

THE ASYMMETRIC TRANSMISSION OF CHINA'S MONETARY POLICY

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ABSTRACT. China monetary policy, as well as its transmission into the economy, is yet to be understood by researchers and policymakers. We propose a new estimation method and use it to quantify the monetary transmission of China's monetary policy within the endogenous-switching nonlinear SVAR framework. We find strong evidence that contributions of monetary policy shocks to the GDP fluctuation are asymmetric across different states of the economy. The effect of monetary policy on output is supported more by medium and long term bank loans than by short term bank loans. This is especially true for the shortfall state, in which an increase of M2 is channeled disproportionately into MLT loans. These findings highlight the role of M2 growth as a primary instrument and the bank lending channel to investment as a key transmission mechanism for monetary policy. Our analysis shows that China monetary policy has unbalanced effects on consumption and investment.

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As China has the features of both a large transition economy and an emerging market economy, the central bank of China and its monetary policy are yet to be well understood by the outside world.

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I. INTRODUCTION

China's economic growth has benefited from a combination of market liberalization and government policy. While the analyses on market forces and technological improvements in China have formed a strand of literature, the role of government policy has been largely ignored. The long-term plan approved by the Eighth National People's Congress in the late 1990s, for example, aimed to promote and support investment in heavy industries by credit expansions. As the government strives to maintain a high level of GDP growth in the midst of recent economic slowdown, understanding and quantifying its role in the promotion of economic growth has become a pressing issue for both researchers and policymakers.

In this paper we focus on one aspect of central government policy: the role of monetary policy in supporting the government's planned GDP growth through the bank lending channel. Despite the importance of China as the second largest economy in the world, monetary policy and its quantitative impact on the economy are largely unknown and there has been relatively scarce research on this important topic. This paper provides a robust empirical analysis of the transmission mechanism of China monetary policy by making several contributions.

First, we propose a nonlinear endogenous-switching SVAR system to quantify the monetary transmission in China. In our SVAR system, the monetary policy rule is nonlinear and its output coefficient switches endogenously to the state of GDP growth. In particular, we allow M2 growth to respond asymmetrically to GDP growth when it is above the target (the normal state) and when actual GDP growth is below the target (the shortfall state). Such nonlinear policy rule captures the central government's preference for promoting GDP growth beyond its annual target while keeping inflation under control. The rest of the system is unrestricted to avoid potentially "incredible restrictions" on the structure of the Chinese economy (Sims, 1980). Because the monetary policy rule is nonlinear, the system becomes nonlinear as well and impulse responses to a monetary policy shock are functions of endogenously-switching coefficients in the monetary policy rule. The cross-equation nonlinear restrictions make solving and estimating the SVAR system a very difficult task.

Second, we develop a new estimation method that enables us to estimate the nonlinear monetary policy rule independently of estimation of the rest of the system. We show that the monetary policy equation and its shock are identified without having to impose restrictions on other equations or identify other shocks. The rest of the system can be estimated with the standard method applied for linear VARs. Thus, our new methodology enables us to distinguish the effect of one policy rule from the effect of another policy rule without violating the Lucas critique. Because this method is straightforward to implement, it can be adapted by the general researcher to tackle similar problems.¹

Finally, in addition to several common effects of monetary policy in the existing literature, our estimation establishes five stylized facts special to the Chinese economy:

- The influence of monetary policy on investment and output in the shortfall state is less effective than in the normal state. In particular, an initial increase of monetary supply in the shortfall state twice as large as that in the normal state is needed to achieve the same quantitative effect on the real economy.
- The importance of an exogenous policy shift, *relative to* other exogenous shocks in the economy, differs across states in explaining the output fluctuation. The monetary policy shock contributes to as high as 40% of the output fluctuation in the shortfall state, in contrast to one fifth in the normal state.
- The effect of monetary policy on output is supported more by medium and long term (MLT) bank loans than by short term (ST) bank loans. This is especially true for the shortfall state, in which an increase of M2 is channelled disproportionately into MLT loans.
- The response of output produced from heavy industries is much stronger than the response of output produced from light industries. Together with the stylized fact of MLT and ST bank loans, this finding is a reflection of the distortion created by the central government's preference for promoting heavy industries that require longer term financing.²
- The response of investment is economically strong and statistically significant. The response of consumption is weak and the statistical significance is marginal at best. This tradeoff is consistent with Nakamura et al. (2016), who use micro data to document a consumption slump during the period of a massive monetary stimulus after the 2008 financial crisis.

¹In their early development stages, for example, newly industrialized economies in East Asia such as Japan implemented pro-growth monetary policy similar to China. We thank Nobu Kiyotaki for this point.

²Heavy industries consist of large and often capital-intensive firms specialized in real estate, infrastructure, transportation, telecommunication, and basic industries such as electricity, chemical products, coal, petroleum processing, and natural gas. They include many state-owned and other overcapacity firms.

Our empirical analysis bears important implications about monetary policy reforms discussed in various Chinese government documents. The discussions center on how quantity-based monetary policy such as controlling M2 growth can be gradually replaced by price-based monetary policy that mimics closely the interest rate rule in other economies with fully functional financial markets. Institutional rigidities must be taken into account when researchers and policymakers discuss the design and implementation of a new policy rule involving policy interest rates. The most conspicuous institutional constraint on monetary policy is the PBC obligation to help achieve and surpass an annual GDP growth target set by the central government. Our estimation shows that the effect of monetary policy on output is transmitted via a reliance on investment in heavy and overcapacity industries at a sacrifice of consumption; such investment is fueled by MLT bank loans, especially in the wake of the global financial crisis. One negative consequence is rising corporate debts that pose potential risks to the financial system.

As long as GDP growth target is a national priority, a transition from M2 growth to some policy interest rate as a primary instrument must take into account this constraint and its positive and negative consequences. During the transition period, researchers should not take for granted that rational agents understand how a new policy works, because agents' past behaviors and beliefs have been based on how the existing policy works. Our estimated M2 growth rule and subsequent SVAR analysis demonstrate that quantity-based monetary policy has been influential in accommodating GDP growth over the past 17 years under the existing institutional environment. Such an environment is unlikely to change abruptly and discontinuously. It is therefore a first but critical step to understand the policy rule that has already been put in place for more than a decade before one could assess the benefits and costs of a regime switch to a different policy rule with a different policy instrument.

The rest of the paper is organized as follows. Section II develops a new estimation method and presents the empirical results of monetary transmission. Section III provides the main estimation results. Section IV discusses the role of external sector in monetary policy. Section V offers further discussions of the unique features of existing monetary policy in China. Section VI concludes.

II. DATA AND EMPIRICAL STRATEGIES

In this section we study the monetary transmission via the dynamic effects of a monetary policy shock on the aggregate economy. To this end we adopt the SVAR approach as pioneered by Sims (1980) and championed by Christiano et al. (2005).

II.1. Data. The sample period for estimation is from 2000Q1 to 2016Q2. This is a period in which the PBC has made M2 growth as an explicit instrument and the Monetary Policy

Report (MPRs) have been available to the public since 2001Q1.³ The sample length for our quarterly data is over 17 years when lags are included. Although the sample is relatively short, it is comparable to the sample length often used for studying U.S. monetary policy during its inflation-targeting period of 16 years prior to the 2008 financial crisis (1992-2007).

As output and inflation may respond to other financial and policy variables, it is necessary to control for these variables when assessing how a monetary policy shock is transmitted to the real economy. Thus, our benchmark model consists of 11 variables, including 10 variables in addition to M2 supply: GDP, CPI, the excess reserve ratio (EER), the actual reserve ratio (ARR), the MLT bank loans, the ST bank loans, the 7-day repo rate (Repo), the bank lending rate (LR), the bank deposit rate (DR), and foreign exchange reserves (FXR).⁴ We denote these variables by an $n \times 1$ vector y_t , where $n = 10$. As in the SVAR literature, we express all the variables in natural log level except for interest rates and ratio variables, which are expressed in level as percent. We follow Bianchi and Bigio (2014) and include both EER and ARR in the system to isolate the effect on EER by controlling for ARR. Similarly, we control for LR and DR to isolate the effect on the market interest rate Repo. The variables other than M2, GDP, and CPI are potentially essential to understanding the monetary transmission. For robustness analysis, we also explore which variables are most important to the monetary transmission in later sections.

One may question the quality of China's official macroeconomic data, especially the GDP and CPI series. For example, Nakamura et al. (2016) argue that the official CPI data underestimate the volatility of CPI inflation since 1995.⁵ Despite the unsettled debates on this issue, the official CPI series is still the headline price series the PBC and other central government units pay attention to when making monetary policy decisions. For this reason we use the official series to estimate the monetary policy rule. In regard to the GDP series,

³The only official release of how the PBC conducts monetary policy each quarter is a published quarterly Monetary Policy Report (MPR). The first publication of MPR was issued in 2001Q1. Opinions expressed in the MPC's meetings are recorded in the form of "meeting minutes." The minutes, if approved by more than two thirds of the MPC members, are attached as an annex to the PBC's proposals on money supply, interest rates, exchange rates, and other monetary variables. This report is then sent to the State Council for approval. Once approved, the MPR provides an executive summary of the state of the economy along with additional descriptions of how the PBC adjusts its monetary policy actions in response to the state of the economy.

⁴See Appendix C for a detailed description of the data.

⁵Ideally we would like to use their series to verify the robustness of our results, but unfortunately their series is only available at annual frequency. Nonetheless, their CPI series is likely to make the CPI response to a monetary policy shock stronger.

our view is that one should *not* abandon the official GDP figures because they are precisely the most important series targeted by the central government.⁶

Our objective is to assess the dynamic impact of a monetary policy shock on the vector y_t . Because the monetary policy rule is nonlinear, estimation of the whole system (including the monetary policy rule) poses conceptual and computational challenges. We develop a new methodology for estimating this nonlinear endogenous-switching SVAR system.

II.2. New estimation methodology. The money supply variable (M_t) and the other $n = 10$ variables form a medium-sized SVAR. One key equation in this SVAR model is the monetary policy equation, which involves the three variables: M2, output, and prices. These variables also enter the other equations in the system.

In a companion paper, Chen et al. (2017) develop a tractable framework that approximates practical monetary policy of China. This framework consists of an endogenous-switching rule underscoring the essential Chinese characteristics of monetary policy that differ from the simple interest rate rule widely used for developed economies. Under such a rule, M2 growth is used as a policy instrument. Our formal econometric estimation of the monetary policy rule reveals that M2 growth responds positively to GDP growth when it is above the target (the normal state), but when actual GDP growth is below the target (the shortfall state), M2 growth takes an unusually aggressive response to stem the shortfall. This asymmetric response to GDP growth in different states of the economy is a unique feature of China pro-growth monetary policy.

To understand the transmission of monetary policy of China, we follow Chen et al. (2017) and characterize China monetary policy rule as

$$g_{m,t} = \gamma_0 + \gamma_m g_{m,t-1} + \gamma_\pi (\pi_{t-1} - \pi^*) + \gamma_{x,t} (g_{x,t-1} - g_{x,t-1}^*) + \sigma_{m,t} \varepsilon_{m,t}, \quad (1)$$

where ($g_{m,t+1} = \Delta M_{t+1}$), $\pi_t = \Delta P_t$ and ($g_{x,t} = x_t - x_{t-1}$) denote quarterly M2 growth, inflation rate, and GDP growth rate, respectively. ($g_{x,t}^*$) is the GDP growth target. Note that all the three variables, M_t , P_t , and x_t , are expressed in natural log. $\varepsilon_{m,t}$ is a serially independent random shock that has a standard normal distribution.

To capture the pro-growth aspect of monetary policy, we allow the output coefficient to be time-varying with the form

$$\gamma_{x,t} = \begin{cases} \gamma_{x,a} & \text{if } g_{x,t-1} - g_{x,t-1}^* \geq 0 \\ \gamma_{x,b} & \text{if } g_{x,t-1} - g_{x,t-1}^* < 0 \end{cases},$$

where the subscript “a” stands for “above the target” and “b” for “below the target”. These coefficients represent two states for policy response to output growth: the normal state when

⁶In a very recent paper, Nie (2016) argues that “official GDP figures remain a useful and valid measure of Chinese economic growth.”

actual GDP growth meets the target as a lower bound and the shortfall state when actual GDP growth falls short of the government's target. We allow heteroskedasticity between the two states when estimating the policy rule so that

$$\sigma_{m,t} = \begin{cases} \sigma_{m,a} & \text{if } g_{x,t-1} - g_{x,t-1}^* \geq 0 \\ \sigma_{m,b} & \text{if } g_{x,t-1} - g_{x,t-1}^* < 0 \end{cases}.$$

We postulate the dynamics of y_t in a general subsystem of simultaneous equations

$$A_0 y_t + b_0 M_t = c + \sum_{\ell=1}^4 A_\ell y_{t-\ell} + \sum_{\ell=1}^4 b_\ell M_{t-\ell} + \xi_t, \quad (2)$$

where $y_{t-\ell}$ is an $n \times 1$ vector of endogenous variables, c is an $n \times 1$ vector of constant term, the $n \times 1$ vector of shocks ξ_t , orthogonal to the monetary policy shock $\varepsilon_{m,t}$, has mean zero and covariance identity matrix, c and b_ℓ are $n \times 1$ coefficient vectors, and A_ℓ is an $n \times n$ coefficient matrix. This is a subsystem because the monetary policy equation is not included here. We impose no restrictions on A_ℓ and b_ℓ (including the contemporaneous coefficient vector b_0 and the contemporaneous coefficient matrix A_0) to avoid “incredible restrictions” and maintain the principle of minimal restrictions on identification (Sims, 1980). This principle is especially relevant to establishing basic stylized facts about the effects of China monetary policy on the aggregate economy as these facts remain largely unknown to academic researchers.

The first practical issue confronting researchers is identification. Since the transformed subsystem

$$(QA_0)y_t + (Qb_0)M_t = (Qc) + \sum_{\ell=1}^4 (QA_\ell)y_{t-\ell} + \sum_{\ell=1}^4 (Qb_\ell)M_{t-\ell} + Q\xi_t$$

by any orthogonal matrix Q generates the same dynamics of y_t as does the original subsystem, the unrestricted subsystem (2) is unidentified.⁷ Because the policy variable M_t is contemporaneously correlated with the rest of the variables (y_t), the identification question arises as to whether the monetary policy equation (1) is identified and whether the effect of $\varepsilon_{m,t}$ on y_t depends on the ordering of the elements of y_t , when equation (1) is estimated *jointly* with subsystem (2). The following proposition establishes the identification of monetary policy.

Proposition 1. When the system represented by (1) and (2) is simultaneously estimated, the following two results hold.

- The monetary policy rule (1) is identified, even though the subsystem (2) is unidentified.

⁷Note that $Q\xi_t$ and ξ_t have exactly the same probability distribution: a normal probability distribution with mean zero and variance identity matrix.

- Impulse responses of y_t to $\varepsilon_{m,t}$ are invariant to the rotation matrix Q or the ordering of elements in y_t .

Proof. See Appendix A. □

The intuition for identification of the monetary policy rule is that M_t is determined before all other variables at time t are determined. In the conventional setup, it is often required that the rest of the system has a recursive structure as well—a very strong assumption. What is new in Proposition 1 is to show that this additional assumption is unnecessary and in fact the rest of the system can be simultaneously determined. This simultaneity allows the interest rate to respond to money supply, output, and prices contemporaneously, while at the same time the monetary policy rule (1) is still identified.

To compute impulse responses to a monetary policy shock, one needs to study the complete system composed of (1) and (2), which can be written in the SVAR form of

$$\underbrace{\begin{bmatrix} \frac{1}{\sigma_{m,t}} & 0 \\ b_0 & A_0 \end{bmatrix}}_{\tilde{A}_{0,t}} \begin{bmatrix} M_t \\ y_t \end{bmatrix} = \underbrace{\begin{bmatrix} \gamma_0 - \gamma_\pi \pi^* - \gamma_{x,t-1} x_{t-1}^* \\ \sigma_{m,t} \\ c \end{bmatrix}}_{\tilde{c}_t} + \underbrace{\begin{bmatrix} \frac{1+\gamma_M}{\sigma_{m,t}} & v(\gamma_{x,t-1}, \sigma_{m,t}) \\ b_1 & A_1 \end{bmatrix}}_{\tilde{A}_{1,t}} \begin{bmatrix} M_{t-1} \\ y_{t-1} \end{bmatrix} \\ + \underbrace{\begin{bmatrix} -\frac{\gamma_M}{\sigma_{m,t}} & 0 \\ b_2 & A_2 \end{bmatrix}}_{\tilde{A}_{2,t}} \begin{bmatrix} M_{t-2} \\ y_{t-2} \end{bmatrix} + \underbrace{\begin{bmatrix} 0 & 0 \\ b_3 & A_3 \end{bmatrix}}_{\tilde{A}_3} \begin{bmatrix} M_{t-3} \\ y_{t-3} \end{bmatrix} + \underbrace{\begin{bmatrix} 0 & 0 \\ b_4 & A_4 \end{bmatrix}}_{\tilde{A}_4} \begin{bmatrix} M_{t-4} \\ y_{t-4} \end{bmatrix} + \begin{bmatrix} \varepsilon_{m,t} \\ \xi_t \end{bmatrix}, \quad (3)$$

where we take the government's targets π^* and x_t^* as given. Note that $v(\gamma_{x,t-1}, \sigma_{m,t})$ is a $1 \times n$ vector of functions of $\gamma_{x,t-1}$ and $\sigma_{m,t}$. For example, if π_t and x_t are the first two elements of the vector y_t , then

$$v(\gamma_{x,t-1}, \sigma_{m,t}) = \begin{bmatrix} \frac{\gamma_\pi}{\sigma_{m,t}} & \frac{\gamma_{x,t-1}}{\sigma_{m,t}} & 0, \dots, 0 \\ & & 1 \times (n-2) \end{bmatrix}.$$

The impulse responses to the monetary policy shock $\varepsilon_{m,t}$ are computed from the conventional form

$$\begin{bmatrix} M_t \\ y_t \end{bmatrix} = \tilde{b}_t + \tilde{B}_{1,t} \begin{bmatrix} M_{t-1} \\ y_{t-1} \end{bmatrix} + \tilde{B}_{2,t} \begin{bmatrix} M_{t-2} \\ y_{t-2} \end{bmatrix} + \tilde{B}_{3,t} \begin{bmatrix} M_{t-3} \\ y_{t-3} \end{bmatrix} + \tilde{B}_{4,t} \begin{bmatrix} M_{t-4} \\ y_{t-4} \end{bmatrix} + \tilde{A}_{0,t}^{-1} \begin{bmatrix} \varepsilon_{m,t} \\ \xi_t \end{bmatrix}, \quad (4)$$

where $\tilde{b}_t = \tilde{A}_{0,t}^{-1} \tilde{c}_t$, $\tilde{B}_{1,t} = \tilde{A}_{0,t}^{-1} \tilde{A}_{1,t}$, $\tilde{B}_{2,t} = \tilde{A}_{0,t}^{-1} \tilde{A}_{2,t}$, $\tilde{B}_{3,t} = \tilde{A}_{0,t}^{-1} \tilde{A}_3$, and $\tilde{B}_{4,t} = \tilde{A}_{0,t}^{-1} \tilde{A}_4$. The coefficient matrix $\tilde{B}_{\ell,t}$ ($\ell = 1, \dots, 4$) is state dependent and involves cross-equation restrictions (i.e., restrictions across the first equation and other equations). For example, the second block of $\tilde{B}_{1,t}$ that corresponds to y_t (the last n variables) is a function of not only $\sigma_{m,t}$ but also $\gamma_{x,t-1}$. Consequently, impulse responses in the shortfall state are different from those in the normal state, as indeed demonstrated in Section III. The state-dependent

nonlinearity and cross-equation restrictions also make it impossible to calculate impulse responses to monetary policy shocks by simply running linear regressions of various variables on estimated monetary policy shocks as in the linear SVAR case.

Because of the state-dependent complexity, there are two additional issues with regard to estimation of the monetary policy rule as well as impulse responses to a monetary policy shock. First, both output coefficient and shock volatility in the monetary policy equation (1) depend on the state of the economy. These endogenous-switching parameters make it computationally challenging to directly estimate this large nonlinear system (4) and the dynamic responses to a monetary policy shock. Second, although the first equation in system (4) is exactly the same as the monetary policy rule represented by (1), parameters in the rest of the equations in system (4) are functions of $\sigma_{m,t}$ and $\gamma_{x,t-1}$. Hence, estimating the monetary policy rule jointly with the rest of the system (4) may not necessarily yield the same results as those based only on equation (1). To address these issues, we propose a new estimation method stated in the following proposition.

Proposition 2. Statistical estimation and inference of the nonlinear system (4) are equivalent to two separate estimation procedures: the nonlinear monetary policy rule (1) and the linear subsystem (2) can be estimated independently. That is, estimation and inference of the subsystem (2) do not depend on the coefficients of equation (1).

Proof. See Appendix B. □

The customary representation in the SVAR literature is system (4), because it facilitates a clear way of understanding how variables respond to a structural shock dynamically. A direct estimation of this nonlinear system, however, is computationally costly and conceptually difficult for the general researcher to handle. Working with the alternative structural form represented by (1) and (2) or by (3) enables one to avoid the needless cost of dealing with the nonlinear system represented by (4). It is for this and other computational (as well as conceptual) advantages that the Bayesian prior of Sims and Zha (1998) is imposed on the structural form represented by (3), not on the form represented by (4) as in the standard literature.⁸ Because system (3) is the structural form of system (4), the estimated results from (3) are the same as those from (4).

Propositions 1 and 2 are important in two aspects. First, they provide a general framework in which one is able to experiment with significant changes of monetary policy rules and examine their effects on the economy. Thus, this framework is an important development for

⁸The hyperparameters for the prior, in the notation of Sims and Zha (1998), are $\lambda_i = 1$ for $i = 0, 1, 2, 4$, $\lambda_3 = 3$, $\mu_5 = \mu_6 = 1$. Except for the hyperparameter λ_3 , the prior setting is standard. The large decay value for λ_3 is necessary for the Chinese data as it helps produce a superior out-of-sample forecasting performance documented by Higgins et al. (2016) and Li (2016).

analyzing policy changes while respecting the Lucas critique (Leeper and Zha, 2003). Second, these propositions provide powerful tools for a general audience. It shows that monetary policy is identified within the framework of a relatively large system and estimation of this nonlinear system can be reduced to two separate estimation procedures. Although the single policy equation (1) is nonlinear, its estimation entails little computational cost. The rest of the system, represented by (2), consists of a linear simultaneous-equation system. Moreover, one can proceed to estimate, equation by equation, system (2) under the prior of Sims and Zha (1998) once the contemporaneous coefficient matrix A_0 is estimated (see Appendix B for the proof). For the most part, therefore, estimation and inference of the entire nonlinear system (3) can be executed equation by equation, making the computation inexpensive.

III. MAIN RESULTS

In this section, we first discuss the identified monetary policy shocks and then explore estimated impulse responses in both normal and shortfall states.

III.1. Monetary policy shocks. A policy shock, although modelled as a random variable, does not mean that policymakers decide on monetary policy actions by flipping a coin. It means that part of policy choice is unpredictable by the public or even by an individual policymaker *within the policymaking group*.⁹ The emphasis on “group” is the key. A policy choice considered to be a systematical response by one person within the group is likely to be unpredictable by others in the same group. In the U.S. and other developed economies, economists and advisors working for policymakers use the same economic information but come up with a wide range of economic forecasts. Each policymaker in the policy committee weighs these different forecast outcomes differently, subject to her or his own economic concerns, and an outcome of these interactions among policymakers is as random as any economic behavior.

In China, dynamic interactions among policymakers are even more unpredictable. Unlike many other central banks, there are no publicly available forecasts of economic variables from the PBC and we are unaware of *systematically produced* forecasts by the staff within the government during the routine monetary policymaking process.¹⁰ Decision makers for monetary policy are not restricted to the PBC and its monetary policy committee. The decision process involves other parts of the central government as well, notably the State Council and the Politburo. This process reflects changes in preferences, political concerns, economic priorities of different policymakers. Such a complex and dynamic interplay among

⁹Leeper et al. (1996) provide detailed discussions of various factors in the policymaking process that can be interpreted as shocks to monetary policy.

¹⁰Moreover we cannot find information in the MPRs that contains quarterly-based quantitative forecasts of future economic conditions.

different entities of the central government, impossible to formulate systematically, makes it reasonable to be approximated by random shocks.

Figure 1 reports the exogenous (shock) component according to the estimated monetary policy rule.¹¹ The monetary policy shock series is the gap between actual M2 growth and the systematic component.¹² By reading through the MPRs and deciphering the nuances in Chinese language, we classify monetary policy shocks into three regimes: loosening, prudent, and tightening. The three regimes we classify are marked in Figure 1. The two darker bars mark loosening regime, the lighter bar marks tightening regime, and prudent regime is unmarked.¹³

Our identified monetary policy shocks are broadly consistent with the MPR statements. In the 2002Q3 MPR, for instance, a shift of priority for monetary policy is described as “enhancing the support to economic growth.” Therefore, a loosening regime begins in 2002Q4. In the 2004Q1 report, the language is shifted to an “orientation of prudent monetary policy in the next stage: moderately tightening,” which marks an ending of the loosening regime since 2002Q4. The 2008Q4 and subsequent MPRs indicate a loosening stance of monetary policy since 2008Q4, consistent with decision of the Politburo on a shift of monetary policy stance to “modestly loosening” since 2008Q4.¹⁴ An announcement of shifting policy stance reflects, to a large extent, an exogenous change not captured by the usual policy response to recent economic fluctuations. The shift of monetary policy stance in 2008Q4 is motivated by the central government’s belief in the “intensified downward pressures on economic growth due to the global financial crisis” (the 2008Q4 MPR). The loosening regime ends in 2011Q1, consistent with the Politburo’s decision to shift monetary policy stance to “prudent” since the beginning of 2011. The reason for this change of stance, as described in the 2011Q2 MPR, is a shift of preference toward “giving top priority to maintaining stability of the general price level with a prudent approach”.

The most interesting episode is the period since 2013Q3. This is a period when actual GDP growth has slowed down so persistently that it has often fallen short of the growth target. Systematic monetary policy would call for a steady increase of M2 growth (the thin solid line in the top panel of Figure 1), but actual M2 growth has instead declined. The decline was driven largely by contractionary policy shocks that are consistent with policymakers’ determined switch toward establishing a “new normal” economy. Such a policy switch is

¹¹Since all the series in the figure are converted to year-over-year changes, the persistence value of the monetary policy shocks is about 0.75, even if the quarterly shocks we identified are i.i.d.

¹²For the estimated monetary policy rule and its comparison to those under conventional monetary policy rule specifications, please see Chen et al. (2017).

¹³Prudent monetary policy often reflects the stance of monetary policy that does not pursue either tightening or loosening in a persistent manner.

¹⁴The stance of monetary policy is routinely announced by the Politburo.

highlighted in the 2013Q3 MPR, which requires monetary policy to deviate from the usual policy response.

In sum, monetary policy shocks for China are consistent with the three possible sources outside of the model: (1) changes in policymakers' preference or taste (e.g., the beginning of a loosening policy in 2002Q4 and the beginning of a tightening policy in 2011Q1); (2) changes in policymakers' belief in strengths or weaknesses of the underlying economy (e.g., a loosening policy in 2008Q4); (3) changes in policymakers' goal that are not captured by the systematic policy (i.e., contractionary monetary policy shocks since 2013Q3).

III.2. Impulse response functions. We first discuss the impulse response functions in the normal state, then in the short fall state.

III.2.1. Normal state. Figure 2 displays the corresponding impulse response of GDP with probability bands. Impulse responses of other macroeconomic variables are displayed in Figure 3. From Figures 2 and 3 one can see that a positive one-standard-deviation shock to monetary policy raises M2 by 0.9% and GDP by 0.35% at their peak values. The output response is hump-shaped, while the money response is much more persistent. Both responses are highly significant both economically and statistically. The CPI response displays little price puzzle, further supporting our argument that the estimated monetary policy shock does not contain endogenous responses to other macroeconomic variables.¹⁵ The correct sign of a price response is one of the building foundations for the SVAR literature (Sims, 1992; Uhlig, 2005). In response to an expansionary monetary policy shock, the excess reserve ratio and the Repo rate decline while foreign exchange reserves rises. These responses are consistent with most theoretical predictions of the effect of a monetary policy shock.¹⁶

What is new is the response of the ratio of MLT to ST bank loans, which rises significantly for many quarters. The response pattern indicates that monetary expansions to increase output are through the channel of directly increasing medium and long term bank loans.¹⁷ The normal interest-rate channel plays little role in the monetary transmission for

¹⁵A price puzzle emerges if the identified monetary shock is contaminated by the endogenous component such that prices do not fall in response to contractionary monetary policy. This point is made forcibly by Sims (1992).

¹⁶The lending and deposit rates respond in a similar fashion. One channel of transmitting monetary policy shocks to the real economy is through bank reserves. This finding is consistent with Fernald et al. (2014)'s emphasis on the role of reserve requirements in influencing macroeconomic fluctuations in China.

¹⁷In conjunction with controlling money supply, the PBC uses additional policy instruments, such as "window guidance," to force commercial banks to increase or decrease lending volumes or activities and to direct loans to certain sectors, *regardless of prevailing interest rates*. Moreover, the PBC controls credit volumes by planning the aggregate credit supply for the coming year and then by negotiating with individual commercial banks for credit allocations (Sheng and Wu, 2008). These instruments make commercial banks' demand for money compatible with changes in money supply

several institutional reasons. First, bond markets in China are not fully developed so that long-term interest rates for investment are largely insulated from changes in short-term interest rates. Second, lending and deposit rates in the banking system have not been fully liberalized to reflect loan risks. Third, heavy-industry firms, protected by the government from bankruptcy, are insensitive to changes in interest rates. Indeed, when we remove all three interest rates from the list of variables in the benchmark SVAR, the estimated response of GDP to a monetary policy shock is almost identical to its benchmark counterpart (Figure 2). This result supports the argument the bank lending channel functions more through credit volumes than through interest rates.

To quantify the potential asymmetric effect on different sectors of an expansionary monetary policy shock, we decompose the real GDP series into value-added output in heavy industries and value-added output in light industries and add these two series to the benchmark model. Figure 4 shows the impulse responses of heavy-industry output and light-industry output along with those of MLT bank loans and ST bank loans. While MLT loans jump up immediately and remain significantly above zero for five quarters in response to a positive monetary policy shock, the short-term loan starts to decrease right after the impact period. Because MLT bank loans respond much more strongly than ST bank loans, heavy-industry output responds much more strongly than light-industry output. This bank lending channel, working through asymmetric effects on different sectors and different types of loans, is a special characteristic of China monetary policy.

Evidence from Figure 5 further shows that investment, not consumption, is a driving engine for the output fluctuation in response to a monetary policy shock. In this figure, we add the investment and consumption series to the benchmark model.¹⁸ As one can see, investment responds strongly to an expansionary monetary policy shock (the response is hump-shaped) while the response of consumption (not hump-shaped) is small in magnitude and, according to the probability bands, its statistical significance is weak. This result is in sharp contrast to the findings for the U.S. economy, where the response of consumption to an expansionary monetary policy shock is hump-shaped, strong, and sizable (Christiano et al., 2005).

Our finding is also confirmed by the estimated variance decompositions attributable to monetary policy shocks relative to other shocks. As reported in Table 1, monetary policy shocks explain about one fifth of the GDP variation. This result is robust across various model specifications. The contribution to the investment fluctuation is about 16%. By contrast, the contribution to the price fluctuation is small (5 – 8%) and the contribution

¹⁸The data on many components of GDP is available but with a delay. In our case, the sample is available only up to 2015Q4 for investment and consumption and 2015Q3 for heavy-industry output and light-industry output.

to the consumption fluctuation is even smaller (under 3% for first 3 years). These results reinforce the previous finding that monetary policy affects the real economy mainly through investment.

III.2.2. *Shortfall state.* Figures 6 and 7 display the estimated impulse responses in the shortfall state.¹⁹ The responses differ from those in the normal state in both timing and magnitude. As a direct result of an asymmetric response of monetary policy to the shortfall of GDP growth, the M2 response peaks within 2 quarters, quicker than that in the normal state, and the GDP response peaks in 3 quarters as compared to a much delayed peak (8 quarters) in the normal state. A similar pattern holds for the responses of investment and heavy-industry output, which peak in 2 and 4 quarters respectively, while the responses of investment and heavy-industry output peak in 4 and 7 quarters respectively in the normal state. By contrast, the response of consumption is almost the same in both peak timing and magnitude for both states. This result shows the Chinese government's reliance on investment to stimulate the aggregate economy, especially when GDP growth is below the target.

The channel for transmitting a monetary policy shock to a stimulation of investment, as the bottom panel of Figure 6 shows, is again through MLT bank loans. Our estimation reveals that the volatility of monetary policy shocks in the shortfall state is twice that in the normal state (0.10 vs 0.005), which leads to a stronger response of M2 supply on impact (a 1% increase in the shortfall state versus a 0.5% increase in the normal state). The response is immediately translated to the banking system with the initial response of MLT loans to a monetary policy shock in the shortfall state almost twice the initial response in the normal state. On the other hand, the response of ST bank loans turns more negative for the next 2 quarters in the shortfall state than the response in the normal state. Clearly, an increase of M2 supply is channeled disproportionately into MLT bank loans in the shortfall state.

The magnitude of GDP response at its peak in the shortfall state, however, is quantitatively similar to that in the normal state. The peak responses of investment and heavy-industry output have a similar magnitude for both states as well. This result implies that firms in the shortfall state refuse to invest as much as in the normal state even though they have twice the amount of loan volume. As a result, a much larger monetary expansion is needed in the shortfall state to achieve the same quantitative effects on investment and output as in the normal state.

¹⁹We assume that the shortfall state would last for 5 years. This assumption is of course counterfactual. One may in principle generate nonlinear impulse responses by studying a scenario in which the state switches, but none of our conclusions about asymmetric impacts between the two states would be affected by this complicated exercise.

The asymmetric responses between the two states are reinforced by the asymmetric importance of monetary policy shocks relative to other shocks in driving GDP variations. In the shortfall state, the GDP fluctuation attributed to monetary policy shocks is about 40%, more than twice the counterpart in the normal state (Table 1). Relative to other shocks in the economy, monetary policy plays a far more important role in stimulating the aggregate economy in the shortfall state than in the normal state.

IV. ROLE OF THE EXTERNAL SECTOR

One aspect of monetary policy under discussion is to maintain “balance of payments in stable conditions” (Chang et al., 2015). This detail is abstracted from our policy rule. A natural question is whether our exogenous monetary policy shocks may contain endogenous movements related to the external sector, say endogenous response to the foreign change rate. To answer this question, we regress the estimated monetary policy shock series on four lags of the foreign exchange rate and net exports (as percent of GDP). We also regress the estimated systematic components of monetary policy on the same variables. Table 2 reports the regression results. These results indicate that the foreign exchange rate and net exports have no explanatory power for exogenous monetary policy shocks, while movements in the external sector are effectively captured by systematic monetary policy. Our identified monetary policy shocks, therefore, are not contaminated by an endogenous response to trade surplus in order to keep the RMB exchange rate stable.

Foreign exchange reserves are a combination of the exchange rate and trade surplus and have thus been an important factor for capital control when China monetary policy is discussed. How important is this variable for the transmission of monetary policy to domestic output? We study this issue by removing foreign exchange reserves from the list of variables in the benchmark SVAR. Figure 2 displays the estimated response of GDP (the circle line) for this case. One can see that the result is very close to the response from the benchmark model. This, again, implies that monetary policy shocks in China work mainly through the bank lending channel. And the PBC’s sterilization operations associated with higher foreign exchange reserves, such as selling central bank bills or raising the reserve requirement ratio, to freeze the excess liquidity in the banking system has a very limited effect on real GDP.

The robustness of our finding suggests that the systematic component of our estimated monetary policy may be “sufficiently encompassing” to the extent that the response of money growth to GDP growth captures the response of money growth to changes in trade surpluses and the RMB exchange rate (Taylor, 1993, 2000). To some extent, the sufficiently encompassing nature of our systematic component of monetary policy is not surprising. As discussed in the text, the central government’s overriding goal is to target *real GDP growth* and promote

this growth beyond the target. All else becomes a means to meet this end. The extensive results reported in this section confirm that the means always remains subordinated to the end and that monetary transmission is mainly through the banking lending channel facilitated by M2 growth.

V. QUANTITY-BASED MONETARY POLICY AND INSTITUTIONAL RIGIDITIES

For two decades, the Chinese central government has leveraged monetary policy to achieve its GDP growth target but at a cost of consumption and investment in light and labor-intensive industries by “arm-twisting” bank loans into investing in heavy and capital-intensive industries (including many large state-owned firms with overcapacity). In the aftermath of the 2008 global financial crisis when GDP growth fell sharply below the target, in particular, monetary policy initiated a massive monetary stimulus that fueled heavy industries with soaring medium and long term debts. The debt problems have called for reforming the current monetary policy framework.

Much of the recent discussion centers on a major reform of moving gradually away from control of M2 growth as a primary policy instrument toward control of short-term nominal interest rates as in the U.S. and other developed economies. The reform contains three main issues: liberalizing financial markets, experimenting with multiple policy interest rates, and assessing how those policy rates affect the real economy.²⁰ While most discussions focus on the first two issues (see various articles contained in Ma and Ji (2016)), the third issue has not been fully explored. It is this issue that remains most important in our view. We address the challenges related to this issue in the context of our empirical findings.

One argument for switching to an interest rate policy rule is the perceived ineffectiveness of M2 growth in recent years as a major instrument to meet the GDP growth target. Our empirical work does not support this perception. As argued in previous sections, the existing policy environment consists of various market and administrative tools used by the government. In particular, the heavy hand of government in influencing how commercial banks make loans to different sectors allows M2 growth to be an effective tool for monetary policy in the past, as demonstrated by our SVAR evidence. In contrast to the common perception that current monetary policy has become increasingly less effective, we find that the slowdown of GDP growth in recent years results largely from contractionary monetary policy shocks.

²⁰For a long time, China has adopted a dual-track interest rate system (Yi, 2009). As early as 1996, China removed control of interbank lending rates (i.e., Chibor and Repo rates), while the deposit and lending rates were still under strict control of the government. Liberalization of the overall financial market has been slow in China even up to today.

On the other hand, interest rates have been *ineffective* in transmitting monetary policy into China's real economy. Our SVAR analysis provides evidence that the interest-rate channel of monetary policy has been muted in the past. When we remove all the three interest rates from the list of variables in the benchmark SVAR, the estimated response of GDP (the plus line) is little different from either the response marked by the circle line or the response marked by the star line (Figure 2). Intuitively, heavy-industry firms and state-owned enterprises (SOEs) are insensitive to interest rates and as a result, monetary policy has worked more through credit volumes than interest rates.²¹

Our finding contrasts to Bernanke and Blinder (1992), who use the federal funds rate to identify the effect of a monetary policy shock. As Bernanke and Blinder (1992) shows, in the U.S. economy, interbank interest rates are smoothly transmitted into the real economy via both bank deposit and bank loan. In China's state-dominated financial system, quantity-based monetary policy has been shown to be more effective in directly affecting the supply of bank loan, regardless of what happens in the interbank markets. With the under-developed security markets, our SAVR evidence suggests that the bank lending channel serves as a key mechanism for monetary policy shocks to transmit into the real economy.²²

In the current policy environment, GDP growth target remains the foremost goal of monetary policy. According to the central government's Thirteenth Five-Year Plan (2016-2020), GDP growth target as a lower bound will continue for the next five years. Premier Keqiang Li of the State Council, when asked by the press at the closing of the 2016 NPC assembly whether his administration would deliver 6.5% of GDP growth, responded firmly that "If you are asking me whether China's economy won't meet the main economic [growth] target that has already been established, that is impossible." High GDP growth vigorously pursued by the central government as the foremost policy target, therefore, puts a severe constraint on how the PBC conducts its monetary policy.

On the other hand, decade-long pro-growth monetary policy, especially in the wake of 2008 financial crisis, has led to rising financial risks for Chinese economy in recent years. Total debt in China rose from 148 per cent in 2007 to a record 237 per cent of gross domestic product in the first quarter of 2016, far above emerging-market counterparts, raising the risk of a financial crisis or a prolonged slowdown in growth.²³ Moreover, many heavy industries, such as steel, have suffered from serious overcapacity. Against this backdrop, the 2015 Central Economic Work Conference, organized jointly by the State Council and the

²¹This finding is consistent with the existing empirical result that variations in neither policy nor market interest rates can explain macroeconomic fluctuations (Sheng and Wu, 2008).

²²see ChenRenZha2017 for a theory on how quantity-based monetary policy works in China via the bank-lending channel.

²³In 2016, corporate debt in China amounted to 160 percent of GDP up from 98 percent in 2008.

Central Committee of Communist Party, called for deleveraging and shedding industrial overcapacities, among other priorities for the medium run. Our evidence suggests that to achieve these goals, it is necessarily for the central government to lower GDP growth target in the short run to relax the institutional constraints for monetary policy.

Continuation of these institutional constraints represents what we call the institutional rigidity, which must be taken into account when researchers and policymakers discuss the implementation of a new policy rule involving multiple policy interest rates. To remove the institutional rigidity, the government must be willing to cease preferential credit policy to promote and protect heavy-industry firms such as those in real estate, SOEs, and large inefficient firms. Given the government's primary concern about social stability, however, it is unclear whether the government is willing to go far with radical reforms in both financial markets and heavy-industry firms.

The Thirteenth Five-Year Plan for "Economic and Social Development," approved by the NPC, pronounces one important element of China's macroeconomic reforms: transform the monetary policy framework "from quantity-based management to price-based management" by gradually changing the intermediate target of monetary policy from M2 supply to policy interest rates.²⁴ The issue of transitioning from one policy rule to another is even more challenging because it requires, at the minimum, an understanding of existing monetary policy and its transmission. As Taylor (1993) argues, people's expectations about the effects of future policy along the transitional path depend on their understanding of how existing policy responds to the state of the economy and in turn influences the real economy. Such expectations matter precisely because of the general implications of the Lucas critique. Therefore, understanding how existing monetary policy works serves as a necessary benchmark to discuss the design of a new policy framework and the transitional path toward that objective.

VI. CONCLUSION

This paper proposes a nonlinear endogenous-switching SVAR system to capture key institutional characteristics of China's monetary policy and use it to quantify the monetary transmission in China. We develop a new estimation method that enables us to estimate the nonlinear monetary policy rule independently of estimation of the rest of the system. We have found that for a long time the central bank of China has been using M2 growth as a primary instrument to support output growth while controlling inflation. The policy effect

²⁴The Central Committee of CPC typically approves a plan proposal in the fall of the year before the plan's five-year span begins. The plan outlines its content in broad terms and then NDRC hammers out the details before the annual session of the NPC, typically held in March, votes to approve the plan.

on the real economy is transmitted through an increase of investment in heavy industries financed by medium and long term bank credit.

The most distinctive characteristic of China monetary policy is its asymmetric transmission into the real economy via the bank lending channel. When actual GDP growth falls short of the government's target, monetary policy reacts more aggressively than in normal times. Moreover, an increase of M2 is channeled disproportionately into MLT loans. Consequently, monetary policy shocks in the shortfall state contribute twice as much to the GDP fluctuation as those in the normal state. At the same time, however, monetary policy becomes less effective when GDP growth falls short of the target.

The costs of monetary policy in supporting GDP growth above the target are potentially high. Our findings in this paper suggest that China pro-growth monetary policy bears downside risks as rapid M2 growth with a monetary stimulus to investment in heavy industries (especially the real estate in recent years) has contributed to rising corporate debts. The debt problem and the health of the banking system are important issues for future research.

Recent discussions in the policy circle center on how China monetary policy would move away from M2 growth to policy interest rates as a primary policy instrument. Our empirical findings about the policy rule, policy shocks, and asymmetric monetary transmission lay foundations for developing a new monetary policy framework during the transition. Specifically, future research should focus on how policy interest rates influence the real economy in a manner that is compatible with the central government's overriding priority to target *real* GDP growth against a backdrop of China's institutional rigidities. This pressing issue has scarcely been addressed in the literature. We hope that our empirical analysis serves as a first step toward stimulating a more comprehensive study on China monetary policy.

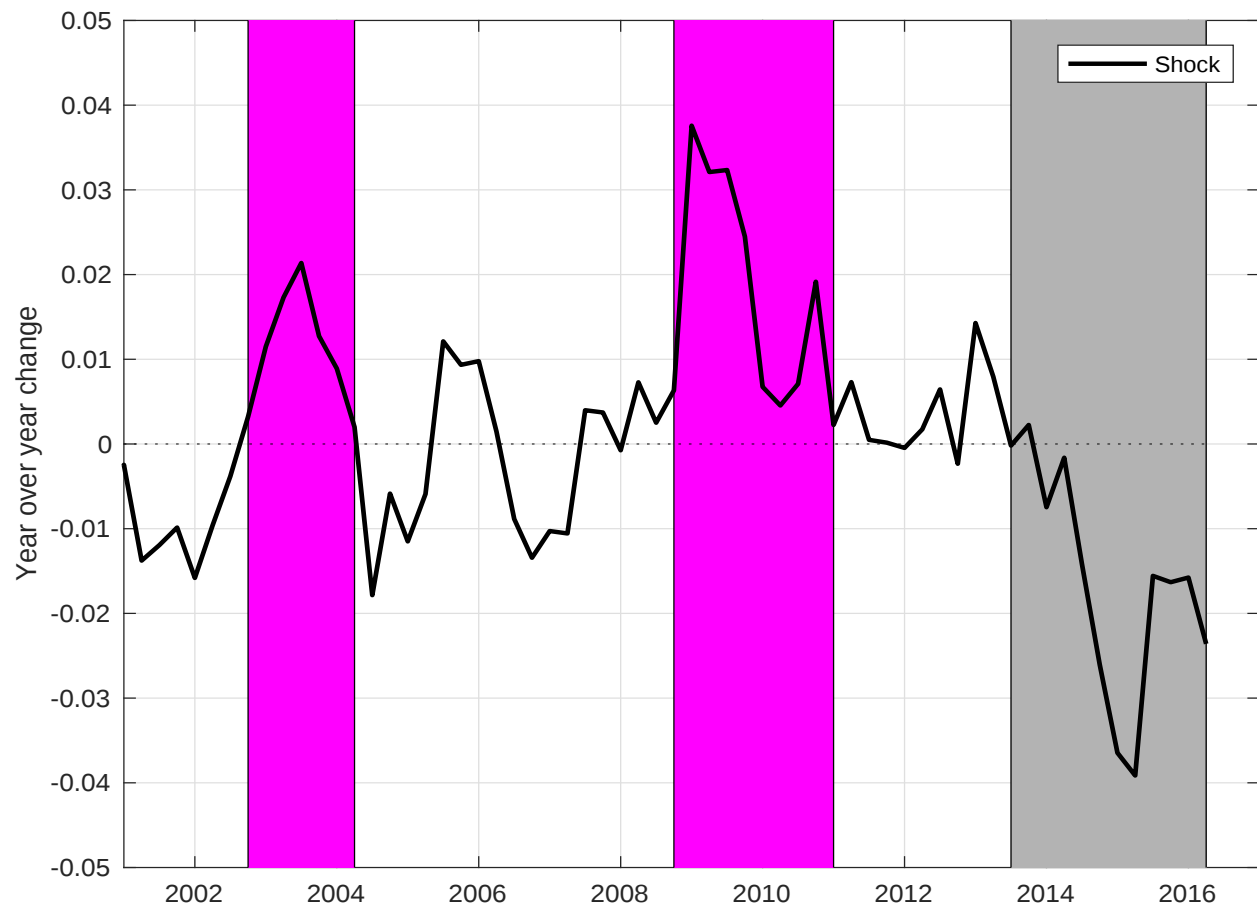


FIGURE 1. The estimated monetary policy shocks. The two darker bars mark periods of loosening monetary policy and the lighter bar marks a period of tightening monetary policy. Periods associated with prudent monetary policy are unmarked.

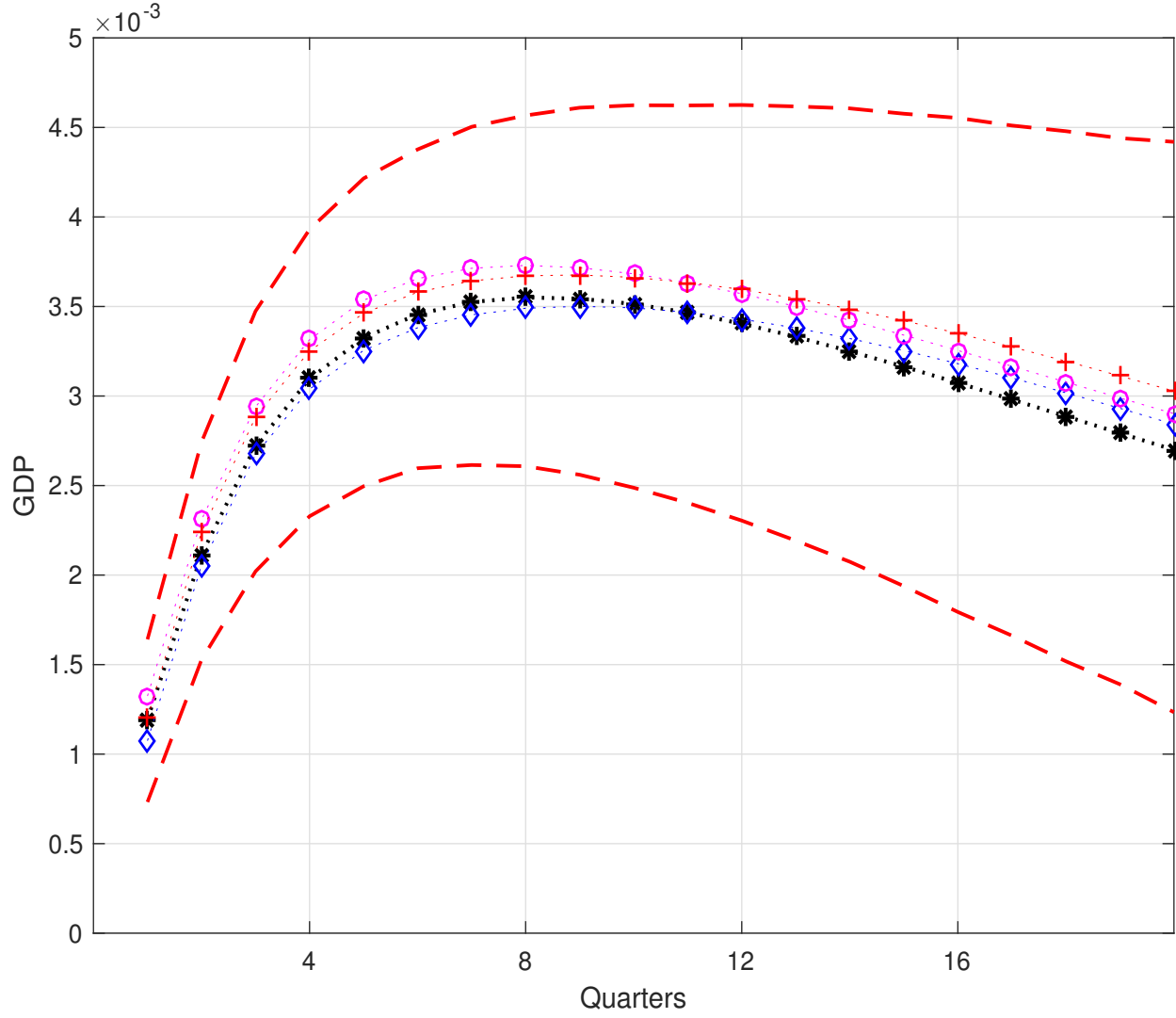


FIGURE 2. Dynamic responses of real GDP to a one-standard-deviation positive monetary policy shock. The asterisk line represents the response estimated from the benchmark SVAR and dashed lines represent the corresponding .68 probability bands. The diamond line represents the response estimated from the SVAR excluding interest rates. The circle line represents the response estimated from the SVAR excluding foreign exchange reserves. The plus line represents the response estimated from the SVAR excluding both interest rates and foreign exchange reserves.

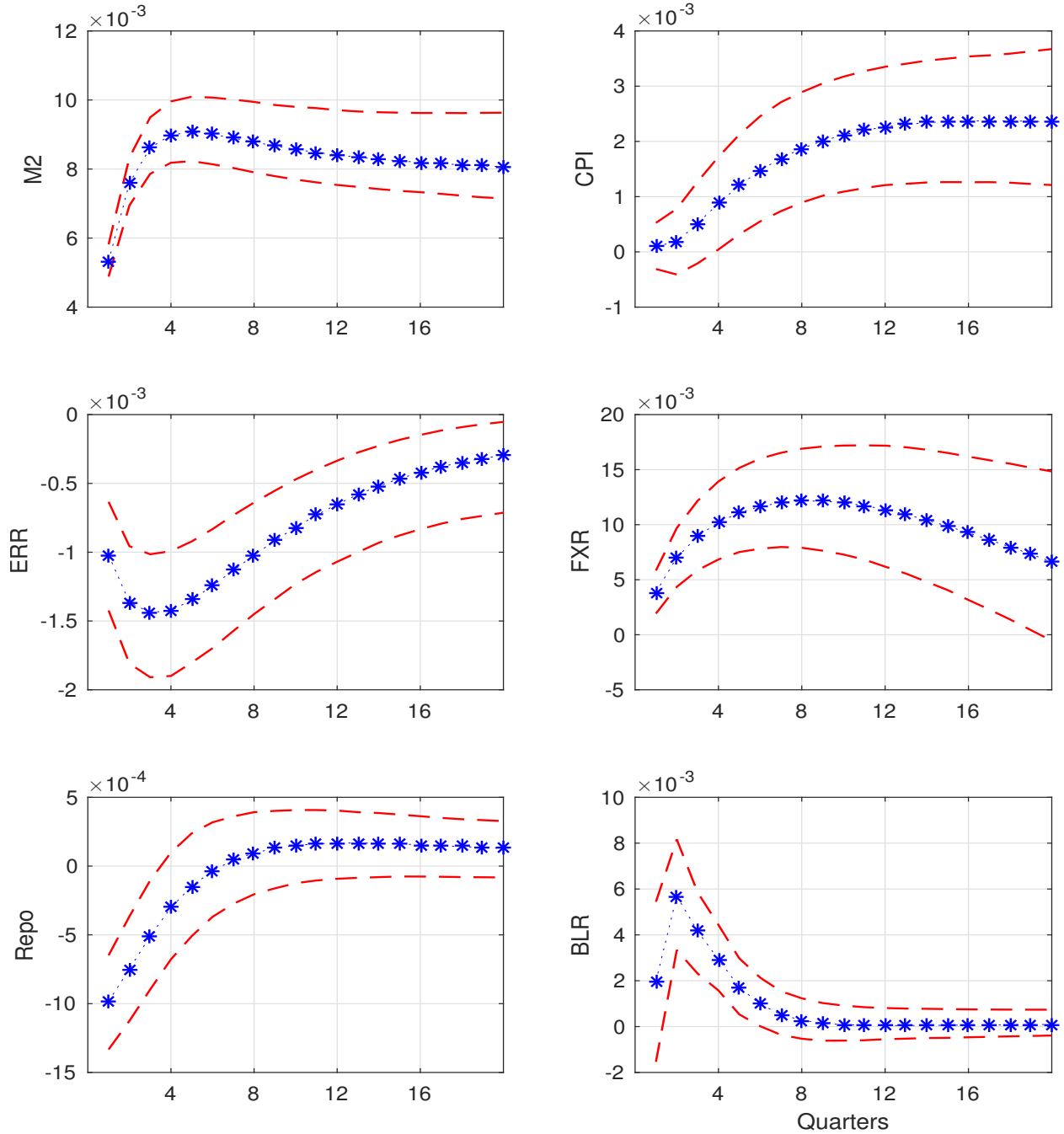


FIGURE 3. Dynamic responses of various key policy variables to a one-standard-deviation positive monetary policy shock. Asterisk lines represent the estimated responses and dashed lines represent the corresponding .68 probability bands. “ERR” stands for the excess reserves ratio in the banking system, “FXR” stands for foreign exchange reserves held by the People’s Bank of China, “Repo” is the 7-day rate for national interbank bond repurchases, and “BLR” is an abbreviation of “bank loan ratio,” which is the ratio of newly-originated MLT bank loans to ST bank loans.

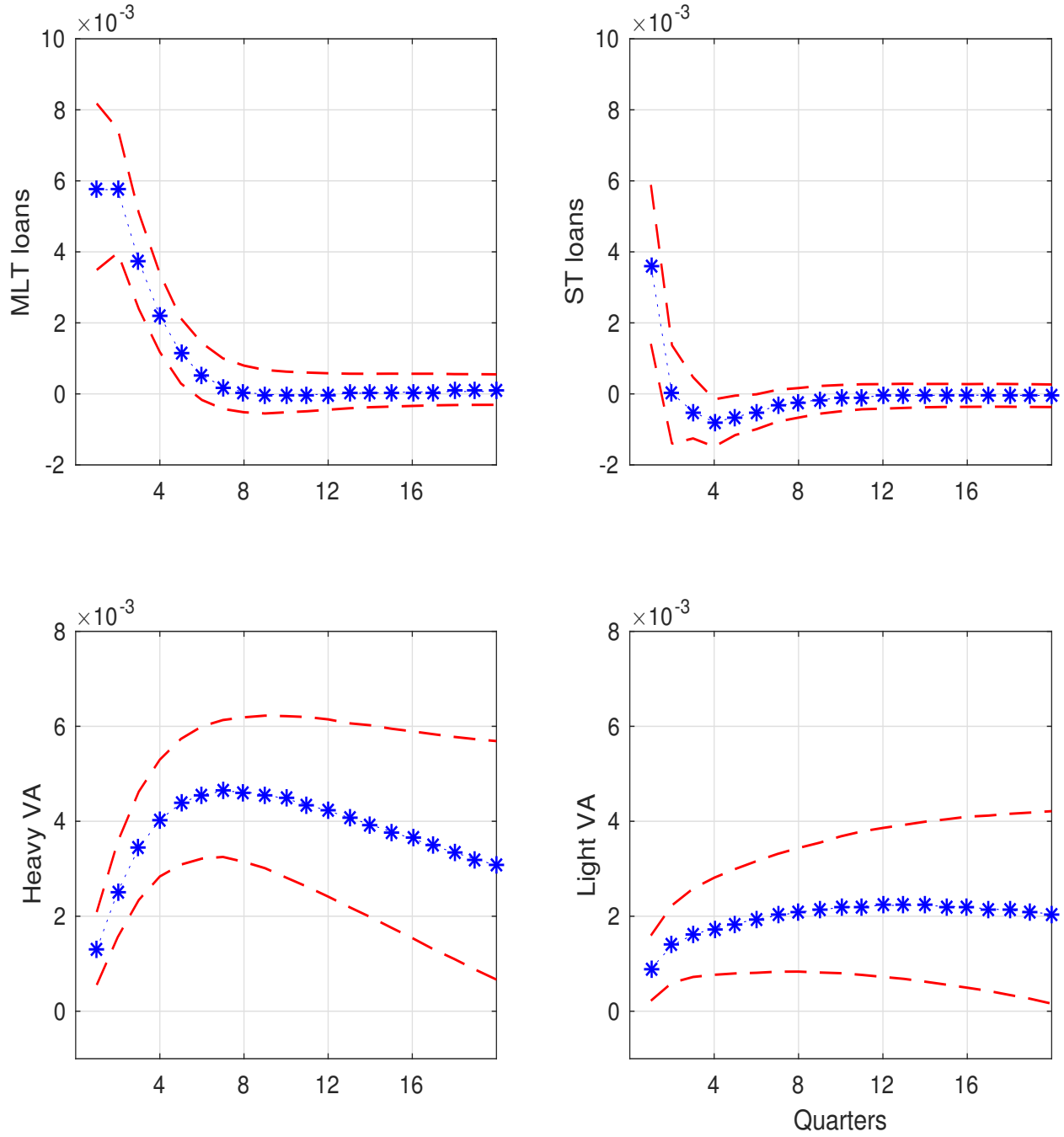


FIGURE 4. Dynamic responses to a one-standard-deviation positive monetary policy shock: medium and long term bank loans (MLT loans), short term bank loans (ST loans), value-added output produced from heavy industries (heavy VA), and value-added output produced from light industries (light VA). Asterisk lines represent the estimated responses and dashed lines represent the corresponding .68 probability bands.

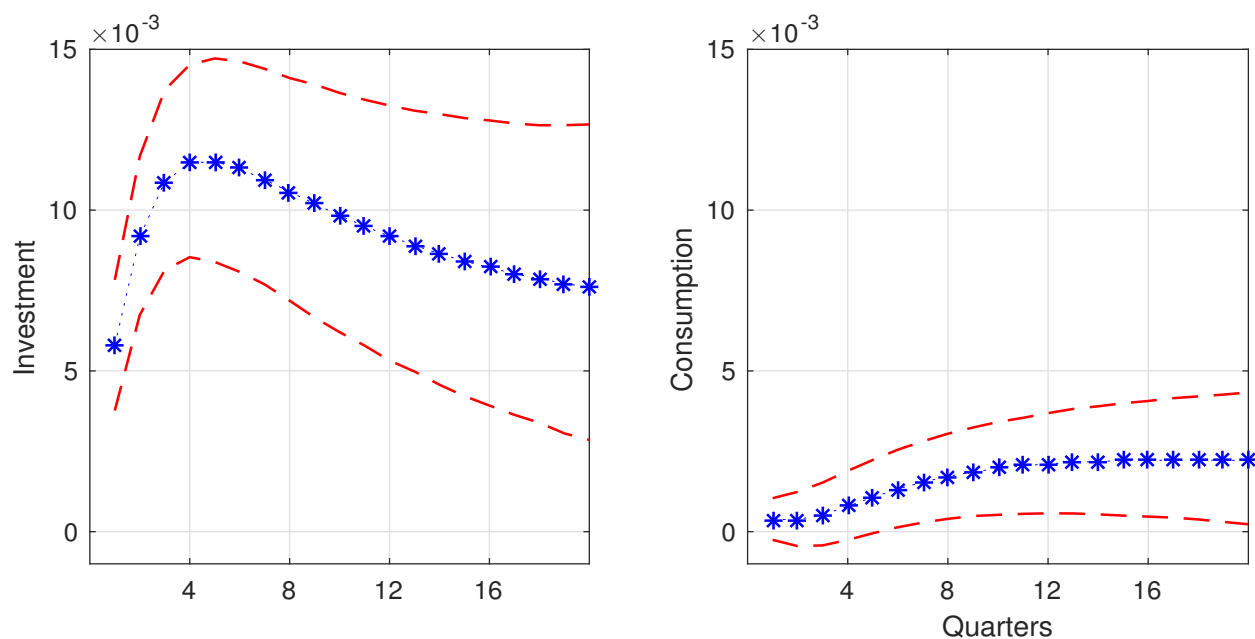


FIGURE 5. Dynamic responses of investment and consumption to a one-standard-deviation positive monetary policy shock. Asterisk lines represent the estimated responses and dashed lines represent the corresponding .68 probability bands.

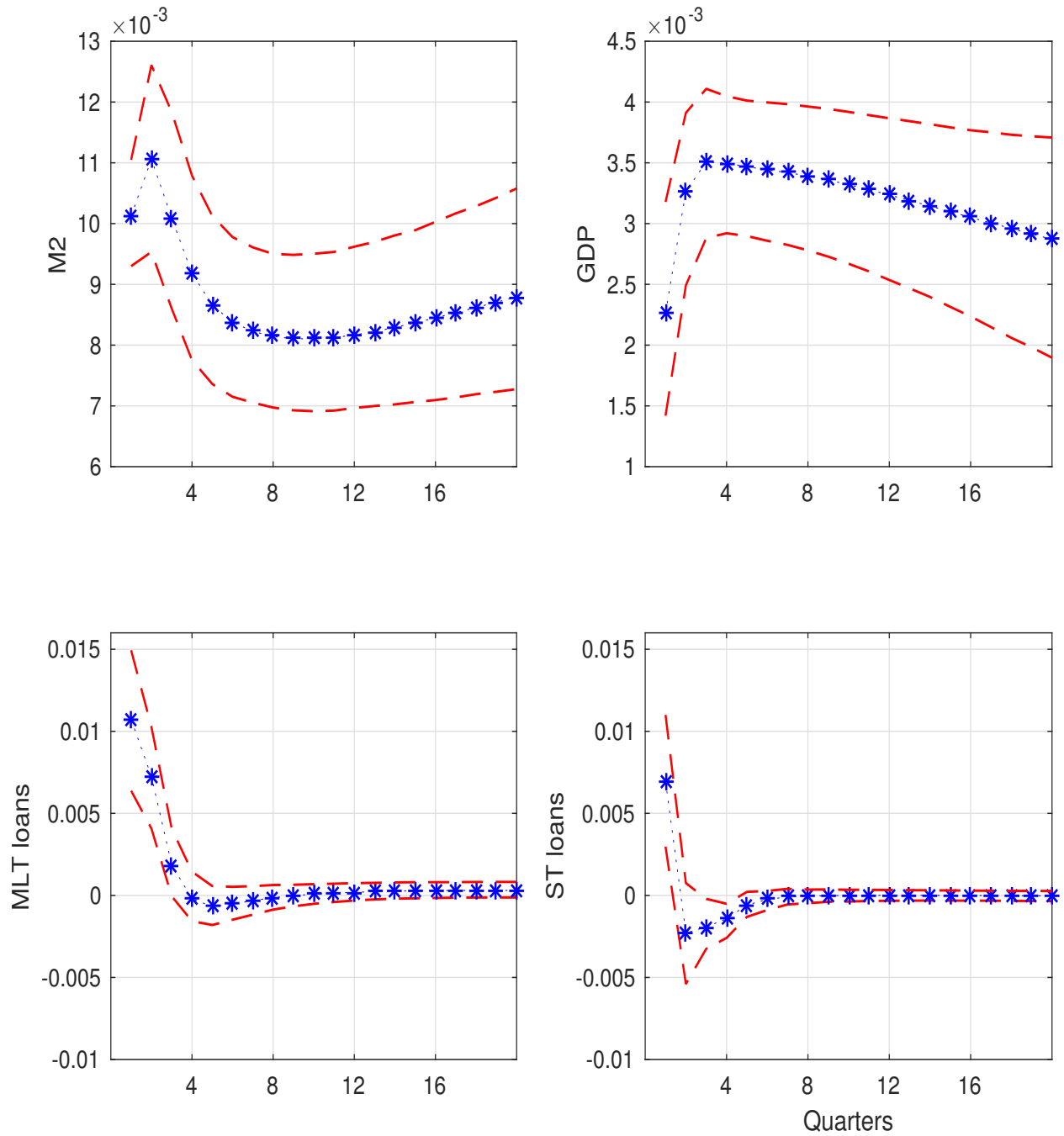


FIGURE 6. Dynamic responses to a one-standard-deviation positive monetary policy shock in the shortfall state. Asterisk lines represent the estimated responses and dashed lines represent the corresponding .68 probability bands.

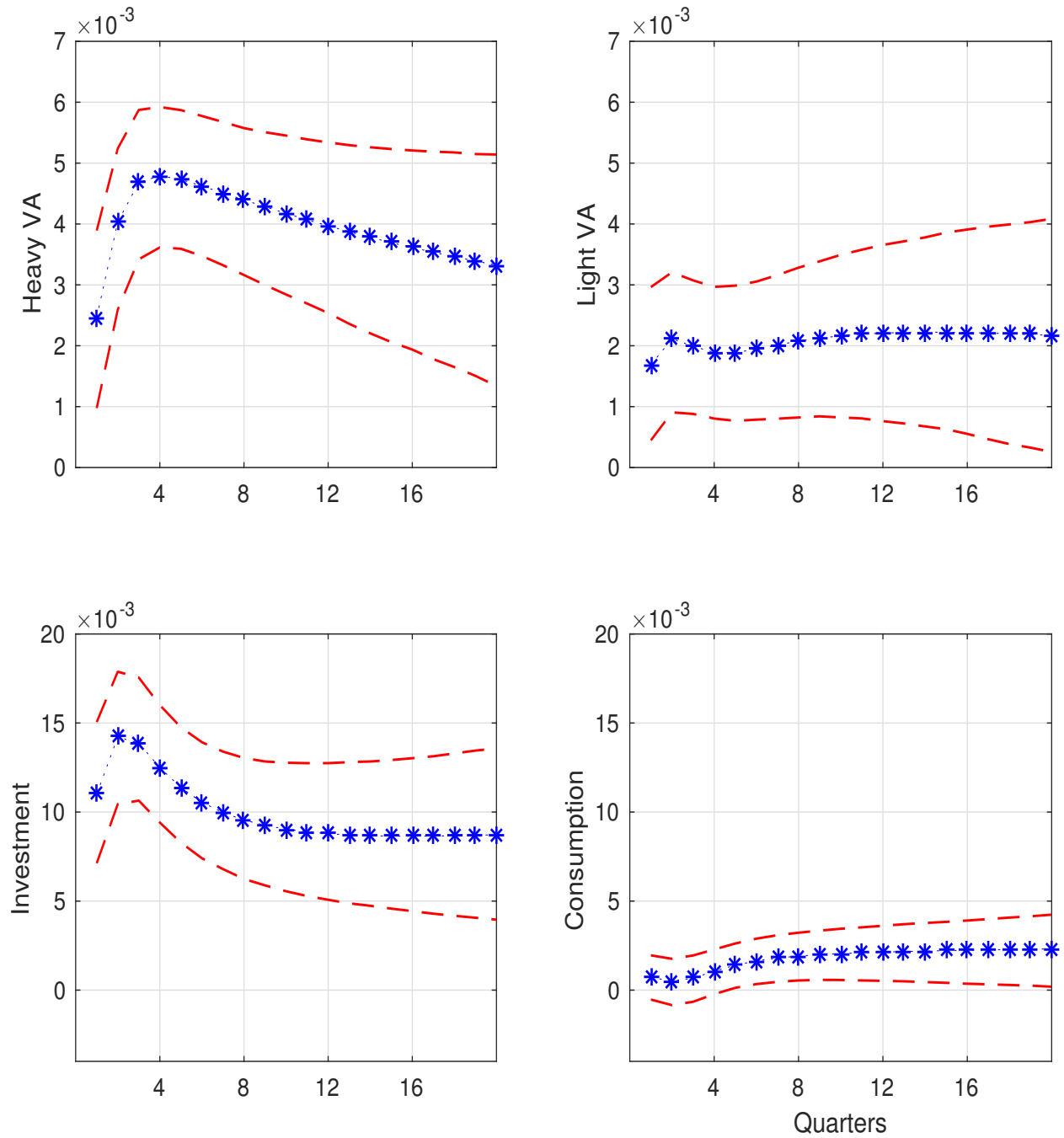


FIGURE 7. Dynamic responses to a one-standard-deviation positive monetary policy shock in the shortfall state. Asterisk lines represent the estimated responses and dashed lines represent the corresponding .68 probability bands.

TABLE 1. Variance decompositions attributed to a monetary policy shock (percent)

Quarter	4	8	12	16	20
GDP (normal state)					
Benchmark model	13.5	18.6	18.7	17.1	15.0
Benchmark model excl Rs	12.5	17.7	19.1	18.9	17.5
Benchmark model excl FXR	14.7	20.1	20.6	19.2	17.2
Benchmark model excl Rs and FXR	13.8	19.1	20.7	20.6	19.5
GDP (shortfall state)					
Benchmark model	35.9	42.9	42.8	40.5	37.3
Benchmark model					
Price (normal state)	0.6	2.9	5.4	7.4	8.8
Investment (normal state)	14.2	16.8	16.4	15.4	14.5
Consumption (normal state)	0.4	1.4	2.5	3.1	3.5

Note. The abbreviation “excl” stands for excluding, “Rs” for all interest rates, and “FXR” for foreign exchange reserves.

TABLE 2. Endogenous and exogenous components of monetary policy

	p-value			Adjusted R^2		
	Shock	Systematic	Output only	Shock	Systematic	Output only
Exchange rate	0.361	0.000***	0.032**			
Net exports	0.968	0.000***	0.000***			
Fit				0.015	0.450	0.456

Note. The testing hypothesis is that all coefficients of the exchange rate are zero or that all coefficients of net exports are zero. The dependent variable is either estimated monetary policy shock or estimated systematic component of monetary policy. The two-star superscript indicates a 5% significance level and the three-star superscript indicates a 1% significance level.

APPENDIX A. PROOF OF PROPOSITION 1

For system (3), we first show that the first equation (the monetary policy rule) is identified. According to Theorem 2 of Rubio-Ramírez et al. (2010), this equation is identified if the following condition is satisfied: for $\tilde{Q}\tilde{A}_{0,t} = \hat{A}_{0,t}$, where $\tilde{Q}$ is an orthogonal matrix and $\hat{A}_{0,t}$ maintains the form of

$$\begin{bmatrix} \hat{A}_{0,t}^{(1,1)} & \hat{A}_{0,t}^{(1,2)} \\ \hat{A}_{0,t}^{(2,1)} & \hat{A}_{0,t}^{(2,2)} \end{bmatrix} = \begin{bmatrix} \hat{A}_{0,t}^{(1,1)} & 0 \\ \hat{A}_{0,t}^{(2,1)} & \hat{A}_{0,t}^{(2,2)} \end{bmatrix}$$

with the superscript of $\hat{A}$ indicating the location of the submatrix, $\tilde{Q}$ must be of the form

$$\begin{bmatrix} \tilde{Q}^{(1,1)} & \tilde{Q}^{(1,2)} \\ \tilde{Q}^{(2,1)} & \tilde{Q}^{(2,2)} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & \tilde{Q}^{(2,2)} \end{bmatrix}. \quad (\text{A.1})$$

To show that the above condition is true, note that $\tilde{Q}\tilde{A}_{0,t} = \hat{A}_{0,t}$ is equivalent to

$$\begin{bmatrix} \tilde{Q}^{(1,1)}\tilde{A}_{0,t}^{(1,1)} + \tilde{Q}^{(1,2)}\tilde{A}_{0,t}^{(2,1)} & \tilde{Q}^{(1,2)}\tilde{A}_{0,t}^{(2,2)} \\ \tilde{Q}^{(2,1)}\tilde{A}_{0,t}^{(1,1)} + \tilde{Q}^{(2,2)}\tilde{A}_{0,t}^{(2,1)} & \tilde{Q}^{(2,2)}\tilde{A}_{0,t}^{(2,2)} \end{bmatrix} = \begin{bmatrix} \hat{A}_{0,t}^{(1,1)} & 0 \\ \hat{A}_{0,t}^{(2,1)} & \hat{A}_{0,t}^{(2,2)} \end{bmatrix}.$$

Since $\tilde{A}_{0,t}^{(2,2)}$ is invertible for the SVAR system and $\tilde{Q}^{(1,2)}\tilde{A}_{0,t}^{(2,2)} = 0$, we have $\tilde{Q}^{(1,2)} = 0$. Because $\tilde{Q}$ is an orthogonal matrix, it must be that $\tilde{Q}^{(2,1)} = 0$. It follows from the orthogonality of $\tilde{Q}$ that $\tilde{Q}^{(1,1)} = 1$. These results prove (A.1).

We now show that impulse responses of y_t to $\varepsilon_{m,t}$ are invariant to the rotation matrix Q or the ordering of elements in y_t . Note that the rotation matrix Q in subsystem (2) is the same as $\tilde{Q}^{(2,2)}$. Because the first equation of system (4) is identified and the rotation matrix $\tilde{Q}$ for the whole system satisfies (A.1), the rotation matrix Q would affect the impulse responses of y_t to ξ_t but not those to $\varepsilon_{m,t}$.

The ordering of elements in y_t relates to a permutation, not a rotation. Since the first equation of system (4) is identified, the invariance of impulse responses of y_t to $\varepsilon_{m,t}$ to any ordering follows directly from Theorem 4 of Zha (1999).

APPENDIX B. PROOF OF PROPOSITION 2

To show the first equation in system (3) can be estimated independently of the rest of the system, it is sufficient to show that the likelihood function (or the posterior probability density function when a proper prior is introduced) for the first equation can be maximized without affecting the likelihood or the posterior probability density for the rest of the system.

Denote

$$z_t = \begin{bmatrix} M_t \\ y_t \end{bmatrix},$$

the i^{th} row of $\tilde{A}_{\ell,t}$ by $\tilde{a}_{\ell,t}^i$, and the i^{th} element of $\tilde{c}_t$ by $\tilde{c}_t^i$, where $i = 1, \dots, 1+n$ and $\ell = 0, \dots, 4$. The likelihood (LH) function for system (3) is

$$\begin{aligned} \text{LH} &\propto \left| \det(\tilde{A}_{0,t}) \right|^T \exp \left\{ -\frac{1}{2} \sum_{t=1}^T \sum_{i=1}^{1+n} \left[\tilde{a}_{0,t}^i z_t - \tilde{c}_t^i - \sum_{\ell=1}^4 \tilde{a}_{\ell,t}^i z_{t-\ell} \right]^2 \right\} \\ &= \sigma_{m,t}^{-T} \exp \left\{ -\frac{1}{2} \sum_{t=1}^T \left[\tilde{a}_{\ell,t}^1 z_t - \tilde{c}_t^1 - \sum_{\ell=1}^4 \tilde{a}_{\ell,t}^1 z_{t-\ell} \right]^2 \right\} \times \\ &\quad \left| \det(\tilde{A}_{0,t}^{2,2}) \right|^T \exp \left\{ -\frac{1}{2} \sum_{i=2}^{1+n} \sum_{t=1}^T \left[\tilde{a}_{0,t}^i z_t - \tilde{c}_t^i - \sum_{\ell=1}^4 \tilde{a}_{\ell,t}^i z_{t-\ell} \right]^2 \right\}. \end{aligned} \quad (\text{B.1})$$

The first part of the right hand side of (B.1) is the likelihood for the first equation and the second part is the likelihood for the rest of the system. Clearly, the maximum likelihood estimation (MLE) of the first equation can be performed independently of the MLE of the second equation. Moreover, it follows from system (3) that the second part of the right hand side of (B.1) is

$$\begin{aligned} &\left| \det(\tilde{A}_{0,t}^{2,2}) \right|^T \exp \left\{ -\frac{1}{2} \sum_{i=2}^{1+n} \sum_{t=1}^T \left[\tilde{a}_{0,t}^i z_t - \tilde{c}_t^i - \sum_{\ell=1}^4 \tilde{a}_{\ell,t}^i z_{t-\ell} \right]^2 \right\} \\ &= \left| \det(\tilde{A}_0^{2,2}) \right|^T \exp \left\{ -\frac{1}{2} \sum_{i=2}^{1+n} \sum_{t=1}^T \left[\tilde{a}_0^i z_t - \tilde{c}^i - \sum_{\ell=1}^4 \tilde{a}_\ell^i z_{t-\ell} \right]^2 \right\}, \end{aligned}$$

where the coefficients $\tilde{A}_{0,t}^{2,2}$, $\tilde{a}_{\ell,t}^i$, and $\tilde{c}_t^i$ are constant across time for $i = 2, \dots, 1+n$. Hence, estimation of this second block is equivalent to estimation of linear VAR system.

Sims and Zha (1998)'s Bayesian prior is designed for the structural form (3), not for the conventional form (4). This important feature ensures that when the prior is applied to the second part of system (3), the posterior probability density function has exactly the same form as the second part of the right hand side of (B.1). Thus, the posterior estimation of the rest of the system can be performed independently of estimation of the first equation. Conditional on the estimated value of $\tilde{A}_{0,t}^{2,2} \equiv A_0$, moreover, each equation in the second block of system (B.1) can be estimated independently of other equations.

APPENDIX C. DATA

The methodology of collecting and constructing the quarterly data series used in this paper is based on Higgins and Zha (2015) and Chang et al. (2016). The main data sources are China National Bureau of Statistics, People's Bank of China, and CEIC. The X11 method is used for seasonal adjustments. We do not use the X12 software package because there

are no independent regressors used to seasonally adjust our quarterly data.²⁵ All series bar interest and exchange rates are seasonally adjusted. All interpolated series are based on the method of Fernandez (1981), as described in Higgins and Zha (2015). One exception is net exports, which are interpolated with the method of Chow and Lin (1971).

- **M2**. M2 supply, quarterly average (RMB billion).
- **GDP**. Real GDP by value added (billions of 2008 RMB).
- **GDP growth target**. Real GDP growth target set by the central government of China.
- **CPI**. Consumer price index.
- **Investment price**. The price index of fixed assets investment.
- **ERR**. Excess reserves ratio computed as the ratio of excess reserves to total deposits in the banking system at the end of the quarter.
- **ARR**. Actual reserves ratio computed as the ratio of total reserves to total deposits in the banking system at the end of the quarter.
- **Lending rate**. One-year benchmark lending rate for commercial banks, set by the PBC, quarterly average.
- **Deposit rate**. One-year benchmark deposit rate at commercial banks for enterprises, set by the PBC, quarterly average.
- **Repo rate**. The 7-day market rate for national interbank bond repurchases, quarterly average.
- **Chibor rates**. The 1-day and 7-day China interbank offered rates, quarterly average.
- **MLT loans**. Newly originated medium and long term bank lending volume to non-financial enterprises (sum of monthly volumes) as percent of GDP.
- **ST loans**. Newly originated short term bank lending volume to non-financial enterprises (sum of monthly volumes) as percent of GDP.
- **FXR**. Foreign exchange reserves (RMB billion).
- **Exchange rate**. The spot RMB/US\$ exchange rate, quarterly average of the monthly series from the Federal Reserve Board. This series has a high correlation (0.99) with the the spot RMB/US\$ exchange rate series provided from China Foreign Exchange Trading Center, which is available only from January 2013 on.
- **Net exports**. Nominal net exports as percent of nominal GDP. Annual measure from national domestic products is interpolated by quarterly U.S. dollar series from General Administration of Customs converted to RMB.

²⁵For monthly series, one should use the X12 package by incorporating independent regressors to account for the Chinese New Year effect that may cause problems for data in January and February. The Census Bureau's X13 program removes outliers before seasonal adjustments using TRAMO/SEATS software from the Bank of Spain. For this paper, the quarterly series since 2000 does not appear to have serious outliers.

- **Investment.** Gross capital formation based on the expenditure side of national domestic products interpolated by fixed-asset investment and deflated by the investment price index. The U.S. counterpart of this series is gross private domestic investment, except our Chinese series includes government and SOE investment.
- **Consumption.** Household consumption based on the expenditure side of national domestic products, interpolated quarterly by retail sales of consumer goods and deflated by the CPI.
- **Heavy value-added output.** Value-added output produced by heavy industries (RMB billion), as classified by Chang et al. (2016).
- **Light value-added output.** Value-added output produced by light industries (RMB billion), as classified by Chang et al. (2016).

REFERENCES

- BERNANKE, B. AND A. BLINDER (1992): "The Federal Funds Rate and the Channels of Monetary Transmission," *American Economic Review*, 82, 901–921.
- BIANCHI, J. AND S. BIGIO (2014): "Banks, Liquidity Management and Monetary Policy," Federal Reserve Bank of Minneapolis Research Department Staff Report 503.
- CHANG, C., K. CHEN, D. F. WAGGONER, AND T. ZHA (2016): "Trends and Cycles in China's Macroeconomy," *NBER Macroeconomics Annual*, 30, 1–84, university of Chicago Press.
- CHANG, C., Z. LIU, AND M. M. SPIEGEL (2015): "Capital Controls and Optimal Chinese Monetary Policy," *Journal of Monetary Economics*, 74, 1–15.
- CHEN, K., J. REN, AND T. ZHA (2017): "The Nexus between Monetary Policy and Shadow Banking in China," Manuscript, Emory University.
- CHOW, G. C. AND A.-L. LIN (1971): "Best Linear Unbiased Interpolation, Distribution, and Extrapolation of Time Series by Related Series," *The Review of Economics and Statistics*, 53, 372–375.
- CHRISTIANO, L. J., M. S. EICHENBAUM, AND C. L. EVANS (2005): "Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy," *Journal of Political Economy*, 113, 1–45.
- FERNALD, J. G., M. M. SPIEGEL, AND E. T. SWANSON (2014): "Monetary Policy Effectiveness in China: Evidence from a FAVAR Model," *Journal of International Money and Finance*, 49, 83–103.
- FERNANDEZ, R. B. (1981): "A Methodological Note on the Estimation of Time Series," *Review of Economics and Statistics*, 63, 471–476.
- HIGGINS, P., T. ZHA, AND W. ZHONG (2016): "Forecasting China's Economic Growth and Inflation," *China Economic Review*, forthcoming.
- HIGGINS, P. C. AND T. ZHA (2015): "China's Macroeconomic Time Series: Methods and Implications," Unpublished Manuscript, Federal Reserve Bank of Atlanta.
- LEEPER, E. M., C. A. SIMS, AND T. ZHA (1996): "What Does Monetary Policy Do?" *Brookings Papers on Economic Activity*, 2, 1–78.
- LEEPER, E. M. AND T. ZHA (2003): "Modest Policy Interventions," *Journal of Monetary Economics*, 50, 1673–1700.
- LI, Z. (2016): "Forecasting China's Economy: A Bayesian Approach," Unpublished Manuscript, Emory University.
- MA, J. AND M. JI, eds. (2016): *Interest Rate Transmission under the New Monetary Policy Framework (in Chinese)*, Beijing: China Finance Publishing House.

- NAKAMURA, E., J. STEINSSON, AND M. LIU (2016): "Are Chinese Growth and Inflation Too Smooth? Evidence from Engel Curves," *American Economic Journal: Macroeconomics*, 8, 113–144.
- NIE, J. (2016): "Gauging the Strength of Chinese GDP Growth," *The Macro Bulletin*, 1–3, <http://macrobulletin.kcfed.org>.
- RUBIO-RAMÍREZ, J. F., D. F. WAGGONER, AND T. ZHA (2010): "Structural Vector Autoregressions: Theory of Identification and Algorithms for Inference," *Review of Economic Studies*, 77, 665–696.
- SHENG, S. AND P. WU (2008): "The Binary Transmission Mechanism of China's Monetary Policy: A Research on the 'Two Intermediaries, Two Targets' Model," *Economic Research Journal (in Chinese)*, 10, 37–51.
- SIMS, C. A. (1980): "Macroeconomics and Reality," *Econometrica*, 48, 1–48.
- (1992): "Interpreting the Macroeconomic Time Series Facts: The Effects of Monetary Policy," *European Economic Review*, 36, 975–1011.
- SIMS, C. A. AND T. ZHA (1998): "Bayesian Methods for Dynamic Multivariate Models," *International Economic Review*, 39, 949–968.
- TAYLOR, J. B. (1993): "Discretion versus Policy Rules in Practice," in *Carnegie-Rochester Conference Series on Public Policy*, ed. by A. H. Meltzer and C. I. Plosser, Amsterdam, vol. 39, 195–214.
- (2000): "Using Monetary Policy Rules in Emerging Market Economies," Unpublished Manuscript, Stanford University.
- UHLIG, H. (2005): "What are the effects of monetary policy on output? Results from an agnostic identification procedure," *Journal of Monetary Economics*, 52, 381–419.
- YI, G. (2009): "The 30-Year-Long Course of China's Market-Based Interest Rate Reform," *Journal of Financial Research (in Chinese)*, 1, 1–14.
- ZHA, T. (1999): "Block Recursion and Structural Vector Autoregressions," *Journal of Econometrics*, 90, 291–316.

EMORY UNIVERSITY AND FEDERAL RESERVE BANK OF ATLANTA; FEDERAL RESERVE BANK OF ATLANTA; FEDERAL RESERVE BANK OF ATLANTA; FEDERAL RESERVE BANK OF ATLANTA, EMORY UNIVERSITY, AND NBER