China Pro-Growth Monetary Policy and Its Asymmetric Transmission

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JEL classification: E5, E02, C3, C13

Key words: monetary transmission, endogenous switching, central government, institutional rigidities, GDP growth target, lower growth bound, nonlinear VAR, systematic monetary policy, policy shocks, heavy industries, investment, bank loans, lending channel

CHINA PRO-GROWTH MONETARY POLICY
AND ITS ASYMMETRIC TRANSMISSION

KAIJI CHEN, PATRICK HIGGINS, DANIEL F. WAGGONER, AND TAO ZHA

ABSTRACT. China monetary policy, as well as its transmission, is yet to be understood by researchers and policymakers. In the spirit of Taylor (1993, 2000), we develop a tractable framework that approximates practical monetary policy of China. The framework, grounded in relevant institutional elements, allows us to quantify the policy effects on output and prices. We find strong evidence that monetary policy is designed to support real GDP growth mandated by the central government while resisting inflation pressures and that contributions of monetary policy shocks to the GDP fluctuation are asymmetric across different states of the economy. 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 sheds light on institutional constraints on a gradual transition from M2 growth to the nominal policy interest rate as a primary instrument for monetary policy.

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 represents a remarkable and unique process driven by three major factors: technological improvement, market liberalization, and central planning. In this paper, we focus on the aspect of central planning and especially on the role of monetary policy in supporting the government's planned GDP growth. Since the late 1990s, the central strategic plan approved by the Eighth National People's Congress has laid long-lasting foundations for actively promoting investment in heavy industries supported by credit expansions. In this investment-driven economy, monetary policy and the bank lending channel play an indispensable role. The top pannel of Figure 1 shows that growth in bank loans has moved in tandem with M2 growth in the past 16 years with a 0.86 contemporaneous correlation. The close dynamic relationship indicates the ability of the People's Bank of China (PBC) in controlling the banking system through M2 growth as a policy instrument.

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 to the research community and the policy circle. And there has been relatively scarce research on this important topic. In this paper we provide an empirical analysis of China monetary policy and make several contributions. First, we establish a formal and evaluable framework that captures the essence of China monetary policy. For the complexity of the Chinese economy, analysis could easily become bogged down with details that make it impracticable to develop a tractable framework. In the spirit of Taylor (1993) and Taylor (2000), however, our framework consists of a simple rule that helps understand the unique Chinese characteristics of monetary policy that differ from the simple interest rate rule widely used for other economies. Under such a simple rule, M2 growth is the policy instrument and the endogenous component of M2 growth tracks actual M2 growth surprisingly well.[1] This suggests that our identified monetary policy rule is capable of representing the central bank's systematic reaction to the state of the economy.

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[1]For emerging market economies, it is not uncommon that a monetary aggregate instead of the interest rate serves as the policy instrument (Taylor, 2000).

A good policy rule should respond to changes in output and inflation, the two key indicators that have been used in policy discussions. Our policy rule involves a systematic response of M2 growth to real GDP growth and CPI inflation.[2] The derivation of this rule is based on unique institutional arrangements in China. The tractability and usefulness of simple rules for policy analysis have been illustrated in the burgeoning literature on dynamic stochastic general equilibrium (DSGE) and structural vector autoregressions (SVAR) models (Del Negro and Schorfheide, 2004; Lubik and Schorfheide, 2004; Christiano, Eichenbaum, and Evans, 2005; Smets and Wouters, 2007; Justiniano and Primiceri, 2008; Cogley and Sbordone, 2008). In the context of the existing literature, the chief advantage is that our simple feedback rule can be incorporated in DSGE or SVAR models. Rigorous and informative policy analysis often relies on model simulations to gauge the magnitude and duration of policy effects on the economy. "Hence, it is important to preserve the concept of a policy rule even in an environment where it is practically impossible to follow mechanically the algebraic formulas economists write down to describe their preferred policy rules" (Taylor, 1993, p.197).

As a second contribution, the paper argues that China monetary policy has been primarily pro-growth. The central government of China, on an annual basis, specifies a GDP growth target for the next calendar year. This target is not suggestive but rather an overarching objective for all government units (including the PBC) to achieve, while everything else is a means. To this end, the National Development and Reform Commission (NDRC) under the State Council, in consultations with other government units, hammers out the detailed mini plans for carrying out this grand target. Thus, the target is not potential growth of GDP but rather represents a *lower bound* for economic growth.

For the monetary authority, the bottom line of its policy is to support the central government's preference for promoting GDP growth beyond its annual target. We approximate this preference by a loss function to capture the idea that the loss is a decreasing function of the growth rate of GDP and that the marginal loss for the government when actual GDP growth misses the target is higher than when it is already above the target. Such a loss function implies asymmetric monetary policy that differs from other conventional policy rules applicable to developed economies but is consistent with our descriptive monetary policy rule.

Our empirical results provide a strong support of both descriptive and theoretical arguments. The bottom panel of Figure 1 exhibits the relationship between GDP growth and M2 growth since 2000 and their quarterly contemporaneous correlation is 0.5 (and as high as 0.87 since 2009 after the global financial crisis). Our formal econometric estimation of

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[2]Henceforward, by GDP we mean real GDP unless we add the word "real" to emphasize that it is not nominal GDP.

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. Despite its pro-growth nature, however, China monetary policy is anti-inflationary. M2 growth tends to fall significantly in response to a rise of inflation.

Our third contribution proposes a new estimation method and uses it to quantify the asymmetric monetary transmission within the nonlinear SVAR framework. In this SVAR system, the monetary policy rule is nonlinear and its output coefficient switches endogenously to the state of GDP growth and the rest of the system is unrestricted to avoid potentially "incredible restrictions" on the structure of the Chinese economy (Sims, 1980). We show that the monetary policy equation and its shock are identified without having to impose restrictions on other equations or identify other shocks. 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. 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. The rest of the system can be estimated with the standard method applied for linear VARs. Because our new method is straightforward to implement, it can be adapted by the general researcher to tackle similar problems.

The estimated results confirm several common findings of the effect of monetary policy in the existing literature. The response of output to a monetary policy shock is hump-shaped, the response of investment is also hump-shaped, excess reserves in the banking system decline, so does the interest rate while foreign exchange reserves rise, and there is no price puzzle (i.e., an expansionary monetary policy shock does not generate a decline in the general price level). In addition to these common features, we find five stylized facts special to the Chinese economy:

- The influence of monetary policy's stimulus 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 the monetary policy shock, *relative to* other shocks, in explaining the output fluctuation differs across states. 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 disproportionally 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 on MLT and ST loans, this finding is consistent with the central government's strategic development plan by promoting heavy industries that require long term financing.[3]

- The response of investment is economically strong and statistically significant, consistent with the government's investment-driven growth strategy. The response of consumption is weak and the statistical significance is marginal at best. The weak consumption response is consistent with Nakamura, Steinsson, and Liu (2016), who use micro data to document a consumption slump during the period of a massive monetary stimulus after the 2008 financial crisis.

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 policy makers 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's obligation to help achieve and surpass an annual GDP growth target set by the central government. As long as GDP growth target is a national priority, a switch from M2 growth to some policy interest rate as a primary instrument must take into account this constraint in designing a transition path.

During this transition period, researchers should not simply assume that rational agents understand how a new policy works when agents' behaviors and beliefs are 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 current 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 in place for more than a decade before one can assess the benefits and costs of a regime switch to a different policy rule.

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[3]Heavy 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.

The rest of the paper is organized as follows. Section II describes the institutional background relevant to the existing monetary policy. Section III establishes a nonlinear but tractable rule that represents the essence of existing monetary policy, provides a theoretical justification of the monetary policy rule, and obtains maximum likelihood estimation of the rule. Section IV discusses the estimated monetary policy shock series. Section V develops a new estimation method and presents the empirical results of monetary transmission. Section VI offers further discussions of the unique features of existing monetary policy in China. Section VII concludes.

II. INSTITUTIONAL BACKGROUND

In this section we provide the relevant institutional background that helps understand the essential elements of how China monetary policy is made and conducted in practice. According to the "Law on the People's Bank of China" passed by the National People's Congress (NPC) in 1995, the objective of monetary policy is to maintain the stability of the currency value and promote economic growth. A further breakdown of this grand objective has four specific parts: maintaining price stability, boosting economic growth, promoting employment, and broadly maintaining balance of payment (Zhou, 2016). As pointed out by Zhou (2016), the objective of employment overlaps with the objective of economic growth. The stability of the currency is also for the purpose of promoting growth. Among all parts of the policy objective, therefore, pro-growth (promoting economic growth) has been a top priority.

II.1. **GDP growth target.** Since 1988 a GDP growth target has been specified in the State Council's Report on the Work of Government (RWG). The Central Economic Work Conference organized jointly by the State Council and the Central Committee of Communist Party of China (CPC), typically held in December of each year, decides on a particular target value of GDP growth for the coming year. Once the target is decided, it will be formally announced by the Premier of the State Council as part of the RWG to be presented to the NPC's annual session during the next spring.[4]

In practice, it is well understood that the central government's GDP growth target for a particular year is regarded as a lower bound of GDP growth for that year. Because of its strongest desire of maintaining social stability, the government views such a lower bound as a crucial factor in keeping unemployment low by means of economic growth. In explaining the 2009 GDP growth target of 8%, for instance, the 2009 RWG states

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[4]See the link http://www.gov.cn/test/2006-02/16/content_200875.htm for the State Council's RWG since 1954.

It is important to note here a GDP growth target of 8% is taking into consideration the development needs and potential. In a developing country with a population of 1.3 billion, to expand urban and rural employment, increase income and maintain social stability, we must maintain a certain growth rate.

Another example is the GDP growth target of at least 6.5% for 2016. In explaining why 6.5% was a targeted lower bound for GDP growth during a press conference for the NPC's 2016 annual assembly, Xu Shaoshi, Head of NDRC, remarked that "The floor is employment, the floor has another implication, which is economic growth. Therefore, we set this lower bound." Clearly, the central government's GDP growth target as a lower bound is an overarching national priority for every government unit, especially the PBC which is under the leadership of the State Council.

II.2. **Practice of monetary policy.** The PBC Monetary Policy Committee (MPC), unlike the Federal Open Market Committee in the U.S., is a consultative body for the making of monetary policy.[5] Nonetheless, the MPC plays an integral part of the policymaking process. The committee performs its advisory functions through regular quarterly meetings, which are typically held at the end of the last quarter or the beginning of the current quarter when a particular policy action is chosen and implemented. The committee provides various analyses of past economic performance and makes suggestions of policy actions for the upcoming quarter.

The 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. Inflation and GDP growth are the two most important and reliable indicators in the report. In Section III and Section IV we utilize various MPRs for understanding our estimated policy rule and the sources of identified monetary policy shocks.

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[5]The MPC is composed of the PBC Governor and two PBC Deputy Governors, a Deputy Secretary-General of the State Council, a Deputy Minister of the NDRC, a Deputy Finance Minister, the Administrator of the State Administration of Foreign Exchange, the Chairman of China Banking Regulatory Commission, the Chairman of China Securities Regulatory Commission, the Chairman of China Insurance Regulatory Commission, the Commissioner of National Bureau of Statistics (NBS), the President of the China Association of Banks, and experts from academia (three academic experts in the current MPC).

II.3. **Monetary policy and PBC's relationship to the central government.** Before 1993, the PBC directly controlled the total volume of bank credit supply and its allocations. In 1993, for the first time, it announced to the public the index of monetary supply; in 1996, it began to use money supply as an instrument for monetary policy. In 1998 the PBC abolished direct control of bank credit supply and announced that M2 supply was the only policy target. Subsequently, open market operations were resumed in May of that year.

In 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, which explains the close relationship between bank credit growth and M2 growth as shown in Figure 1.

According to the Chinese law, the PBC must formulate and implement monetary policy under the leadership of the State Council. Consistent with the GDP growth target, the PBC adjusts M2 growth on a quarterly basis in response to the state of the economy. Decisions on switching an overall monetary policy stance, however, are made by the Politburo consisting of General Secretary of CPC, Premier of the State Council, and other top central government officials. In the 2010 Politburo meeting, for instance, monetary policy stance was switched from "modestly loose" to "prudent."[6] Unlike the Federal Reserve System in the U.S., therefore, the PBC is not independent of other central government units and its decision on quarterly changes of monetary policy is severely constrained by its obligation of meeting the ultimate goal of surpassing targeted GDP growth and by the central government's view about how monetary policy should be conducted.[7]

III. A tractable rule describing China monetary policy

We begin with development of a tractable rule that characterizes the essence of the otherwise intractably complex operations of China monetary policy, then provide a theoretical

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[6]China monetary policy stance is classified into "loose", "appropriately loose", "prudent", "appropriately tight", and "tight" with much room for flexibility on a particular classification. In this paper, we streamline these nuances into three categories of policy changes: loosening, prudent, and tightening. See Section IV for detailed discussions.

[7]As an example, the 2009Q1 MPR states: "In line with the overall arrangements of the CPC Central Committee and the State Council, and in order to serve the overall objective of supporting economic growth, expanding domestic demand, and restructuring the economy, the PBC implemented a moderately loose monetary policy, adopted flexible and effective measures to step up financial support for economic growth, and ensured that aggregate money and credit supply satisfy the needs of economic development."

justification for our descriptive policy rule, and close the section with maximum likelihood estimation of the policy rule.

III.1. **Description of the monetary policy rule.** Because financial markets have not been fully developed in China and the concept of potential GDP is much less defined than in countries with well functioning financial markets, the original interest rule of Taylor (1993), called the Taylor rule, is inapplicable to the Chinese policymaking environment.[8] The main function of China monetary policy is to control M2 growth in support of rapid economic growth. In March 1996, the Eighth National People's Congress passed the National Economic and Social Development and Ninth Five-Year Program called "Vision and Goals for 2010," prepared by the State Council. This program was the first long term plan that set up a policy goal to gradually concentrate medium and long term bank loans on heavy industries for the next 15 years. To support this national policy goal, the PBC made M2 growth an explicit policy instrument in 1999-2000 and began in 2001 to publish quarterly MPRs.

The PBC is able to control M2 growth because it has tight control of commercial banks in the nation. The five largest commercial banks are state owned and other large commercial banks are heavily regulated by the government. At the end of each year, the central government outlines overall M2 growth consistent with targeted GDP growth for the next year. Within each year, the MPC meets at the end of each quarter t (or the beginning of the next quarter) to decide on a policy action for the next quarter (i.e., quarterly M2 growth $g_{m,t+1} = \Delta M_{t+1}$) in response to CPI inflation $\pi_t = \Delta P_t$ and to whether GDP growth ($g_{x,t} = x_t - x_{t-1}$) in the current quarter meets the GDP growth target ($g_{x,t}^*$). Note that all the three variables, M_t, P_t, and x_t, are expressed in natural log. As discussed in Section II, the GDP growth target set by the State Council serves as a lower bound for monetary policy. When actual GDP growth in each quarter is above the target, therefore, M2 growth increases to accommodate such output growth as long as inflation is not a serious threat.

The RWGs discuss other macroeconomic targets such as inflation, employment, trade balance, currency stability, household income growth, and environmental protection. All these targets are more suggestive than mandatory and are in fact subordinate to the GDP growth target. Among all these variables, inflation is the crucial indicator for monetary policy. As our estimate in the latter part of this section shows, the government contracts M2 growth when inflation rises. The bottom panel of Figure 1 displays the time series of M2 growth and GDP growth and Figure 2 displays the time series of GDP growth less its target and CPI inflation. One can see from these two figures that when inflation rose between late 2003 and the middle of 2004, M2 growth declined sharply during the same period. When both GDP growth and CPI inflation rose sharply in 2007 and early 2008, M2 growth was held

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[8]See Section VI for further discussions and also Taylor (2000).

steady as an outcome of two opposing effects: anti-inflation monetary policy and pro-growth monetary policy.

To provide a formal econometric analysis on these two opposing effects, we characterize China monetary policy rule as

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

where $\varepsilon_{m,t}$ is a serially independent random shock that has a standard normal distribution. Every quarter the PBC adjusts M2 growth in response to inflation and output growth in the previous quarter, a practice consistent with the decision making process of the PBC monetary policy committee. The inflation coefficient γ_π is expected to be negative if monetary policy is anti-inflationary.[9] 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 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. During the period of robust economic growth, GDP growth is driven largely by an increase in bank loans to investment. Adequate M2 growth provides commercial banks the needed liquidity for expansions of bank credit to support economic growth. *After we control for inflation*, a higher GDP growth rate is always desirable for China as an emerging market economy. During the normal time, therefore, we expect the coefficient $\gamma_{x,a}$ to be positive. On the other hand, when actual GDP growth is below its target, we expecte the coefficient $\gamma_{x,b}$ to be negative. This is particularly true for the post financial crisis period from late 2008 to early 2009 but also true for other shortfall periods (Figure 2). This asymmetric response reflects the central government's determination in making economic growth an overriding priority, which we term pro-growth monetary policy. We allow heteroskedasticity between the two states when estimating the policy rule so that

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

Lagged quarterly M2 growth enters the policy rule to reflect the PBC's commitment to providing liquidity to the banking system through money supply, especially MLT bank loans

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[9]Discussions in the MPRs indicate that the annual CPI inflation target is around $3\% - 4\%$. We set π^* at 3.5% (a quarterly rate).

to sustain investment in heavy industries. We show that the asymmetric form of the monetary rule (1) has both theoretical justification (Section III.2) and empirical support via econometric testing (Section III.3).

III.2. **Theoretical justification.** The purpose of this section is to show the existence of a loss function for output growth that leads to optimal monetary policy consistent with the systematic component of our descriptive nonlinear monetary policy rule in both functional form and coefficient sign. The conventional loss function for output growth is quadratic:

$$L_t^x = \delta \left(g_{x,t} - \bar{g}_{x,t}\right)^2, \tag{2}$$

where $\bar{g}_{x,t}$ often represents the potential GDP growth but can also represent the GDP growth target $g_{x,t}^*$. The overall loss function is

$$L_t = (1 - \phi) \lambda L_t^x + \phi \lambda \left(\pi_t - \pi^*\right)^2 + \left(g_{m,t} - g_m^*\right)^2. \tag{3}$$

In Appendix A, we minimize the loss function (3) subject to three generic structural equations to derive optimal monetary policy. These equations are the standard money demand function, the standard IS curve, and an inflation dynamics equation based on Gilchrist, Schoenle, Sim, and Zakrajsek (2016). The derived optimal monetary policy, consistent with the systematic part of the conventional monetary policy rule

$$g_{m,t} = \gamma_0 + \gamma_m g_{m,t-1} + \gamma_\pi (\pi_{t-1} - \pi^*) + \gamma_x \left(g_{x,t-1} - \bar{g}_{x,t-1}\right) + \sigma_m \varepsilon_{m,t}, \tag{4}$$

implies that $\gamma_\pi < 0$ (anti-inflation) and $\gamma_x < 0$ (stabilization). When we estimate the conventional rule (4) with $\bar{g}_{x,t-1} = g_{x,t-1}^*$ or $\bar{g}_{x,t-1} = \bar{x}_{t-1} - x_{t-2}$ in which $\bar{x}_{t-1}$ is the potential GDP approximated by the HP filter or log-linear trend, the estimate of γ_π is always negative and highly significant as reported in Appendix B, implying that monetary policy is firmly anti-inflationary. But the estimate γ_x is always positive (Appendix B), implying that the government has been de-stabilizing the economy.[10] The positive estimate is contradictory to the fact that the Chinese government has not just stabilized the economy populated by 1.38 billion people but made a miracle of economic growth in the past decades.

The problematic result stems from two sources. First, for transitional economies like China, the concept of potential GDP is not well defined. The transition path for the Chinese economy is characterized by steady increases of the share of investment in GDP, the share of MLT loans in total loans, and the share of revenues in heavy industries in total output since the late 1990s (Chang, Chen, Waggoner, and Zha, 2016). All these features still exist in China today. In such a policy environment, it is practically difficult, if not impossible, to define what constitutes potential or trend output growth. Second, even if we avoid the issue related to the concept of potential GDP by setting $\bar{g}_{x,t} = g_{x,t}^*$, the quadratic output loss

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[10]This estimate, however, is not always statistically significant.

function (2) *fails* to represent the Chinese government's preference for growth to be above the target (that is, more growth is preferred by the Chinese government).

If we set $\bar{g}_{x,t}$ to $g_{x,t}^*$ and generalize the loss function (2) to be

$$L_t^x = \delta_t \left(g_{x,t} - g_{x,t}^* \right)^2 + c_t \tag{5}$$

with

$$\delta_t = \begin{cases} \delta_b & \text{if } g_{x,t} - g_{x,t}^* < 0 \\ -\delta_a & \text{if } 0 \le g_{x,t} - g_{x,t}^* < b^* \\ \delta_b & \text{if } b^* \le g_{x,t} - g_{x,t}^* \end{cases},$$

and

$$c_t = \begin{cases} 0 & \text{if } g_{x,t} - g_{x,t}^* < 0 \\ 0 & \text{if } 0 \le g_{x,t} - g_{x,t}^* < b^* \\ -(\delta_a + \delta_b)b^{*\,2} & \text{if } b^* \le g_{x,t} - g_{x,t}^* \end{cases},$$

where $\delta_b > \delta_a > 0$, this loss function becomes asymmetric. We assume that b^* is a growth rate sufficiently large to be irrelevant for our observed sample.[11] For the observed region $g_{x,t} - g_{x,t}^* < b^*$, the parametric constraint, $\delta_b > \delta_a > 0$, implies that the marginal loss for the government when actual GDP growth misses the target is larger than the marginal gain when actual GDP growth is already above the target. The negative sign for the weight on $(g_{x,t} - g_{x,t}^*)^2$ is necessary to ensure that the loss declines as GDP growth continues to rise in the growth region $0 \le g_{x,t} - g_{x,t}^* < b^*$; and the piecewise quadratic form of loss function (5) is necessary for obtaining a closed-form solution to optimal monetary policy as shown in Appendix A.

In short, there exists a loss function, represented by the piecewise quadratic form (5), that makes our analytical derivation tractable and at the same time captures the Chinese government's taste for more rapid growth. Such preference is reflected in the government's ambitious long term goal for economic growth beyond its annual (short term) lower bound target.[12] It is consistent with Li and Zhou (2005)'s empirical findings of the Chinese leadership's strong desire and incentive to promote economic growth beyond short term targets.

The purpose of this paper is not to derive the generalized loss function (5), especially for the growth region $g_{x,t} - g_{x,t}^* < b^*$, from a micro foundation. The Chinese government's objective function is unlikely to be the same as the objective function of the representative agent for an economy with a 1.38 billion population. Among others, political and social

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[11]The conventional loss function represented by (2) is a special case of the general form represented by (5) when $\bar{g}_{x,t}$ is set to $g_{x,t}^*$, δ_b is set to δ, and δ_a is set to $-\delta$.

[12]For example, in the thirteenth Five-Year (2016-2020) Plan on National Economic and Social Development, the government emphasizes maintaining economic growth at a medium level with the aim to double the 2010 GDP level as well as the 2010 per capita income by 2020.

stability is a top priority of the government; maintaining control of the communist party over economic and social activities is another. Building a micro foundation of the Chinese government's loss function is a complex issue and a challenging task and thus merits a separate research paper.[13]

Given the generalized loss function (5), however, we achieve two relevant results. One is that the derived optimal monetary policy has the same functional form as the systematic component of our descriptive monetary policy rule (1). The other result is that the coefficient signs for optimal monetary policy are the same as those for our monetary policy rule, especially for the asymmetric coefficient $\gamma_{x,t}$ of output growth. That is, $\gamma_{x,t} > 0$ when actual GDP growth is above the target and $\gamma_{x,t} < 0$ when it is below the target.

III.3. **The estimated monetary policy rule.** We now estimate the monetary policy rule (1) to quantify the coefficients and test whether they are statistically significant. 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 MPRs have been available to the public since 2001Q1. The endogenous-switching rule is estimated with the maximum likelihood approach of Hamilton (1994). The data used for estimation are described in Appendix C. Table 1 reports the results, which show that all the estimates are statistically significant. The coefficient for lagged M2 growth is estimated to be 0.39%, implying that monetary policy is somewhat inertial. According to the estimates, when GDP growth is above the target, annualized M2 growth is estimated to rise by 0.72% (0.18 × 4) in support of a 1% annualized GDP growth rate above its target. Such a pro-growth nature of monetary policy is evident in various issues of MPR. In explaining the fast M2 growth since the beginning of 2005, for example, the 2005Q2 MPR states: "Since the beginning of 2005, the central bank has conducted open market operations in a flexible manner, providing a relatively accommodating liquidity environment for commercial banks to maintain an appropriate growth of lending. At the end of June, M2 grew by 15.7% year over year, basically consistent with economic growth."[14]

In the shortfall state, the estimate of $\gamma_{x,b}$ shows that annualized M2 growth rises by 5.20% (= 1.30 × 4) in response to a 1% annualized GDP growth short of its target. Thus, the negative sign of $\gamma_{x,b}$ and its estimated magnitude reveal that monetary policy takes an unusually aggressive response in order to stem a shortfall in meeting the GDP growth

[13]See Li and Zhou (2005) for a description of Chinese leaders' own preferences and incentives as well as Backus, Routledge, and Zin (2005) for a survey of exotic preferences in the theoretical literature.

[14]Another example is 2002Q4 MPR, which states "since the beginning of 2002, the growth rates of M2 and M1 have been increasing each month, which reflects the need for money growth to accommodate to the recovery of the economy, the enhanced support of commercial banks for economic growth, and the consistency between banking credit supply and the speed and outlook of economic growth."

target. During and after the 2008 global financial crisis, China's GDP growth descended precipitously to a rate below the government's target (the top panel of Figure 2). M2 growth remained stable even though GDP growth fell sharply during the 2008 crisis, but as soon as GDP growth was below the target, M2 growth shot up to an unprecedented level since 2000 (Figure 1).

The asymmetry in China monetary policy is also reflected in the volatility of its policy shocks. The shock volatility in the shortfall state is twice as large as its counterpart in the normal state (0.10 vs 0.005). Together with the asymmetric response of monetary policy, the finding of different shock volatilities between the two states supports our argument that the central government of China views the GDP growth target as a lower bound and acts more aggressively when actual GDP growth falls below this threshold.

Good monetary policy must respond to inflation pressures. China monetary policy is no exception. The estimate of the inflation coefficient in the monetary policy rule is negative and highly significant. The negative inflation coefficient γ_π reveals anti-inflationary monetary policy: annualized M2 growth contracts 1.6% (0.40% × 4) in response to a 1% increase of annual inflation. This strong anti-inflation policy can be clearly seen in the data. After the stimulus of unprecedented M2 growth, inflation rose rapidly in 2010-2011 to a level of 6% (the bottom panel of Figure 2). In response, M2 growth contracted rapidly during the same period (Figure 1). Even though China's rapid GDP growth path has surpassed most economists' expectations, our estimation shows that monetary policy has remained systematically anti-inflationary throughout the sample.

We test the endogenous-switching policy rule, represented by (1), against other alternatives. One alternative is the same rule without any of the time-varying features (i.e., $\gamma_{x,t} = \gamma_x$ and $\sigma_{x,t} = \sigma_x$). The log maximum likelihood value for the constant-parameter rule is 192.42. We then allow $\gamma_{x,t}$ to depend on the two different states of the economy (the normal and shortfall states). The log maximum likelihood value for this rule is 198.49. The log maximum likelihood value for our endogenous-switching rule (i.e., allowing $\sigma_{m,t}$ to be time varying in addition to $\gamma_{x,t}$) is 203.78. The likelihood ratio test for a comparison between the rule with time-varying $\gamma_{x,t}$ only and the constant-parameter rule rejects the constant-parameter rule at a 0.05% level of statistical significance, implying that the data strongly favor the time-varying parameter $\gamma_{x,t}$. The likelihood ratio test for a comparison between the rule with both time-varying $\gamma_{x,t}$ and $\sigma_{m,t}$ and the rule with time-varying $\gamma_{x,t}$ only rejects the latter rule at a 0.11% level of statistical significance, implying that the data strongly favor additional time-varying volatility.[15] These econometric testing rationalizes the statistical results of high significance reported in Table 1.

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[15]The two tests are supported by both the Bayesian information criterion (BIC) and the Akaike information criterion (AIC).

As stated in the introduction section, the goal of this paper is to provide a monetary policy rule that is simple and transparent enough for researchers and policymakers to understand the essence of China monetary policy. One aspect of monetary policy under discussion is to maintain "balance of payments in stable conditions" (Chang, Liu, and Spiegel, 2015). This detail is abstracted from our policy rule. 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 test this hypothesis, we regress the estimated systematic component of monetary policy on the RMB exchange rate and net exports and find the coefficients statistically significant. On the other hand, when we regress the estimated exogenous policy shock series on the same variables, we find the coefficients statistically insignificant (see Appendix D for a detailed report). These results indicate that our estimated systematic component of monetary policy has already encompassed possible responses to the movements of the exchange rate and net exports and that our estimated series of monetary policy shocks is not contaminated by the same variables.

IV. 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*.[16] 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.[17] 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

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[16]Leeper, Sims, and Zha (1996) provide detailed discussions of various factors in the policymaking process that can be interpreted as shocks to monetary policy.

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

Council and the Politburo. This process reflects changes in preferences, political concerns, economic priorities of different policymakers. Such a complex and dynamic interplay among different entities of the central government, impossible to formulate systematically, makes it reasonable to be approximated by random shocks.

Figure 3 reports the decompositions of M2 growth into the endogenous (systematic) component and the exogenous (shock) component according to the estimated monetary policy rule.[18] We see that systematic monetary policy tracks the series of actual M2 growth rates very closely. This suggests that a large fraction of the variation in M2 growth can be attributed to the systematic reaction of policy authorities to the state of the economy, which is what one would expect of good monetary policy.

The monetary policy shock series is the gap between actual M2 growth and the systematic component. 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 3. The two darker bars mark loosening regime, the lighter bar marks tightening regime, and prudent regime is unmarked.[19]

The purpose of this paper is to formulate and estimate a monetary policy rule that can be used for SVAR or DSGE studies; it is not to use the MPR narrative to identify monetary policy shocks. In particular, we do not intend to use the three classified policy regimes to justify our estimated policy shocks, but rather to show that these 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.[20] 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

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[18]Since 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.

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

[20]The stance of monetary policy is routinely announced by the Politburo.

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 3), 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 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).

V. Quantifying the monetary transmission

The preceding analysis establishes and estimates a simple and evaluable rule for China monetary policy. 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, Eichenbaum, and Evans (2005).

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 includes 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).[21] 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.

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[21]See Appendix C for a detailed description of the data.

One may question the quality of China's official macroeconomic data, especially the GDP and CPI series. For example, Nakamura, Steinsson, and Liu (2016) argue that the official CPI data underestimate the volatility of CPI inflation since 1995.[22] 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, 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.[23]

Our objective is to assess the dynamic impact of a monetary policy shock on the vector y_t. For robustness analysis, we explore which variables are most important to the monetary transmission in Appendix D. 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.

V.1. **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. We postulate the dynamics of y_t in a general subsystem of simultaneous equations

$$A_0 y_t + b_0 M_t = c + \sum_{\ell=1}^{4} A_\ell y_{t-\ell} + \sum_{\ell=1}^{4} b_\ell M_{t-\ell} + \xi_t, \qquad (6)$$

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.

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[22]Ideally 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.

[23]In a very recent paper, Nie (2016) argues that "official GDP figures remain a useful and valid measure of Chinese economic growth."

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 (6) is unidentified.[24] 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 (6). The following proposition establishes the identification of monetary policy.

Proposition 1. When the system represented by (1) and (6) is simultaneously estimated, the following two results hold.

- The monetary policy rule (1) is identified, even though the subsystem (6) is unidentified.
- 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 E.   □

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 (6), which can be written in the SVAR form of

$$\underbrace{\begin{bmatrix} \frac{1}{\sigma_{m,t}} & 0_{1\times n} \\ b_0 & A_0 \end{bmatrix}}_{\widetilde{A}_{0,t}} \begin{bmatrix} M_t \\ y_t \end{bmatrix} = \underbrace{\begin{bmatrix} \frac{\gamma_0 - \gamma_\pi \, \pi^* - \gamma_{x,t-1}\, x^*_{t-1}}{\sigma_{m,t}} \\ c \end{bmatrix}}_{\tilde{c}_t} + \underbrace{\begin{bmatrix} \frac{1+\gamma_M}{\sigma_{m,t}} & \underbrace{v\left(\gamma_{x,t-1}, \sigma_{m,t}\right)}_{1\times n} \\ b_1 & A_1 \end{bmatrix}}_{\widetilde{A}_{1,t}} \begin{bmatrix} M_{t-1} \\ y_{t-1} \end{bmatrix}$$

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

$$+ \underbrace{\begin{bmatrix} -\frac{\gamma_M}{\sigma_{m,t}} & 0 \\ & 1 \times n \\ b_2 & A_2 \end{bmatrix}}_{\widetilde{A}_{2,t}} \begin{bmatrix} M_{t-2} \\ y_{t-2} \end{bmatrix} + \underbrace{\begin{bmatrix} 0 & 0 \\ & 1 \times n \\ b_3 & A_3 \end{bmatrix}}_{\widetilde{A}_3} \begin{bmatrix} M_{t-3} \\ y_{t-3} \end{bmatrix} + \underbrace{\begin{bmatrix} 0 & 0 \\ & 1 \times n \\ b_4 & A_4 \end{bmatrix}}_{\widetilde{A}_4} \begin{bmatrix} M_{t-4} \\ y_{t-4} \end{bmatrix} + \begin{bmatrix} \varepsilon_{m,t} \\ \xi_t \end{bmatrix}, \quad (7)$$

where we take the government's targets π^* and x_t^* as given. Note that $v\left(\gamma_{x,t-1}, \sigma_{m,t}\right)$ 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

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

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

$$\begin{bmatrix} M_t \\ y_t \end{bmatrix} = \tilde{b}_t + \widetilde{B}_{1,t} \begin{bmatrix} M_{t-1} \\ y_{t-1} \end{bmatrix} + \widetilde{B}_{2,t} \begin{bmatrix} M_{t-2} \\ y_{t-2} \end{bmatrix} + \widetilde{B}_{3,t} \begin{bmatrix} M_{t-3} \\ y_{t-3} \end{bmatrix} + \widetilde{B}_{4,t} \begin{bmatrix} M_{t-4} \\ y_{t-4} \end{bmatrix} + \widetilde{A}_{0,t}^{-1} \begin{bmatrix} \varepsilon_{m,t} \\ \xi_t \end{bmatrix}, \quad (8)$$

where $\tilde{b}_t = \widetilde{A}_{0,t}^{-1} \tilde{c}_t$, $\widetilde{B}_{1,t} = \widetilde{A}_{0,t}^{-1} \widetilde{A}_{1,t}$, $\widetilde{B}_{2,t} = \widetilde{A}_{0,t}^{-1} \widetilde{A}_{2,t}$, $\widetilde{B}_{3,t} = \widetilde{A}_{0,t}^{-1} \widetilde{A}_3$, and $\widetilde{B}_{4,t} = \widetilde{A}_{0,t}^{-1} \widetilde{A}_4$. The coefficient matrix $\widetilde{B}_{\ell,t}$ ($\ell = 1, \ldots, 4$) is state dependent and involves cross-equation restrictions (i.e., restrictions across the first equation and other equations). For example, the second block of $\widetilde{B}_{1,t}$ 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 V.2. 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 (8) and the dynamic responses to a monetary policy shock. Second, although the first equation in system (8) is exactly the same as the monetary policy rule represented by (1), parameters in the rest of the equations in system (8) are functions of $\sigma_{m,t}$ and $\gamma_{x,t-1}$. Hence, estimating the monetary policy rule jointly with the rest of the system (8) may not necessarily yield the same results as those based only on equation (1) in Section III. 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 (8) are equivalent to two separate estimation procedures: the nonlinear monetary policy rule (1) and the linear

subsystem (6) can be estimated independently. That is, estimation and inference of the subsystem (6) do not depend on the coefficients of equation (1).

Proof. See Appendix F.   □

The customary representation in the SVAR literature is system (8), 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 (6) or by (7) enables one to avoid the needless cost of dealing with the nonlinear system represented by (8). 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 (7), not on the form represented by (8) as in the stantard literature. Because system (7) is the structural form of system (8), the estimated results from (7) are the same as those from (8).

Propositions 1 and 2 provide powerful tools for the general researcher. 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 (6), consists of a linear simultaneous-equation system. Moreover, one can proceed to estimate, equation by equation, system (6) under the prior of Sims and Zha (1998) once the contemporaneous coefficient matrix A_0 is estimated (see Appendix F for the proof). For the most part, therefore, estimation and inference of the entire nonlinear system (7) can be executed equation by equation, making the computation inexpensive.

V.2. **Empirical results.** Our benchmark model consists of 11 variables. The sample for estimation is from 2000Q1 to 2016Q2, excluding four lags. The Bayesian prior of Sims and Zha (1998) is applied to system (6).[25] 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). We first discuss the estimated impulse responses in the normal state and then explore those in the shortfall state.

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[25]The 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, Zha, and Zhong (2016) and Li (2016).

V.2.1. *Normal state.* Figure 4 displays the corresponding impulse response of GDP with probability bands. Impulse responses of other macroeconomic variables are displayed in Figure 5. From Figures 4 and 5 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 earlier conclusion that the estimated monetary policy shock does not contain endogenous responses to other macroeconomic variables.[26] 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.[27]

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. The normal interest-rate channel plays little role in the monetary transmission for 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 4). 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 6 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

[26]A 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).

[27]The 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, Spiegel, and Swanson (2014)'s emphasis on the role of reserve requirements in influencing macroeconomic fluctuations in China.

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 7 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.[28] 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, Eichenbaum, and Evans, 2005).

Our finding is also confirmed by the estimated variance decompositions attributable to monetary policy shocks relative to other shocks. As reported in Table 2, 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 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.

V.2.2. *Shortfall state.* Figures 8 and 9 display the estimated impulse responses in the shortfall state.[29] 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

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[28]The 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.

[29]We 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.

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 8 shows, is again through MLT bank loans. The estimation obtained in Section III reveals that the volatility of monetary policy shocks in the shortfall state is twice that in the normal state, 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 channelled disproportionally 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.

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 2). 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.

VI. Quantity-based monetary policy and institutional rigidities

Recent discussions of China monetary policy entertain a major reform of moving gradually away from control of M2 growth as a major policy tool 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.[30] While most discussions focus on

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[30]For 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

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 towards interest rate-based policy rules is the perceived increasing ineffectiveness of M2 growth in recent years as the major policy instrument. 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.

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 4). 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.[31]

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.

Continuation of these institutional constraints represents what we call institutional rigidies, 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 rigidies, the government must be willing to cease preferential credit policy to

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were still under strict control of the government. Liberalization of the overall financial market has been slow in China even up to today.

[31]This 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).

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.[32] 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.

VII. Conclusion

As remarked by Governor Zhou of the PBC, China monetary policy is yet to be understood by the outside world. To this end, we establish a monetary policy rule that is tractable for practical analysis and at the same time representative to capture key institutional characteristics. We find that for a long time the central bank of China has been using M2 growth as the major tool to support output growth and control inflation. The systematic response of the estimated rule to the state of the economy is successful in tracking the actual M2 growth path over the sample period. The effect on the economy of this pro-growth policy 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 rule is its asymmetric response to the state of the economy. When actual GDP growth falls short of the government's target, monetary policy reacts more aggressively than in normal times. Consequently, monetary policy shocks in the shortfall state contribute twice as much to the GDP fluctuation as those in the normal state.

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[32]The 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.

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 designing and implementing transitional paths toward a new monetary policy framework. 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. We hope that our empirical analysis serves as a first step toward stimulating a more comprehensive study on China monetary policy.
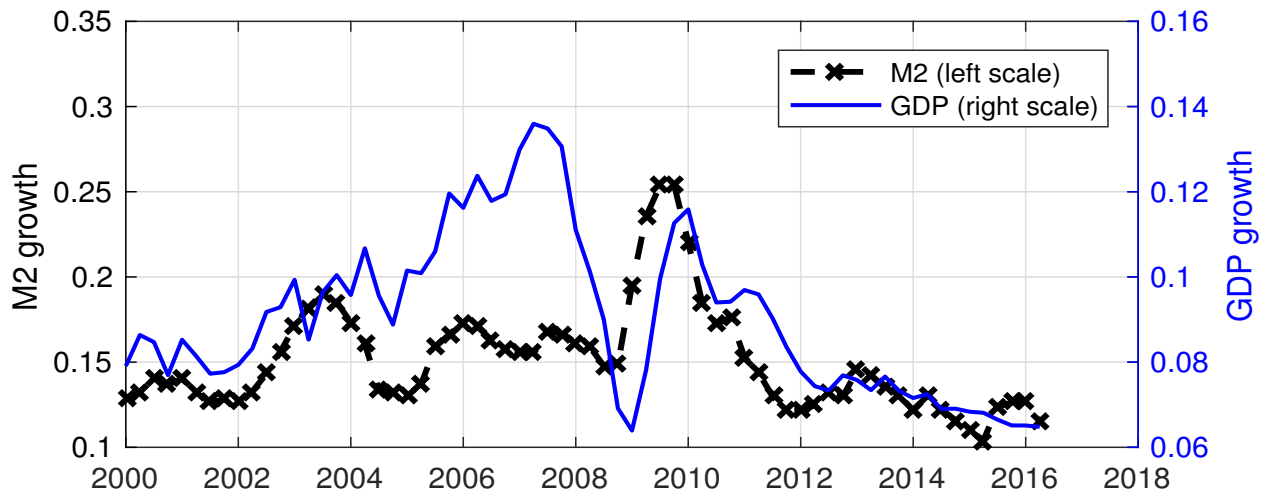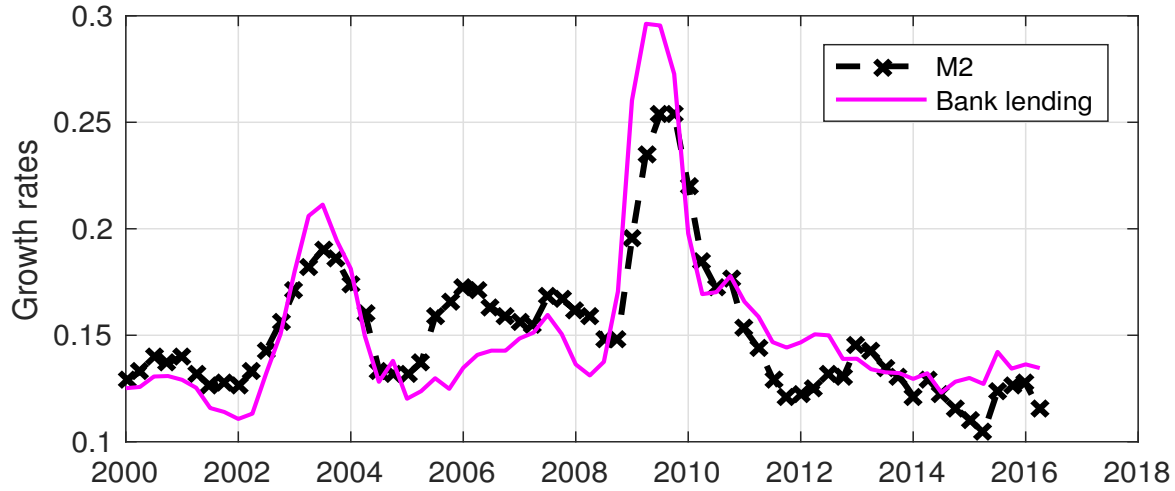
FIGURE 1. Growth rates are expressed as annual rates (year over year) at quarterly frequency. The contemporaneous correlation between M2 growth and bank loan growth is 0.86 (0.89 since 2009). The contemporaneous correlation between M2 growth and real GDP growth is 0.50 (0.87 since 2009).
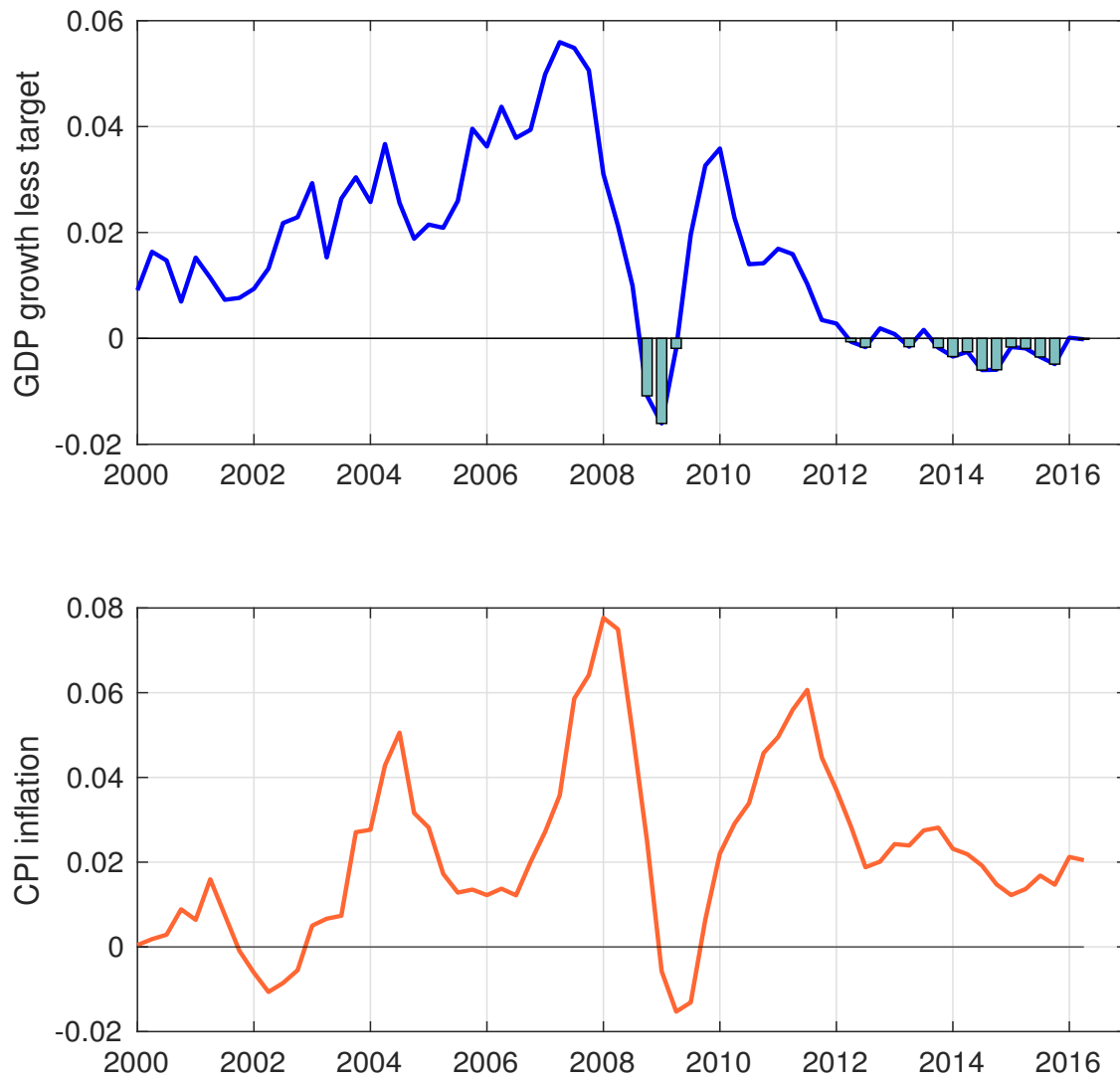
FIGURE 2. Top panel: annual real GDP growth rate minus the growth target set by the State Council. The bar areas mark periods in which an actual GDP growth rate is less than the GDP growth target. Bottom panel: annual CPI inflation rate.

FIGURE 3. Annual M2 growth rates and the estimated systematic (endogenous) response of monetary policy. The gap between the actual M2 growth path and the systematic response path represents the series of 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.

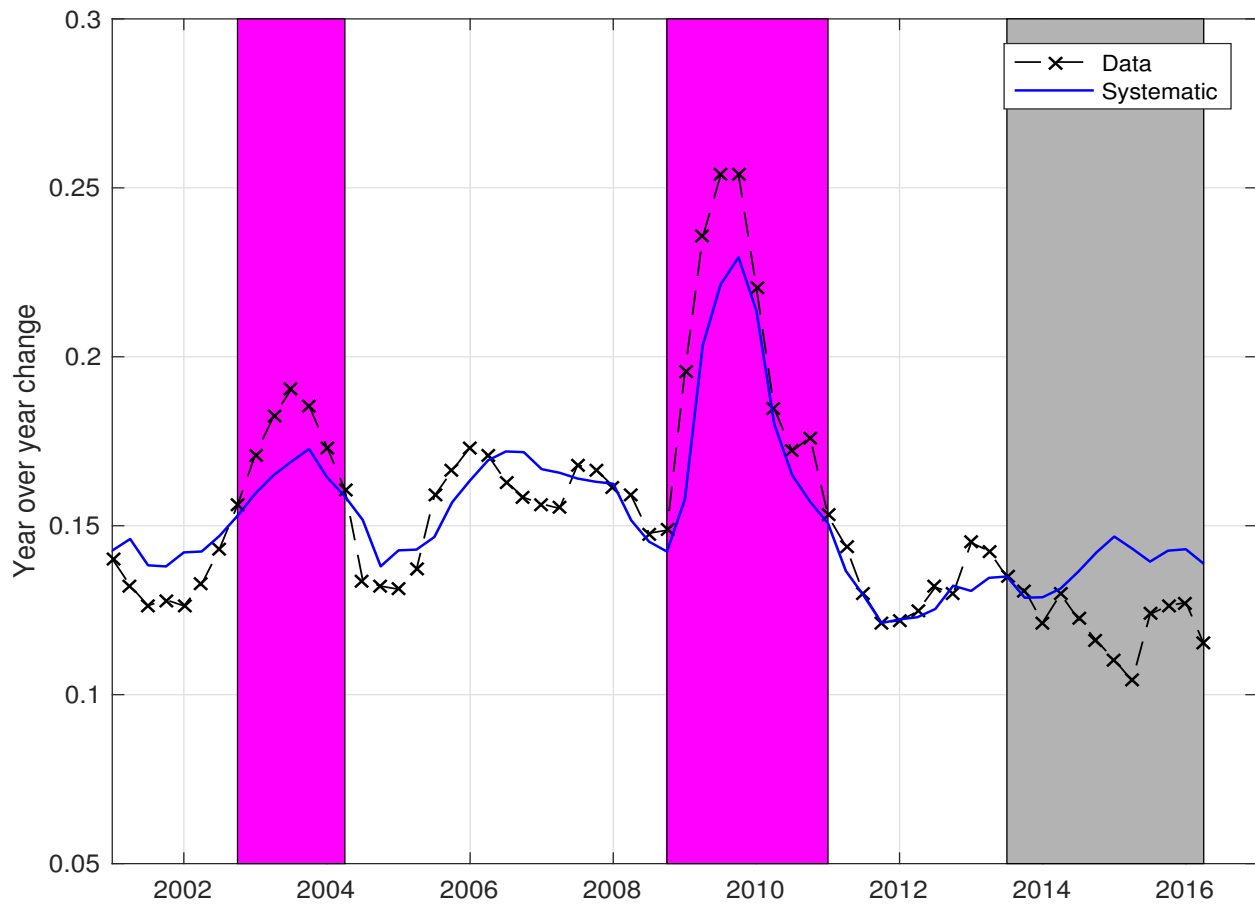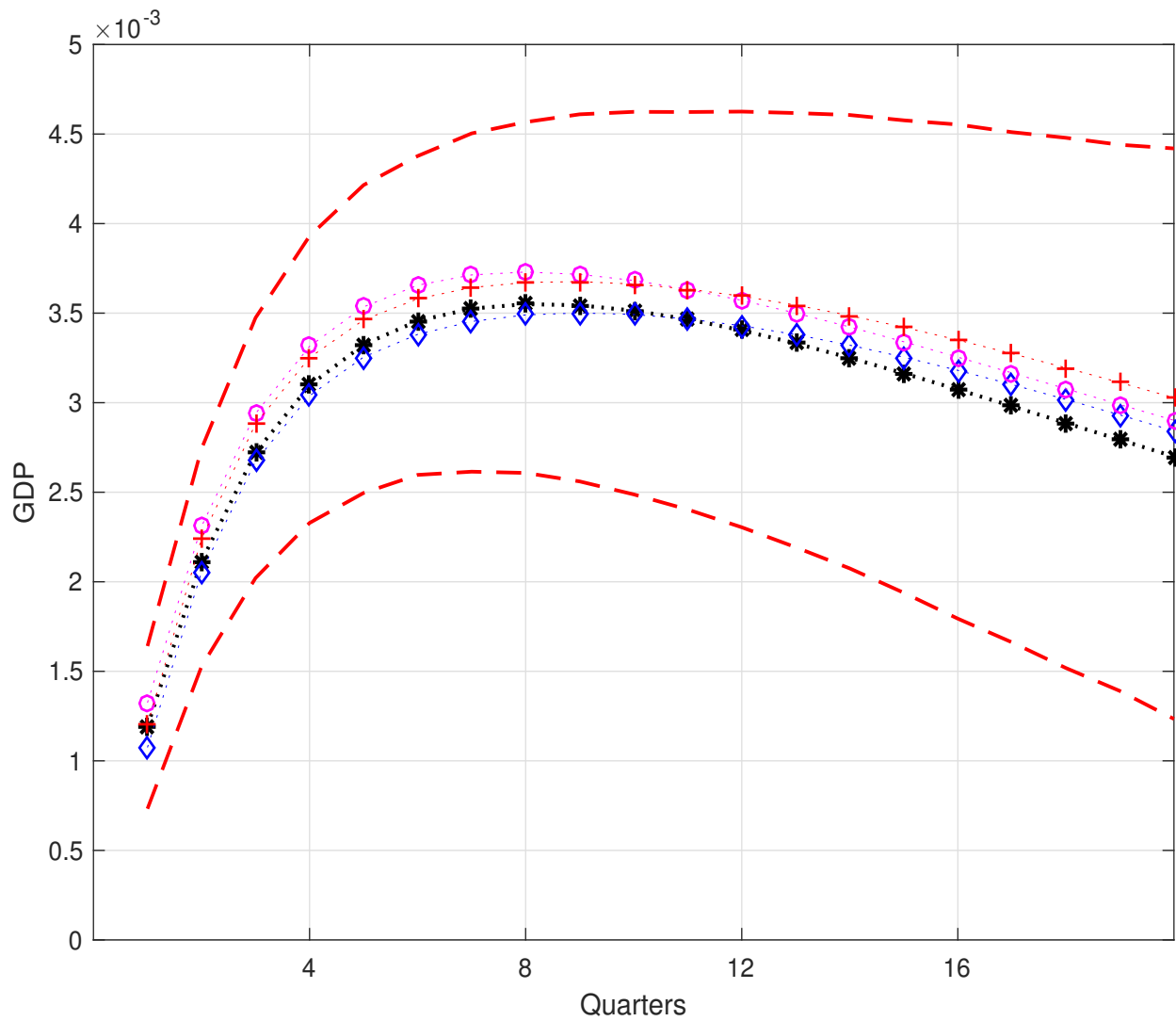FIGURE 4. Dynamic responses of real GDP to a one-standard-deviation positive monetary policy shock. The asterisk line represents the response estimated from the benchmark SVAR and dashed lines represent the corresponding .68 probability bands. The diamond line represents the response estimated from the 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 5. 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.
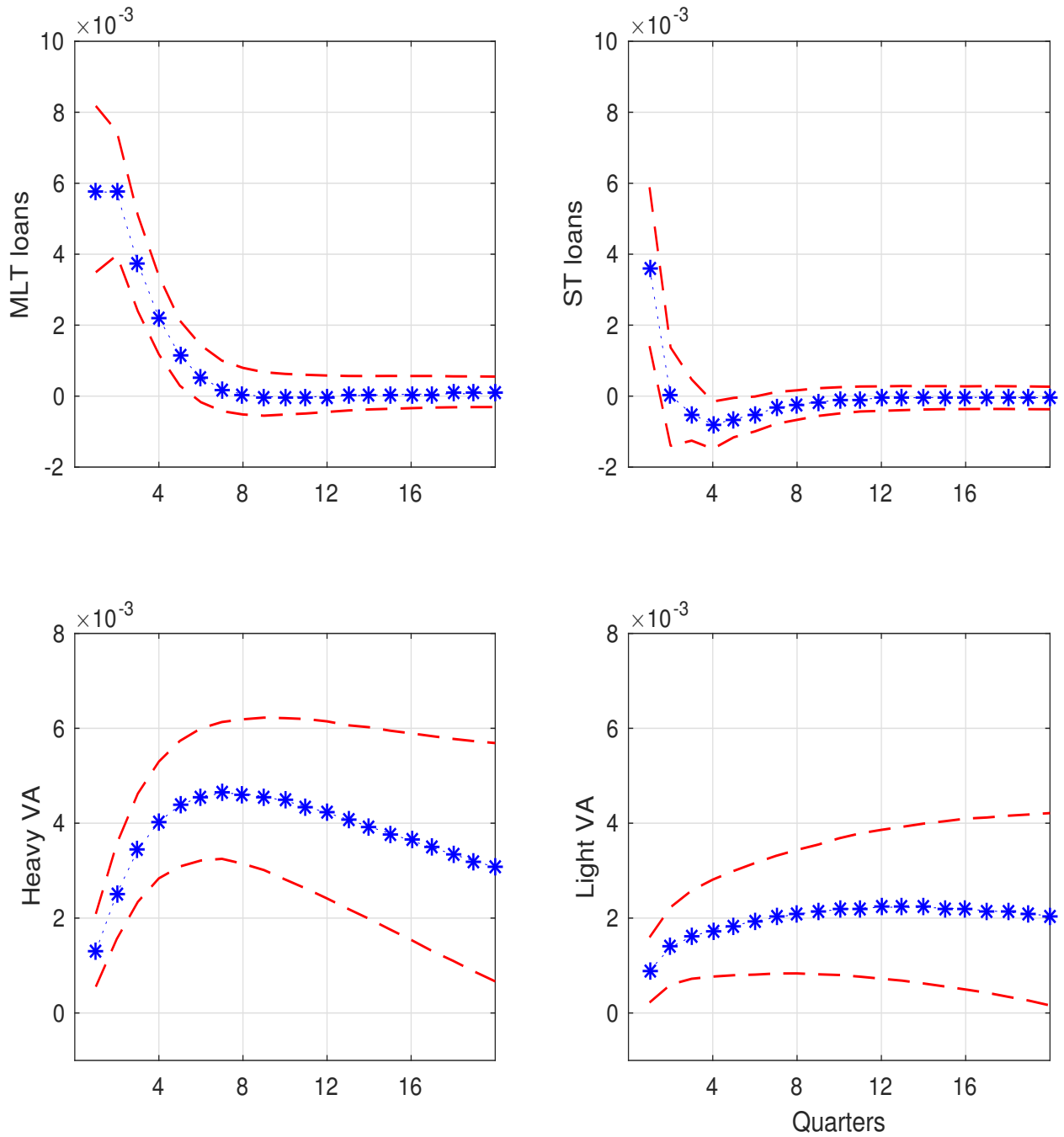
FIGURE 6. Dynamic responses to a one-standard-deviation positive monetary policy shock: medium and long term bank loans (MLT loans), short term bank loans (ST loans), value-added output produced from heavy industries (heavy VA), and value-added output produced from light industries (light VA). Asterisk lines represent the estimated responses and dashed lines represent the corresponding .68 probability bands.
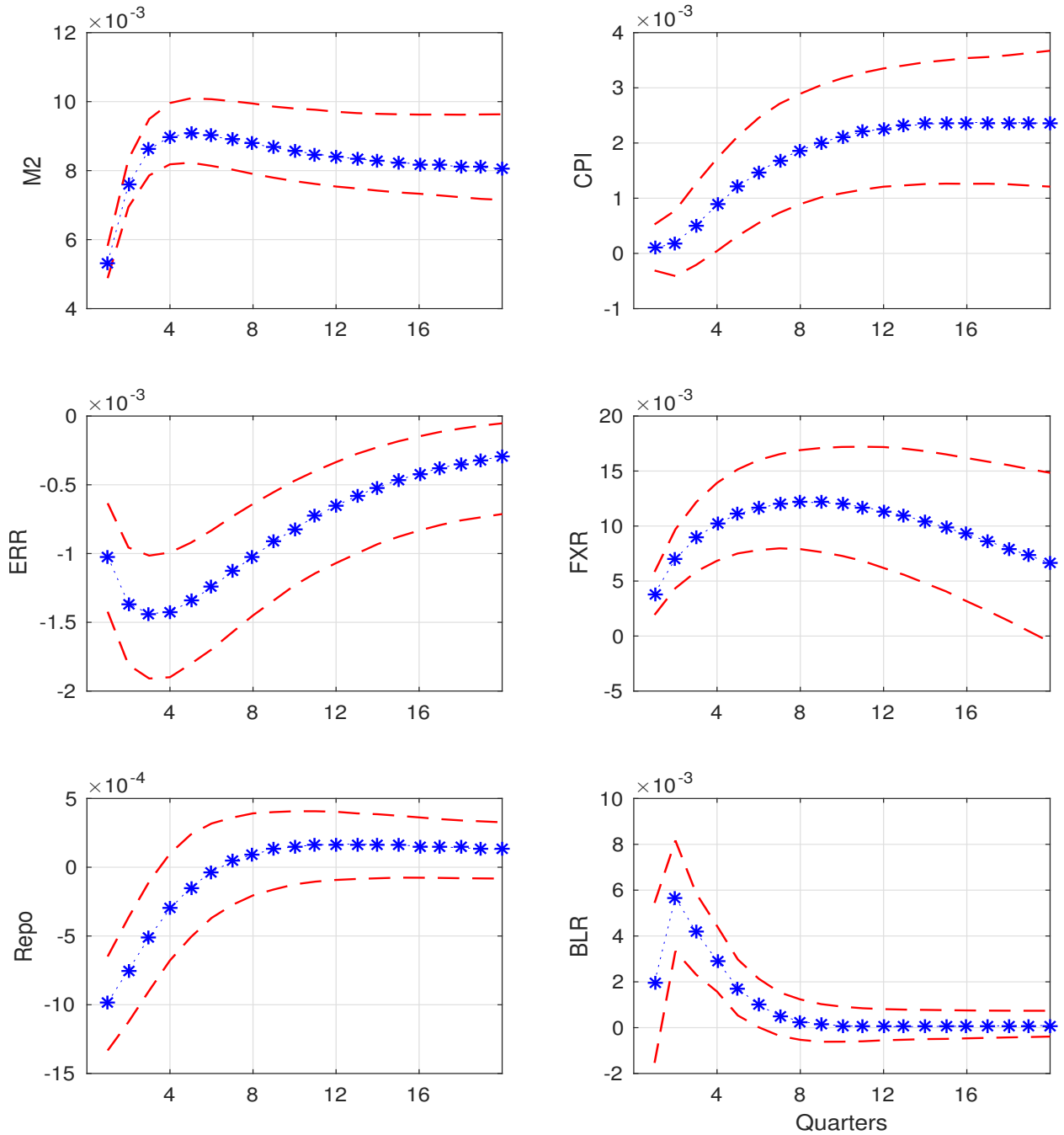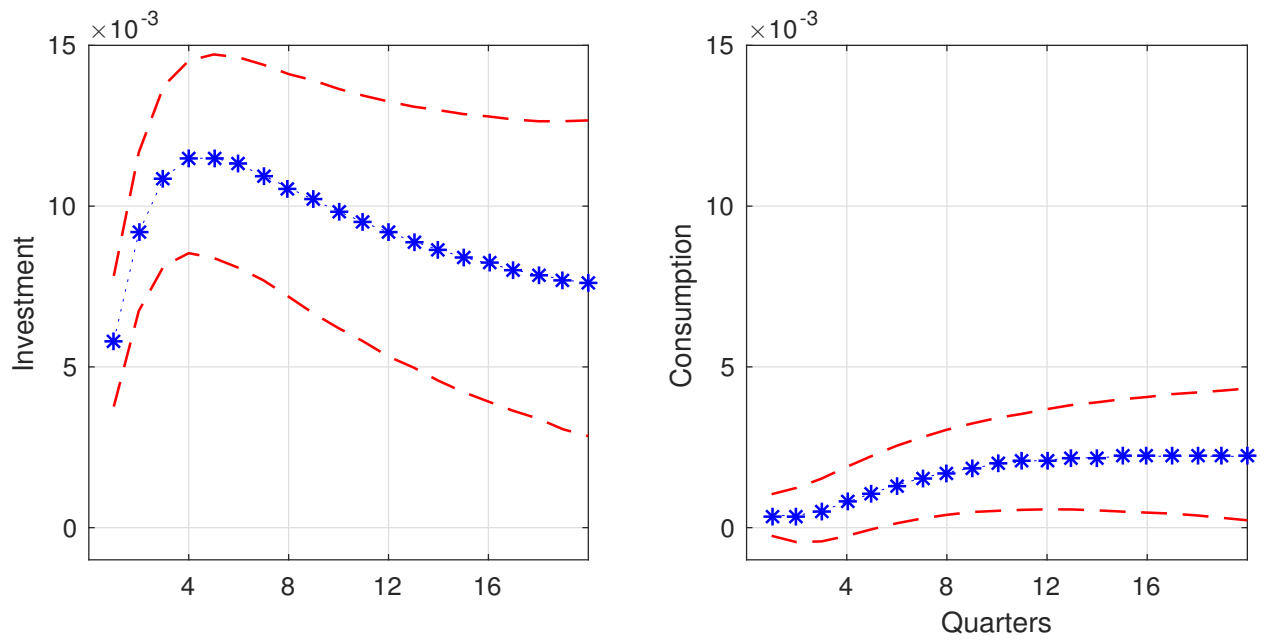
FIGURE 7. Dynamic responses of investment and consumption to a one-standard-deviation positive monetary policy shock. Asterisk lines represent the estimated responses and dashed lines represent the corresponding .68 probability bands.
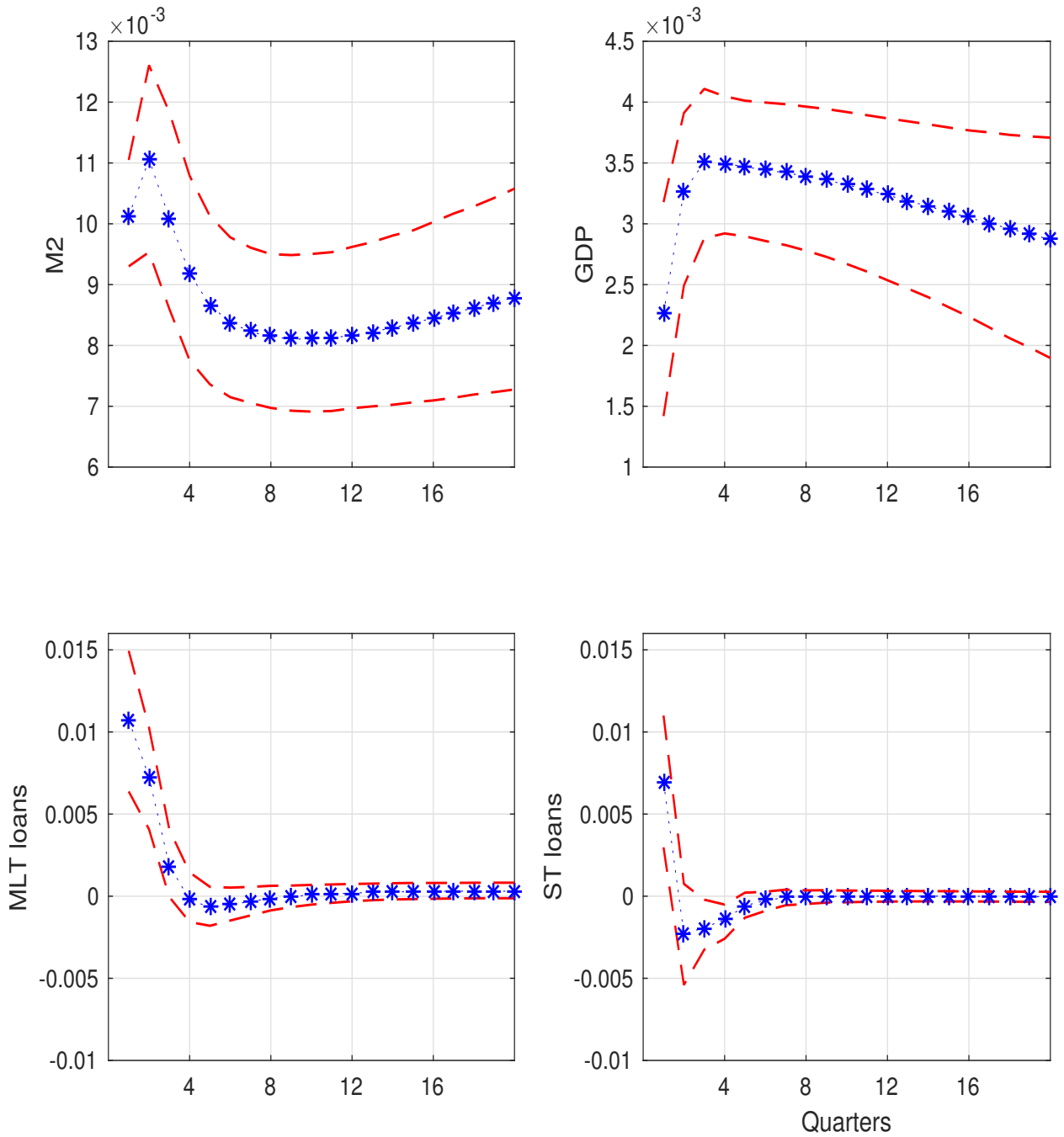
FIGURE 8. Dynamic responses to a one-standard-deviation positive monetary policy shock in the shortfall state. Asterisk lines represent the estimated responses and dashed lines represent the corresponding .68 probability bands.
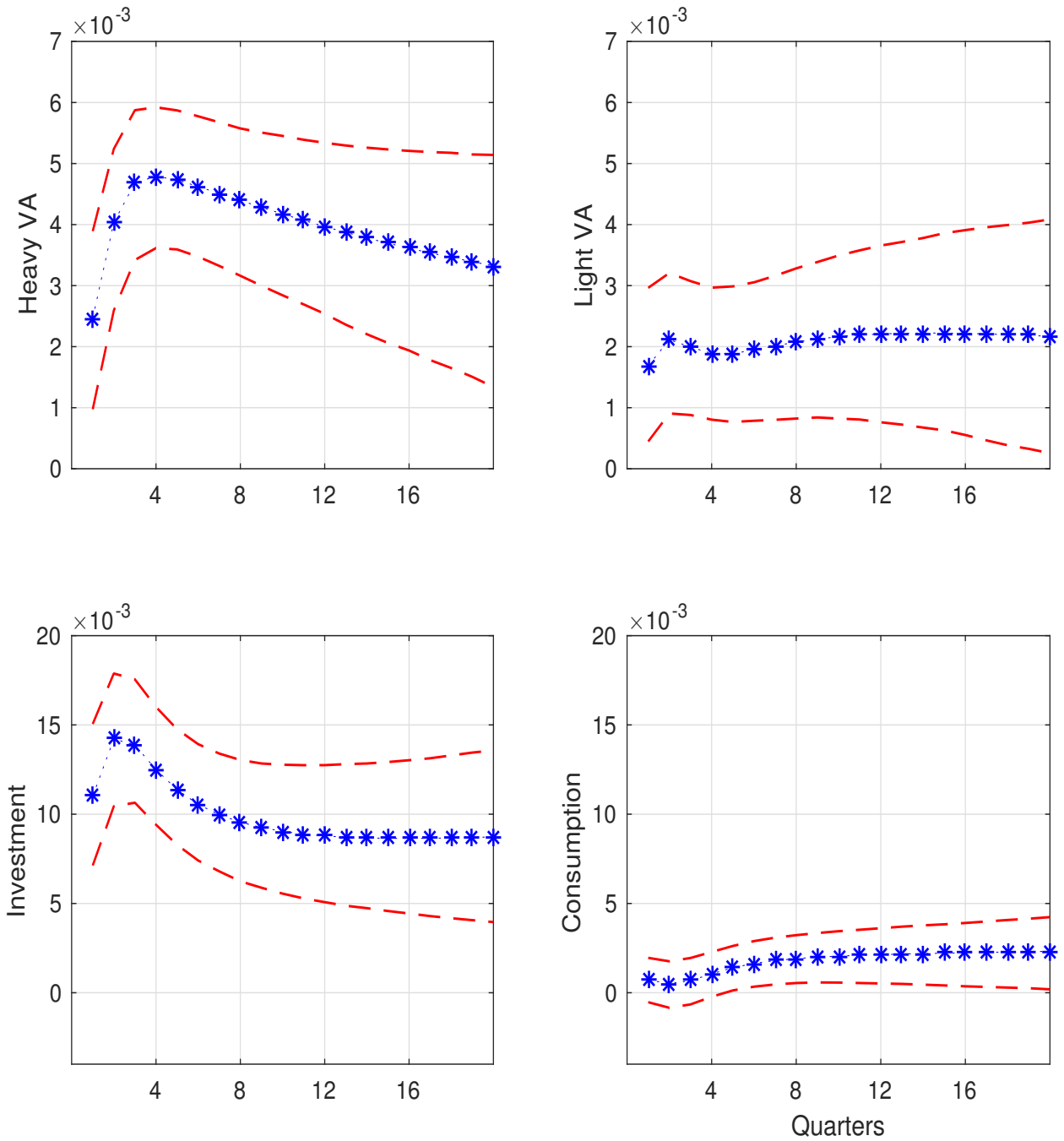
FIGURE 9. Dynamic responses to a one-standard-deviation positive monetary policy shock in the shortfall state. Asterisk lines represent the estimated responses and dashed lines represent the corresponding .68 probability bands.

TABLE 1. Estimated monetary policy

Coefficient	Estimate	SE	p-value
γ_m	0.391***	0.101	0.000
γ_π	−0.397***	0.121	0.001
$\gamma_{x,a}$	0.183***	0.060	0.002
$\gamma_{x,b}$	−1.299***	0.499	0.009
$\sigma_{m,a}$	0.005***	0.001	0.000
$\sigma_{m,b}$	0.010***	0.002	0.000

Note. "SE" stands for standard error. The three-star superscript indicates a 1% significance level.

TABLE 2. 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.

Appendix A. Optimal monetary policy

In this section we derive optimal monetary policy under two alternative loss functions. We first consider the pro-growth loss function composed of (3) and (5). Optimal policy is to choose $\{g_{x,t}, \pi_t, g_{m,t}\}_{t=0}^{\infty}$ to minimize the loss function

$$E_0 \sum_{t=0}^{\infty} \beta^t L_t, \tag{A.1}$$

subject to the three structural equations

$$g_{m,t} - \pi_t = \eta_x g_{x,t} - \eta_R (R_t - R_{t-1}), \tag{A.2}$$

$$E_t g_{x,t+1} = \theta_x g_{x,t} + \theta_1 E_t (R_{t+1} - \pi_{t+1}) + \theta_2 (R_t - \pi_t) + \varepsilon_{x,t}, \tag{A.3}$$

$$E_t \pi_{t+1} = \kappa_\pi \pi_t + \kappa_1 E_t \left(g_{x,t+1} - g_{x,t+1}^*\right) + \kappa_2 \left(g_{x,t} - g_{x,t}^*\right) + \varepsilon_{\pi,t}, \tag{A.4}$$

where R_t is the net nominal interest rate, $g_{x,t}^* = x_t^* - x_{t-1}$, and $g_{x,t} = x_t - x_{t-1}$. As a result, $g_{x,t} - g_{x,t}^* = x_t - x_t^*$. Note that $\theta_x > 0$ and $\kappa_\pi > 0$.

Equation $(A.2)$ comes from the standard money demand function (e.g., Blanchard and Fischer (1989)). Equation $(A.3)$ is obtained from the consumer's Euler equation. Both equations are expressed in first difference to allow $g_{x,t}$ to be an explicit choice variable.

Equation $(A.4)$ is a variant of the Philips curve.[33] It is intuitive that an inflation rate is positively related to GDP growth in the current quarter, as implied by the upward sloping aggregate supply curve. Different from the standard Philips curve, however, equation $(A.4)$ implies that current inflation is also related to future GDP growth, which reflects firms' pricing strategies in customer markets (Gilchrist, Schoenle, Sim, and Zakrajsek, 2016). The intuition is as follows: if a firm expects greater benefits from the future customer base (or consumption habit), it is more willing to lower the current price to build the customer base.

We now show that optimal monetary policy under a certain parameter configuration delivers a functional form that is the same as the systematic component of our descriptive monetary policy rule:

$$\gamma_0 + \gamma_m g_{m,t-1} + \gamma_\pi \pi_{t-1} + \gamma_{x,t} \left(g_{x,t-1} - g_{x,t-1}^*\right),$$

---

[33]We derive Equation $(A.4)$ from the inflation dynamics equation

$$\pi_t = \alpha_0 E_t \pi_{t+1} + \alpha_1 (x_t - x_t^*) + \alpha_2 E_t \left(x_{t+1} - x_{t+1}^*\right) + \epsilon_{\pi,t}.$$

Reordering the above equation and using $x_t - x_t^* = g_{x,t} - g_{x,t}^*$, we have

$$E_t \pi_{t+1} = \frac{1}{\alpha_0} \pi_t - \frac{\alpha_2}{\alpha_0} E_t \left(g_{x,t+1} - g_{x,t+1}^*\right) - \frac{\alpha_1}{\alpha_0} \left(g_{x,t} - g_{x,t}^*\right) - \frac{1}{\alpha_0} \epsilon_{\pi,t}.$$

Defining $\kappa_\pi \equiv \frac{1}{\alpha_0}, \kappa_1 \equiv -\frac{\alpha_2}{\alpha_0}, \kappa_2 \equiv -\frac{\alpha_1}{\alpha_0}$, and $\varepsilon_{\pi,t} = -\frac{1}{\alpha_0} \epsilon_{\pi,t}$, we obtain Equation $(A.4)$.

where the output coefficient is time-varying as

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

Note that all right hand variables are lagged one period relative to money growth $g_{m,t}$ in the systematic component.

Without loss of generality, we follow the convention and solve for optimal monetary policy under perfect foresight.

Proposition A.1. Under the parameter configuration such that $\theta_1 = -\theta_2$ and $\frac{\kappa_2}{\kappa_1} = -\kappa_\pi$ and within the growth region $g_{x,t-1} - g^*_{x,t-1} < b^*$, optimal monetary policy for the planner problem $(A.1)$ has the form

$$
g_{m,t} = \gamma_0 + \gamma_m g_{m,t-1} + \gamma_\pi \pi_{t-1} + \gamma_{x,t} \left(g_{x,t-1} - g^*_{x,t-1} \right), \tag{A.5}
$$

where $\gamma_\pi < 0$ and the output coefficient is time-varying as

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

Proof. Reordering Equation $(A.2)$ and forwarding one period, we have

$$
R_{t+1} - R_t = \frac{\eta_x}{\eta_R} g_{x,t+1} - \frac{1}{\eta_R} g_{m,t+1} + \frac{1}{\eta_R} \pi_{t+1} \tag{A.6}
$$

Using the assumption $\theta_1 = -\theta_2$, substituting $(A.6)$ into $(A.3)$ and reordering the terms, we obtain

$$
g_{x,t+1} = \frac{\theta_x}{1 - \eta_x\theta_1/\eta_R} g_{x,t} - \frac{\theta_1/\eta_R}{1 - \eta_x\theta_1/\eta_R} g_{m,t+1} + \frac{\theta_1/\eta_R - \theta_1}{1 - \eta_x\theta_1/\eta_R} \pi_{t+1} - \frac{\theta_2}{1 - \eta_x\theta_1/\eta_R} \pi_t + \widetilde{\varepsilon}_{x,t}, \tag{A.7}
$$

where $\widetilde{\varepsilon}_{x,t} = \varepsilon_{x,t} / \left(1 - \eta_x\theta_1/\eta_R \right)$.

With the Lagrangian multipliers $\mu_{1,t}$ for $(A.4)$ and $\mu_{2,t}$ for $(A.7)$, the planner's problem becomes minimizing

$$
\sum_{t=0}^{\infty} \beta^t \left\{ \begin{array}{l} \frac{1}{2} \left[(1-\phi) \lambda L^x_t + \phi\lambda \left(\pi_t - \pi^* \right)^2 + \left(g_{m,t} - g^*_m \right)^2 \right] \\ + \mu_{1,t} \left[\pi_{t+1} - \kappa_\pi \pi_t - \kappa_1 \left(g_{x,t+1} - g^*_{x,t+1} \right) - \kappa_2 \left(g_{x,t} - g^*_{x,t} \right) - \varepsilon_{\pi,t} \right] \\ + \mu_{2,t} \left[g_{x,t+1} - \frac{\theta_x}{1-\eta_x\theta_1/\eta_R} g_{x,t} + \frac{\theta_1/\eta_R}{1-\eta_x\theta_1/\eta_R} g_{m,t+1} - \frac{\theta_1/\eta_R-\theta_1}{1-\eta_x\theta_1/\eta_R} \pi_{t+1} + \frac{\theta_2}{1-\eta_x\theta_1/\eta_R} \pi_t - \widetilde{\varepsilon}_{x,t} \right] \end{array} \right\} .
$$

The first order conditions with respect to $\pi_t, g_{x,t}$, and $g_{m,t}$ are

$$
\phi\lambda \left(\pi_t - \pi^* \right) - \kappa_\pi \mu_{1,t} + \frac{\theta_2}{1 - \eta_x\theta_1/\eta_R} \mu_{2,t} + \beta^{-1} \mu_{1,t-1} - \beta^{-1} \frac{\theta_1/\eta_R - \theta_1}{1 - \eta_x\theta_1/\eta_R} \mu_{2,t-1} = 0, \tag{A.8}
$$

$$
g_{m,t} - g^*_m + \beta^{-1} \frac{\theta_1/\eta_R}{1 - \eta_x\theta_1/\eta_R} \mu_{2,t-1} = 0, \tag{A.9}
$$

$$
(1-\phi)\lambda \frac{\partial L^x_t}{\partial g_{x,t}} - \kappa_2 \mu_{1,t} - \frac{\theta_x}{1 - \eta_x\theta_1/\eta_R} \mu_{2,t} - \beta^{-1} \kappa_1 \mu_{1,t-1} + \beta^{-1} \mu_{2,t-1} = 0, \tag{A.10}
$$

where

$$\frac{\partial L_t^x}{\partial g_{x,t}} = \delta_t \left(g_{x,t} - g_{x,t}^* \right). \tag{A.11}$$

Reordering $(A.8)$ and $(A.10)$, we obtain

$$\beta^{-1} \mu_{1,t-1} - \kappa_\pi \mu_{1,t} = -\phi\lambda \left(\pi_t - \pi^* \right) - \frac{\theta_2}{1 - \eta_x \theta_1/\eta_R} \mu_{2,t} + \beta^{-1} \frac{\theta_1/\eta_R - \theta_1}{1 - \eta_x \theta_1/\eta_R} \mu_{2,t-1}, \tag{A.12}$$

$$\beta^{-1} \mu_{1,t-1} + \frac{\kappa_2}{\kappa_1} \mu_{1,t} = \frac{1}{\kappa_1} \left[(1-\phi)\lambda \frac{\partial L_t^x}{\partial g_{x,t}} - \frac{\theta_x}{1 - \eta_x \theta_1/\eta_R} \mu_{2,t} + \beta^{-1} \mu_{2,t-1} \right]. \tag{A.13}$$

Because $\frac{\kappa_2}{\kappa_1} = -\kappa_\pi$, we combine $(A.12)$ and $(A.13)$ and reorder the terms to obtain

$$\left[\frac{\theta_2}{1 - \eta_x \theta_1/\eta_R} - \frac{1}{\kappa_1} \frac{\theta_x}{1 - \eta_x \theta_1/\eta_R} \right] \mu_{2,t} = -\frac{(1-\phi)\lambda}{\kappa_1} \frac{\partial L_t^x}{\partial g_{x,t}} - \phi\lambda\pi_t +$$

$$\phi\lambda\pi^* + \left[\frac{\theta_1/\eta_R + \theta_1}{1 - \eta_x \theta_1/\eta_R} - \frac{1}{\kappa_1} \right] \beta^{-1} \mu_{2,t-1}. \tag{A.14}$$

Equation $(A.9)$ gives

$$\beta^{-1} \mu_{2,t-1} = -\frac{1 - \eta_x \theta_1/\eta_R}{\theta_1/\eta_R} \left(g_{m,t} - g_m^* \right). \tag{A.15}$$

Substituting $(A.15)$ into $(A.14)$ and reordering the terms, we have

$$\beta \frac{-\theta_2 + \theta_x/\kappa_1}{\theta_1/\eta_R} \left(g_{m,t+1} - g_m^* \right) = -\frac{(1-\phi)\lambda}{\kappa_1} \frac{\partial L_t^x}{\partial g_{x,t}} - \phi\lambda\pi_t + \phi\lambda\pi^*$$

$$+ \left[\frac{(1 - \eta_x \theta_1/\eta_R)/\kappa_1 - (\theta_1/\eta_R + \theta_1)}{\theta_1/\eta_R} \right] \left(g_{m,t} - g_m^* \right). \tag{A.16}$$

or

$$g_{m,t+1} = -\frac{(1-\phi)\lambda}{\kappa_1} \frac{\theta_1/\eta_R}{\beta \left(-\theta_2 + \theta_x/\kappa_1 \right)} \delta_t \left(g_{x,t} - g_{x,t}^* \right)$$

$$-\frac{\phi\lambda\theta_1/\eta_R}{\beta \left(-\theta_2 + \theta_x/\kappa_1 \right)} \pi_t + \left[\frac{(1 - \eta_x \theta_1/\eta_R)/\kappa_1 - (\theta_1/\eta_R - \theta_1)}{\beta \left(-\theta_2 + \theta_x/\kappa_1 \right)} \right] g_{m,t}$$

$$+ g_m^* \left(1 - \frac{(1 - \eta_x \theta_1/\eta_R)/\kappa_1 - (\theta_1/\eta_R + \theta_1)}{\beta \left(-\theta_2 + \theta_x/\kappa_1 \right)} \right) + \frac{\phi\lambda\theta_1/\eta_R}{\beta \left(-\theta_2 + \theta_x/\kappa_1 \right)} \pi^*. \tag{A.17}$$

Define

$$\gamma_m = \frac{(1 - \eta_x \theta_1/\eta_R)/\kappa_1 - (\theta_1/\eta_R + \theta_1)}{\beta \left(-\theta_2 + \theta_x/\kappa_1 \right)}$$

$$\gamma_\pi = -\frac{\phi\lambda\theta_1/\eta_R}{\beta \left(-\theta_2 + \theta_x/\kappa_1 \right)},$$

$$\gamma_0 = (1 - \gamma_m) g_m^* - \gamma_\pi \pi^*,$$

$$\gamma_{x,t} = \begin{cases} \gamma_{x,a} = \frac{(1-\phi)\lambda}{\kappa_1} \frac{\theta_1/\eta_R}{\beta(-\theta_2+\theta_x/\kappa_1)} \delta_a & \text{if } g_{x,t} - g_{x,t}^* \geq 0 \\ \gamma_{x,b} = -\frac{(1-\phi)\lambda}{\kappa_1} \frac{\theta_1/\eta_R}{\beta(-\theta_2+\theta_x/\kappa_1)} \delta_b & \text{if } g_{x,t} - g_{x,t}^* < 0 \end{cases}.$$

By moving the time script backward one period, we obtain the monetary policy rule as in $(A.5)$.

To determine the coefficient signs for the derived optimal policy, note that $\eta_x > 0$ and $\eta_R > 0$ for the money demand equation $(A.2)$ because money demand increases with aggregate output and decreases with the nominal interest rate. For the IS-curve equation (A.3), we have $\theta_1 > 0$ and $\theta_2 < 0$ because consumption growth in the current period moves positively with the real interest rate in the current period and consumption growth in the future and negatively with the real interest rate in the future. For the inflation dynamics equation (A.4), $\kappa_1 > 0$ reflects firms' pricing strategies in customer markets (Gilchrist, Schoenle, Sim, and Zakrajsek, 2016).[34] Accordingly, we have

$$\gamma_\pi = -\frac{\phi\lambda\theta_1/\eta_R}{\beta\left(-\theta_2 + \theta_x/\kappa_1\right)} < 0,$$

$$\gamma_{x,a} = \frac{(1-\phi)\lambda}{\kappa_1}\frac{\theta_1/\eta_R}{\beta\left(-\theta_2 + \theta_x/\kappa_1\right)}\delta_a > 0,$$

$$\gamma_{x,b} = -\frac{(1-\phi)\lambda}{\kappa_1}\frac{\theta_1/\eta_R}{\beta\left(-\theta_2 + \theta_x/\kappa_1\right)}\delta_b < 0.$$

Moreover, given $\delta_b > \delta_a$, we have $|\gamma_{x,b}| > |\gamma_{x,a}|$ as found empirically. □

Now consider the conventional function (2) for output loss. We have $\frac{\partial L_t^x}{\partial g_{x,t}} = \delta\left(g_{x,t} - g_{x,t}^*\right)$. Substituting this term into $(A.16)$ and reordering the terms, we obtain the conventional form of optimal monetary policy as

$$\begin{aligned}
g_{m,t+1} = &\left[\frac{(1 - \eta_x\theta_1/\eta_R)/\kappa_1 - (\theta_1/\eta_R - \theta_1)}{\beta\left(-\theta_2 + \theta_x/\kappa_1\right)}\right] g_{m,t} \\
&- \frac{\phi\lambda\theta_1/\eta_R}{\beta\left(-\theta_2 + \theta_x/\kappa_1\right)}\left(\pi_t - \pi^*\right) + \gamma_x\left(g_{x,t} - g_{x,t}^*\right) \\
&+ g_m^*\left(1 - \frac{(1 - \eta_x\theta_1/\eta_R)/\kappa_1 - (\theta_1/\eta_R + \theta_1)}{\beta\left(-\theta_2 + \theta_x/\kappa_1\right)}\right),
\end{aligned} \quad (A.18)$$

where $\gamma_x = -\frac{(1-\phi)\lambda}{\kappa_1}\frac{\theta_1/\eta_R}{\beta(-\theta_2+\theta_x/\kappa_1)}\delta$. It is straightforward to see that γ_x is always negative, even in the normal state when $g_{x,t} > g_{x,t}^*$, a result at odds with our empirical finding for China.

APPENDIX B. CONVENTIONAL MONETARY POLICY RULE SPECIFICATIONS

As discussed in the text, there is no applicable concept of potential GDP for emerging-market economies like China. Nonetheless, if one wishes to estimate conventional monetary policy rules mechanically with the Chinese data, one could obtain $\bar{x}_t$ using either the HP filtered series with the smoothing parameter set at 1600 for the quarterly series or the fitted log-linear trend. We estimate the conventional monetary policy rule (4) using "output gap" constructed from one of the these trended series. Table B.1 reports the regression results. As one can see, the estimated coefficient of "output gap" is statistically insignificant for the HP

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[34]Given $\kappa_\pi > 0$ and $\kappa_1 > 0$, we have $\kappa_2 < 0$, consistent with the original inflation dynamics equation in footnote 33 in which both α_0 and α_1 are positive.

TABLE B.1. Estimation of conventional monetary policy rules for M2 growth

Coefficient	HP filtered			Log-linear detrended			$\bar{g}_{x,t} = g_{x,t}^*$		
	Estimate	SE	p-value	Estimate	SE	p-value	Estimate	SE	p-value
γ_m	0.607***	0.095	0.000	0.514***	0.096	0.000	0.568***	0.093	0.000
γ_π	−0.551***	0.191	0.005	−0.628***	0.155	0.000	−0.554***	0.159	0.000
γ_x	0.131	0.142	0.358	0.085***	0.032	0.009	0.094	0.063	0.138

Note. "SE" stands for standard error. The three-star superscript indicates a 1% significance level.

filtered approach or carries a wrong sign for the log-linear detrending method. The positive sign of output coefficient implies destabilizing monetary policy. These results confirm our argument that the standard concept of output gap is inappropriate for understanding China monetary policy.

We also estimate the conventional monetary policy rule (4) using $\bar{g}_{x,t} = g_{x,t}^*$, which is consistent with optimal monetary policy under the output loss function represented by (2). The estimates are also reported in Table B.1. As seen in the table, their magnitude is remarkably similar to that when potential GDP is approximated by either HP filter or log-linear trend. What is common across the three cases (HP filter, log-linear trend, and $\bar{g}_{x,t} = g_{x,t}^*$) is that monetary policy is strongly anti-inflation. But the output coefficient for the $\bar{g}_{x,t} = g_{x,t}^*$ case has a wrong sign and is statistically insignificant.

Another conventional specification for monetary policy is the widely-used empirical Taylor rule for many developed economies as described in Rotemberg and Woodford (1997):

$$R_t = \alpha_0 + \alpha_R R_{t-1} + \alpha_\pi \left(\pi_t - \pi^* \right) + \alpha_x \left(x_t - \bar{x}_t \right) + \varepsilon_{R,t}, \tag{B.1}$$

where R_t is the (net) nominal interest rate. Table B.2 reports the estimated results with various short-term market interest rates. As one can see, although the persistence parameter α_R is statistically significant, α_π is statistically insignificant at a 10% level for all four cases while α_x is statistically significant only at a 10% level for three out of four interest rates. These results imply that monetary policy does not care at all about inflation pressures, contradictory to the MPRs (the central bank's own reports). Worse than this implication, these results are unstable as they are sensitive to how potential output is computed. When log-linear trend is applied to output as potential GDP and the 7-day Repo rate is used, for example, the output coefficient becomes statistically insignificant at a 49% significance level but the inflation coefficient is now significant at a 1.6% significance level. When lagged output gap and inflation are used as regressors instead of the contemporaneous counterparts, α_π is often statistically significant at a 1% significance level but α_x is statistically insignificant

TABLE B.2. Estimation of the widely-used Taylor rule

Coefficient	1-day Repo			7-day Repo		
	Estimate	SE	p-value	Estimate	SE	p-value
α_R	0.706***	0.078	0.000	0.770***	0.063	0.000
α_π	0.007	0.103	0.948	0.144	0.098	0.144
α_x	0.139*	0.078	0.079	0.147*	0.076	0.057
Coefficient	1-day Chibor			7-day Chibor		
	Estimate	SE	p-value	Estimate	SE	p-value
α_R	0.707***	0.078	0.000	0.779***	0.063	0.000
α_π	-0.010	0.101	0.919	0.149	0.096	0.123
α_x	0.132*	0.076	0.085	0.117	0.074	0.119

Note. "SE" stands for standard error. The one-star superscript indicates a 10% significance level and the three-star superscript a 1% significance level.

at a 10% significance level, a result similar to the conventional monetary policy rules for M2 growth. Clearly, the results for the interest rate rules are all over the map, depending on which interest rate, which potential output, or which variable (lagged or contemporaneous) is used.

Such unstable and contradictory results are not surprising; they only confirm our argument that Chinese financial markets are yet to be fully developed and that the standard interest rate rule may be incompatible with the central government's ultimate target of *real GDP growth*. This target is achieved by carefully planning M2 growth to support the central government's strategy of allocating medium and long term bank credits to investment in heavy industries. The standard interest rate rule (B.1) does not take into account these key institutional factors.

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, Chen, Waggoner, and Zha (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 indenpendent regressors used to seasonally adjust our quarterly data.[35]

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[35]For 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.

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.
- **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.

Table D.1. 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.

- **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, Chen, Waggoner, and Zha (2016).
- **Light value-added output**. Value-added output produced by light industries (RMB billion), as classified by Chang, Chen, Waggoner, and Zha (2016).

Appendix D. Simple but sufficiently encompassing monetary policy rule

To study the role of the external sector for the effect of monetary policy, one question is whether our exogenous monetary policy shocks may contain endogenous movements in the external sector. 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 D.1 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 4 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.

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.

Appendix E. Proof of Proposition 1

For system (7), we first show that the first equation (the monetary policy rule) is identified. According to Theorem 2 of Rubio-Ramírez, Waggoner, and Zha (2010), this equation is identified if the following condition is satisfied: for $\widetilde{Q}\widehat{A}_{0,t} = \widehat{A}_{0,t}$, where $\widetilde{Q}$ is an orthogonal matrix and $\widehat{A}_{0,t}$ maintains the form of

$$\begin{bmatrix} \widehat{A}_{0,t}^{(1,1)} & \widehat{A}_{0,t}^{(1,2)} \\ \widehat{A}_{0,t}^{(2,1)} & \widehat{A}_{0,t}^{(2,2)} \end{bmatrix} = \begin{bmatrix} \widehat{A}_{0,t}^{(1,1)} & \underset{1\times n}{0} \\ \widehat{A}_{0,t}^{(2,1)} & \widehat{A}_{0,t}^{(2,2)} \end{bmatrix}$$

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

$$\begin{bmatrix} \widetilde{Q}^{(1,1)} & \widetilde{Q}^{(1,2)} \\ \widetilde{Q}^{(2,1)} & \widetilde{Q}^{(2,2)} \end{bmatrix} = \begin{bmatrix} 1 & \underset{1\times n}{0} \\ \underset{n\times 1}{0} & \widetilde{Q}^{(2,2)} \end{bmatrix}. \tag{E.1}$$

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

$$\begin{bmatrix} \widetilde{Q}^{(1,1)}\widetilde{A}_{0,t}^{(1,1)} + \widetilde{Q}^{(1,2)}\widetilde{A}_{0,t}^{(2,1)} & \widetilde{Q}^{(1,2)}\widetilde{A}_{0,t}^{(2,2)} \\ \widetilde{Q}^{(2,1)}\widetilde{A}_{0,t}^{(1,1)} + \widetilde{Q}^{(2,2)}\widetilde{A}_{0,t}^{(2,1)} & \widetilde{Q}^{(2,2)}\widetilde{A}_{0,t}^{(2,2)} \end{bmatrix} = \begin{bmatrix} \widehat{A}_{0,t}^{(1,1)} & \underset{1\times n}{0} \\ \widehat{A}_{0,t}^{(2,1)} & \widehat{A}_{0,t}^{(2,2)} \end{bmatrix}.$$

Since $\widetilde{A}_{0,t}^{(2,2)}$ is invertible for the SVAR system and $\widetilde{Q}^{(1,2)}\widetilde{A}_{0,t}^{(2,2)} = 0$, we have $\widetilde{Q}^{(1,2)} = 0$. Because $\widetilde{Q}$ is an orthogonal matrix, it must be that $\widetilde{Q}^{(2,1)} = 0$. It follows from the orthogonality of $\widetilde{Q}$ that $\widetilde{Q}^{(1,1)} = 1$. These results prove (E.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 (6) is the same as $\widetilde{Q}^{(2,2)}$. Because the first equation of system (8) is identified and the rotation matrix $\widetilde{Q}$ for the whole system satisfies (E.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 (8) 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 F. PROOF OF PROPOSITION 2

To show the first equation in system (7) 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

$$
\underset{(1+n)\times 1}{z_t} = \begin{bmatrix} M_t \\ y_t \end{bmatrix},
$$

the ith row of $\widetilde{A}_{\ell,t}$ by $\tilde{a}_{\ell,t}^i$, and the ith element of $\tilde{c}_t$ by $\tilde{c}_t^i$, where $i = 1,\ldots,1+n$ and $\ell = 0,\ldots,4$. The likelihood (LH) function for system (7) is

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

$$
= \sigma_{m,t}^{-T}\exp\left\{ -\frac{1}{2}\sum_{t=1}^{T}\left[\tilde{a}_{\ell,t}^1 z_t - \tilde{c}_t^1 - \sum_{\ell=1}^{4}\tilde{a}_{\ell,t}^1 z_{t-\ell}\right]^2 \right\} \times
$$

$$
\left|\det(\widetilde{A}_{0,t}^{2,2})\right|^T \exp\left\{ -\frac{1}{2}\sum_{i=2}^{1+n}\sum_{t=1}^{T}\left[\tilde{a}_{0,t}^i z_t - \tilde{c}_t^i - \sum_{\ell=1}^{4}\tilde{a}_{\ell,t}^i z_{t-\ell}\right]^2 \right\}. \qquad \text{(F.1)}
$$

The first part of the right hand side of (F.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 (7) that the second part of the right hand side of (F.1) is

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

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

where the coefficients $\widetilde{A}_{0,t}^{2,2}$, $\tilde{a}_{\ell,t}^i$, and $\tilde{c}_t^i$ are constant across time for $i = 2,\ldots,1+n$. 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 (7), not for the conventional form (8). This important feature ensures that when the prior is applied to the

second part of system (7), the posterior probability density function has exactly the same form as the second part of the right hand side of (F.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 $\widetilde{A}_{0,t}^{2,2} \equiv A_0$, moreover, each equation in the second block of system (F.1) can be estimated independently of other equations.

REFERENCES

BACKUS, D. K., B. R. ROUTLEDGE, AND S. E. ZIN (2005): "Exotic Preferences for Macroeconomists," *NBER Macroeconomics Annual 2004*, 19, 319–390, MIT Press.

BIANCHI, J., AND S. BIGIO (2014): "Banks, Liquidity Management and Monetary Policy," Federal Reserve Bank of Minneapolis Research Department Staff Report 503.

BLANCHARD, O. J., AND S. FISCHER (1989): *Lectures on Macroeconomics.* MIT Press, Cambridge, Massachusetts.

CHANG, C., K. CHEN, D. F. WAGGONER, AND T. ZHA (2016): "Trends and Cycles in China's Macroeconomy," *NBER Macroeconomics Annual 2015*, 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.

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(4), 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.

COGLEY, T., AND A. SBORDONE (2008): "Trend Inflation, Indexation, and Inflation Persistence in the New Keynesian Phillips Curve," *American Economic Review*, 98, 2101–2126.

DEL NEGRO, M., AND F. SCHORFHEIDE (2004): "Priors from General Equilibrium Models for VARs," *International Economic Review*, 45, 643–673.

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(A), 83–103.

FERNANDEZ, R. B. (1981): "A Methodological Note on the Estimation of Time Series," *Review of Economics and Statistics*, 63(3), 471–476.

GILCHRIST, S., R. SCHOENLE, J. SIM, AND E. ZAKRAJSEK (2016): "Inflation Dynamics During the Financial Crisis," Unpublished Manuscript, Boston University.

HAMILTON, J. D. (1994): *Times Series Analysis.* Princeton University Press, Princeton, NJ.

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.

JUSTINIANO, A., AND G. E. PRIMICERI (2008): "The Time Varying Volatility of Macroeconomic Fluctuations," *American Economic Review*, 98(3), 604–641.

LEEPER, E. M., C. A. SIMS, AND T. ZHA (1996): "What Does Monetary Policy Do?," *Brookings Papers on Economic Activity*, 2, 1–78.

LI, H., AND L.-A. ZHOU (2005): "Political Turnover and Economic Performance: the Incentive Role of Personnel Control in China," *Journal of Public Economics*, 89, 1743–1762.

LI, Z. (2016): "Forecasting China's Economy: A Bayesian Approach," Unpublished Manuscript, Emory University.

LUBIK, T. A., AND F. SCHORFHEIDE (2004): "Testing for Indeterminacy: An Application to U.S. Monetary Policy," *American Economic Review*, 94(1), 190–217.

MA, J., AND M. JI (eds.) (2016): *Interest Rate Transmission under the New Monetary Policy Framework (in Chinese)*. China Finance Publishing House, Beijing.

NAKAMURA, E., J. STEINSSON, AND M. LIU (2016): "Are Chinese Growth and Inflation Too Smooth? Evidence from Engel Curves," *American Economic Journal: Macroeconomics*, 8(3), 113–144.

NIE, J. (2016): "Gauging the Strenth of Chinese GDP Growth," *The Macro Bulletin*, pp. 1–3, http://macrobulletin.kcfed.org.

ROTEMBERG, J. J., AND M. WOODFORD (1997): "An Optimization-Based Econometric Framework for the Evaluation of Monetary Policy," in *NBER Macroeconomics Annual*, ed. by B. S. Bernanke, and J. J. Rotemberg, pp. 297–346. The MIT Press, Cambridge (MA).

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), 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(4), 949–968.

SMETS, F., AND R. WOUTERS (2007): "Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach," *American Economic Review*, 97, 586–606.

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, vol. 39, pp. 195–214. Amsterdam.

——— (2000): "Using Monetary Policy Rules in Emerging Market Economies," Unpublished Manuscript, Standford University.

UHLIG, H. (2005): "What are the effects of monetary policy on output? Results from an agnostic identification procedure," *Journal of Monetary Economics*, 52(2), 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(2), 291–316.

ZHOU, X. (2016): "Managing Multi-Objective Monetary Policy: From the Perspective of Transitioning Chinese Economy," Michel Camdessus Central Banking Lecture at International Monetary Fund.

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