China's Monetary Policy in A Time Varying Parameter Vector Autoregression Model*

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Abstract

This paper studies the monetary policy of China in a time varying parameter vector autoregression model with stochastic volatility, with a focus on the monetary policy regime change around 2009 when the 4 trillion RMB stimulus started. We find that China's monetary policy has been transited from money quantity based to interest rate based since 2009. The effectiveness of the traditional money quantity policy tool was dampened and that of the interest rate policy tool was enhanced, along with the stimulus which features colossal shadow banking in the economy. Intuitively it is because the money quantity policy can't influence the unobserved shadow banking but the interest rate policy still can. Counterfactual analysis indicates that the stimulus during the financial crisis smoothed the GDP growth rate but the policy effect, 0.7 percentage point increase at most, is less than found in other studies.

Keywords: Monetary Policy; TVP-VAR-SV; Stimulus; China.

JEL Codes: C11; C32; E52.

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1 Introduction

The monetary policy of China has long targeted the money quantity of M2 ever since 1998 (Chen et al. (2018)). And the central bank of China has been proclaiming the monetary policy would be transited from money-based to interest-based. Did China really change its intermediate target of the monetary policy? What are the effects of the monetary policy on the macroeconomy of China along the transition process? This paper studies China's monetary policy in a time varying parameter vector autoregression model with four macroeconomic variables, the GDP growth rate, the inflation rate, the interest rate, and the money growth rate. The forecast error variance decomposition shows that China has been transiting from targeting the money growth rate to targeting the interest rate since 2009 when the 4 trillion RMB stimulus started.

Last four decades have witnessed high and persistent economic growth of China after the reform and opening policy. China has been transiting from a planned economy to a market-based economy. Even until now, all aspects in this economy are still undergoing fierce reform including the important monetary policy. In 1998, the People's Bank of China officially announced that it transited from directly targeting the money quantity, the bank loans, to indirectly targeting the money quantity, M2, and ever since 2000 the central bank discussed from time to time it would continue to reform to make the interest rate as the intermediate monetary policy target.

The monetary policy regime of China is always in the process of reform with change, transition, and hence nonlinearities in the underlying macroeconomic relationships. The time varying parameter vector autoregression model with stochastic volatility (TVP-VAR-SV) is the appropriate apparatus to analyze the monetary policy of China for two reasons. One is that the VAR model imposes minimal restrictions on the economic system except the identification assumption(Sims (1980)). The other is that the time varying parameters and stochastic volatilities can manifest the underlying change and transition of the macroeconomy(Cogley and Sargent (2001, 2005),Primiceri (2005),Lubik and Matthes (2015)).

We follow Primiceri (2005) to estimate the time varying lag coefficients and stochastic volatility by the Bayesian method. The impulse response functions varied little before the enaction of the 4 trillion RMB stimulus during the financial crisis but did vary a lot after this time. The impulse responses of economic growth and inflation to the interest rate shock enlarged while those to the money growth rate shock shrank after the stimulus. The forecast error variance decomposition shows that the interest rate shock contributed more to the variances of the GDP growth rate and the inflation rate after 2009 when the large

stimulus was carried out. This is the evidence that the monetary policy was transited from money-based to interest-based by the central bank.

One explanation for the results lies in the large stimulus and rampant shadow banking caused by the stimulus. After 2009, the large stimulus began and then local governments and state-owned enterprises counted more on shadow banking to finance various projects (Bai et al. (2016),Chen et al. (2018)). The central bank partly lost control of the money supply, as shadow banking is not observed by the central bank. That is probably the reason why impulse response functions of the money growth rate shock shrank after 2009. However, interest rates can still influence the cost of shadow banking after the interest rate reform started. So impulse response functions of the interest rate shock enlarged after 2009. Because targeting the interest rate is more effective than targeting the money growth rate, the central bank transited from targeting money growth rate to targeting the interest rate to stabilize the economy, which is indicated by the forecast error variance decomposition analysis.

Counterfactual analysis shows that the 4 trillion RMB stimulus smoothed GDP growth rate but the policy effect, 0.7 percentage point increase at most, is less than found in other studies (Ouyang and Peng (2015),Chen et al. (2017)).

This paper relates to three strands of literature. One strand is the time varying parameter VAR literature. Cogley and Sargent (2001, 2005), Primiceri (2005), and Del Negro and Primiceri (2015) start and contribute to the research of the U.S. monetary policy in the TVP-VAR-SV model. They find that the high volatilities of the policy shocks can explain the high inflation and unemployment episodes in the U.S..

The other strand are studies of emerging economies including China by the VAR method. Sanchez-Fung (2013) follows Bernanke and Blinder (1992)'s seminal work and finds that money quantity M1 can forecast future movements of inflation of China. Fernald et al. (2014) use the constant parameter FAVAR model to study the effectiveness of China's monetary policy and find that China has moved to an interest-based rule monetary policy as other western economies. Cross and Nguyen (2016, 2018) research the relationship between international oil price and China's macroeconomy in the time varying environment. The effects of monetary policy or fiscal policy of BRICS countries are studied in the constant parameter VAR model in Granville and Mallick (2006), Mallick and Sousa (2012), Jawadi et al. (2014, 2016), and Holtemller and Mallick (2016).

The third strand of literature is the study of China's monetary policy during the financial crisis. Argued by Ouyang and Peng (2015), Wen and Wu (2017), and Chen et al. (2017), the 4 trillion RMB stimulus during the financial crisis saved China from a deep recession but

other studies like Chen et al. (2018) and Bai et al. (2016) discuss the dark side of shadow banking caused by the stimulus.

We contribute to the literature in three folds: first, to our best knowledge, this is the first paper that takes account of the goals and intermediate targets of China's monetary policy in a TVP-VAR-SV model of China. We complement the TVP-VAR-SV literature of studying emerging markets; second, we provide evidence that China had been transiting from money-based monetary policy rule to interest-based monetary policy rule; third, we complement the literature of the 4 trillion RMB stimulus of China and find that the large stimulus smoothed economic growth rate.

The rest of the paper goes as follows. Section 2 discusses the monetary policy institution of China. Section 3 introduces the econometric framework including the data, the TVP-VAR-SV model, the identification strategy, and the Bayesian estimation method. Section 4 contains the estimation results and robustness checks. And Section 5 concludes.

2 The Institution of China's Monetary Policy

After the reform and opening up in 1978, the economic institution of China underwent dramatic change from the planned economy to the market-driven economy. In the transition process the monetary policy regime has been switching more frequently than advanced economies.

2.1 Objectives of China's Monetary Policy

The objectives of China's monetary policy are to sustain economic growth, control inflation, maintain full employment, and keep international payment balanced. Similar to other emerging market, the most important one among the multiple objectives of the monetary policy is to sustain high and persistent economic growth. This feature is different from the practice of advanced economies such as the U.S. in which the monetary policy aims to keep inflation stable and sustain low unemployment. Therefore we select GDP growth rate and inflation rate to evaluate the macroeconomic status instead of unemployment rate and inflation rate, or output gap and inflation rate as studies of advanced economies, since the most important objectives of monetary policy are sustaining economic growth and then keeping price stable in China.

We notice the goals of China's monetary policy, especially the objective of economic growth which is included in our analysis. This is ignored in other time varying parameter

quantitative studies that use output gap as a representative of the macroeconomic status. Our approach conforms to the practice of China's monetary policy.

2.2 Intermediate Targets of China's Monetary Policy

To achieve the objectives of China's monetary policy, the People's Bank of China (PBC) chose different toolkits to influence the markets. The PBC chose bank credits as the intermediate target between 1978 and 1998, then switched to the money growth rate of M2 after 1998. In 2000, the PBC proposed that it would reform and further liberalize interest rates, and would transit from the quantity-based monetary policy to the price-based monetary policy.

However, interest rate liberalization should come first before the monetary policy's switch to the interest rate rule. Interest rates were strictly regulated by the PBC in China and not determined by market forces long before the liberalization of interest rates. The PBC had to choose money quantity as the instrument of the monetary policy because the strictly-regulated interest rates could not transmit the change of the monetary policy then. After 1996, the wholesale banking markets were deregulated that the interbank offered rate, public bond rate, and the repo rate were determined by market forces. However, the retail markets are still highly regulated and the retail interest rates are determined by the PBC except that the floating area is widened.

Along with the interest rate liberalization, the PBC also emphasized on the monetary policy reform from time to time. In 2016 "The Thirteenth Five-Year Plan (2016-2020) for Economic and Social Development" proclaimed that China would shift the intermediate target of monetary policy from quantity-based to price-based [1]. From 2000, the intermediate targets of China's monetary policy is not unique, money quantity or interest rate, but both of them. Yi (2016), the president of the PBC, remarks the hybrid rule of targeting both money quantity and interest rate is the important feature of the current monetary policy of China.

This institution difference is noticed recently in the literature (Chen et al. (2017),Chen et al. (2018)). It is different from advanced economies where the short-term nominal interest rate is the unique intermediate target. Thus we include both interest rate and money growth rate to evaluate the stance of China's monetary policy considering the fact that the PBC conducts the monetary policy according to a hybrid rule of targeting both money quantity

[1]The Thirteenth Five-Year Plan can be downloaded from the website of the National Development and Reform Commission of China: http://www.ndrc.gov.cn/gzdt/201603/P020160318576353824805.pdf

and interest rate[2]. Omitting either variable is a loss of important information in analyzing the dynamics of China's economy.

3 The Econometric Framework

3.1 Data

To construct the four macroeconomic series including two private sector variables GDP growth rate and inflation rate, and two policy variables interest rate and money growth rate, we collect data series of real GDP, GDP deflation index, 7-day Repo rate and M2 from Chang et al. (2015)[3]. The data series are quarterly and seasonally adjusted covering the period from 1996:Q1 to 2017:Q4. The staring period is determined by the availability of 7-data Repo rate series. Real GDP Growth rate, inflation rate, and money growth rate are computed as percentage changes on a year-over-year basis.

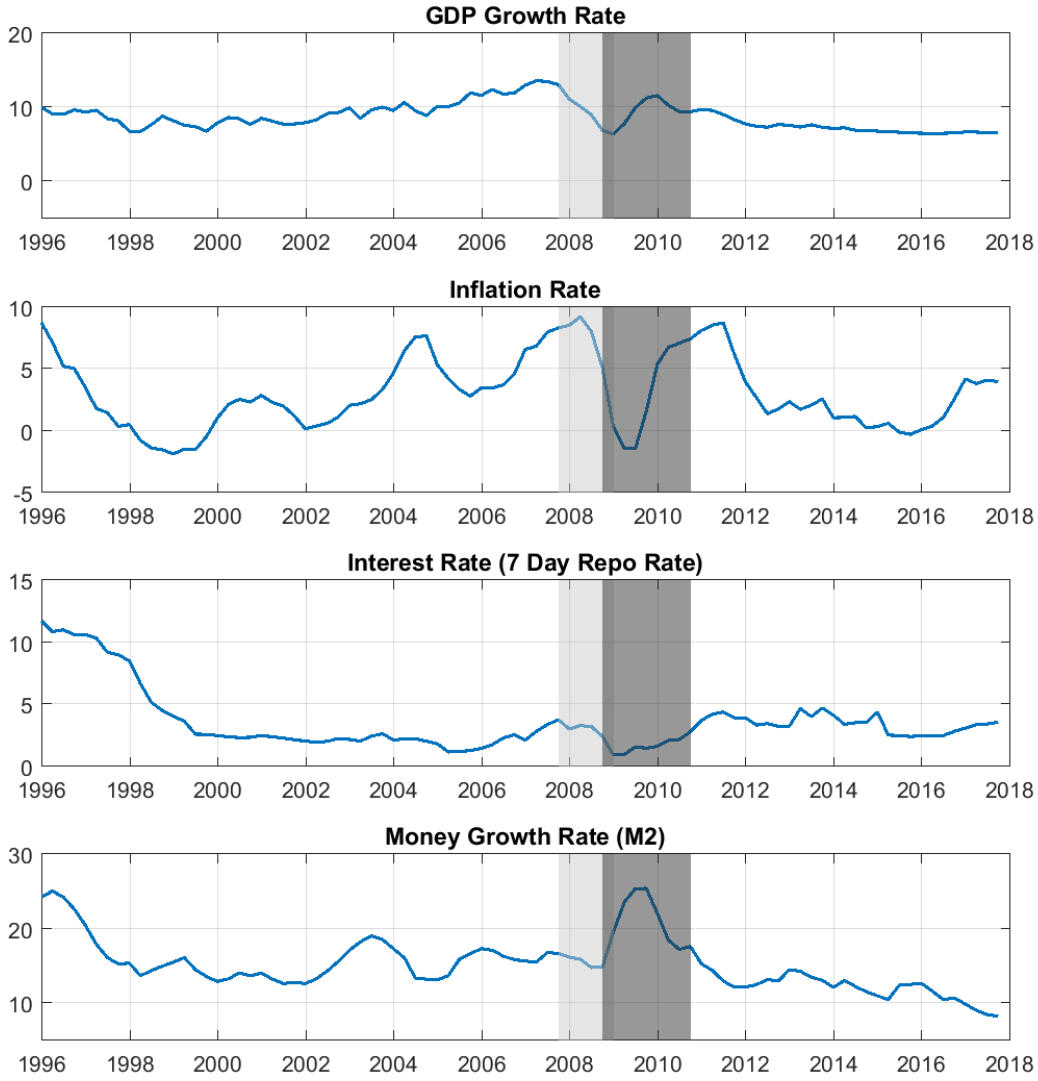
Figure 1 displays the four macroeconomic variables. The economic growth of China is remarkable in the whole period from 1996 to 2017 even if the growth rate slumped from averagely 10% to around 7% recently. In the beginning of the sample, the inflation rate and interest rate (7-day Repo rate) were about 10%, much higher than the recent levels. The money growth rate (M2) is averagely 15% and it decreased to below 10% after 2017. During the 2007-2009 financial crisis, the economic activity slumped suddenly that all four series plummeted sharply. After the government acted fiercely by the 4 trillion stimulus, all four macroeconomic variables lifted up and China escaped from the great recession.

We should notice that the relationship between interest rate and money growth rate is unstable that interest rate varied positively with money growth rate in the beginning but moved negatively with money after 2009. During the financial crisis, the two series co-moved downward. We can see this relationship from the correlation coefficients in Table 1. The correlation is 0.310 in the whole period from 1996:Q1 to 2017:Q4. We divide the sample into two sub-samples by 2009. The coefficient is 0.637 in the first half, bigger than that of the whole period, while this number becomes negative -0.637 in the second half. This is another piece of evidence, except the narrative evidence in Section 2.2, that China adopts a hybrid monetary policy of targeting both interest rate and money growth rate instead of a unique

[2]Chen et al. (2016) use a three-variable VAR with time varying parameter to study China's monetary policy. But they only consider the unique policy interest rate. Also they choose output gap and inflation as private sector variables and thus omit the fact that the monetary policy of China is mainly pro-growth. Their approach does not conform to the institution of China especially the practice of the monetary policy.

[3]The dataset can be downloaded from the website of the Federal Reserve Bank of Atlanta: https://www.frbatlanta.org/cqer/research/china-macroeconomy.aspx?panel=1

Figure 1: Macroeconomic Variables of China



Note: The raw data are from Chang et al. (2015). They are seasonally adjusted. GDP growth rate, inflation rate, M2 growth rate are calculated as percentage changes on a year-over-year basis from the raw data. The light gray area is the 2007-2009 financial crisis period and the dark gray area is the 4 trillion stimulus period.

rule because the information of either variable is different from the other one.

Different from the economies adopting the unique rule in which the short-run interest rate can forecast the real movements and thus already has information of money quantities[4], both interest rate and money growth rate of China have crucial and different information about the dynamics of the macroeconomy. This has important implication for our analysis

[4]Bernanke and Blinder (1992) finds that the federal funds rate can forecast the movement of real activities significantly and reject the hypothesis that the control variables, money quantities, act any roles.

of China's monetary policy regime.

Table 1: Correlation Coefficients between Interest Rate and Money Growth Rate of China

Period	1996:Q1-2017:Q4	1996:Q1-2008:Q4	2009:Q1-2017:Q4
Correlation Coefficient	0.310	0.637	-0.637

Notes: The table shows the correlation coefficients between interest rate and money growth rate in different periods.

3.2 The TVP-VAR-SV Model

We use the time varying parameter vector autoregression model with stochastic volatility (TVP-VAR-SV) to analyze China's monetary policy. The VAR model describes the evolution of y_t as a linear function of its own lags up to order p and a vector of innovations u_t . As we discuss in Section 2, we incorporate GDP growth rate g_t, inflation rate π_t, interest rate i_t, and money growth rate m_t as the endogenous variables in y_t.

$$y_t = (g_t, \pi_t, i_t, m_t)' \tag{1}$$

Sims (2001) points out that the econometricians cannot differentiate the VAR model with constant coefficients and time-varying volatilities from that with time varying coefficients and constant volatilities. We do not restrict where the underlying nonlinearity comes from, the lag coefficients or the variance, but consider both coefficients and variance time varying. Also we choose 2 lags following the TVP-VAR convention.

$$y_t = B_{0,t} + B_{1,t}y_{t-1} + B_{2,t}y_{t-2} + u_t, \qquad t = 1, \cdots, T. \tag{2}$$

$B_{0,t}$ is the intercept term and $B_{1,t}, B_{2,t}$ are the lag coefficient matrices. u_t is the innovation vector with variance covariance matrix Ω_t, which is decomposed as:

$$\Omega_t = A_t^{-1}\Sigma_t\Sigma_t'A_t^{-1'}. \tag{3}$$

where Σ_t is a diagonal matrix and A_t is a lower-triangular matrix with ones in the diagonal entries.

$$A_t = \begin{bmatrix} 1 & 0 & 0 & 0 \\ \alpha_{21,t} & 1 & 0 & 0 \\ \alpha_{31,t} & \alpha_{32,t} & 1 & 0 \\ \alpha_{41,t} & \alpha_{42,t} & \alpha_{43,t} & 1 \end{bmatrix} \qquad \Sigma_t = \begin{bmatrix} \sigma_{1,t} & 0 & 0 & 0 \\ 0 & \sigma_{2,t} & 0 & 0 \\ 0 & 0 & \sigma_{3,t} & 0 \\ 0 & 0 & 0 & \sigma_{4,t} \end{bmatrix}$$

Let $X_t = (1, y'_{t-1}, y'_{t-2})$ and $B_t = (B_{0,t}, B_{1,t}, B_{2,t})'$. Equation (2) can be stacked as:

$$y_t = B'_t X'_t + A_t^{-1} \Sigma_t \epsilon_t. \tag{4}$$

where $\epsilon_t \sim N(0_4, I_4)$. Stack all the columns of B_t into a vector $\beta_t = vec(B_t)$ and then we have the following stacked VAR:

$$y_t = (I_4 \otimes X_t)\beta_t + A_t^{-1} \Sigma_t \epsilon_t. \tag{5}$$

Collect all the non-zero and non-one elements into a vector $\alpha_t = (\alpha_t^1, \alpha_t^2, \alpha_t^3)'$ where α_t^i corresponds to the vector of the non-zero non-one elements of the $(i+1)_{th}$ row of A. Collect all the diagonal elements of Σ_t and let $\sigma_t = (\sigma_{1,t}, \sigma_{2,t}, \sigma_{3,t}, \sigma_{4,t})'$. Take the logarithm of σ_t and get $h_t = (\log \sigma_{1,t}, \log \sigma_{2,t}, \log \sigma_{3,t}, \log \sigma_{4,t})'$.

We assume that the time varying parameters follow the random walk process:

$$\begin{aligned} \beta_t &= \beta_{t-1} + \epsilon_{\beta,t} \\ \alpha_t^i &= \alpha_{t-1}^i + \epsilon_{\alpha,t}^i, \quad i = 1, \cdots, n-1 \\ h_t &= h_{t-1} + \epsilon_{h,t}. \end{aligned} \tag{6}$$

We assume that $\epsilon_t, \epsilon_{\beta,t}, \epsilon_{\alpha^i,t}, \epsilon_{h,t}$ are mutually independent.

$$\begin{bmatrix} \epsilon_t \\ \epsilon_{\beta,t} \\ \epsilon_{\alpha,t} \\ \epsilon_{h,t} \end{bmatrix} \sim N(0, V) \quad V = \begin{bmatrix} I_n & 0 & 0 & 0 \\ 0 & \Sigma_\beta & 0 & 0 \\ 0 & 0 & \Sigma_\alpha & 0 \\ 0 & 0 & 0 & \Sigma_h \end{bmatrix}.$$

Here Σ_α is block diagonal with each block corresponding to the non-zero non-one elements

in each row of A_t.

$$\Sigma_\alpha = \begin{bmatrix} \Sigma_{\alpha^1} & 0 & 0 \\ 0 & \Sigma_{\alpha^2} & 0 \\ 0 & 0 & \Sigma_{\alpha^3} \end{bmatrix}.$$

3.3 Bayesian Estimation

We estimate the model by Bayesian method of Primiceri (2005). We use the first 5 years 1996:Q1 to 2000:Q4 to calibrate the priors. The OLS estimates are denoted by marking the subscript "OLS". The priors[5] are set as:

$$\begin{aligned}
\beta_0 &\sim N(\hat{\beta}_{OLS}, 4 \cdot \hat{V}_{\beta,OLS}). \\
\alpha_0 &\sim N(\hat{\alpha}_{OLS}, 4 \cdot \hat{V}_{\beta,OLS}). \\
h_0 &\sim N(\hat{h}_{OLS}, I_4). \\
\Sigma_\beta &\sim IW(k_\beta^2 \cdot 40 \cdot \hat{V}_{\beta,OLS}, 40). \\
\Sigma_{\alpha^1} &\sim IW(k_\alpha^2 \cdot 2 \cdot \hat{V}_{\alpha^1,OLS}, 2). \\
\Sigma_{\alpha^2} &\sim IW(k_\alpha^2 \cdot 3 \cdot \hat{V}_{\alpha^2,OLS}, 3). \\
\Sigma_{\alpha^3} &\sim IW(k_\alpha^2 \cdot 4 \cdot \hat{V}_{\alpha^3,OLS}, 4). \\
\Sigma_h &\sim IW(k_h^2 \cdot 5 \cdot I_n, 5).
\end{aligned}$$

where $k_\beta = 0.01, k_\alpha = 0.1, k_h = 0.01$.

The VAR system (5) and the random walk process of parameters (6) consist of a state space system with the parameters β_t, α_t, h_t as the states and y_t as the observations. Then we can use Kalman filter to compute the likelihood of the data given the parameters $p(y^T|\Theta)$. Combine the distribution of priors and we can compute the posterior distribution as:

$$p(\Theta|y^T) \propto p(y^T|\Theta)p(\Theta), \quad \Theta = \beta^T, \alpha^T, h^T, V.$$

We then follow Primiceri (2005)'s method and use algorithm 2 of Del Negro and Primiceri (2015) [6] to estimate the TVP-VAR-SV model. We draw 10000 samples from the posterior distributions and discard the first 2000 draws. Convergence diagnostics show the chains are converged.

[5] Primiceri (2005) sets the degree of freedom of the inverse-Wishart distribution of Σ_β as the size of the presample, 40. But our presample has only 20 observations less than the number of parameters in β_t 36. So we still set the degree of freedom as 40 in the prior of Σ_β.

[6] Del Negro and Primiceri (2015) corrects ordering of the various MCMC steps in Primiceri (2005).

3.4 Identification

We arrange the variable order as GDP growth rate g_t, inflation rate π_t, interest rate i_t, and money growth rate m_t aligning the structural VAR recursive tradition assuming that the former variable responds to the latter variables with lags and latter variable respond to the former variables contemporaneously.

$$y_t = (g_t, \pi_t, i_t, m_t)'. \tag{7}$$

Basically policy sector variables i_t and m_t respond contemporaneously to private sector variables g_t and π_t but private sector variables react to policy variables with lags. We follow the VAR literature (Leeper et al. (1996), Christiano et al. (1999)) considering the private sector variables output and inflation are sticky and do not respond to monetary policy shocks contemporaneously. This time convention of different macroeconomic variables also exists in China and thus the recursive identification is suitable for China, even though the institution of China is so different from western economies.

In the private sector, GDP growth rate is arranged first and inflation rate comes second in the sense that real terms change more slowly than the monetary terms. In the policy sector, interest rate is arranged before the money growth rate with the assumption that money quantity changes faster than the interest rate.

The recursive identification can be achieved by the Cholesky decomposition, which has been coincidently done in the variance decomposition of Equation (3).

$$\Omega_t = C_t C_t' = (A_t^{-1}\Sigma_t)(A_t^{-1}\Sigma_t)'. \tag{8}$$

The non-zero and non-one elements α_t of A_t are the opposite of the contemporaneous response parameters $-\alpha_t$ of the endogenous variables to other endogenous variables shown in Appendix A. The diagonal elements σ_t of Σ_t are the standard errors of the structural shocks $\Sigma_t \epsilon_t$ in the identified VAR[7].

4 Estimation Results

We report four kinds of results in this section. The first are the parameter estimates including both the lag coefficients and the stochastic volatility. The second are the impulse

[7]The diagonal matrix Σ_t represents the standard errors of the independent shocks because the matrix A_t with ones in the diagonal already absorbs the contemporaneous correlations between the VAR innovations u_t under recursive identification.

response functions for different time slots over the estimated period. The third are variance decompositions of growth rate and inflation rate over different horizons in the estimated period. Last we do a counterfactual analysis to show the effect of the large stimulus of China during the financial crisis. Then we discuss three robustness checks.

4.1 Parameters

We report the parameters β_t, $-\alpha_t$, and σ_t in Figure 2 to 4 respectively. The estimated TVP-VAR-SV model attributes most of the time variation to the stochastic volatility and little to the changes in the lag coefficients in the period 2001:Q3 to 2017:Q4. Though several lag coefficients are time varying, the time varying pattern is still similar to the lessons found in the literature that TVP-VAR-SV model attributes more time variations to the stochastic volatilities.

Figure 2 reports the posterior median estimates of the lag coefficients β_t. Each of the four panels corresponds to the plot of the parameters of one equation. A typical impression is that there are more time variations in the lag coefficients β_t than found in the literature (Lubik and Matthes (2015)) for the U.S. economy, even though most of the coefficients are almost flat across the estimated period. This indicates China has more underlying nonlinearity in the systematic monetary policy regime and thus more time variation in the transmission of the monetary policy than the U.S..

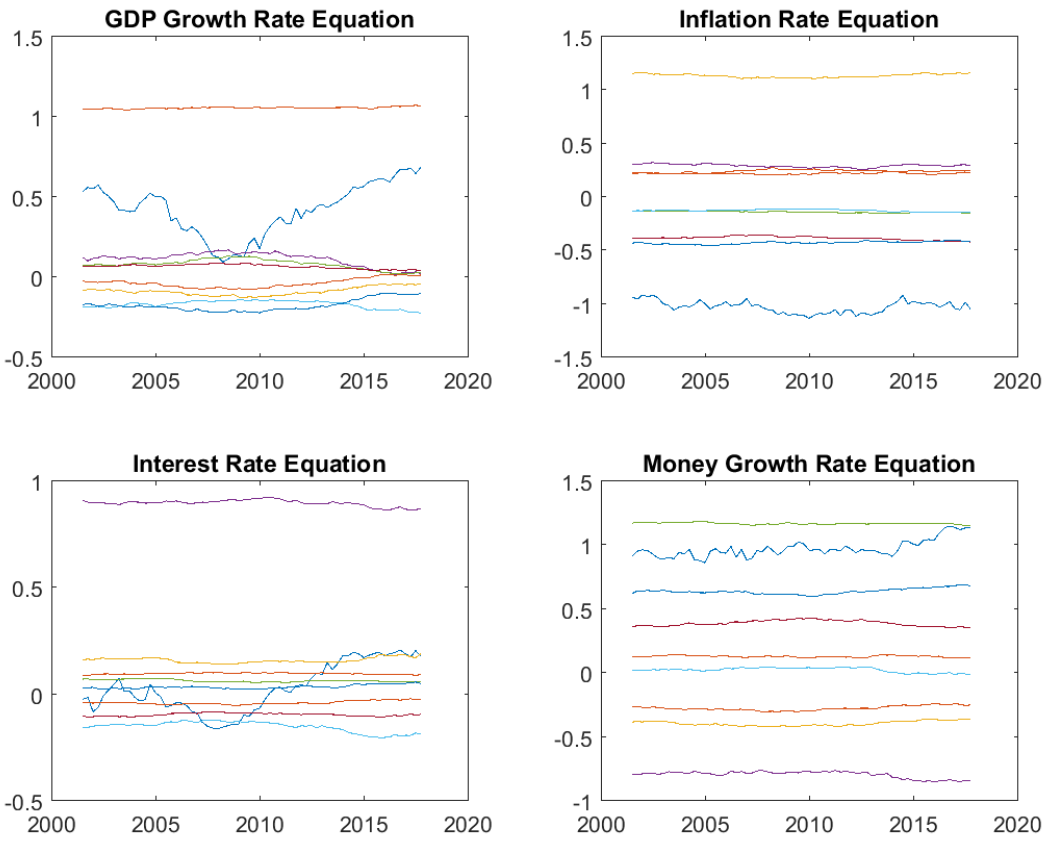
Figure 3 and Figure 4 draw the posterior median and 16th/84th percentile estimates of $-\alpha_t$[8] and σ_t which belong to the components of the variance $\Omega_t = A_t^{-1}\Sigma_t\Sigma_t' A_t^{-1'}$. The TVP-VAR-SV model attributes more time variations to the variance than the lag coefficients. After 2009, when the large stimulus was carried out, the standard errors of the GDP growth rate shock, inflation rate shock, and money growth rate shock reduced while the standard error of the interest rate shock increased in Figure 4.

4.2 Impulse Response Functions

We are interested in the time varying impulse responses of the private sector variables GDP growth rate and inflation rate to the structural shocks of policy variables interest rate and money growth rate across different periods. Figure 5 to 8 show the above information. Panel (1) of these four figures illustrates the median impulse responses of the whole estimated period 2001:Q3 to 2017:Q4. Panel (2) exhibits the median impulse responses of four selected

[8]Figure 3 illustrates the median and 16th/84th percentile estimates of the contemporaneous response parameters $-\alpha_t$ of the endogenous variables to other endogenous variables, which equals to the opposite of the non-zero and non-one elements of A_t as shown in Appendix A.

Figure 2: Posterior Median Estimates of β_t

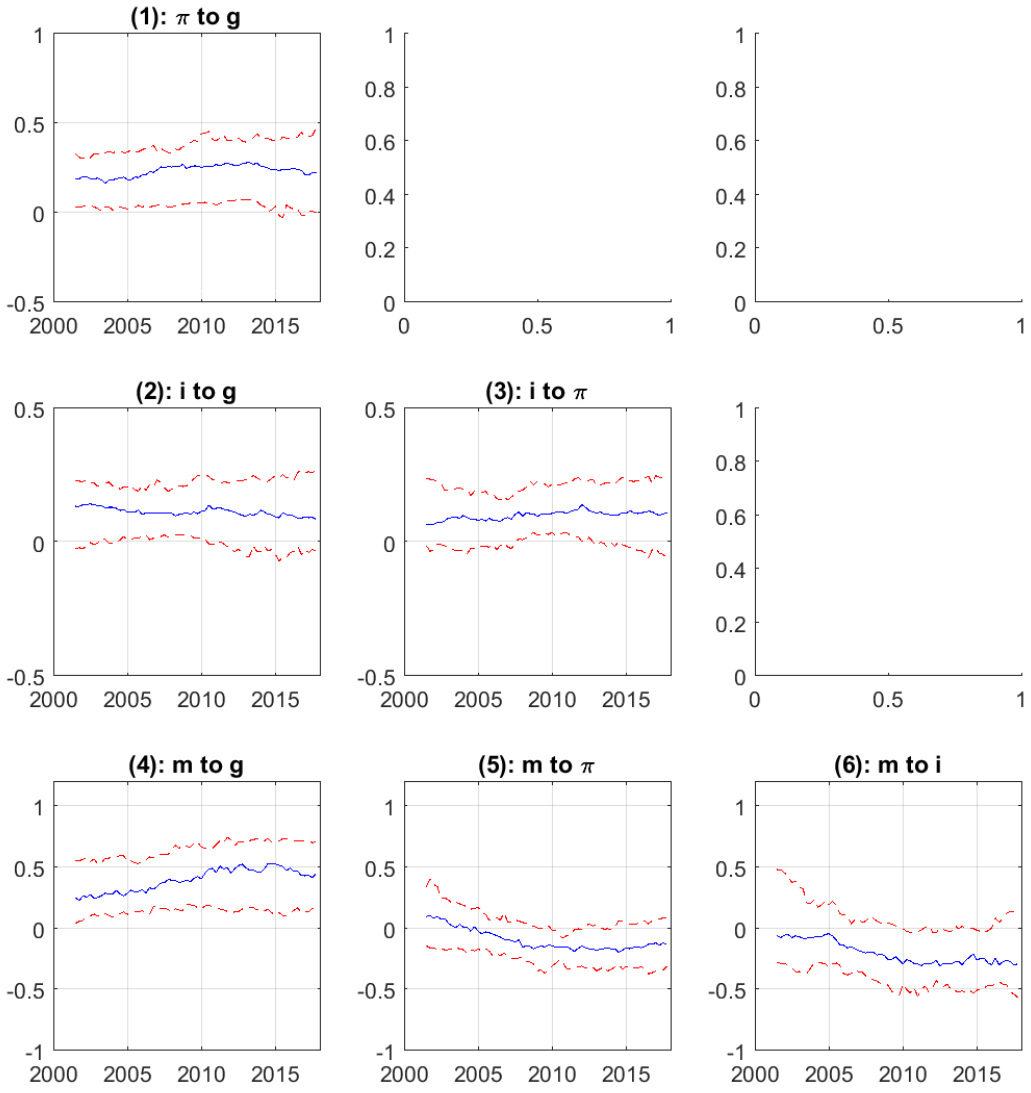


Note: We sample 10000 draws from the posterior distribution and discard the first 2000 draws as the burnin process. The graph shows the posterior medians of β_t of every parameter. Each panel corresponds to the parameters of one equation in the VAR.

episodes to see the time variations before and after the financial crisis along with the stimulus. Panel (3) shows the median and 16th/84th percentile impulse responses of three specific quarters 2006:Q3, 2010:Q3, and 2012:Q3, each of which is chosen from the episode before the financial crisis, after the enaction of the stimulus of China, and after the end of the stimulus. Panel (4) to (6) show the posterior median and 16th/84th percentile differences between the impulse responses in 2006:Q3 and 2010:Q3, 2006:Q3 and 2012:Q3, and 2010:Q3 and 2012:Q3.

Figure 5 and 6 illustrates the impulse response functions of GDP growth rate to 1% interest rate shock and money growth rate shock respectively. As expected, the GDP growth rate decreases after one percentage recessionary interest rate shock and the trough effect takes place after six quarters. Economic growth rate increases after one percentage expansionary money growth rate shock and the peak effect happens after four quarters.

Figure 3: Posterior Median and 16th/84th Percentile Estimates of $-\alpha_t$

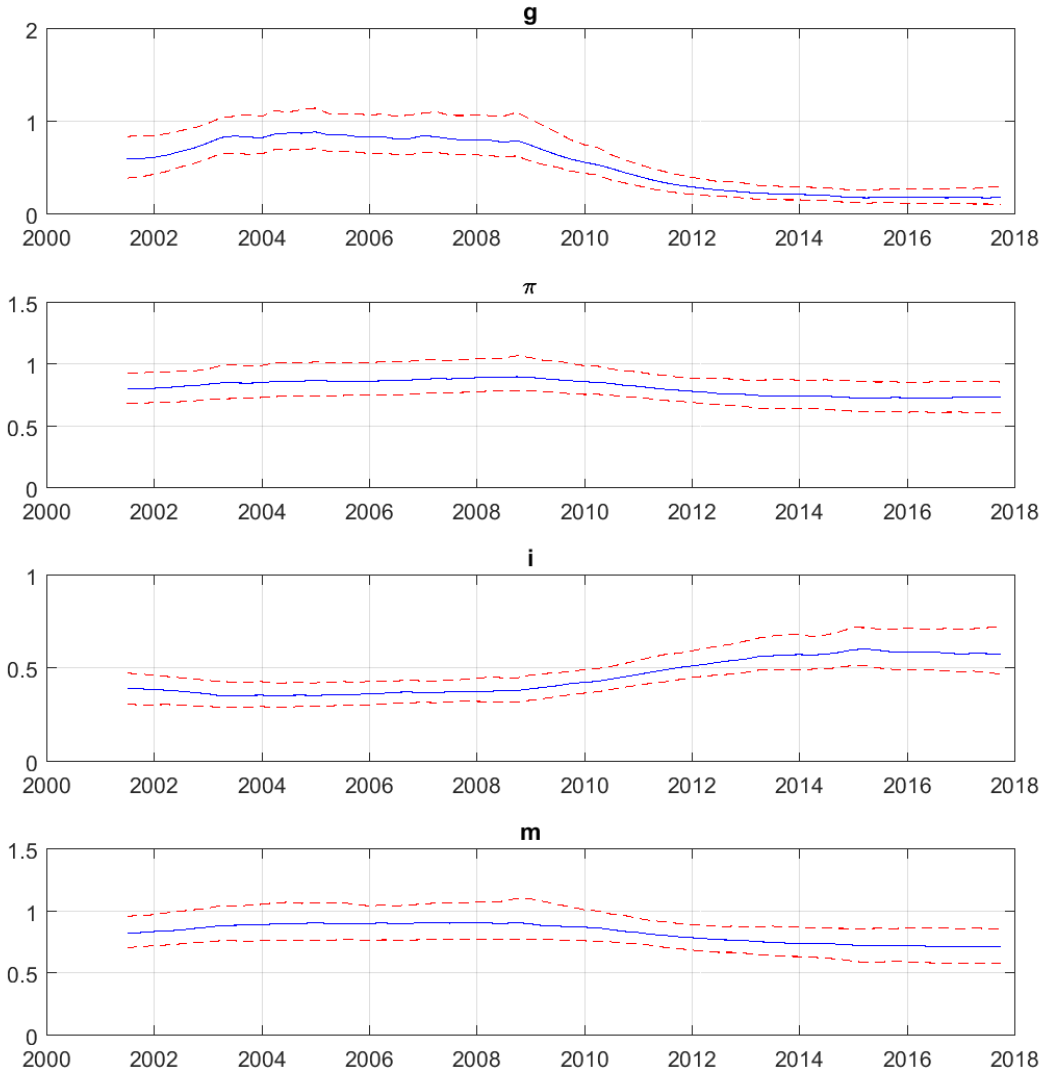


Note: We sample 10000 draws from the posterior distribution and discard the first 2000 draws as the burnin process. The graph shows the posterior medians and 16th/84th percentiles of $-\alpha_t$ of every parameter.

The impulse responses of inflation also exhibit the price puzzle in China as shown in Figure 7. Positive interest rate shocks inflate the price level at the beginning but soon deflate the price level. The trough effect takes place after 9 quarters. Figure 8 shows the impulse response of inflation to the money growth rate shock is positive as expected. The peak effect takes place after 6 quarters.

One conclusion from Panel (1) in these four impulse response figures emerges that there

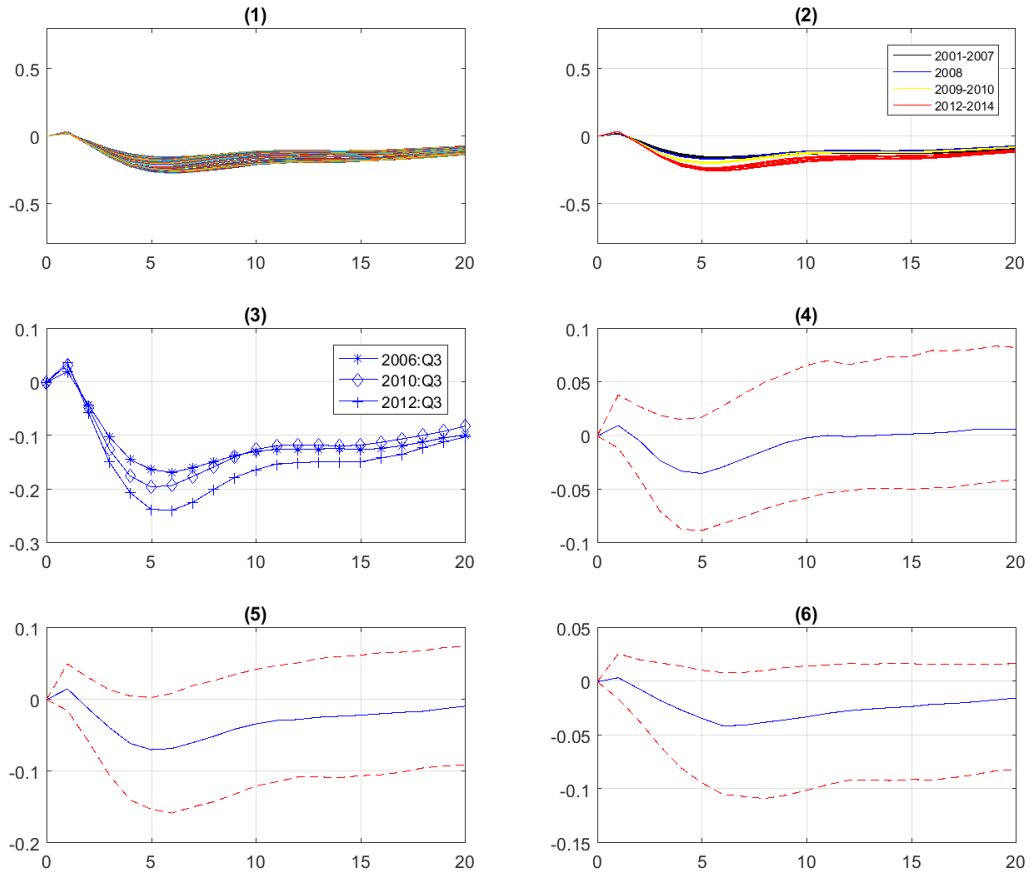
Figure 4: Posterior Median and 16th/84th Percentiles of σ_t



Note: We sample 10000 draws from the posterior distribution and discard the first 2000 draws as the burnin process. The graph shows the posterior medians and 16th/84th percentiles of σ_t every parameter.

are remarkable time variations over the estimated period. This is strongly contrasted with the U.S. that response functions of different periods are similar (Primiceri (2005), Lubik and Matthes (2015)). This evidence suggests that the regime of China's macroeconomy undergoes dramatic change across the estimated period. Compare the time variations of impulse response functions of the two private sector variables to two policy variables interest rate and money growth rate shocks over the estimated period. The interest rate shock induces more volatile impulse responses than the money growth rate shock over the estimated period.

Figure 5: Impulse Response Functions of GDP Growth Rate to 1% Interest Rate Shock

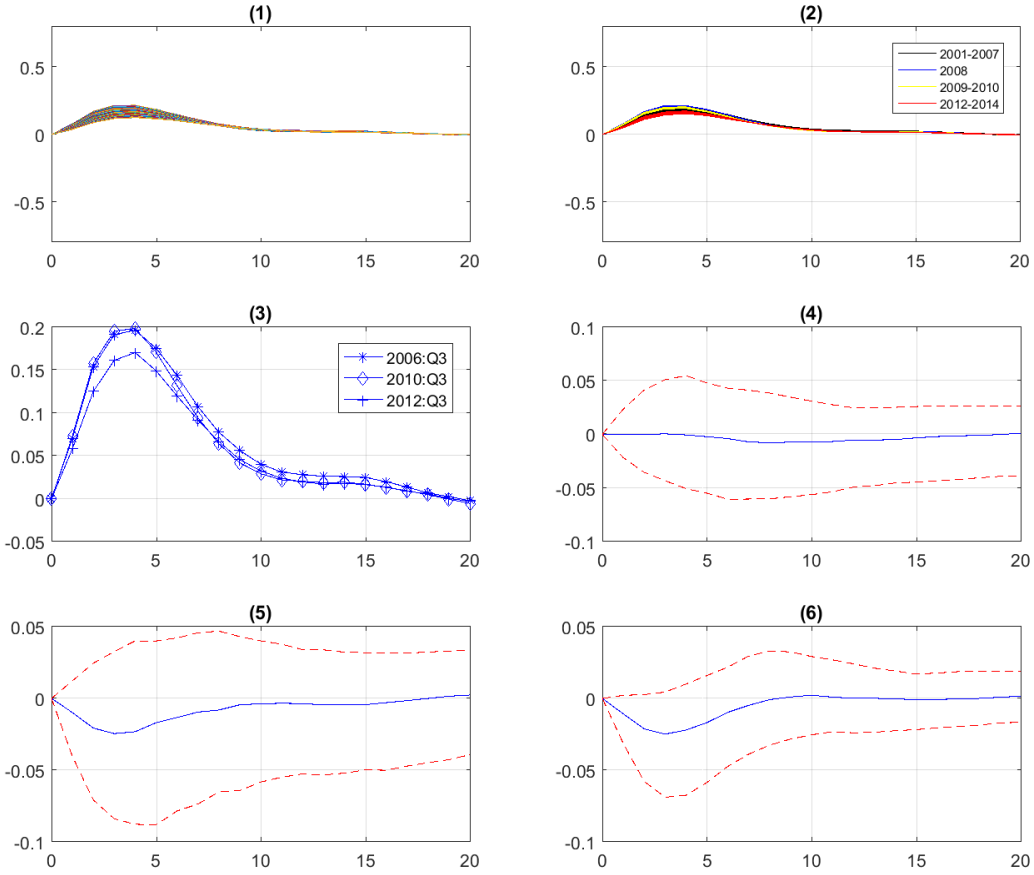


Note: We compute the impulse response functions using the parameter values of the corresponding time slot. (1) median impulse responses of GDP growth rate to 1 % interest rate shock of all quarters from 2001:Q3 to 2017:Q4, (2) median impulse responses in four episodes: 2001-2007, 2008, 2009-2010, and 2012-2014, (3) median impulse responses in 2006:Q3, 2010:Q3, and 2012:Q3 (4) difference between the responses in 2006:Q3 and 2010:Q3 with 16th and 84th percentiles, (5) difference between the responses in 2006:Q3, 2012:Q3 with 16th and 84th percentiles, (6)difference between the responses in 2010:Q3 and 2012:Q3 with 16th and 84th percentiles.

Panel (2) depicts the median impulse responses of four episodes: the episode before the financial crisis 2001-2007 (the black region), the episode during the financial crisis but before the stimulus 2008 (the blue region), the episode during the financial crisis with the stimulus 2009-2010 (the yellow region), and the episode after the stimulus 2012-2014 (the red region).

The black region, which are the impulse responses between 2001 and 2007, narrows down a lot in contrast with Panel (1). This suggests that there are not many nonlinearities before the financial crisis. The blue area are impulse responses from 2008:Q1 to 2008:Q4 when China was hit by the global financial crisis but hadn't acted fiercely yet. The blue area and black intertwines with each other. We cannot differentiate clearly the episode before the financial

Figure 6: Impulse Response Functions of GDP Growth Rate to 1% Money Growth Rate Shock

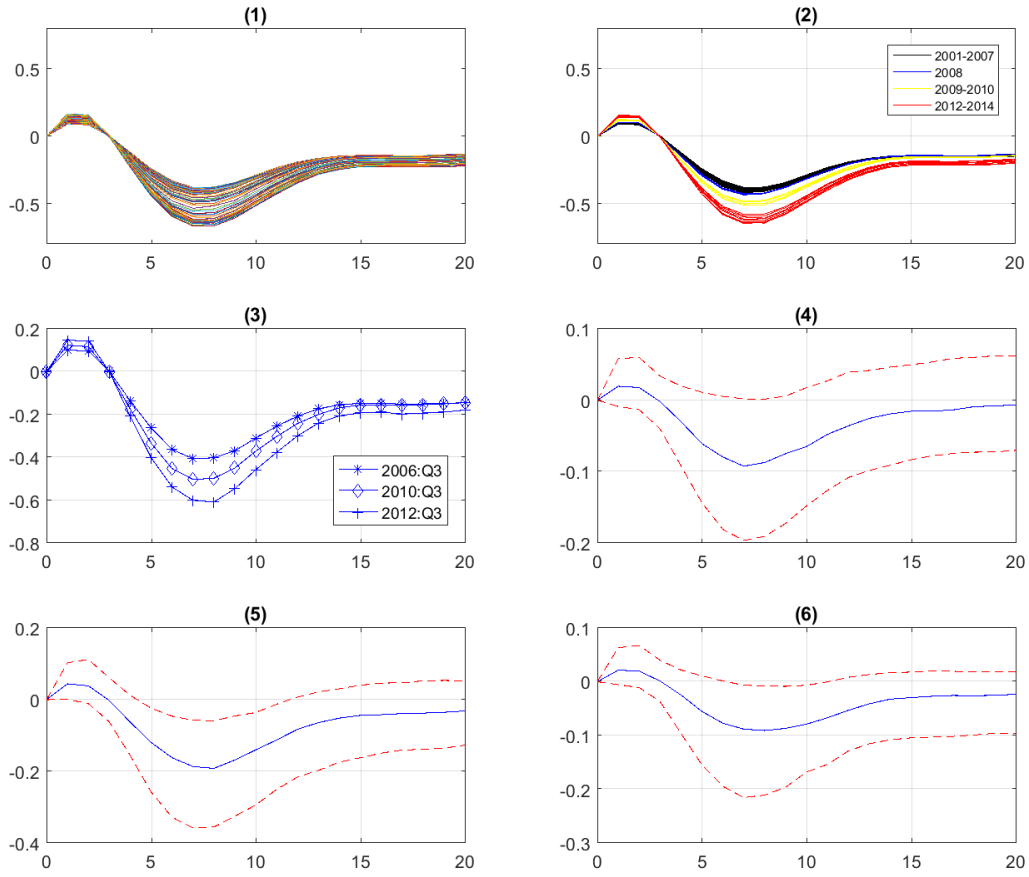


Note: We compute the impulse response functions using the parameter values of the corresponding time slot. (1) median impulse responses of GDP growth rate to 1 % money growth rate shock of all quarters from 2001:Q3 to 2017:Q4, (2) median impulse responses in four episodes: 2001-2007, 2008, 2009-2010, and 2012-2014, (3) median impulse responses in 2006:Q3, 2010:Q3, and 2012:Q3 (4) difference between the responses in 2006:Q3 and 2010:Q3 with 16th and 84th percentiles, (5) difference between the responses in 2006:Q3, 2012:Q3 with 16th and 84th percentiles, (6)difference between the responses in 2010:Q3 and 2012:Q3 with 16th and 84th percentiles.

crisis and the episode in the crisis but before the stimulus. One possible explanation is that colossal negative shocks took longer time to make the relations between macroeconomic variables change, though the central government acted promptly in 2008. And the other reason is that the central bank didn't change the monetary policy practice.

The period after the enaction of the stimulus has seen obvious time variations for the impulse response functions of both policy shocks. The yellow region of Panel (2), which are the impulse response functions during 2009-2010, shows that the effects of the interest rate shock enlarged but those to the money growth rate shock shrank. Additionally, the red

Figure 7: Impulse Response Functions of Inflation Rate to 1% Interest Rate Shock

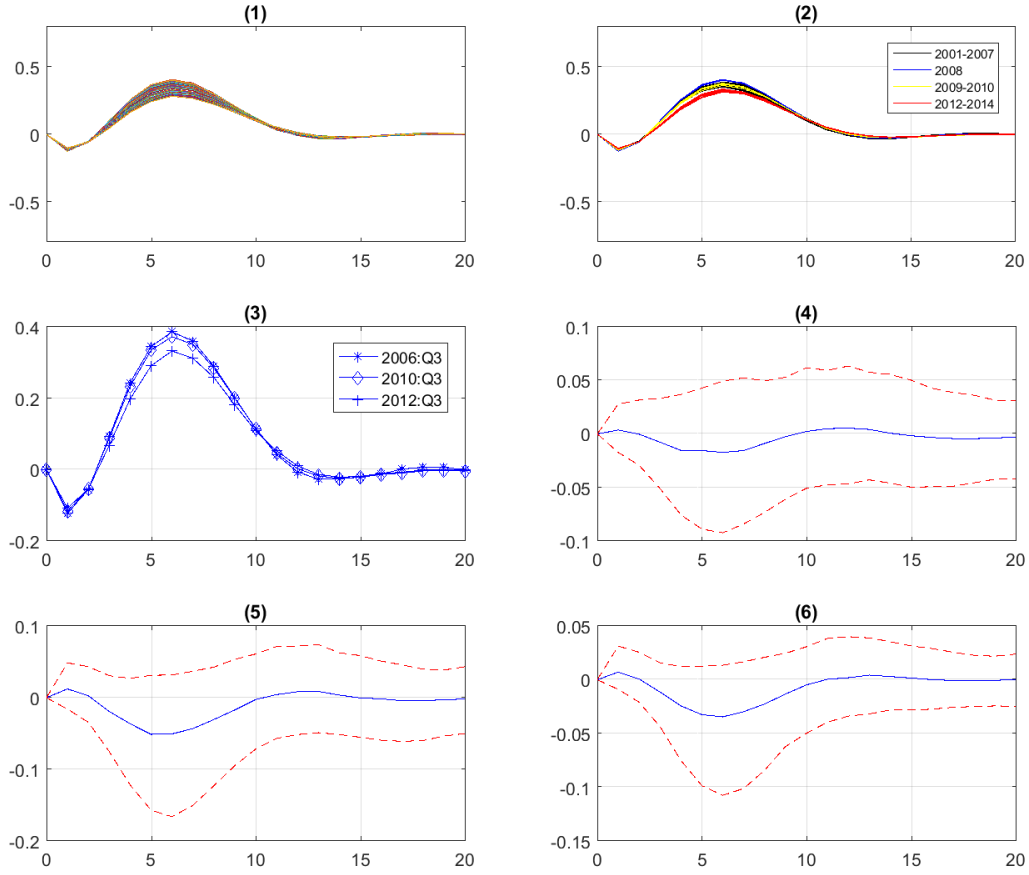


Note: We compute the impulse response functions using the parameter values of the corresponding time slot. (1) median impulse responses of inflation rate to 1 % interest rate shock of all quarters from 2001:Q3 to 2017:Q4, (2) median impulse responses in four episodes: 2001-2007, 2008, 2009-2010, and 2012-2014, (3) median impulse responses in 2006:Q3, 2010:Q3, and 2012:Q3 (4) difference between the responses in 2006:Q3 and 2010:Q3 with 16th and 84th percentiles, (5) difference between the responses in 2006:Q3, 2012:Q3 with 16th and 84th percentiles, (6)difference between the responses in 2010:Q3 and 2012:Q3 with 16th and 84th percentiles.

region which are the impulse response functions during 2012-2014 shows that the effects of the interest rate shock enlarged further while those of the money growth rate shock shrank further . The macroeconomy was more and more sensitive to interest rate shock, but less to money growth shock after 2009.

We also select three specific quarter 2006:Q3, 2010:Q3, and 2012:Q3 from these four episodes to underline this conclusion . As the impulse responses of the former two episodes intertwine, we select one quarter 2006:Q3 for the period before the beginning of the large stimulus. Panel (3) are the median impulse responses of the three quarters. Panel (4), (5), and (6) are the median and 16th/84th percentile difference between the impulse responses

Figure 8: Impulse Response Functions of Inflation Rate to 1% Money Growth Rate Shock



Note: We compute the impulse response functions using the parameter values of the corresponding time slot. (1) median impulse responses of inflation rate to 1 % money rate shock of all quarters from 2001:Q3 to 2017:Q4, (2) median impulse responses in four episodes: 2001-2007, 2008, 2009-2010, and 2012-2014, (3) median impulse responses in 2006:Q3, 2010:Q3, and 2012:Q3 (4) difference between the responses in 2006:Q3 and 2010:Q3 with 16th and 84th percentiles, (5) difference between the responses in 2006:Q3, 2012:Q3 with 16th and 84th percentiles, (6)difference between the responses in 2010:Q3 and 2012:Q3 with 16th and 84th percentiles.

in 2006:Q3 and 2010:Q3, 2006:Q3 and 2012:Q3, and 2010:Q3 and 2012:Q3. We can see that the impulse response difference are significant, especially the difference between 2006:Q3 and 2012:Q3 in Panel (5). Specifically the trough difference in the impulse response of GDP growth rate to interest rate shock attains nearly -0.1 in Figure 5 while the trough difference in the impulse response of inflation to the interest rate shock attains -0.2 in Figure 7.

One reason of this time variation pattern is that the shadow banking was rampant in China after the stimulus enacted. This phenomenon has been stated in various studies like Bai et al. (2016), Chen et al. (2017) and Chen et al. (2018). The official M2 statistics doesn't incorporate the large shadow banking which are not observable by the central bank. As

shadow banking accounts for larger proportion in the money supply of China's economy after 2009[9], the quantity based monetary policy has less effect on the macroeconomic variables. The interest rate can still affect the cost of shadow banking after China started to liberalize the interest rates in 2000s. So the central bank relied more on the price target to influence the whole economy. We provide another piece of evidence to Chen et al. (2018) who explain why the shadow banking after 2009 dampened the effect of money quantity policy of China.

In conclusion, the impulse response functions didn't change much before the enaction of the large stimulus in the end of 2008 but varied a lot after that time. The rampant shadow banking after 2009 makes the money quantity based monetary policy paralyzed and the effect of the interest-based monetary policy increased along the same time.

4.3 Forecast Error Variance Decomposition

Figure 9 and Figure 10 show the posterior median and 16th/84th percentile contributions of the four shocks in the forecast error variances of GDP growth rate and inflation rate over the period between 2001:Q3 to 2017:Q4 at 1, 2, 4, 8, and 16 quarters' horizon. There are phenomenal time variations across the whole period at 4, 8, and 16 quarters' horizons.

At one quarter's horizon, the GDP growth rate shock accounts for nearly 100 percent in the forecast error variance of GDP growth itself. So does inflation rate shock in the contribution of inflation rate forecast error variance except GDP growth shock accounted for a bit in the beginning.

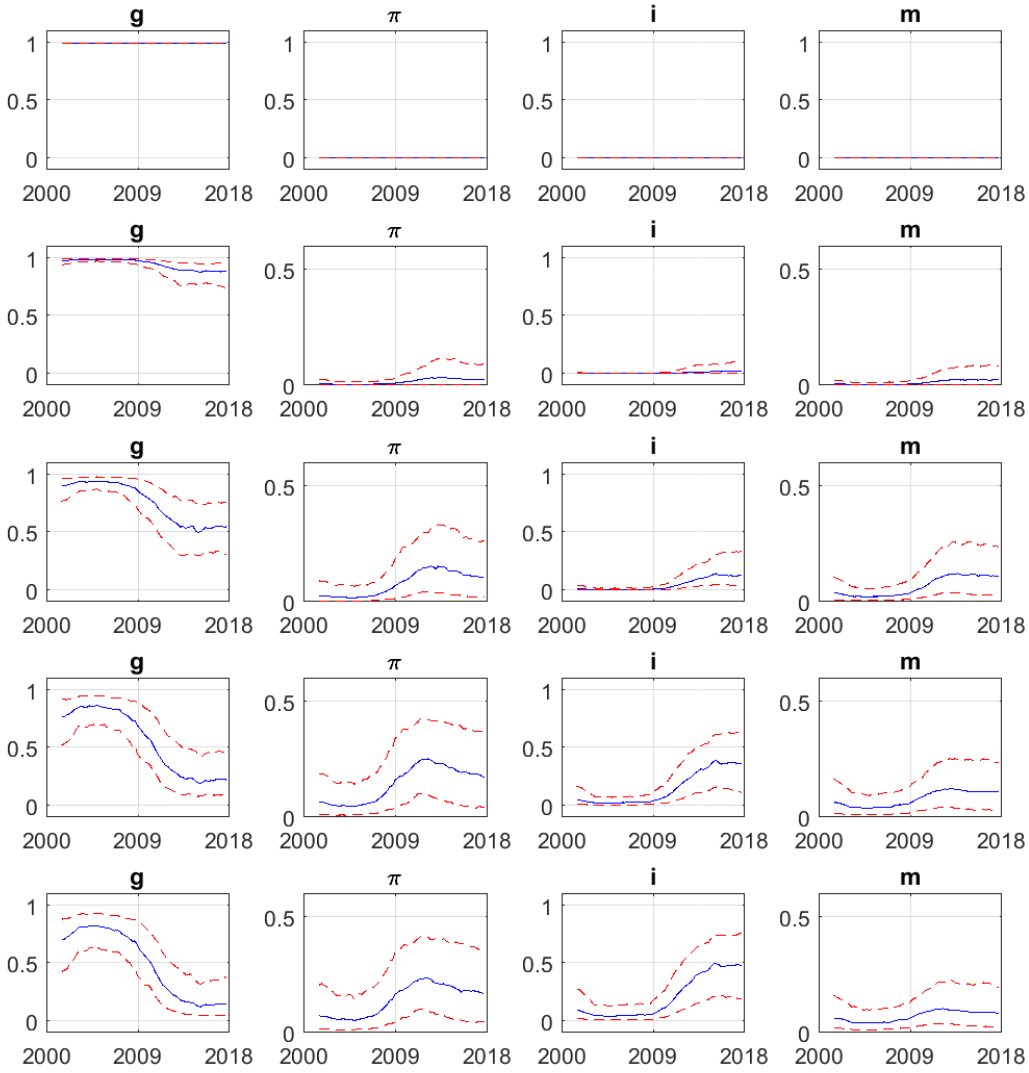
At two quarters' horizon, we can see the time variations now. After 2009, the contribution of GDP growth rate shock decreased a bit in the forecast error variance of GDP growth rate. The contributions of other three shocks increased.

At longer horizons especially 8 and 16, from the start to 2004, economic growth rate shock itself contributed the bulk nearly 80% in its own variance in Figure 9. After 2004, the proportion of economic growth rate shock started to decrease, and inflation rate shock's contribution started to climb. After 2009 when the large stimulus enacted, the interest rate shock's contribution increased and dominated the proportion in the variance of economic growth rate, more than 40%. The contribution of money growth rate shock did increase a bit in the variance of GDP growth rate.

At longer horizons especially 8 and 16, from the beginning of the estimated period 2001,

[9]Spendings by the off-balance sheet companies accounted for roughly 10 % of GDP each year after 2009, discussed in Bai et al. (2016)

Figure 9: Forecast Error Variance Decomposition of GDP Growth Rate

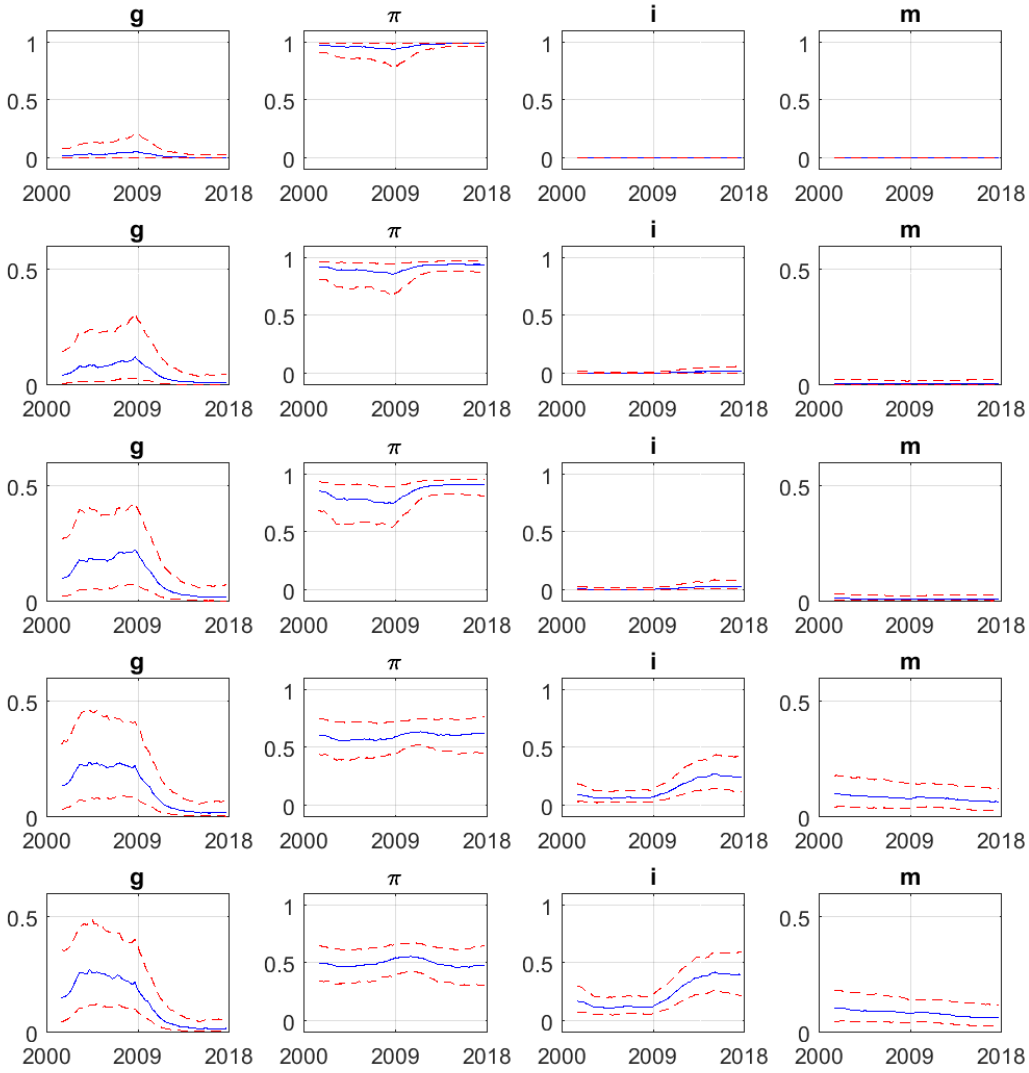


Note: Forecast error variance decomposition is computed by the posterior mean and 16th/84th percentile of the parameters of each quarter. Row 1 to 5 correspond to variance decompositions of 1,2, 4, 8, and 16 step ahead horizons. Column 1 to 4 correspond to contributions of the GDP growth rate shock, inflation rate shock, interest rate shock, and money growth rate shock in every horizon.

inflation rate shock contributed most in the its own variance, more than 50% in Figure 10. After 2009, the contribution of interest rate shock climbed significantly while that of the money growth rate shock decreased.

A clear conclusion from the variance decomposition is that the contribution of interest rate shock expanded significantly in the forecast error variances of both economic growth rate and inflation rate after 2009, while the contribution of money growth rate shock in the

Figure 10: Forecast Error Variance Decomposition of Inflation Rate



Note: Forecast error variance decomposition is computed by the posterior mean and 16th/84th percentile of the parameters of each quarter. Row 1 to 5 correspond to variance decompositions of 1,2, 4, 8, and 16 step ahead horizons. Column 1 to 4 correspond to contributions of the GDP growth rate shock, inflation rate shock, interest rate shock, and money growth rate shock in every horizon.

forecast error variance of the GDP growth rate increased a little bit and the contribution in the variance of the inflation rate decreased significantly. This evidence clearly shows that the interest rate policy had more proportion in the central bank's toolbox while money growth acted as a weaker role in the monetary policy after 2009. This unambiguously indicates that the PBC has been transiting from targeting money quantity to targeting the interest rate.

The reason why the PBC had to transit to count more on interest rate tool to stabilize the

economy probably lies in the result that the effects of money quantity tool were dampened and those of interest rate tool amplified after 2009, shown in the impulse response function analysis.

4.4 Counterfactual Analysis

The time varying VAR model is a natural tool to do counterfactual analysis since the time varying parameters can show the nonlinearity of the macroeconomy. To analyze the effect of a policy, we can simulate the counterfactual series by using the parameters before the policy period and the realized shocks over the policy period and then compare the couterfactual and actual variables to isolate the effect of policy.

During the financial crisis, China promptly enacted and carried out the 4 trillion RMB stimulus to hinder the negative effect of the sudden plummet of international demand in the fourth quarter of 2008. A couple of recent studies give controversial conclusions about the effect of the large stimulus policy. Some (Ouyang and Peng (2015),Chen et al. (2017),Wen and Wu (2017)) argue that the stimulus saved China from the great recession, while others (Bai et al. (2016) and Chen et al. (2018)) focus on the dark side of the stimulus that it exacerbated local governments' debt burden and brought about high economic risk to China.

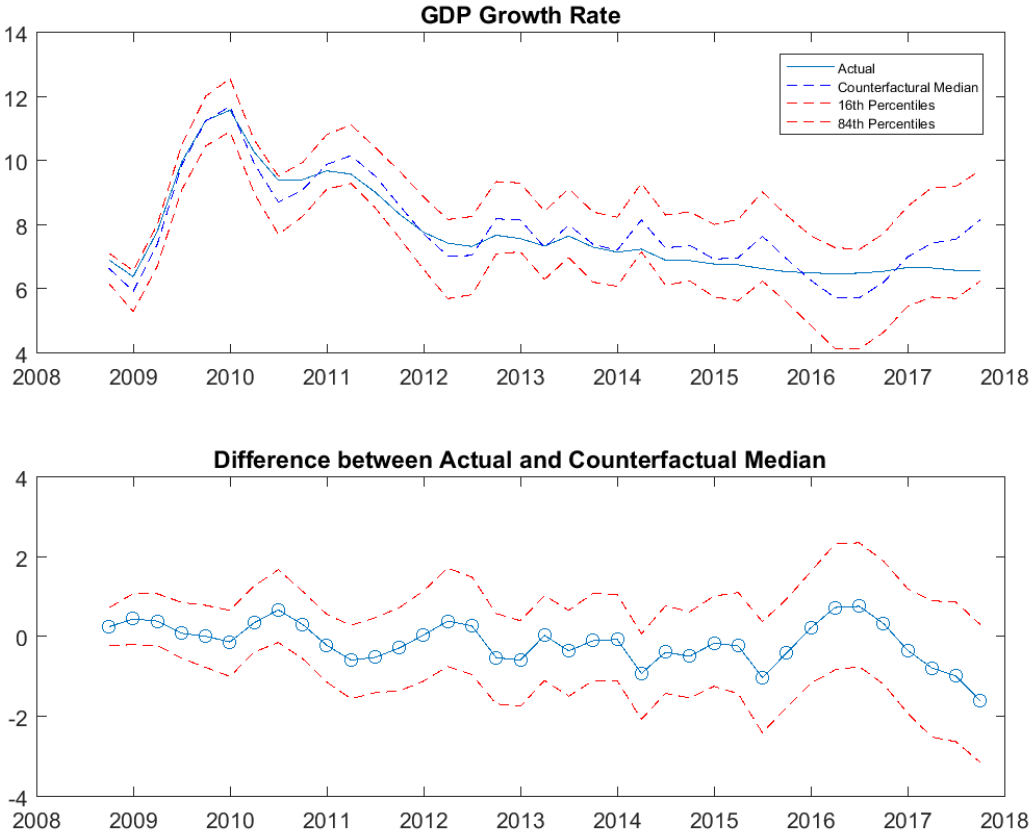
We simulate the counterfactual GDP growth rate and inflation rate in the TVP-VAR by using the parameter values of the average of the posterior means of eight quarters before 2007:Q3 and the actual realized shocks over the period 2008:Q4 to 2017:Q4.

Figure 11 depicts the counterfactual GDP growth rate with 16th/84th percentiles over the aftermath period of large stimulus. We can see that the actual growth rate is smoother than the counterfactual series. The bottom panel shows the difference between the actual and counterfactual growth rates. The stimulus policy increases the actual growth rate by at most 0.7 percentage point than the growth rate without the large stimulus in 2010. After the stimulus ended in 2010:Q4, actual growth rate went below the counterfactual series.

Figure 12 illustrates the counterfactual inflation rate with 16th/84th percentiles over the same period. After the stimulus, the actual inflation rate was lower in a year but soon higher than the counterfactual series. The peak difference is 0.9 percentage point in 2010 corresponding to the largest policy effect on economic growth. After the stimulus ended in the fourth quarter of 2010, the actual inflation is lower than the counterfactual series for the most of time.

The counterfactual analysis show that the 4 trillion RMB stimulus smoothed the GDP

Figure 11: Counterfactual GDP Growth Rate over 2008:Q4 to 2017:Q4



Note: Counterfactual GDP growth rate is generated from the TVP-VAR-SV by using the parameters of average of posterior means of eight quarters ahead of 2007:Q3 and the realized shocks backed out from the actual errors over the period 2008:Q4 to 2017:Q4

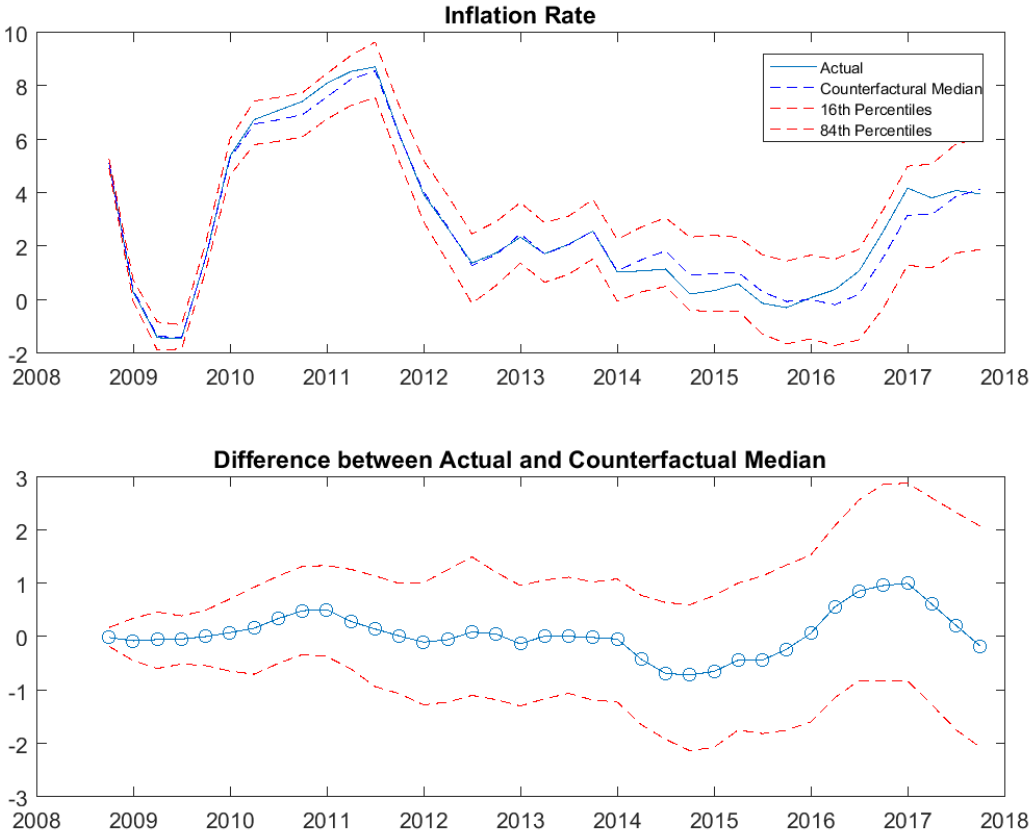
growth rate but the effect, 0.7 percentage point at most, is less than the number (3.2 point in Ouyang and Peng (2015) and 4 point in Chen et al. (2017)) found in the literature.

4.5 Robustness

We discuss robustness checks of alternative priors and specifications in this subsection: (1) use the data from 1996 to 2005 as the presample to calibrate the priors; (2) exclude interest rate in the VAR; (3) exclude money growth rate in the VAR. The complete graphs are shown in the online appendix.

The results of the TVP-VAR-SV may be sensitive to the selection of priors. Primiceri

Figure 12: Counterfactual Inflation Rate over 2008:Q4 to 2017:Q4



Note: Counterfactual inflation rate is generated from the TVP-VAR-SV by using the parameters of average of posterior means of eight quarters ahead of 2007:Q3 and the realized shocks backed out from the actual errors over the period 2008:Q4 to 2017:Q4

(2005) chose the first 10 years as the presample to calibrate the priors. To check this sensitivity, we extend the presample to 10 years from 1996 to 2005[10]. The results are similar to the benchmark ones.

As we analyze in Section 2, China adopts a hybrid monetary policy of targeting both interest rate and money growth rate. The correlation coefficients in Table 1 also show that these two series have different information. We can expect excluding either variable would produce different dynamic results since important information is lost in the three-

[10]Fernald et al. (2014) argues that the data before 2000 is not appropriate for present institution study of China since China underwent dramatic institution change in 1990s. This is not a problem for the TVP-VAR-SV model because time varying parameter model is proposed to study regime changes. Extending the size of the presample to calibrate the priors is a way to check this sensitivity.

variable VAR. As discussed in Sims (1992), excluding one important variable will result in the "omitted variable" problem. The price puzzle is a famous example.

Appendix B and C shows impulse response functions and variance decompositions of the two three-variable VAR of the robustness checks (2) and (3). We can still find the same pattern as the benchmark results. The impulse response functions of money growth rate shock shrank in Figure B-1 and B-2 and those of interest rate shock enlarged in Figure C-1 and C-2 after 2009.

When excluding one important variable, the remaining variable accounts for more proportion in the forecast error variance of the GDP growth rate and inflation rate after 2009 at longer horizons. Therefore the money growth rate shock's contribution increased after 2009 in the case excluding interest rate shock in Figure B-3 and B-4. So did the interest rate in the case excluding money growth rate shock in Figure C-3 and C-4. The contribution of the money growth rate in the forecast error variance of inflation rate in B-4 is different from our benchmark result in Figure 10 that the contribution of money growth rate shock declined. We should interpret this result with caution since the results may be distorted by excluding one important policy variable in the VAR.

Generally the benchmark results are robust to the three alternative changes.

5 Conclusion

This paper studies the monetary policy of China in a small scale TVP-VAR-SV model. According to monetary policy goals and intermediate targets of the central bank of China, we select four macroeconomic variables GDP growth rate, inflation rate, interest rate, and money growth rate in the VAR system. We then apply the method of Primiceri (2005) to estimate the parameters. Recursive assumption is assumed to achieve identification for the structural VAR system.

Basically as in the literature the TVP-VAR model with stochastic volatility attributes most of the variations to the stochastic volatilities, though the lag coefficients are a little bit more volatile than U.S. found in other studies. Impulse response functions showed no variation before the enaction of large financial crisis stimulus in the end of 2008 but changed considerably after that time. The responses of economic growth and inflation enlarged while the responses of money growth rate shrank after 2009. The forecast error variance decomposition shows that the interest rate shock's contribution climbed steeply in the forecast error decomposition of both GDP growth and inflation after 2009 , which implies that the

central bank had been transiting from targeting money quantity to targeting interest rate. Counterfactual analysis indicates that the stimulus smoothed the GDP growth rate but the magnitude, 0.7 percentage increase, is less than found in the literature.

Due to lack of unemployment data, we do not incorporate labor information in the VAR, which may be important to macroeconomic dynamics of China. We could add employment related information to the VAR in the future research. Another extension goes to large-scale VAR system, including more macroeconomic variables like industrial production, capital formation, and financial series.

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Appendix A Decomposition of A_t

Decompose A_t as

$$A_t = I_4 - A_t^+ \tag{9}$$

where

$$A_t^+ = \begin{bmatrix} 0 & 0 & 0 & 0 \\ -\alpha_{21,t} & 0 & 0 & 0 \\ -\alpha_{31,t} & -\alpha_{32,t} & 0 & 0 \\ -\alpha_{41,t} & -\alpha_{42,t} & -\alpha_{43,t} & 0 \end{bmatrix} \tag{10}$$

After multiplying and decomosing A_t, we can write the identified VAR system (4) as:

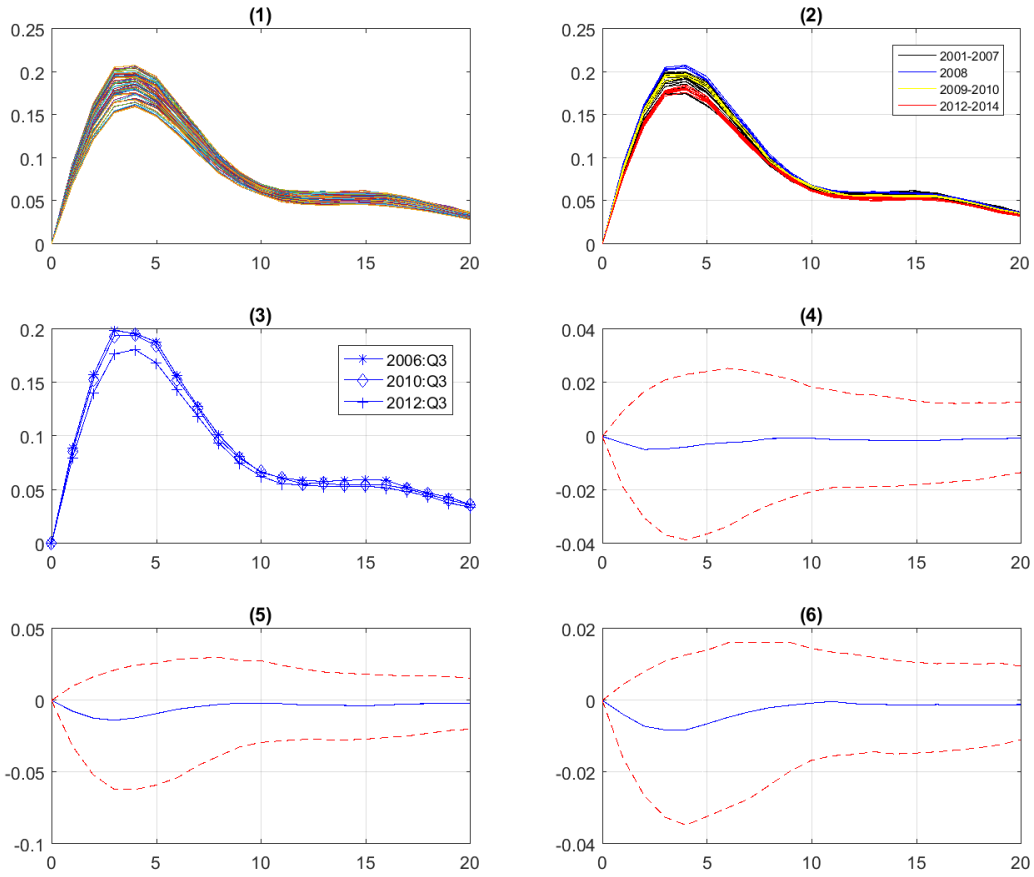
$$y_t = A_t^+ y_t + A_t B_t' X_t' + \Sigma_t \epsilon_t \tag{11}$$

A_t^+ is the contemporaneous response matrix of endogenous variables to other endogenous variables, the non-zero elements of which are equal to $-\alpha_t$ and are the opposite of the non-zero non-one elements α_t of A_t in the identified structural VAR.

Appendix B Graphs of Robustness (2): VAR Excluding the Interest Rate

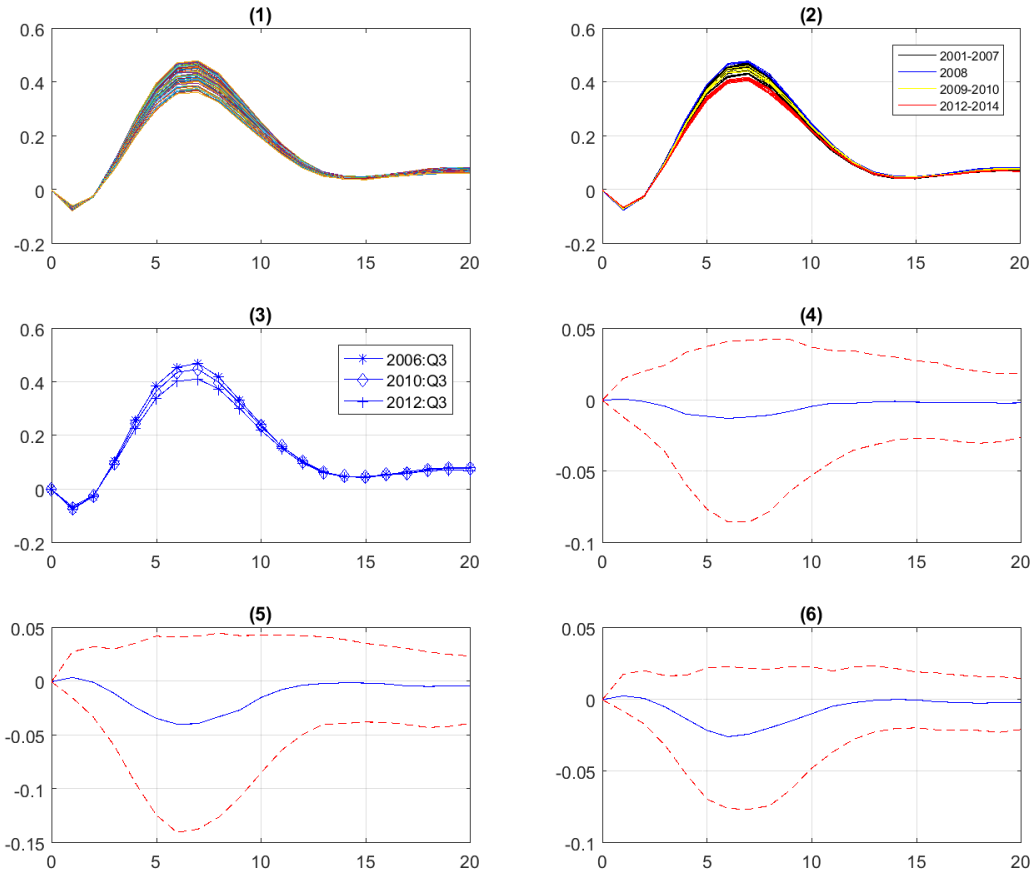
Here below are impulse response and forecast error decomposition graphs in the three-variable VAR excluding the interest rate.

Figure B-1: Impulse Response Functions of GDP Growth Rate to 1% Money Growth Rate Shock



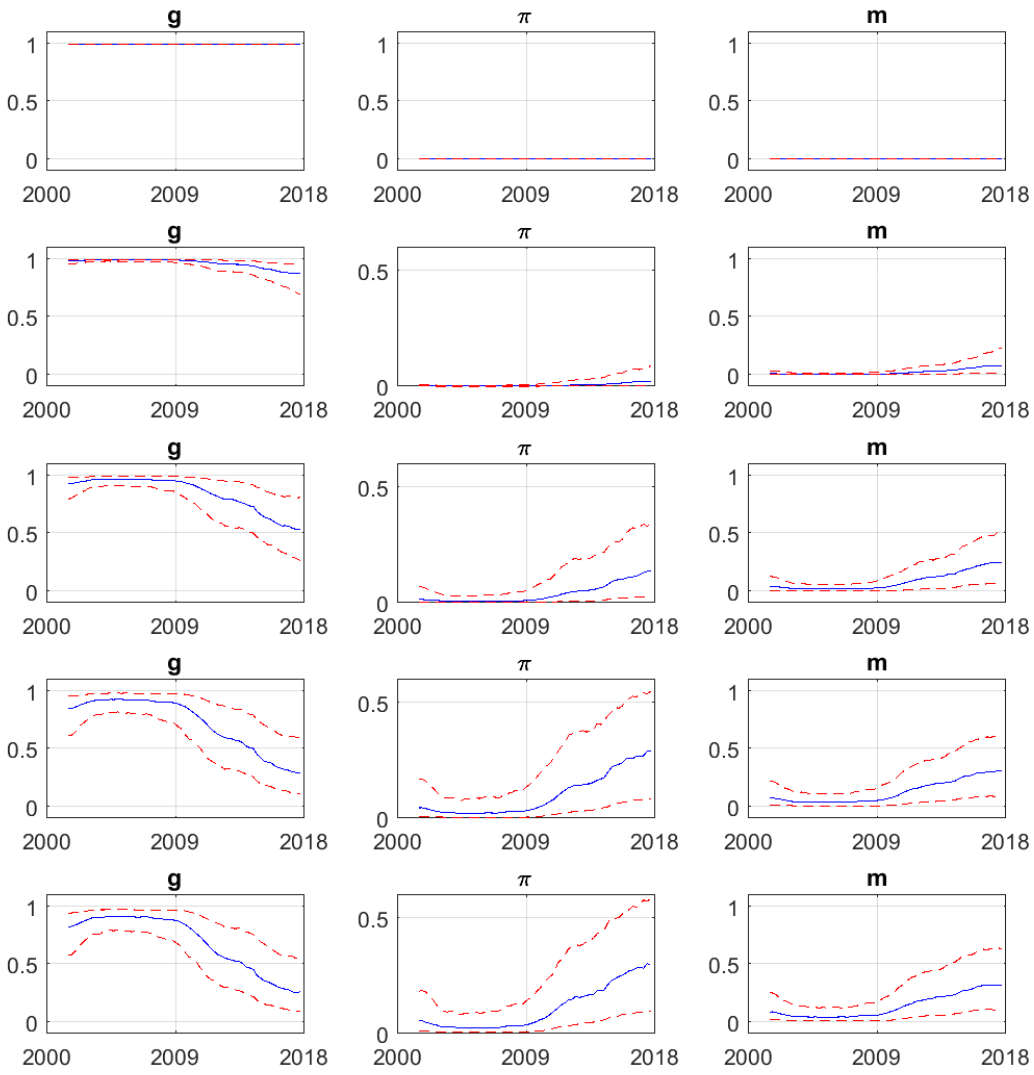
Note: We compute the impulse response functions using the parameter values of the corresponding time slot. (1) median impulse responses of GDP growth rate to 1 % money growth rate shock of all quarters from 2001:Q3 to 2017:Q4, (2) median impulse responses in four episodes: 2001-2007, 2008, 2009-2010, and 2012-2014, (3) median impulse responses in 2006:Q3, 2010:Q3, and 2012:Q3 (4) difference between the responses in 2006:Q3 and 2010:Q3 with 16th and 84th percentiles, (5) difference between the responses in 2006:Q3, 2012:Q3 with 16th and 84th percentiles, (6)difference between the responses in 2010:Q3 and 2012:Q3 with 16th and 84th percentiles.

Figure B-2: Impulse Response Functions of Inflation Rate to 1% Money Growth Rate Shock



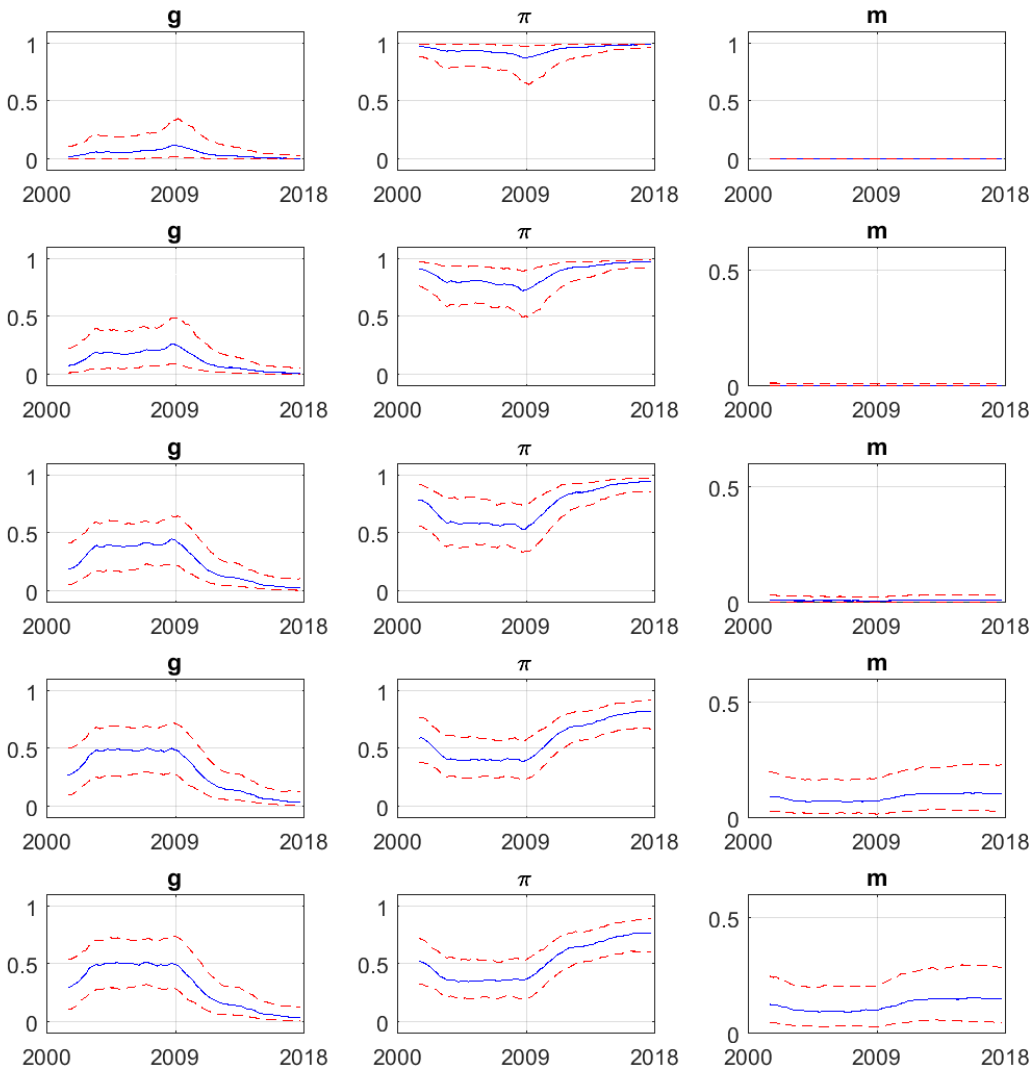
Note: We compute the impulse response functions using the parameter values of the corresponding time slot. (1) median impulse responses of inflation rate to 1 % money rate shock of all quarters from 2001:Q3 to 2017:Q4, (2) median impulse responses in four episodes: 2001-2007, 2008, 2009-2010, and 2012-2014, (3) median impulse responses in 2006:Q3, 2010:Q3, and 2012:Q3 (4) difference between the responses in 2006:Q3 and 2010:Q3 with 16th and 84th percentiles, (5) difference between the responses in 2006:Q3, 2012:Q3 with 16th and 84th percentiles, (6)difference between the responses in 2010:Q3 and 2012:Q3 with 16th and 84th percentiles.

Figure B-3: Forecast Error Variance Decomposition of GDP Growth Rate



Note: Forecast error variance decomposition is computed by the posterior mean and 16th/84th percentile of the parameters of each quarter. Row 1 to 5 correspond to variance decompositions of 1,2, 4, 8, and 16 step ahead horizons. Column 1 to 3 correspond to contributions of the GDP growth rate shock, inflation rate shock, and money growth rate shock in every horizon.

Figure B-4: Forecast Error Variance Decomposition of Inflation Rate

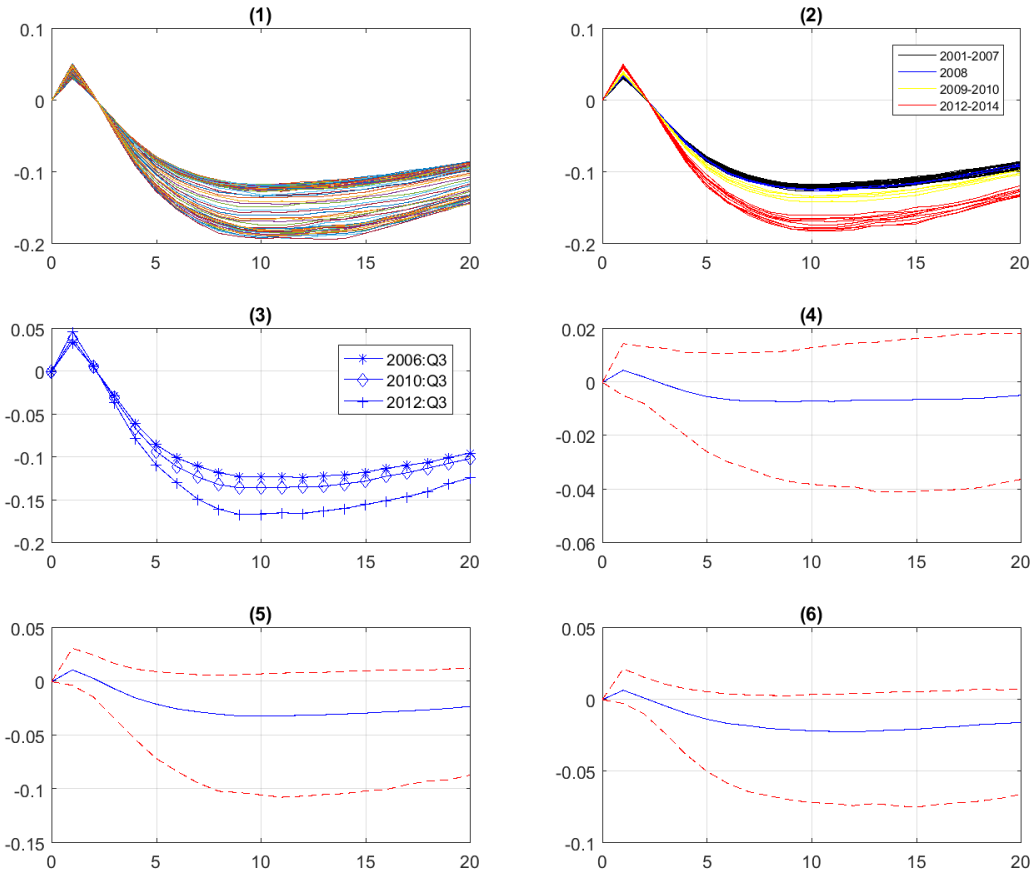


Note: Forecast error variance decomposition is computed by the posterior mean and 16th/84th percentile of the parameters of each quarter. Row 1 to 5 correspond to variance decompositions of 1,2, 4, 8, and 16 step ahead horizons. Column 1 to 3 correspond to contributions of the GDP growth rate shock, inflation rate shock, and money growth rate shock in every horizon.

Appendix C Graphs of Robustness (3): VAR Excluding the Money Growth Rate

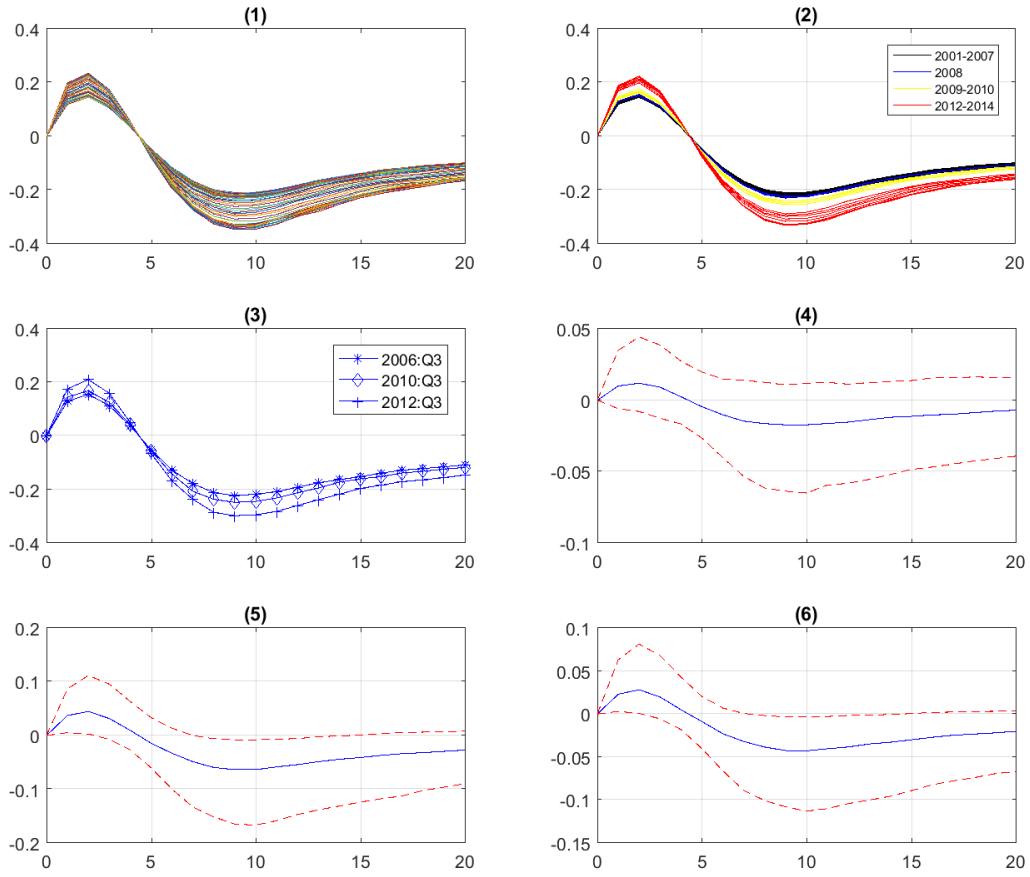
Here below are impulse response and forecast error decomposition graphs in the three-variable VAR excluding the money growth rate.

Figure C-1: Impulse Response Functions of GDP Growth Rate to 1% Interest Rate Shock



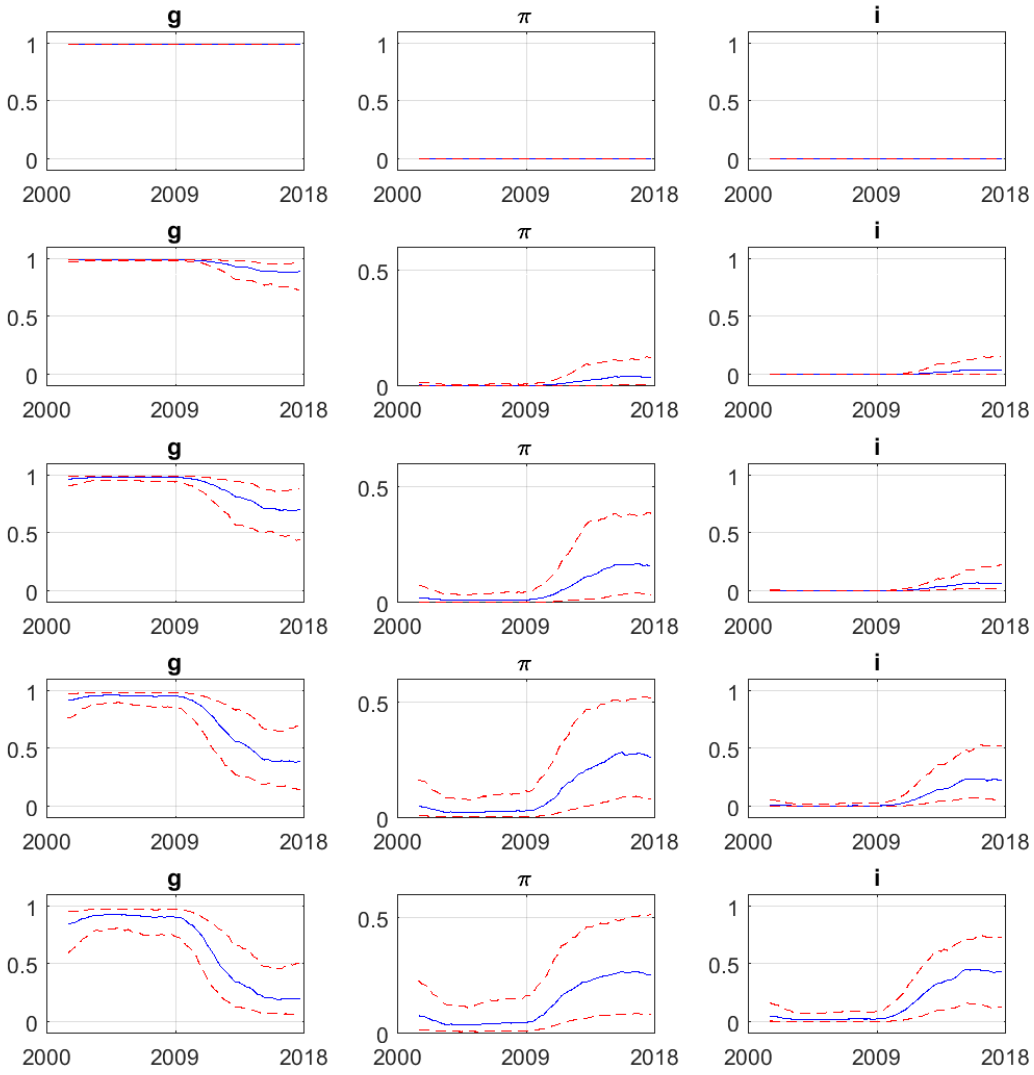
Note: We compute the impulse response functions using the parameter values of the corresponding time slot. (1) median impulse responses of GDP growth rate to 1 % interest rate shock of all quarters from 2001:Q3 to 2017:Q4, (2) median impulse responses in four episodes: 2001-2007, 2008, 2009-2010, and 2012-2014, (3) median impulse responses in 2006:Q3, 2010:Q3, and 2012:Q3 (4) difference between the responses in 2006:Q3 and 2010:Q3 with 16th and 84th percentiles, (5) difference between the responses in 2006:Q3, 2012:Q3 with 16th and 84th percentiles, (6)difference between the responses in 2010:Q3 and 2012:Q3 with 16th and 84th percentiles.

Figure C-2: Impulse Response Functions of Inflation Rate to 1% Interest Rate Shock



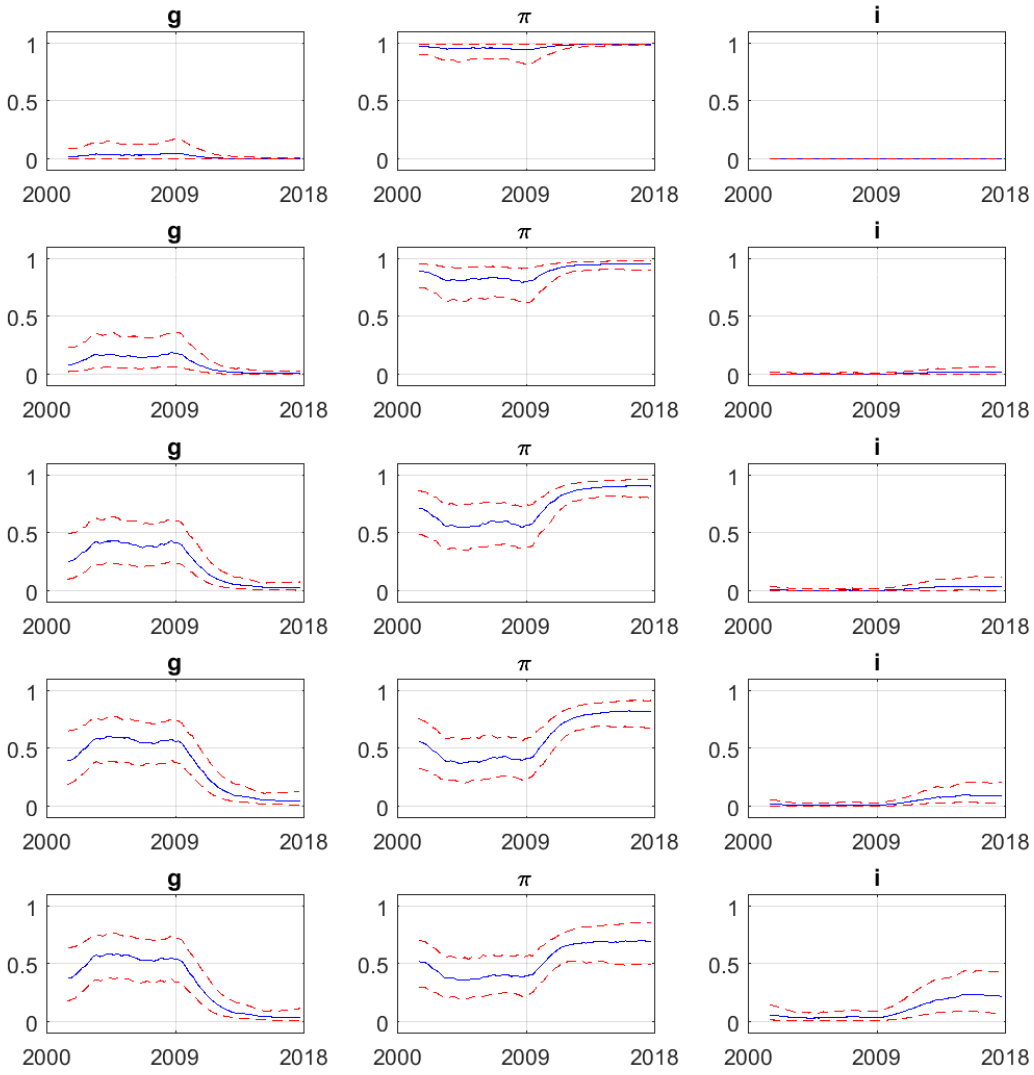
Note: We compute the impulse response functions using the parameter values of the corresponding time slot. (1) median impulse responses of inflation rate to 1 % interest rate shock of all quarters from 2001:Q3 to 2017:Q4, (2) median impulse responses in four episodes: 2001-2007, 2008, 2009-2010, and 2012-2014, (3) median impulse responses in 2006:Q3, 2010:Q3, and 2012:Q3 (4) difference between the responses in 2006:Q3 and 2010:Q3 with 16th and 84th percentiles, (5) difference between the responses in 2006:Q3, 2012:Q3 with 16th and 84th percentiles, (6)difference between the responses in 2010:Q3 and 2012:Q3 with 16th and 84th percentiles.

Figure C-3: Forecast Error Variance Decomposition of GDP Growth Rate



Note: Forecast error variance decomposition is computed by the posterior mean and 16th/84th percentile of the parameters of each quarter. Row 1 to 5 correspond to variance decompositions of 1,2, 4, 8, and 16 step ahead horizons. Column 1 to 3 correspond to contributions of the GDP growth rate shock, inflation rate shock, and interest rate shock in every horizon.

Figure C-4: Forecast Error Variance Decomposition of Inflation Rate



Note: Forecast error variance decomposition is computed by the posterior mean and 16th/84th percentile of the parameters of each quarter. Row 1 to 5 correspond to variance decompositions of 1,2, 4, 8, and 16 step ahead horizons. Column 1 to 3 correspond to contributions of the GDP growth rate shock, inflation rate shock, and interest rate shock in every horizon.