investment, and consumption; and second, we fail to reject the null hypothesis of symmetry in house prices.

Figure 6 illustrates the impulse response of loans to entrepreneurs, loans to impatient households, and the corresponding Lagrange multipliers. As noted above, the constraints tend to remain binding when the interest rate becomes high, yet become slack when the interest rate goes down. The properties of the two borrowing constraints can be observed from the response of the corresponding Lagrange multipliers. When a tight monetary policy is conducted, the Lagrange multipliers for both borrowing constraints increase and remain positive. Hence, the constraints are always binding and the loans to firms and impatient households decrease, whereas when an easy monetary policy is adopted, the fall in the interest rate means the borrowing constraints become slack. The Lagrange multipliers bottom out at zero and stay at zero for about 14 quarters,[8] and then gradually rise back to their steady state level. As a consequence, loans increase in response to the decline in the interest rate but the reaction is much smoother than is the case for a shock of equal size but with the opposite sign.

4.1 Simplified Model with One Constraint

To better understand the underlying dynamic mechanism of our nonlinear DSGE model, in this section, we modify our baseline model with two constraints into a simplified model in which there is only one constraint. That is, we examine further the difference between a two-friction model and a one-friction model. We choose to remove the role of impatient households

[8] The number of periods that the Lagrange multipliers remain at zero depends on the agents' discount factor. For example, the time for which the borrowing constraint stays slack can increase if we raise the impatient household's discount factor, and vice versa.

and to retain the setting with entrepreneurs and their related borrowing constraint because entrepreneurs serve as goods producers in our model and cannot be removed.

Thus, the entrepreneur's production function and borrowing constraint become

$$Y_t = A_t K_{t-1}^{\mu} h_{t-1}^{\nu} L_t'^{1-\mu-\nu}$$

$$\frac{Y_t}{X_t} + b_t = c_t + q_t \Delta h_t + I_t + w_t' L_t' + \frac{R_{t-1} b_{t-1}}{\pi_t} + \xi_{e,t} + \xi_{K,t},$$

where the variable L_t'' in the baseline model is erased.

Figure 7 presents the impulse response of the selected variables to positive and negative interest rate shocks in the simplified one-friction model. The notation and legend are the same as those in Figures 5 and 6. From Figure 7, we see that the asymmetric properties remain in the simplified model with only one constraint but the asymmetric effects are less profound than their counterparts in the baseline model with two frictions. For example, a 1% fall in the interest rate leads to a 0.69% rise in output in the two-friction model compared with a 0.67% rise for the one-friction model. However, when a shock of the same magnitude but with the opposite sign hits, output falls by 0.96% in the baseline model but only by 0.86% in the simplified model. The responses of investment and consumption to a monetary policy shock follow a similar pattern. That is, the asymmetric property is weakened in the model with only one constraint.

The reason for the less significant asymmetry is the absence of the impatient households and their borrowing constraint. Recall that the asymmetry that we revealed largely depends on whether the borrowing constraints are binding. Therefore, the one-friction model suffers less from the impact of the borrowing constraints.

5 Conclusion

In this paper, we use a structural vector autoregression model and extend the sample period to the latest data to examine whether the economy responds asymmetrically to expansionary and contractionary monetary policies. We find that there are asymmetries in some macroeconomic aggregates, including output and investment, whereas the evidence that consumption, house prices, and loans respond asymmetrically to monetary policy is somewhat weaker.

To provide an explanation of such asymmetric effects, we use a nonlinear general equilibrium model in which collateral constraints are occasionally binding over the business cycle. By applying the OccBin toolkit, our model is able to generate asymmetric responses of the main macroeconomic variables in response to monetary policy shocks. The intuition for asymmetries is as follows. When an easy monetary policy is implemented, the expected future value of assets increases on the one hand; on the other hand, borrowing constraints are more likely to become slack. The funds that individuals and investors are able to obtain increase and thus aggregate variables, including investment, output, and consumption, increase. However, the responses of the aggregate variables are less smooth compared with the case when a tight monetary policy shock hits because the constraints are relaxed. We use a simplified model with one constraint to compare the results with the baseline model with two constraints. Again, we verify the asymmetry property arising from the borrowing constraint. The impulse responses to positive and negative shocks confirm the empirical results that output and investment react asymmetrically to monetary policies.

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Figure 1: Data Series in Level

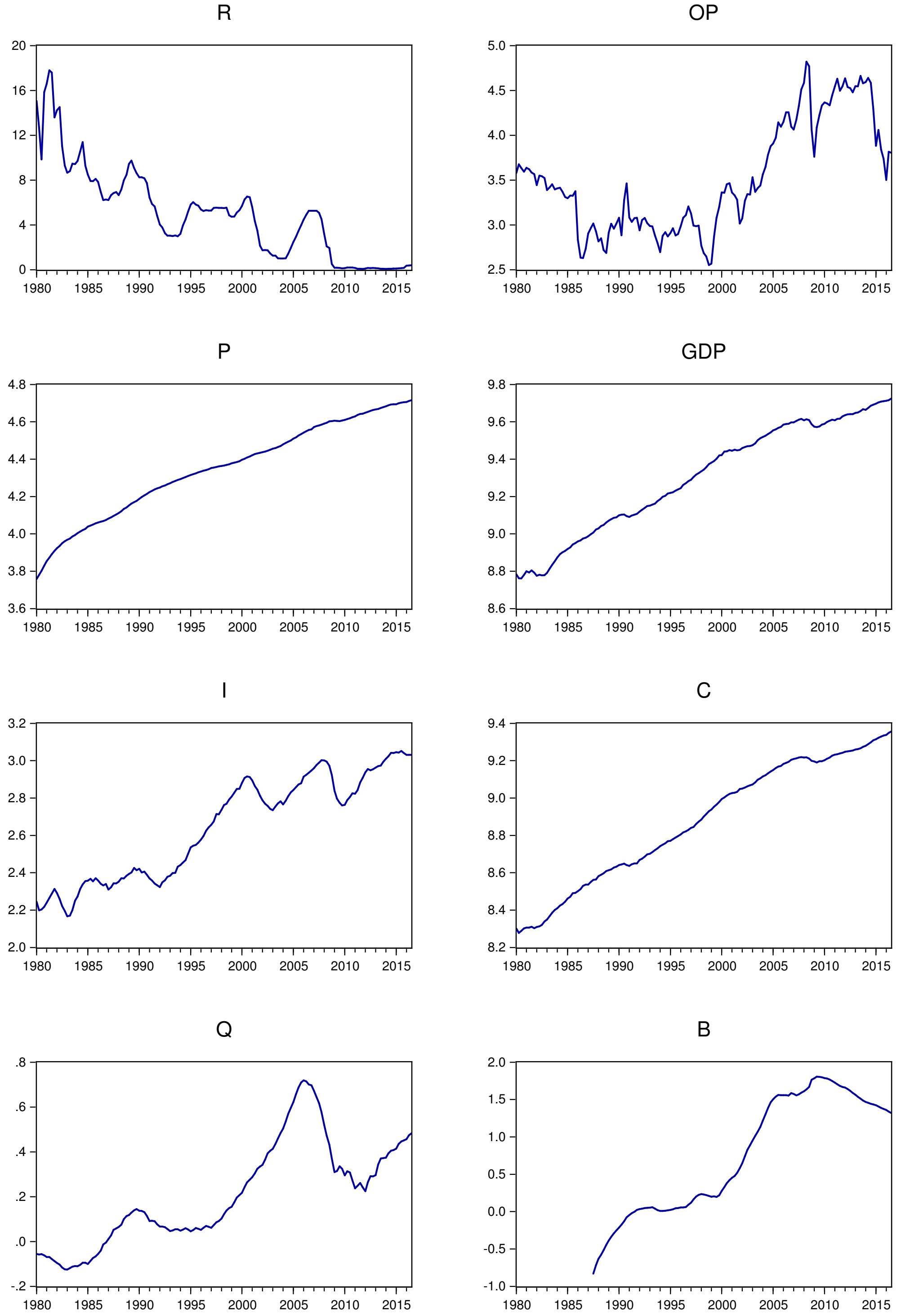


Figure 2: Data Series in First-Difference

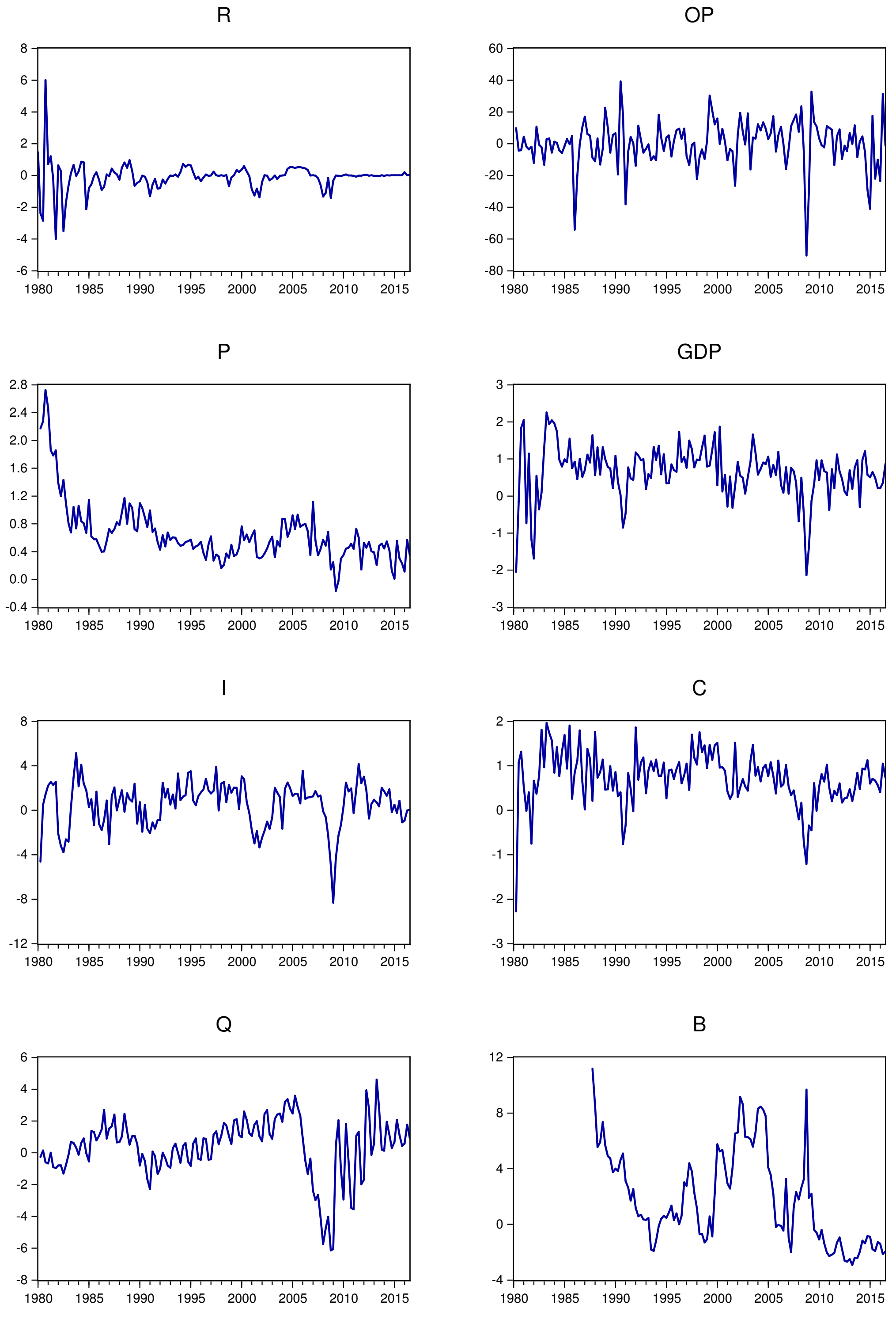


Figure 3: Structural Shock on Interest Rates e_t^R

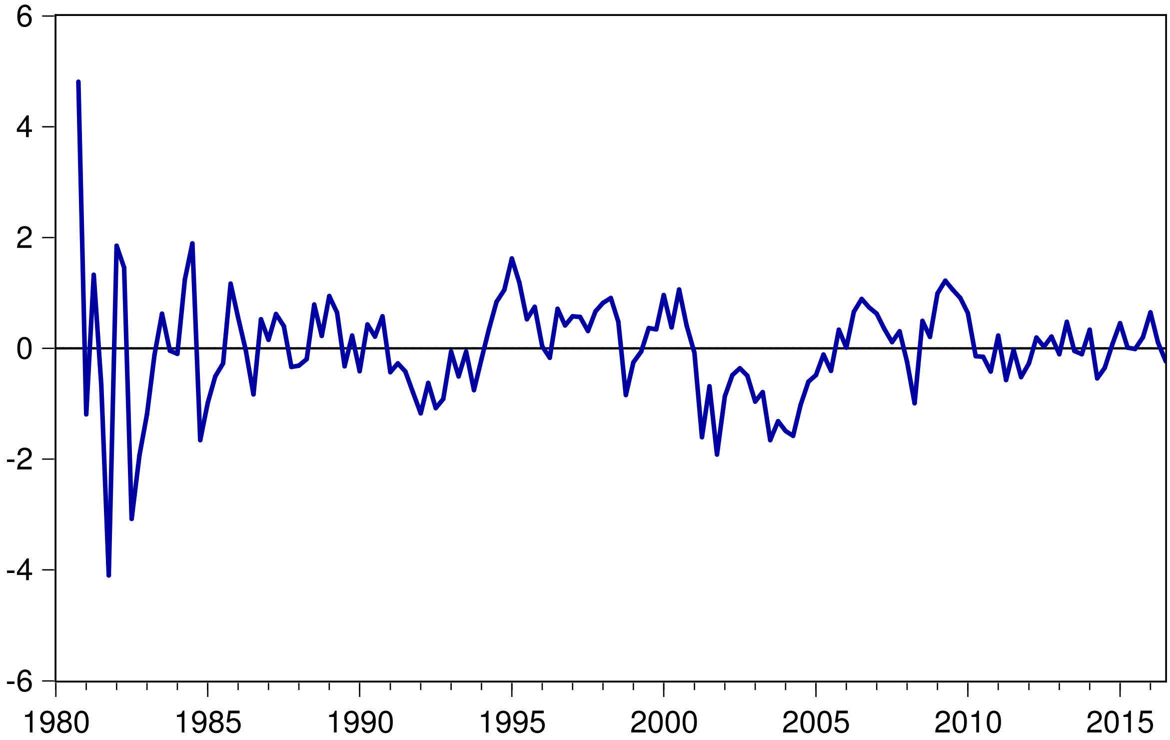
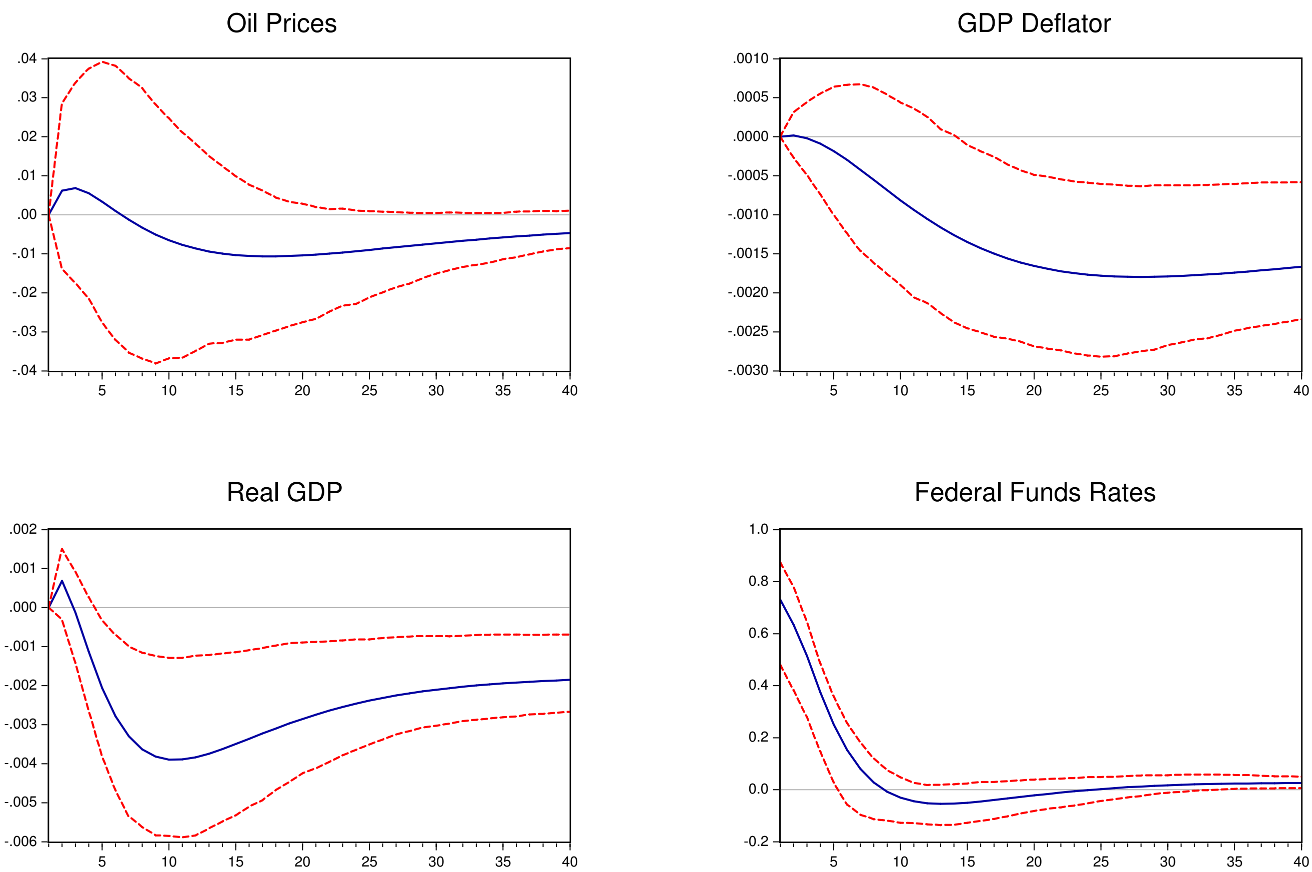
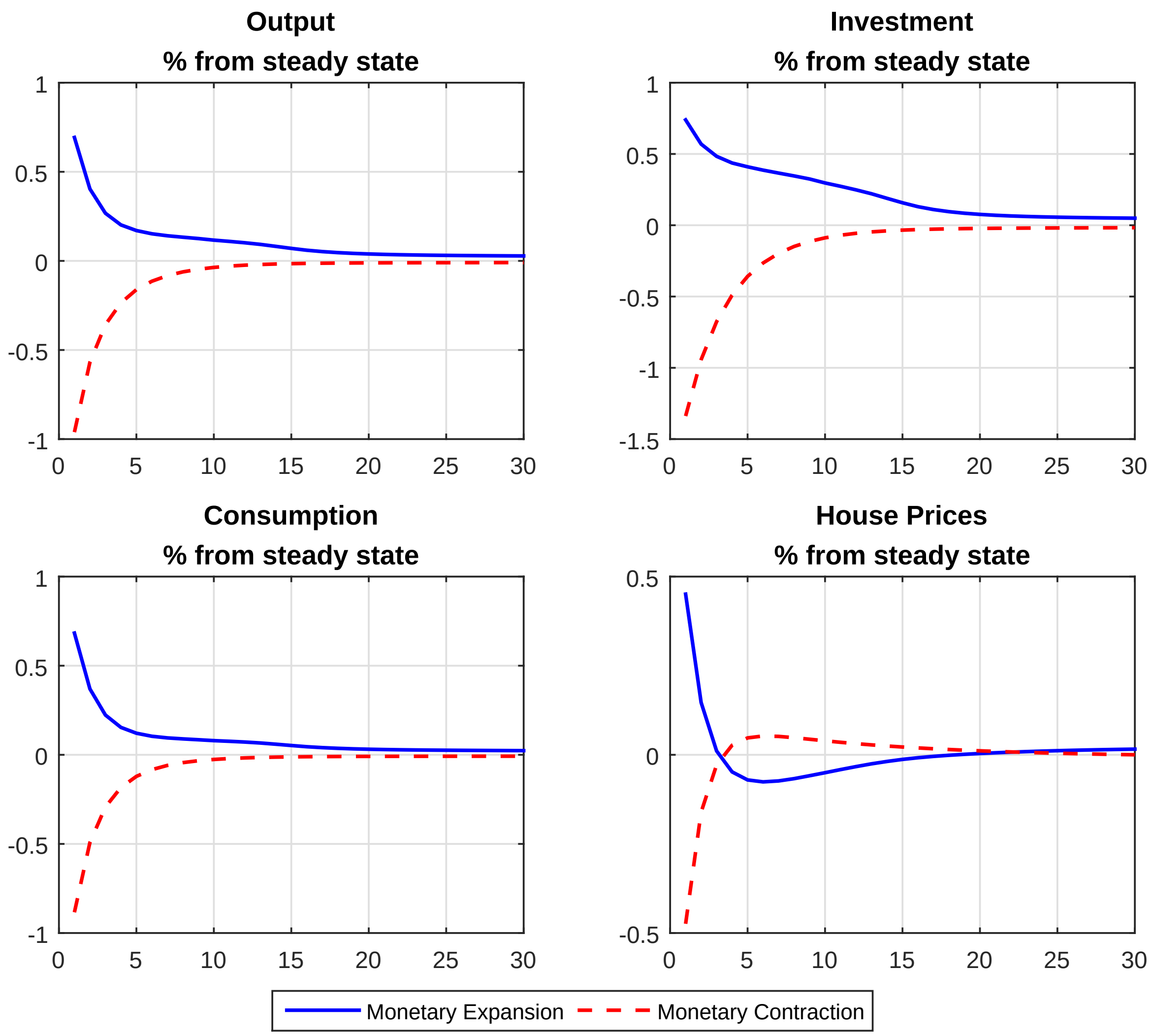


Figure 4: Impulse Responses to Monetary Policy Shocks (e_t^R)



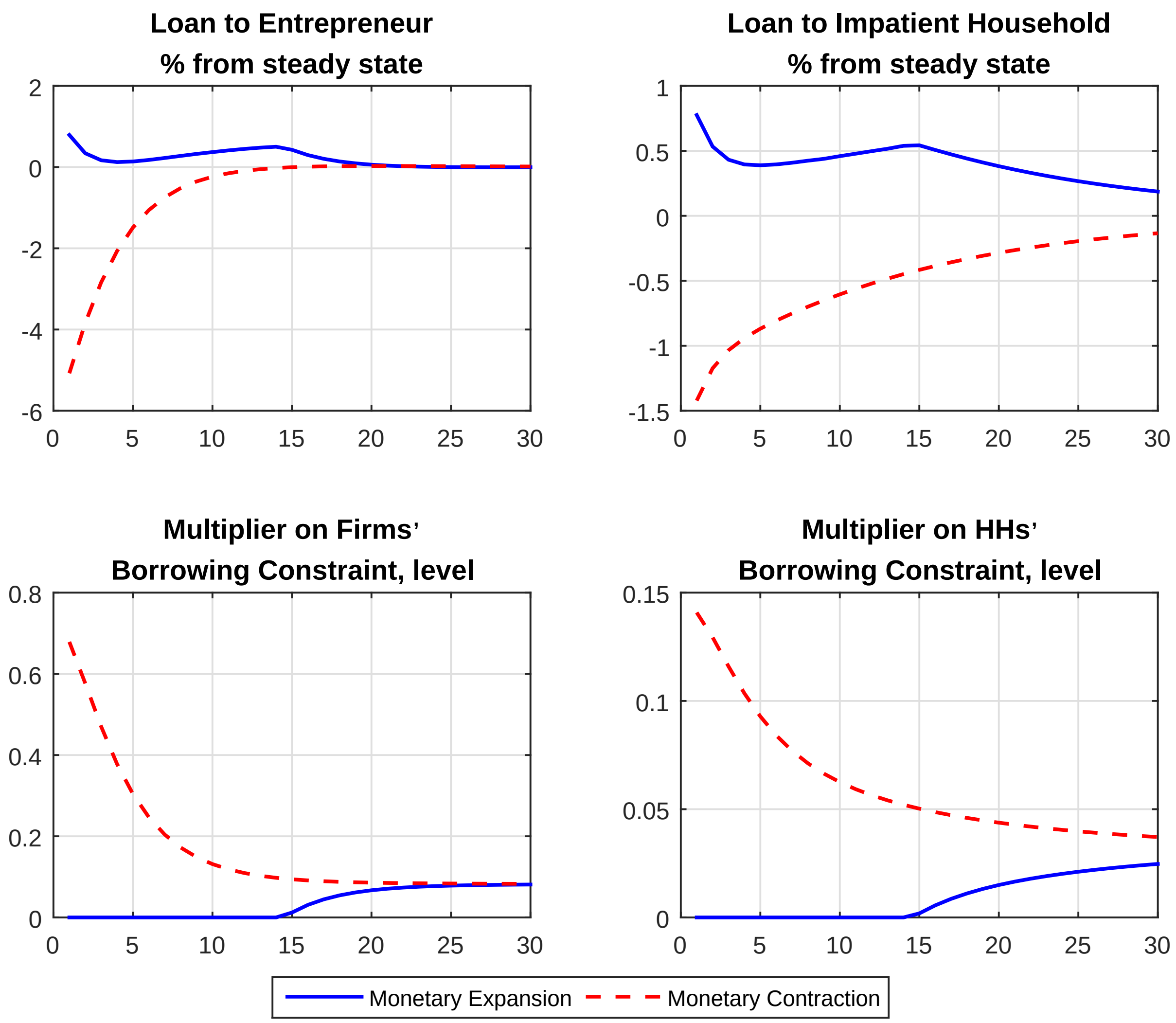
Note: Horizon in quarters. The 95% confidence intervals (red dashed lines) are constructed by bootstrapping with 1000 replications.

Figure 5: Impulse Response to Positive and Negative Monetary Policy Shocks



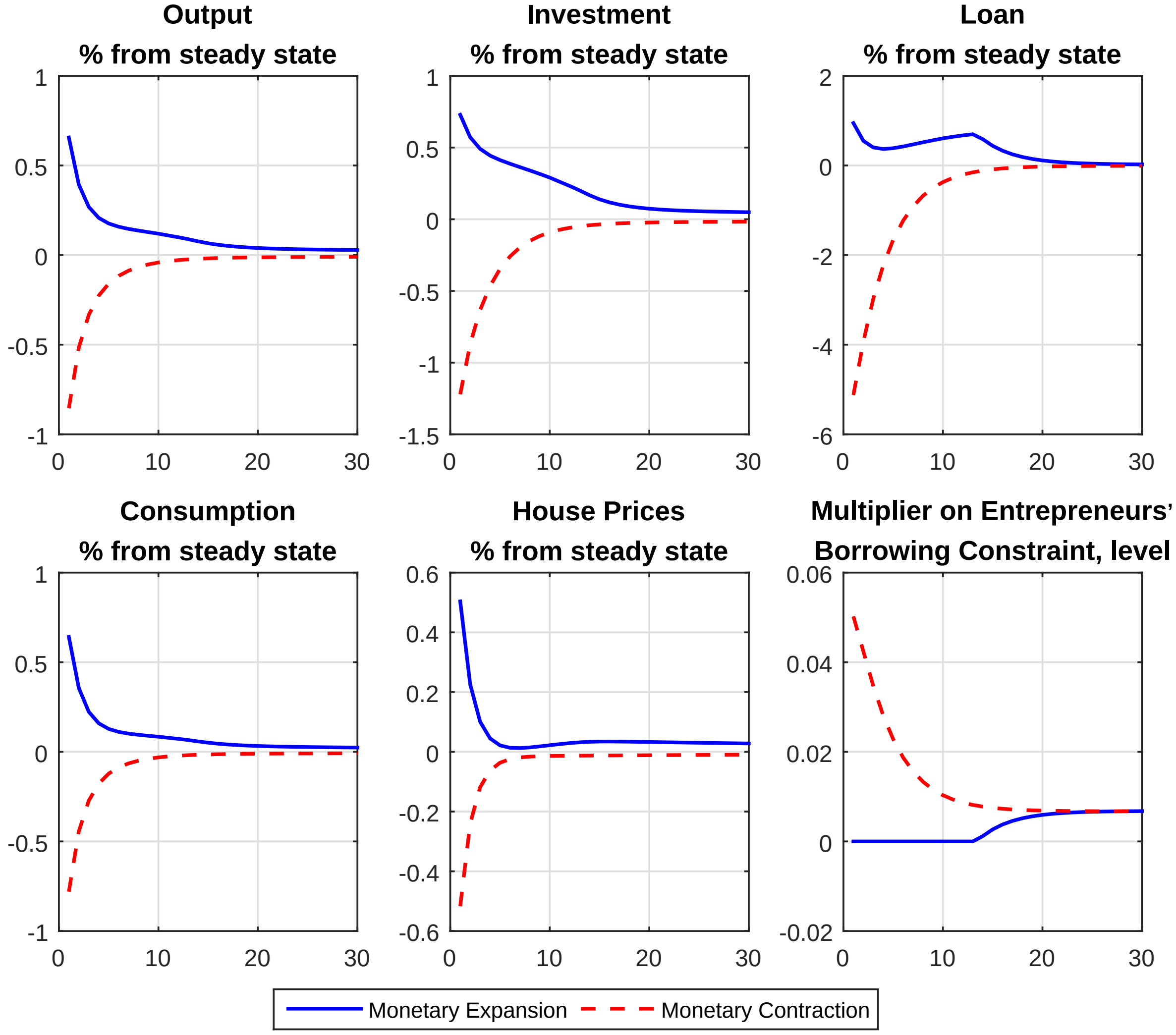
Note: Horizon in quarters. The simulation shows the dynamic responses to monetary policy shocks of equal size but opposite sign that move nominal interest rates up (monetary contraction) and down (monetary expansion) by 1 percent away from the steady state.

Figure 6: Impulse Response to Positive and Negative Monetary Policy Shocks



Note: Horizon in quarters. The simulation shows the dynamic responses to monetary policy shocks of equal size but opposite sign that move nominal interest rates up (monetary contraction) and down (monetary expansion) by 1 percent away from the steady state.

Figure 7: Impulse Response to Positive and Negative Monetary Policy Shocks in a model with one borrowing constraint



Note: Horizon in quarters. The simulation shows the dynamic responses to monetary policy shocks of equal size but opposite sign that move nominal interest rates up (monetary contraction) and down (monetary expansion) by 1 percent away from the steady state.

Table 1: Estimation results

	(1)	(2)	(3)	(4)	(5)
X	Output	Investment	Consumption	House prices	Loan
ΔX_{t-1}	**0.2504**	**0.5167**	**0.2036**	**0.8133**	**0.8243**
	[0.1266]	[0.0986]	[0.0892]	[0.1445]	[0.1295]
ΔX_{t-2}	**0.1980**	**0.2384**	**0.2395**	**-0.5784**	0.1085
	[0.0965]	[0.0859]	[0.0855]	[0.1516]	[0.1459]
ΔX_{t-3}	0.0698	-0.0145	**0.2816**	**0.5798**	-0.0015
	[0.1077]	[0.0871]	[0.0915]	[0.1305]	[0.1237]
ΔX_{t-4}	-0.0144	**-0.1339**	-0.0565	0.0701	-0.0497
	[0.0866]	[0.0676]	[0.0982]	[0.1399]	[0.0725]
e_t^{R+}	**-0.4963**	**-0.6295**	-0.1530	-0.0272	-0.7216
	[0.1510]	[0.3775]	[0.1085]	[0.2083]	[0.7267]
e_t^{R-}	0.1783	0.1391	-0.0511	-0.0448	-0.1227
	[0.1615]	[0.1785]	[0.1392]	[0.1334]	[0.4926]
constant	**0.5025**	**0.4195**	**0.2710**	0.0533	0.2702
	[0.1573]	[0.1627]	[0.1179]	[0.1820]	[0.2905]
$\bar{R}^2$	0.3027	0.4415	0.3200	0.7021	0.7801
χ^2 ($\beta^+ = \beta^-$)	5.4578	2.8387	0.2771	0.0036	0.2999
p-value	0.0195	0.0920	0.5986	0.9520	0.5839

Notes: Numbers reported in square brackets are standard errors. Values in bold type indicate statistical significance at the 10% level or less. χ^2 is the Wald statistic to test the null hypothesis $\beta^+ = \beta^-$. The corresponding p-value is displayed below.

Table 2: Calibrated and estimated parameters

Description	Parameters	Value
Patient household discount rate	β	0.99
Impatient household discount rate	β''	0.983
Entrepreneur discount rate	γ	0.98
Labor supply aversion	η	1.01
Weighting on housing services	j	0.10
Capital share	μ	0.30
Housing share	ν	0.03
Patient households wage share	α	0.64
Capital depreciation rate	δ	0.03
Adjustment cost of housing	ϕ	0.00
Loan-to-value ratio household	m''	0.55
Loan-to-value ratio entrepreneur	m	0.89
Steady-state gross markup	X	1.05
Probability of keeping the price constant	θ	0.75
Interest rate smoothing parameter	r_R	0.73
Inflation coefficient in the Taylor rule	r_π	0.27
Output coefficient in the Taylor rule	r_Y	0.13

Source: Iacoviello (2005)