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ABSTRACT

We develop a new empirical framework to identify and estimate the effects of monetary stimulus on the real economy. The framework is applied to the Chinese economy when monetary policy in normal times was switched to an extraordinarily expansionary regime to combat the impact of the 2008 financial crisis. We show that this unprecedented monetary stimulus accounted for as high as a 4% increase of real GDP growth rate by the end of 2009. Monetary transmission to the real economy was through bank credit allocated disproportionately to financing investment in real estate and heavy industries. Such an asymmetric credit allocation resulted in the persistently high investment rate and debt-to-GDP ratio. Our findings provide a broad perspective on a tradeoff between short-run GDP growth and longer-run accumulated debt in response to large monetary interventions.

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I. Introduction

In the aftermath of the 2008 global financial crisis, central banks around the world (Federal Reserve System, European Central Bank, Bank of Japan, and People's Bank of China) have initiated massive monetary stimulus in an attempt to combat the crisis and rescue the sagging economy. What are the consequences of such an unusual change of monetary policy on the financial system and the real economy? To answer this important question, one needs an empirical framework to first identify the change of monetary policy and then assess the monetary transmission channel through which the policy change affects the real economy.

In this paper we propose such a framework and apply it to the Chinese economy. As China is now the second largest economy, understanding the effect of monetary stimulus on China's macroeconomy provides a general perspective on monetary transmission mechanisms in the global economy. The complexity of the Chinese economy merits a thorough study that takes into account China's institutional facts. Figures 1-3 display several key facets of China's macroeconomy. During the global financial crisis, growth of China's real gross domestic product (GDP) plummeted from 13.6% in 2007Q2 to 6.4% in 2009Q1 (top left graph of Figure 1). In November 2008, China's State Council announced a plan to invest 4 trillion RMB over the two-year period from 2009Q1 to 2010Q4 in an attempt to stem the sharp fall of aggregate output. The rectangular box in each graph marks this plan period. This stimulus plan resulted in a 25% growth rate of M2 supply and a 30% growth rate of bank loans in 2009 (top right graph of Figure 1). While GDP growth bounced back in 2009Q1 and peaked at 11.6% in 2010Q1, both investment-to-GDP ratio and loans-to-GDP ratio surged during the stimulus to 48% and 110% and persisted at high levels long after the stimulus was over (bottom two graphs of Figure 1).[1]

A conventional view is that state owned enterprises (SOEs) play a crucial role in the stimulus because China has long been a planned economy. The data, however, provides little support for this view. Figure 2 plots the share of SOEs in industrial sales revenue (left panel) and in aggregate fixed investment (right panel). As both series have experienced a secular decline, the SOE share was already very low prior to the stimulus, about 30% in sales revenue and 24% in fixed investment. The stimulus did not reverse the declining trend: the SOE share in sales revenue decreased to 28% in 2009 and its share in fixed investment increased by only 1% to 25% in 2009Q2. This evidence indicates that SOEs were not a key player during the stimulus period.

Rather than relying on SOEs, the Chinese government placed more emphasis on certain industries for their stimulus plan. These industries include real estate, infrastructure, and manufacturing industries often labeled by the Chinese government as "heavy industries."

[1] In 2009-2010, bank credit accounted for at least 75% of the overall debt-to-GDP ratio.

Following Chang, Chen, Waggoner, and Zha (2016), we group all these capital-intensive industries into one sector called "heavy sector" and the remaining industries (e.g., education, healthcare, and scientific research) into the other called 'light sector."[2] Since the late 1990s, the government has viewed most industries in the heavy sector as strategically important and supported them with preferential credit. As the top left graph of Figure 3 shows, bank loans for financing investment in the heavy sector ("heavy loans") as a share of GDP was 7.1% prior to the stimulus, much higher than a level of 1.3% for the light sector ("light loans"). More important is the asymmetry of credit allocation in the stimulus: the increase of heavy loans as a percent of GDP (from 7.1% in 2008Q4 to 9.4% in 2009Q4) was three times as large as that of light loans (from 1.3% to 2.1% for the same period). A majority of the increase in heavy loans was channeled to real estate, as the ratio of real estate loans to GDP rose to 4.2% during 2009-2010, which was close to half of the ratio of heavy loans to GDP (the top right graph of Figure 3). Accordingly, the share in GDP of value-added output produced by the heavy sector rose sharply during 2009-2010, implying that the GDP growth under the stimulus was mainly driven by output growth in the heavy sector (bottom graphs of Figure 3).

The empirical framework in this paper is developed to answer the question of how much of these observed macroeconomic movements is caused by monetary stimulus—the stimulus initiated by massive monetary injection. To disentangle how much of monetary stimulus is attributable to a policy change from the effect of such a change, we base our framework on a dynamic multivariate system in the context of the structural vector autoregression (SVAR) literature (Leeper, Sims, and Zha, 1996; Christiano, Eichenbaum, and Evans, 1999; Uhlig, 2005; Christiano, Eichenbaum, and Evans, 2005). One identified equation in this system is monetary policy as described by Chen, Ren, and Zha (2017), who argue that China's monetary policy is quantity-based with M2 growth as the primary policy instrument. In particular, M2 growth responds nonlinearly to GDP growth, depending on whether actual growth is above the government's target (the normal state) or below the target (the shortfall state). We therefore embed this endogenous-switching monetary policy equation in our multivariate system, which allows us to trace out the dynamic effects on multiple macroeconomic variables of monetary stimulus.

Within such a framework, China's monetary stimulus is a result of monetary policy switching to a much more aggressive regime to combat the fall of GDP growth below its official target. As it turned out, the Chinese government's 4-trillion stimulus plan was not even close to its actual action. Most of the monetary injection occurred in 2009. M2 increased by 4.2 trillion in 2009Q1 alone and by a total of 11.5 trillion during the 2009Q1-Q3 period.

[2]See Appendix A for the detailed classification of heavy and light sectors.

These three crucial quarters of massive monetary injections observed in the data match the period identified by our empirical model as a switch in monetary policy regime.

Estimating such an endogenous switching model involves both identification and computational strategies. As a key methodological contribution, we show that the dynamic impacts on the real economy of such a monetary policy switch are uniquely determined in our multivariate framework without any restrictions on equations other than the monetary policy equation. Sims and Zha (2006) propose a regime-switching SVAR approach to analyzing how a shift in monetary policy regime affects the real economy. There are two major shortcomings in their approach. First, regime switching is assumed to be exogenous. Second, they impose identifying restrictions on all the other equations in addition to the monetary policy equation. One persistent criticism is that such restrictions are often too strong to be credible for many applications. Our framework makes important advancements in these two dimensions. That is, monetary policy regime is endogenously determined; and there are no restrictions on all the equations other than the monetary policy equation, which avoids what Sims (1980) calls "incredible restrictions."[3]

To assess the dynamic impacts on the real economy of this regime change in monetary policy requires taking two steps sequentially. First, we need to compute the impulse responses in each state of the economy. The impulse responses to a monetary policy shock in each state describe the mechanism of monetary transmission. We estimate the model for both normal and shortfall states and obtain several stylized facts about the dynamic effects of monetary policy on key macroeconomic variables. Among these stylized facts, we highlight three sets of general results.

(1) Monetary policy is more important in the shortfall state than in normal times. The monetary policy shock contributes to as high as 45% of the GDP fluctuation in the shortfall state, in contrast to only one fifth in the normal state.
(2) Monetary policy has asymmetric effects on bank credit allocation. In response to a monetary policy shock, more credit is allocated to financing investment in the heavy sector than in the light sector for both normal and shortfall states. The asymmetry of credit allocation is exacerbated in the shortfall state.
(3) Asymmetric credit allocation to the heavy sector plays a critical role in promoting growth of investment over that of consumption. And growth of heavy GDP is a driving force of GDP growth in the whole economy.

These results form the basis for our quantitative assessment of the impacts of monetary stimulus. The mechanism is the same whether the effects are triggered by an exogenous shock or by an endogenous switch. But assessing the effects of an endogenous switch in

[3]Our new approach advances the existing SVAR literature in which the system is customarily identified by strong assumptions such as Choleski or sign restrictions.

monetary policy regime requires additional analysis because they are nonlinear and depend on the initial condition. In the second step, we compute the nonlinear effects of switching from one state to the other. We choose the 2009 monetary stimulus event as a natural experiment and prove that our multivariate framework is suitable for analyzing the effects of a shift in monetary policy regime by disentangling policy change from its effect.

Within this framework we study a counterfactual economy in which monetary policy had not switched to a new regime so that M2 growth had remained at 15% instead of shooting up to 25% in 2009Q1-Q3. Comparing the counterfactual and actual economies, we find that this unprecedented expansion of M2 growth boosted annual GDP growth by as high as 4% by the end of 2009, which accounted for 85% of the annual growth rate of GDP between 2008Q4 and 2009Q4.

Such an impressive effect on GDP growth was mainly through bank loans allocated more to financing investment in the heavy sector than in the light sector. In particular, the increase of bank credit to real estate attributable to the monetary stimulus accounted for more than half of the increase of the credit allocated to the heavy sector. We find that while the effect of the 2009 monetary stimulus on GDP growth was short lived (about two years), its effects on investment-to-GDP and debt-to-GDP ratios were much more persistent and lasted for a longer period. These findings signify two problems facing today's China: overinvestment in industries with excess capacity, such as real estate, and rapidly growing debt. Equally important is their broad implication that an extraordinary monetary stimulus can generate an intertemporal tradeoff between short-run GDP growth and longer-run indebtedness.

The rest of the paper is organized as follows. Section II discusses the collection and construction of time series data and develops a new estimation method. Section III presents the main estimation results about the monetary transmission mechanism. Section IV quantifies the dynamic impacts of the 2009 monetary stimulus on credit allocation and the macroeconomy. Section V concludes.

II. Data and empirical framework

In this section we discuss the quarterly time series constructed for the subsequent empirical analysis and propose a new econometric methodology

II.1. **Data.** The sample period for estimation is from 1999Q1 to 2016Q2, including the initial four lags in our dynamic system. This is a period in which the PBC has made M2 growth an explicit policy instrument and the PBC's official Monetary Policy Reports (MPRs) have been made available to the public since 2001Q1.[4] The sample length for our quarterly data is

[4]The only official release of how the PBC conducts monetary policy each quarter is a published quarterly MPR. The first publication of MPR was issued in 2001Q1. Opinions expressed in the monetary policy committee (MPC)'s meetings are recorded in the form of "meeting minutes." The minutes, if approved by

over 17 years, 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).

When assessing how a change in monetary policy regime is transmitted to the real economy, it is necessary to control for other macroeconomic variables than M2 stock. Our benchmark model consists of 11 variables with the following 10 variables besides M2 supply: GDP, consumer price index (CPI), the excess reserve ratio (EER), the actual reserve ratio (ARR), total bank loans, short-term (ST) bank loans, the 7-day repo rate (Repo), the bank lending rate (LR), the bank deposit rate (DR), and foreign exchange reserves (FXR).[5] We denote these variables by y_t, an $n \times 1$ vector with $n = 10$ for the benchmark model. As in the SVAR literature, we express all the variables in natural log except for interest rates and ratio variables, which are expressed in level as a fraction. 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. These variables would be potentially important for the monetary transmission mechanism. In later sections we examine whether the interest rate channel is important by removing the interest rates from our benchmark specification.

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.[6] Despite the unsettled debates on this issue, the official CPI series is the headline price series the PBC and other central government units have routinely relied on *when making monetary policy decisions*. For this reason we need to use the official series to estimate the monetary policy equation. A similar argument applies to the GDP series. One should *not* abandon the official GDP figures because they are precisely the most important series targeted by the central government for formulating monetary policy.[7]

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more than two thirds of the MPC members, are attached as an annex to the PBC's proposal on money supply, interest rates, exchange rates, and other monetary variables. The proposal 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, mainly M2 growth rates, in response to the state of the economy.

[5]See Appendix A for a detailed description of the data.

[6]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.

[7]In a recent paper, Nie (2016) argues that "official GDP figures remain a useful and valid measure of Chinese economic growth." There is widespread suspicion that the GDP growth rates published by the National Bureau of Statistics of China have overstated actual growth in China, especially for the last several years. New research by Clark, Pinkovskiy, and Sala-i-Martin (2017), however, argue that China's GDP

Four additional quarterly time series are constructed for this paper: heavy GDP, light GDP, heavy loans, and light loans. We collect industry level data on value added and newly originated bank loans for fixed asset investment from the National Bureau of Statistics (NBS). We then add up these series to construct the aggregate series of heavy GDP, light GDP, heavy loans, and light loans. To understand the monetary transmission mechanism for the Chinese economy, we use these four new series as well as other additional series to estimate several variations of the benchmark model.

II.2. **Empirical framework.** The M2 variable (M_t) and the other $n = 10$ variables form a medium-sized dynamic model. One key equation in this model, following Chen, Ren, and Zha (2017), is the monetary policy equation in which monetary policy switches endogenously between two regimes, depending on whether the gap between GDP growth and its target is positive or not. For the Chinese government, M2 growth has been used as the primary policy instrument. Use of M2 growth in the monetary policy equation captures China's quantity-based policy that differs from the interest-rate based policy widely used for developed economies.

Denote $g_{m,t} = \Delta M_t$, $\pi_t = \Delta P_t$, $g_{x,t} = \Delta x_t$, and $g^*_{x,t} = x^*_t - x_{t-1}$. The (log) GDP level target is x^*_t and thus $g^*_{x,t}$ measures the targeted GDP growth. Chen, Ren, and Zha (2017)'s regime-switching monetary policy equation is specified as

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

where $\varepsilon_{m,t}$ is a serially independent monetary policy shock with the standard normal distribution. The time-varying coefficients take the form of

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

The subscript "a" stands for "above the target" and "b" for "below the target". Note that $\gamma_{x,t}$ and $\sigma_{m,t}$ have the time t subscript because they have to be estimated with the time t variable $g_{m,t}$. There are two parts associated with a switch in monetary policy regime: exogenous shock and endogenous change of monetary policy from the normal regime to a more aggressive regime. The time-varying coefficients, $\gamma_{x,t}$ and $\sigma_{m,t}$, represent two policy regimes in response to output growth: (a) the normal state when actual GDP growth meets the target set by the government *as a lower bound* and supported by monetary expansion and (b) the shortfall state when actual GDP growth falls short of its target.[8] The Chinese

growth may be understated. All these debates imply that one should not simply abandon official GDP statistics without viable and authoritative alternatives, especially when analyzing monetary policy.

[8]The overall impact of monetary stimulus depends on changes in both $\gamma_{x,t}$ and $\sigma_{m,t}$. In Section IV, we show that most of the dynamic impact of monetary stimulus in 2009 was explained by a change in the value of $\gamma_{x,t}$ (i.e., a change in the rule).

government's GDP growth target, by weighing social and political considerations heavily, is politically mandated and takes precedence over all other economic objectives. In estimation, we take π^* and $g^*_{x,t}$ as given.[9]

To quantify how monetary policy affects M_t as well as other macroeconomic variables y_t, we postulate the dynamics of y_t in a general system of simultaneous equations

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

where $y_{t-\ell}$ is an $n \times 1$ vector of endogenous variables, c is an $n \times 1$ vector of constant terms, 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. The variable vector y_t includes π_t and x_t as well as other variables; for a later analysis in Proposition 2, we let the first two elements of y_t be π_t and x_t.

In the existing literature (Christiano, Eichenbaum, and Evans, 1999; Sims and Zha, 2006), strong identifying restrictions are imposed on A_0 to identify system (2). To maintain the principle of minimal restrictions on identification (Sims, 1980), we impose no restrictions on A_ℓ and b_ℓ (including the contemporaneous coefficient vector b_0 and the contemporaneous coefficient matrix A_0). The principle of minimal restrictions is especially relevant to the Chinese economy because the relationships among its key macroeconomic variables remain largely unknown to the research community.

Without any restrictions, system (2) is unidentified because the transformed system

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

obtained by multiplying any orthogonal matrix Q generates the same dynamics of y_t as does the original system.[10] Because the policy variable M_t is contemporaneously correlated with the rest of the variables (y_t), the identification question arises as to whether monetary policy equation (1) is identified and whether the effect of a monetary policy shock $\varepsilon_{m,t}$ on the economy indexed by y_t depends on the rotation matrix Q, when equation (1) is estimated *jointly* with subsystem (2). The following proposition answers this question by establishing the identification of monetary policy in the dynamic system.

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

- Monetary policy equation (1) is identified, even though subsystem (2) is unidentified.
- Impulse responses of y_t to $\varepsilon_{m,t}$ are invariant to the rotation matrix Q.

[9]The government specifies the CPI inflation target between 3% and 4%. The value of π^* is set at 3.5%.

[10]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.

Proof. See Appendix B. □

The intuition for identification of the monetary policy equation is that M_t is determined before all other variables are determined at time t. In most of the SVAR literature, it is required that the rest of the system has a recursive structure as well—an incredibly strong assumption. What is new in Proposition 1 is that this additional assumption is unnecessary and moreover the responses of all variables in the system to a monetary policy shock can be *uniquely* determined.

To assess the effect of monetary policy, one must be able to estimate the impulse responses to a monetary policy shock. The following proposition shows that the impulse responses are nonlinear and regime-dependent.

Proposition 2. The impulse responses to a monetary policy shock, $\varepsilon_{m,t}$, can be computed from the following regime-dependent system:

$$\begin{bmatrix} M_t \\ y_t \end{bmatrix} = \tilde{b}_t + \sum_{\ell=1}^{4} \underbrace{\begin{bmatrix} \widetilde{B}_{\ell,t}^{11} & \widetilde{B}_{\ell,t}^{12} \\ \widetilde{B}_{\ell,t}^{21} & \widetilde{B}_{\ell,t}^{22} \end{bmatrix}}_{\widetilde{B}_{\ell,t}} \begin{bmatrix} M_{t-\ell} \\ y_{t-\ell} \end{bmatrix} + \widetilde{D}_t \begin{bmatrix} \varepsilon_{m,t} \\ \xi_t \end{bmatrix}, \tag{3}$$

where $\widetilde{B}_{1,t}^{12}$ is a function of $\gamma_{x,t}$ and γ_π and $\widetilde{B}_{1,t}^{22}$ is a function of $\gamma_{x,t}$, γ_π, b_0, and A_0.

To prove Proposition 2, consider the complete system composed of (1) and (2), which can be written in the SVAR form of

$$\underbrace{\begin{bmatrix} \frac{1}{\sigma_{m,t}} & \underset{1\times n}{0} \\ b_0 & A_0 \end{bmatrix}}_{\widetilde{A}_{0,t}} \begin{bmatrix} M_t \\ y_t \end{bmatrix} = \underbrace{\begin{bmatrix} \frac{\gamma_0 - \gamma_\pi \pi^* - \gamma_{x,t} x_{t-1}^*}{\sigma_{m,t}} \\ c \end{bmatrix}}_{\tilde{c}_t} + \underbrace{\begin{bmatrix} \frac{1+\gamma_m}{\sigma_{m,t}} & \begin{bmatrix} \frac{\gamma_\pi}{\sigma_{m,t}} & \frac{\gamma_{x,t}}{\sigma_{m,t}} & \underset{1\times(n-2)}{0} \end{bmatrix} \\ b_1 & A_1 \end{bmatrix}}_{\widetilde{A}_{1,t}} \begin{bmatrix} M_{t-1} \\ y_{t-1} \end{bmatrix}$$

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

It follows that $\tilde{b}_t = \widetilde{A}_{0,t}^{-1}\tilde{c}_t$, $\widetilde{B}_{\ell,t} = \widetilde{A}_{0,t}^{-1}\widetilde{A}_{\ell,t}$, and $\widetilde{D}_t = \widetilde{A}_{0,t}^{-1}$, where

$$\widetilde{A}_{0,t}^{-1} = \begin{bmatrix} \sigma_{m,t} & \underset{1\times n}{0} \\ -\sigma_{m,t} A_0^{-1} b_0 & A_0^{-1} \end{bmatrix}.$$

It is straightforward to see that $\widetilde{B}_{1,t}$ and $\widetilde{B}_{2,t}$ embody cross-equation restrictions (i.e., restrictions across the first equation and the rest of the equations). One can also see that $\widetilde{B}_{1,t}^{12}$ depends on $\gamma_{x,t}$ and γ_π and $\widetilde{B}_{1,t}^{22}$ depends on $\gamma_{x,t}$, γ_π, b_0, and A_0. The dependence of the reduced-form coefficient $\widetilde{B}_{1,t}^{22}$ on $\gamma_{x,t}$ implies that the impulse responses in the shortfall state are different from those in the normal state, as will be demonstrated in Section III.

The regime dependence and cross-equation restrictions make estimation of impulse responses an extremely difficult task in two aspects. First, both output coefficient and shock volatility in monetary policy equation (1) depend on the state of the economy. These endogenous-switching parameters make it computationally challenging to estimate the medium-sized nonlinear system (3).[11] Second, although the first equation in system (3) is exactly the same as the monetary policy equation represented by (1), the parameters in the other equations of system (3) are functions of $\sigma_{m,t}$ and $\gamma_{x,t}$. In principle, therefore, estimating the monetary policy equation *jointly* with the rest of system (3) may not yield the same results as does estimation of equation (1) alone.

To overcome these difficulties, we propose a new estimation method stated in the following proposition.

Proposition 3. Statistical estimation and inference of nonlinear system (3) are equivalent to two separate estimation procedures such that nonlinear monetary policy equation (1) and linear system (2) can be estimated independently. That is, estimation and inference of system (2) do not depend on the coefficients of equation (1).

Proof. See Appendix C. □

Corollary 1. The reduced form of system (2) is

$$y_t = d + \sum_{\ell=1}^{4} B_\ell y_{t-\ell} + \sum_{\ell=0}^{4} h_\ell M_{t-\ell} + u_t, \tag{5}$$

where $d = A_0^{-1}c$, $B_\ell = A_0^{-1}A_\ell$, $h_\ell = A_0^{-1}b_\ell$, and $u_t = A_0^{-1}\xi_t$. This reduced-form linear system can be estimated independently of monetary policy equation (1). That is, a regime shift in monetary policy does not affect estimation of the reduced-form system represented by (5).

Although y_t depends on M_t in equation (5), the separation property in Proposition 3 or Corolary 1 still holds because M_t is predetermined by the monetary policy equation alone. The customary SVAR representation is the reduced-form system represented by (3). This representation facilitates a clear way of understanding how variables respond to a structural shock dynamically (in our case, the monetary policy shock $\varepsilon_{m,t}$). Direct estimation of this nonlinear system, however, is computationally expensive and conceptually difficult for the general researcher to handle. Working with the alternative form represented by (1) and (5) enables one to avoid the needless cost of dealing with the nonlinear system represented by (3).

Equivalent to the system represented by (1) and (5) is the one represented by (1) and (2). There are two advantages of working directly on (1) and (2). First, one can use the

[11]In fact, in the initial stage of this research, we tried to estimate such a nonlinear system without much success. The main problem is the time involved in computation.

standard Bayesian prior of Sims and Zha (1998), which is imposed directly on the structural form.[12] Second, once estimation of the contemporaneous coefficient matrix A_0 is obtained, one can proceed to estimate, equation by equation, system (2) (see Appendix C for the proof). Although the monetary policy equation represented by (1) is nonlinear, its estimation entails little computational cost on estimation of the rest of the system.[13]

In summary, Propositions 1 and 3, together with Corollary 1, provide a general framework in which one is able to quantify how a regime change in monetary policy affects the aggregate economy without violating the Lucas critique (Leeper and Zha, 2003; Sims and Zha, 2006). They also provide a powerful toolkit for estimating a relatively large nonlinear system with minimal computational costs.

III. Monetary policy transmission

Assessing the impacts of monetary stimulus as a result of a shift in monetary policy regime requires one to estimate the impulse responses to a monetary policy shock in both normal and shortfall states. In this section, we provide an analysis of these impulse responses and discuss several key results that are the driving force behind the dynamic impacts of monetary stimulus on the banking system and the real economy.

III.1. **Impulse responses in the normal state.** In normal times when GDP growth is above the government's target, what is the impact of monetary policy on aggregate output? Figure 4 displays the impulse response of GDP to a monetary policy shock along with probability bands. The impulse responses of other macroeconomic variables for the benchmark model 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 0.37% at their peak values. The output response is hump-shaped, while the M2 response is much more persistent. Both responses are highly significant both economically and statistically. The CPI response displays little price puzzle, further supporting our argument that the estimated monetary policy shock does not contain endogenous responses to other macroeconomic variables.[14] The correct sign of a price response is one of the building foundations for the SVAR

[12]The hyperparameters for the prior, in the notation of Sims and Zha (1998), are $\lambda_i = 1$ for $i = 0, 1, 2, 4$, $\lambda_3 = 4$, $\mu_5 = \mu_6 = 1$. 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).

[13]All the coefficients in equation (1) are very tightly estimated (including those in the shortfall state) and the estimates are $\gamma_m = 0.391, \gamma_\pi = -0.397, \gamma_{x,a} = 0.183, \gamma_{x,b} = -1.299, \sigma_{m,a} = 0.005, \sigma_{m,b} = 0.010$. Note that there are a total of 15 shortfall periods, including the three quarters of 2009Q1-Q3.

[14]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).

literature (Sims, 1992; Uhlig, 2005). In response to an expansionary monetary policy shock, the excess reserve ratio and the Repo rate fall in the initial periods.[15] These responses are consistent with most theoretical predictions of the effect of a monetary policy shock.

The response of total (real) bank loans has a pattern very similar to the M2 response (Figure 6), indicating that monetary expansion increases output through an increase of bank lending. To see how monetary policy affects different sectors, we add the time series of either heavy GDP or light GDP to the benchmark model. The bottom row of Figure 6 reports the estimated impulse responses: heavy GDP responds more strongly than light GDP does. Because bank credit to industries such as real estate is typically not of short term, these heavy and light GDP responses are consistent with our next finding that most of the increase in bank loans does not stem from an increase of short-term loans. As shown in the top row of Figure 6, the response of short-term bank loans is much smaller in magnitude than that of total bank loans and its wide probability bands further indicate weak statistical significance.

Such a finding about bank lending is reinforced by how investment and consumption respond to expansionary monetary policy. Most industries in the heavy sector are capital intensive with higher investment rates than those in the light sector. This fact, together with our previous finding of the larger response of heavy GDP than light GDP to a monetary policy shock, indicates that investment rather than consumption is a driving engine behind the output fluctuation. Indeed, Figure 7 shows that investment responds strongly to an expansionary monetary policy shock (hump-shaped response) while the response of consumption (no hump shape) is small in magnitude and its statistical significance, according to the probability bands, is very weak.[16] The result is in sharp contrast to the finding of Christiano, Eichenbaum, and Evans (2005) for the U.S. economy that the response of consumption to an expansionary monetary policy shock is hump-shaped, strong, and sizable.

Some key variance decompositions attributable to the monetary policy shock relative to all other shocks are reported in Table 1. The monetary policy shock explains one fifth of the GDP variation at the peak value. This result is robust across various model specifications. The contribution to the investment fluctuation reaches 16% at its peak; the contribution to the bank-loan fluctuation is over 23% for the five-year horizon. By contrast, the contribution to the fluctuation in short-term bank loans is small ($3-6\%$), the contribution to the price fluctuation is also small ($0.5-7\%$), and the contribution to the consumption fluctuation is

[15]The lending and deposit rates respond in a similar fashion.

[16]This result is generated by a larger model that expands the benchmark model to inclusion of the investment and consumption series. The data on many components of GDP is available but with a long delay. In our case, the sample is available only up to 2015Q4 for investment and consumption and 2015Q3 for heavy GDP and light GDP.

even smaller (under 3.1% for the first four years). These results reinforce our argument that monetary policy affects the real economy mainly through bank credit to investment in the heavy sector whose evidence is presented in the next section.

III.2. **Impulse responses in the shortfall state.** The estimated impulse responses in the shortfall state differ from those in the normal state in both timing and magnitude. Figures 8-11 plot the estimated impulse responses in the shortfall state. Our subsequent analysis focuses on the first one year horizon in which the impulse responses differ most from those in the normal state. We discuss impulse responses over longer horizons in Section IV.3.

As a direct result of aggressive monetary policy to stem the shortfall of GDP growth, the M2 response peaks within 2 quarters, faster than the response in the normal state, and the GDP response peaks within 3 quarters as compared to a much delayed peak (9 quarters) in the normal state. According to our estimates, the volatility of a monetary policy shock in the shortfall state is twice as high as in the normal state (0.10 vs 0.005), which leads to a stronger response of M2 supply on impact (a 1% increase in the shortfall state versus a 0.5% increase in the normal state). The response is immediately translated to the banking system with the initial response of bank lending to a monetary policy shock in the shortfall state almost doubling the initial response in the normal state (1% vs. 0.55%). By contrast, short-term bank loans rise only 0.5% for the first year (the bottom right panel of Figure 8).

Longer term bank loans are typically used for investment. Bank lending to investment can be divided into credit to heavy and light sectors. We expand the benchmark model with two new credit series: newly originated bank loans to heavy and light sectors (as a percent of GDP). Figure 9 reports the estimated impulse responses for these two series across the normal and shortfall states. In the normal state, the magnitude of responses of heavy loans to a monetary policy shock is more than twice as large as that of responses of light loans (dotted lines in Figure 9). This asymmetric response is exacerbated in the shortfall state (solid lines in Figure 9), as an increase of money supply is channelled disproportionally into heavy loans. As an outcome, the response of new credit to the heavy sector in the shortfall state is almost twice as large as in the normal state. These results are consistent with the additional finding that the response of heavy GDP is much stronger than the response of light GDP (Figure 10).

In the shortfall state, because most of the new bank credit is allocated to financing investment in the heavy sector, the response of consumption is almost the same as that in the normal state (comparing Figures 7 and 11). By contrast, the peak response of investment in the shortfall state, occurring two quarters earlier, is significantly higher than in the normal state (1.5% vs. 1.1% by comparing Figure 11 and Figure 7). Thus, the early GDP responses rely on investment rather than on consumption.

The asymmetric responses of bank credit across the states as well as across the sectors lead to the asymmetry of monetary policy's impacts on the real economy across the states. Table 1 reports the asymmetric importance of the monetary policy shock in driving the GDP fluctuation. In the shortfall state, the GDP variation attributed to the monetary policy shock is as high as 45%, more than twice as much as the counterpart in the normal state. Relative to all 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.

The impulse response analysis illustrates the powerful mechanism of monetary transmission for each of the two states. When the economy switches from the normal state to the shortfall state, monetary policy switches accordingly in response to the shortfall of GDP growth. The nonlinear effects on the aggregate economy of this endogenous change of monetary policy are discussed in Section IV.

III.3. **Role of interest rates.** Much of the recent policy discussion centers on reforms of moving gradually away from control of M2 growth as the primary policy instrument toward control of short-term nominal interest rates as in the U.S. and other developed economies. Yet there are few academic studies on how effective the interest rate channel would be for the Chinese economy.

Our empirical analysis provides strong evidence that interest rates have been *ineffective* in transmitting monetary policy into China's real economy. When we remove the three interest rates from the list of variables in the benchmark model, the estimated response of GDP to a monetary policy shock is almost identical to its benchmark counterpart (Figure 4). This finding is consistent with the existing empirical result that variations in market interest rates cannot explain macroeconomic fluctuations (Sheng and Wu, 2008) and supports the argument that the transmission of monetary policy works through credit volumes rather than through interest rates.[17]

Our finding is in contrast to Bernanke and Blinder (1992), who use the federal funds rate to identify the effect of a monetary policy shock. As Bernanke and Blinder (1992) show, interbank interest rates in the U.S. economy are transmitted into the real economy through broad financial markets. In China's state-dominated financial system, quantity-based monetary policy has been more effective in directly influencing the supply of bank loans, *regardless of what happens to interest rates* in interbank markets.[18] Our evidence

[17]The external sector is also unimportant to monetary transmission. When we remove foreign exchange reserves from the list of variables in the benchmark model, the impulse responses (circle and plus lines in Figure 4) are essentially identical to its benchmark counterpart.

[18]To control bank credit volumes effectively, the PBC uses additional policy instruments, such as "window guidance" and regulatory rules, to force commercial banks to increase or decrease lending volumes or activities and to direct loans to certain industries, regardless of the prevailing interest rates. Moreover, the PBC

indicates that bank lending volumes constitute the key transmission mechanism for the effect of monetary policy on the real economy.

There are several institutional reasons for the normal interest-rate channel to fail in the monetary transmission mechanism. First, since bond markets in China are not fully developed, 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 the risk to bank loans.[19] Third, firms in the heavy sector, protected by the government from bankruptcy, are insensitive to changes in interest rates.[20] As a result, there are no efficient financial markets to price out the external finance premium for firms.

IV. The impact of the 2009 monetary stimulus

The goal of this paper is to assess the dynamic impacts of monetary stimulus on credit allocation and the real economy. The preceding analysis of impulse responses in normal and shortfall states provides a foundation for quantifying these impacts. Because the effects of monetary policy are uniquely determined in our empirical framework and the rest of the system is not affected by a switch in monetary policy regime, we are able to use the posterior estimates to simulate a counterfactual economy in which we assume that monetary policy regime had not changed in 2009Q1-Q3 from the normal accommodative monetary policy and there were no expansionary monetary policy shocks during these periods. Following Sims and Zha (2006), we back out the monetary policy shock sequence $\varepsilon_{m,t}$ and all the other reduced-form shock sequences u_t. We keep these shocks intact in our counterfactual simulations except for monetary policy shocks in 2009Q1-Q3. The difference between actual and counterfactual paths measures the impact of the unprecedented monetary stimulations (both exogenous and endogenous) during the first three quarters of 2009.

IV.1. **Impacts on the aggregate economy.** The stimulus plan announced in November 2008 by the Chinese government called for massive investment in ten areas of Chinese economy to promote GDP growth in the face of the 2008 global financial crisis.[21] Among the ten

controls credit volumes by planning the aggregate credit supply for the coming year and then by negotiating with individual commercial banks for credit allocations.

[19]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), but deposit and lending rates have since then been under strict control of the government. Liberalization of the overall financial market has been slow in China. See Liu, Wang, and Xu (2017) for theoretical implications of interest rate liberalization on the Chinese economy.

[20]Li, Liu, and Wang (2016) argue that strategic industries in China have been enjoying monopoly power given by the government, rather than facing market competition.

[21]See the official website of the State Council for the details of such a plan at `http://www.gov.cn/ldhd/2008-11/09/content_1143689.htm`.

areas of investment in the stimulus package, real estate was listed as the number one area of focus and consequently received a significant amount of bank credit.[22]

A regime switch in monetary policy played the most conspicuous role in implementing the government's stimulus package.[23] With our empirical framework we are able to separate a change in monetary policy from the effect of this change. The shortfall state lasted for only three quarters from 2009Q1 to 2009Q3 in which monetary policy switched to stimulation. By the third quarter of 2009, M2 growth sprang up to 25% from the average of 15% in normal times. Figure 12 shows the effect of this policy switch on M2 growth. The shaded bar marks the period 2009Q1-2009Q3 in which monetary policy changed. High M2 growth in the period after 2009Q3 was the *consequence* of this policy change. If the PBC had not changed its policy by increasing M2 supply drastically, M2 growth would have been hovering around 15% for the next two years (the circle line in Figure 12).

Such a monetary stimulus had a significant impact on GDP growth. The left panel of Figure 13 indicates that as high as 85% of actual GDP growth in 2009-2010 was attributable to the stimulus. By the end of 2009, GDP growth reached 11.59% with an increase of 4.67% above the 6.91% growth rate in 2008Q4. The portion attributable to the stimulus, measured by the difference between actual and counterfactual paths (right panel of Figure 13), reached 4% in 2009Q4, which accounted for 85% of the 4.67% increase.

Without the stimulus, actual GDP growth would have been below its official 8% target in 2009 (left panel of Figure 13) and would have been lower by as much as 4% during the next two years (right panel of Figure 13). As also shown in the right panel of Figure 13, most of the impact (about $70\% - 80\%$) was driven by an endogenous switch in the monetary policy rule in response to the shortfall of GDP growth, not by a change in shock volatility or by exogenous monetary policy shocks. Thus, it is this endogenous switch in the policy rule that offers the key to understanding the stimulus effect on GDP growth. Despite the economic significance, however, the effect of this monetary stimulus on GDP growth was transitory. The gap between the actual and counterfactual paths began to narrow in 2010 and became negligible by the end of 2011.

Unlike many developed economies such as the U.S., the effect of China's monetary stimulus on GDP growth is through investment, rather than through consumption (which includes consumer durable goods). Figure 14 displays the sharp contrast between the impacts on investment and consumption. The regime switch to extraordinarily expansionary monetary policy in 2009Q1-2009Q3 had a negligible effect on consumption growth, but it increased

[22]The remaining areas are rural infrastructure, transportation, health and education, environment, basic industries, disaster rebuilding, income-building, tax cuts, and finance.

[23]To facilitate the effects of monetary injection on bank credit, credit quotas to commercial banks were eliminated during this monetary stimulus.

investment growth by as much as 13% (the difference between the actual and counterfactual paths). With the 40% investment-to-GDP ratio at the end of 2008, a 13% increase in investment growth should contribute to a 4% increase in GDP growth by accounting, which is perfectly in line with the magnitude of the stimulus effect on GDP growth.

Consistent with its unbalanced impact on investment and consumption, the 2009 monetary stimulus exerted asymmetric impacts on industries with different capital intensities. Figure 15 shows that the monetary stimulus led to a significantly larger increase of heavy output than light output. At the end of 2008, growth of heavy GDP was 5.7%. After the stimulus, growth of heavy GDP reached 15.5% in 2010Q1, a 9.8% increase ($9.8 = 15.5 - 5.7$). The stimulus contributed to 4.6%, close to a half of the increase.[24] While light GDP growth fell after the stimulus period, a rapid rise in heavy GDP growth more than compensated this fall. As a result, GDP growth after 2009Q3 was driven by growth in the heavy sector.

IV.2. **Impacts on credit allocation.** The mechanism underlying the effect of monetary stimulus on the macroeconomy is the credit channel specific to China. The left panel of Figure 16 shows that the 2009 monetary stimulus increased *real* bank loans by as high as 10% (the difference between actual and counterfactual paths), which has a magnitude close to its impact on M2 growth. Most of the increase in M2 supply is channeled to the real economy through bank loans with terms longer than one year. As one can see from the right panel of Figure 16, monetary stimulus had a considerably smaller effect on the increase of short term loans.

Longer term loans are mainly used to finance investment in physical capital. Since most industries in the heavy sector are capital intensive with higher investment rates, one would expect that more bank credit was allocated to the heavy sector during the stimulus period. According to the 2010Q1 MPR, most of newly issued medium and long term (MLT) bank loans went to real estate, infrastructure, and other supporting industries such as steel and cement: in 2010Q1, the growth rate of new loans allocated to real estate was 38.5%; the growth rate of new loans allocated to infrastructure was 33.3%. Our counterfactual experiment shows that monetary stimulus plays a crucial role for this asymmetry of credit allocation. The increase of heavy loans (in percent of GDP) attributable to the monetary stimulus was 1.1% in 2009Q4, which accounted for half of the overall increase in heavy loans

[24]Other factors than the stimulus, such as the implicit guarantee provided by the government on bank credit to targeted industries (e.g., real estate and supporting industries), continued to play an important role in the rising share of heavy-sector output in GDP. Chang, Chen, Waggoner, and Zha (2016) provide a theoretical model to show that a positive financial shock on the collateral constraint faced by entrepreneurs in the heavy sector would lead to an increase in aggregate investment via capital reallocation from light to heavy sectors and consequently an increase in aggregate output.

(1.1% out of 2.3%). By contrast, the impact of monetary stimulus on light loans as percent of GDP was small (0.48%).

To shed light on the transmission of monetary stimulus on the macroeconomy through credit allocation, we compare the magnitude and timing of the stimulus effects on output and credit allocation across heavy and light sectors. The left panel of Figure 18 shows that the growth rate of heavy GDP was much higher than the growth rate of light GDP after the monetary stimulus (4.8% versus 2.4% at the peak). The asymmetric effect on output growth in these two sectors was sustained by asymmetric credit allocation to investment in the two sectors: the increase in newly originated loans to investment in the heavy sector was considerably higher than that in the light sector (1% versus 0.5% at the peak). The peak for credit increase occurred one quater earlier than the peak for output growth, underscoring the leading role of asymmetric credit allocation in the asymmetric effects of the 2009 monetary stimulus on the real economy.

IV.3. **Importance of real estate.** In this section we focus on the effect of the 2009 monetary stimulus on the real estate sector.[25] We begin by studying the impact on real estate prices after adjusting for CPI inflation. The effect on CPI inflation of the regime switch to more aggressive monetary policy in 2009Q1-Q3 was marginal (the left panel of Figure 19). Most of the rapid rise of inflation from a negative rate in 2009 to 6% in 2011 was attributable to monetary policy that had already been put in place at the speed of 15% per year for M2 growth. By contrast, the impact of the same monetary stimulus on land prices (after adjustments of CPI inflation) was sizable: the stimulus was responsible for half of the 40% increase in land prices at the end of 2009 (the difference between actual and counterfactual values in the right panel of Figure 19).

The sharp rise in land prices was fueled by new credit disproportionately allocated to real estate. The monetary stimulus increased newly originated loans to real estate (as percent of GDP) by 0.58% in 2009Q3-Q4, accounting for more than half of the increase in new credit to the heavy sector. In the U.S. and other developed economies, the credit boom was associated with mortgage loans demanded by households. In China, a majority of new bank credit was allocated to investment, especially in the heavy sector. This preferential credit allocation pushed up the demand for land. Given the limited supply of land in large cities, therefore, an increase of bank credit to real estate generated soaring (real) land prices during and after the stimulus period.[26]

[25]According to the 2009Q2 MPR, newly originated MLT loans to the real estate industry in the first half of 2009 totaled 350.1 billion RMB, 1.5 times the amount of new bank credit to real estate for the entire year of 2008. Our data confirms that 45% of the increase in new loans to the heavy sector was allocated to real estate in 2009.

[26]Chen and Wen (2017) provide a theory to explain the rapid increase of house/land prices in China.

The close relationship between real estate loans and land prices can be seen in Figure 21. The stimulus effects on real estate loans and land prices were very similar in 2009 and 2010. The finding is consistent with the theoretical prediction based on two-way interactions: an increase of real estate loans pushed up the land price, which in turn relaxed the collateral constraint and encouraged banks to lend more to real estate developers with real estate as collateral.[27]

One question is why the actual growth paths of land prices and bank loans fell below the counterfactual paths after 2010Q2. To answer this question, consider the following simple example as illustration:

$$z_t = B_t z_{t-1} + \epsilon_t,$$

where z_t is an $(n+1) \times 1$ vector with the first element being M2 and the first element of the shock vector ϵ_t is an exogenous monetary policy shock. The time-varying coefficient is defined as $B_t = B_n$ in normal times and $B_t = B_s$ in the shortfall state. At time 1, the economy enters the shortfall state; at time 4, the economy returns to the normal state. The quarterly dynamics of z_t can be traced out recursively:

$$\begin{aligned}
z_1 &= B_s z_0 + \epsilon_1, \\
z_2 &= B_s^2 z_0 + B_s \epsilon_1 + \epsilon_2, \\
z_3 &= B_s^3 z_0 + B_s^2 \epsilon_1 + B_s \epsilon_2 + \epsilon_3, \\
z_4 &= B_n B_s^3 z_0 + B_n B_s^2 \epsilon_1 + B_n B_s \epsilon_2 + B_n \epsilon_3 + \epsilon_4, \\
&\vdots
\end{aligned}$$

For the first term on the right hand side of the equation, for example, the effect due to endogenous switching from the normal state to the shortfall state can be measured by $(B_s - B_n)z_0$ for the first quarter and $(B_n B_s^3 - B_n^4)z_0$ for the fourth quarter. Clearly, although the shortfall state lasts for only three quarters, the coefficient B_s influences the dynamics of z_t beyond the third period. The time series displayed in Figure 1 shows that M2 growth rose sharply in 2009Q1-Q3 but fell sharply as well after 2009. When we fit the model to the data, the coefficients B_s and B_n are jointly estimated to reflect this sharp rise and fall pattern. Consequently, even though our hypothetical length of the shortfall state for impulse responses lasts more than three quarters, they tend to fall at the speed faster than those in the normal state after the initial four quarters.

We assemble the impulse responses of four related variables in one figure for comparison (Figure 22): M2, total bank loans, real estate loans, and land prices. All these impulse responses exhibit similar patterns across the two states: the responses in the shortfall state are stronger than in the normal state for the first four quarters, but decline at a faster speed

[27]See Iacoviello and Neri (2010); Jermann and Quadrini (2012); Liu, Wang, and Zha (2013).

since then, and eventually fall below their counterparts in the normal state. As discussed previously, the sharper fall of land prices originates from the transitory surge in M2 growth during the shortfall state, which translates into temporary surges in bank loans, real estate loans, and land prices. These results provide strong evidence for the credit channel unique to China's monetary policy transmission.

The transmission of monetary stimulus to the macroeconomy via asymmetric credit allocation bears lasting consequences. Despite an already high investment rate at the end of 2008, the 2009 monetary stimulus raised the investment-to-GDP ratio by more than 4% (left panel of Figure 23) and the debt-to-GDP ratio by as high as 13% (right panel of Figure 23) by 2016. Most of new bank loans during the stimulus period were advanced to the heavy sector for financing time-to-build investment and thus were allocated as MLT loans. This made the impacts on the investment-to-GDP and debt-to-GDP ratios persistent, even though the stimulus itself was temporary (i.e., only three quarters).

Such persistent effects have exposed China's economy to overinvestment. Indeed, the IMF 2016 Country Report No. 16/270 and 2017 Country Report No. 17/247 express concerns about "excess capacity in real estate and heavy industry" in China and its impact on global commodity prices. In 2015, for example, there were six industries that suffered the most severe overcapacity problem measured by the rate of capacity utilization: steel (67%), coal (64.9%), cement (73.8%), flat glass (68.0%), electrolytic aluminum (75.4%), and shipbuilding (69%).[28] All these six industries are heavy industries by the Chinese government's official classification.

Perhaps a graver situation is the fast accumulation of the vacant real estate stock. Measured by the floor space, real estate vacancy increased from 199.47 million square meters in 2009 to 718.53 million square meters in 2015. To give a sense of how severe this overly built real estate stock is, the space of 718.53 million square meters can accommodate 24 million individuals in China. This oversupply of real estate properties has raised serious concerns for the rising debt to GDP ratio, as more than a half of newly originated bank credit during the 2009 stimulus was allocated to the real estate sector. To deal with the problems of rising debt, industrial overcapacity, and oversupply in real estate, the Central Economic Work Conference organized jointly by the State Council and the Central Committee of Communist Party of China (CPC) has listed, among top major tasks, three specific objectives: deleveraging debt, reducing excess capacity, and destocking real estate. Our analysis demonstrates

[28]These figures were published in the 12/23/2016 Economic Research Report of the State Council's National Development and Reform Commission (`http://www.sic.gov.cn/News/455/7349.htm`). By the international standard, an industry has excess capacity if its rate of capacity utilization is between 75% and 79% and suffers severe overcapacity if the rate is below 75%.

that underlying all these problems facing the Chinese government is the asymmetric credit allocation wrought by its 2009 monetary stimulus.

V. Conclusion

We show two distinctive facets of China's monetary transmission: (1) monetary policy's nonlinear effect on GDP growth across two different states of the economy and (2) asymmetric credit allocation across two different sectors. In normal times, the effect of monetary policy on output is achieved with more credit allocated to financing investment in the heavy sector than in the light sector. When GDP growth falls short of the government's official target, the monetary authority responds to the shortfall state by switching to much more expansionary policy than in normal times. As a result, this expansionary stimulation contributes to more output growth by exacerbating the asymmetric credit allocation in favor of investment in real estate and heavy industries.

We find that the 2009 monetary stimulus contributed to a temporary 4% increase of GDP growth, out of which three fourths was accounted for by a switch of the monetary rule itself rather than a change in shock volatility. Higher GDP growth was not achieved by an increase in consumption but by a disproportionate increase of bank credit to real estate and heavy industries with excess capacity. As a result, this monetary stimulus had large and persistent effects on the investment ratio and debt-to-GDP ratio. The high investment-to-GDP and debt-to-GDP ratios have been concerns for policymakers. Our framework is potentially useful for the Chinese government to design and implement new policy initiatives to strike a balance between stimulating growth and deleveraging debt.[29] This paper serves as a first step toward opening up further studies on the dynamic impacts of monetary policy on the Chinese economy and its banking system.

Although this paper focuses on China, there are two general developments in our empirical methodology. One is that we impose minimal identifying restrictions on the model, in contrast to the existing literature that often imposes strong assumptions such as Choleski or sign restrictions. The other is the computational strategy that separates estimation of the monetary policy equation from that of the rest of the system. This development makes it practical for one to quantify the dynamic impacts of monetary stimulus within the endogenous-switching framework. Our new econometric methodology can be used to study the transmission mechanism of large or unconventional interventions by the monetary authorities in other countries.

[29] In the speech during the 2017 annual International Monetary and Financial Committee (Zhou, 2017), the PBC governor Xiaochuan Zhou states: "Monetary policy will remain prudent and neutral, striking a better balance between stabilizing growth and the task of deleveraging, preventing asset bubbles, and containing the accumulation of systemic risks."

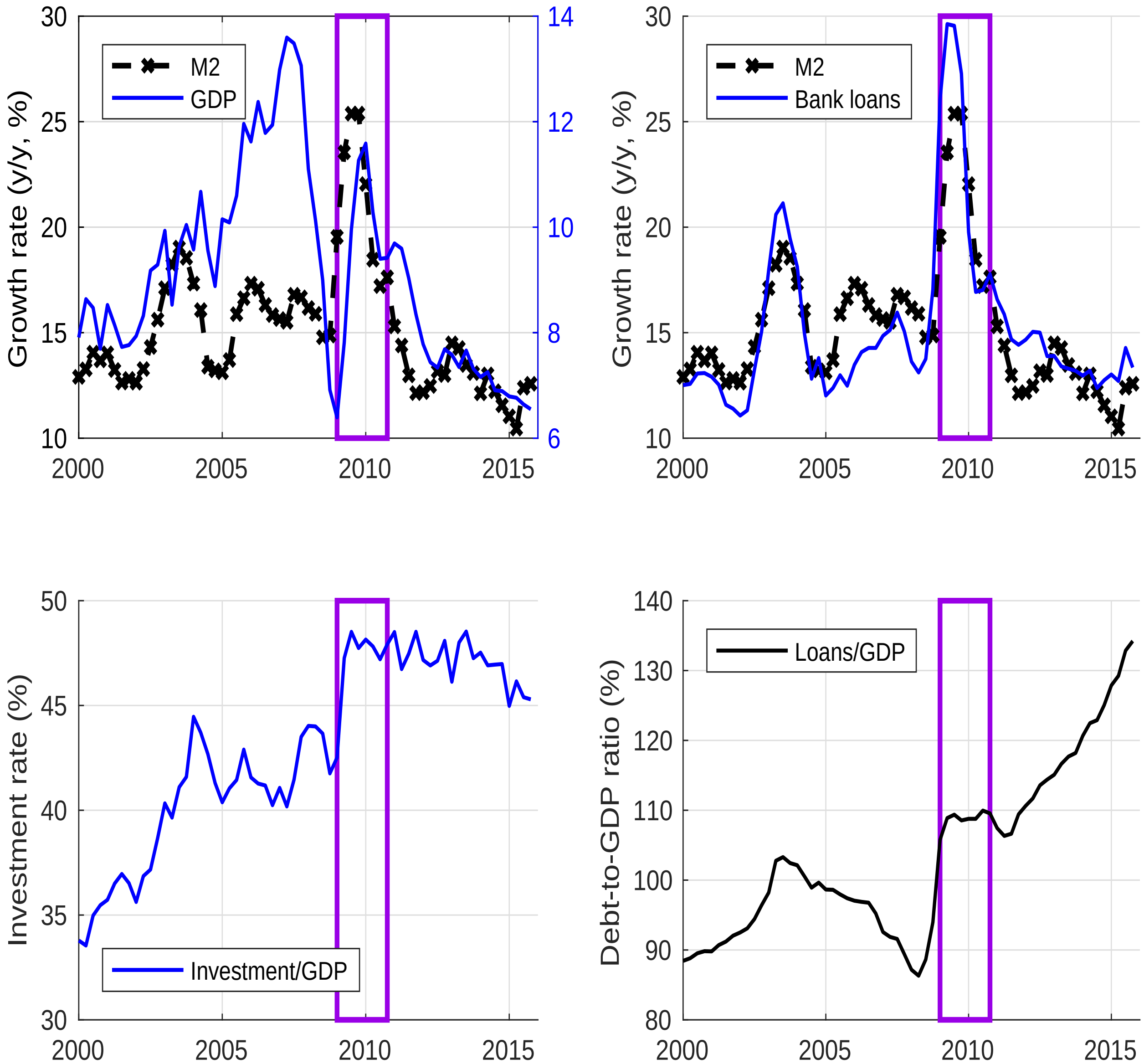

FIGURE 1. Macroeconomic time series. In the upper left panel of the figure, the scale for GDP growth is to the right and the scale for M2 growth is to the left. The rectangular box in each graph marks the period from 2009Q1 to 2010Q4. At the end of 2008, China's State Council announced a plan to invest 4 trillion RMB over this period in an attempt to minimize the impact of the global financial crisis on its economy.

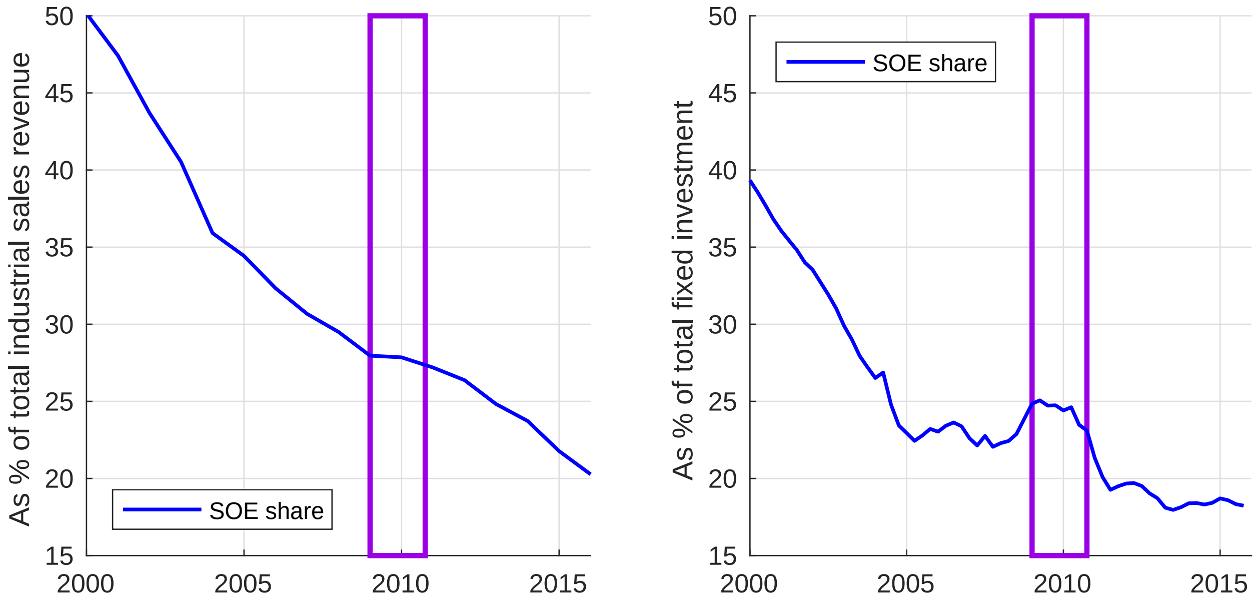

FIGURE 2. Macroeconomic time series (continued). The rectangular box in each graph marks the period from 2009Q1 to 2010Q4. At the end of 2008, China's State Council announced a plan to invest 4 trillion RMB over this period in an attempt to minimize the impact of the global financial crisis on its economy.

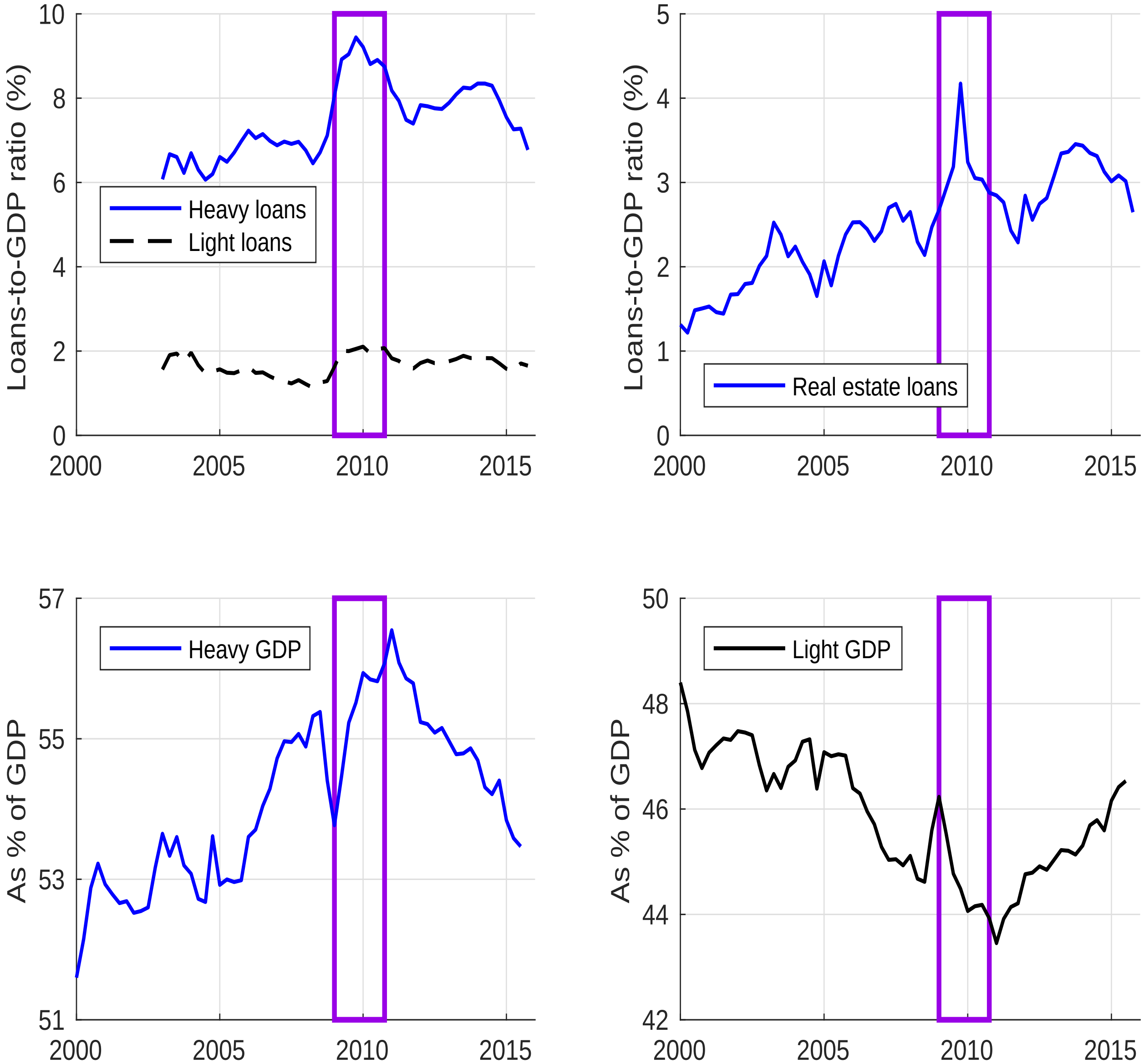

FIGURE 3. Macroeconomic time series (continued). The rectangular box in each graph marks the period from 2009Q1 to 2010Q4. At the end of 2008, China's State Council announced a plan to invest 4 trillion RMB over this period in an attempt to minimize the impact of the global financial crisis on its economy.

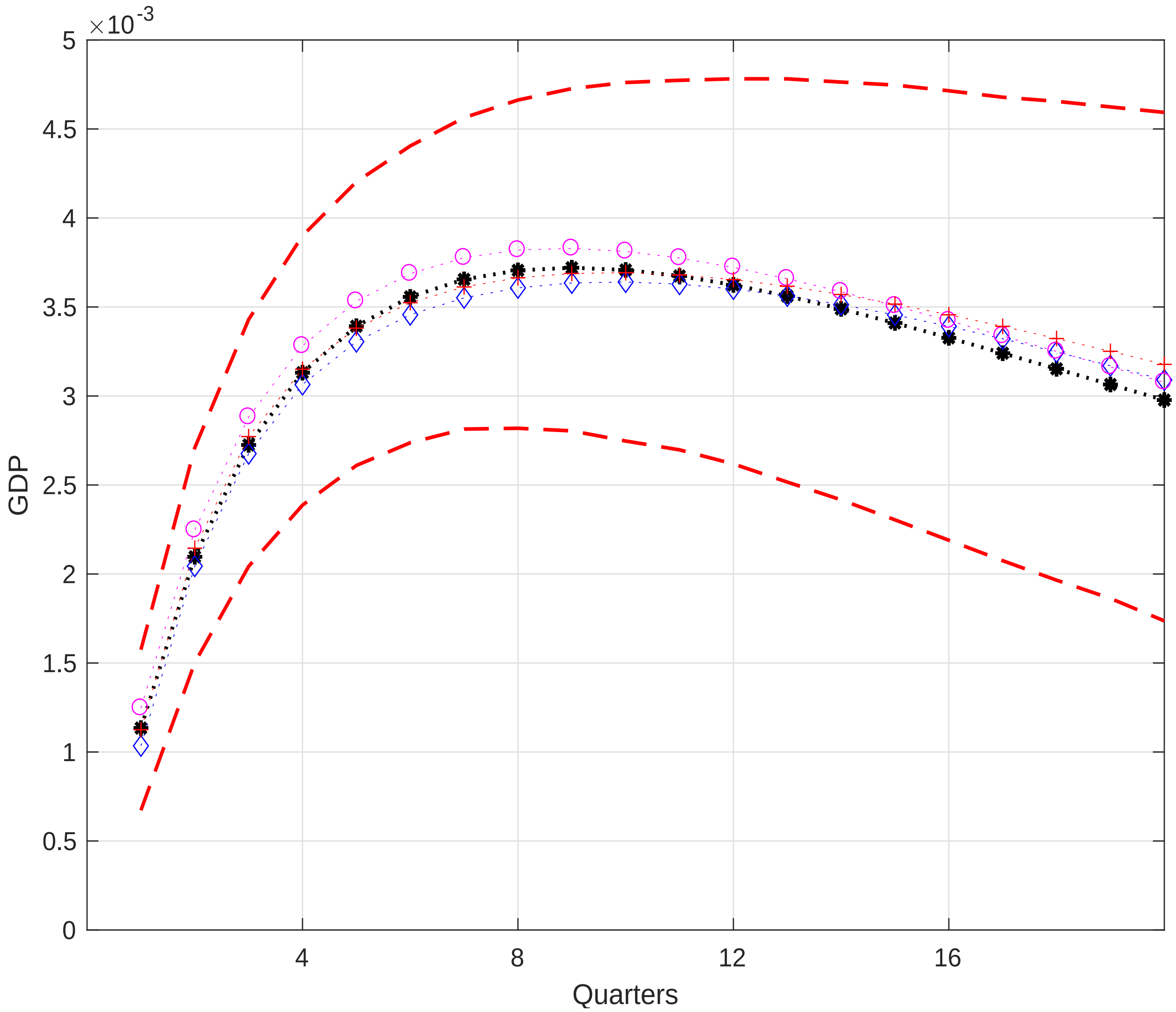

FIGURE 4. Dynamic responses of real GDP to a one-standard-deviation positive monetary policy shock. The asterisk line represents the response estimated from the benchmark model and dashed lines represent the corresponding .68 probability bands. The diamond line represents the response estimated from the model excluding interest rates. The circle line represents the response estimated from the model excluding foreign exchange reserves. The plus line represents the response estimated from the model excluding both interest rates and foreign exchange reserves.

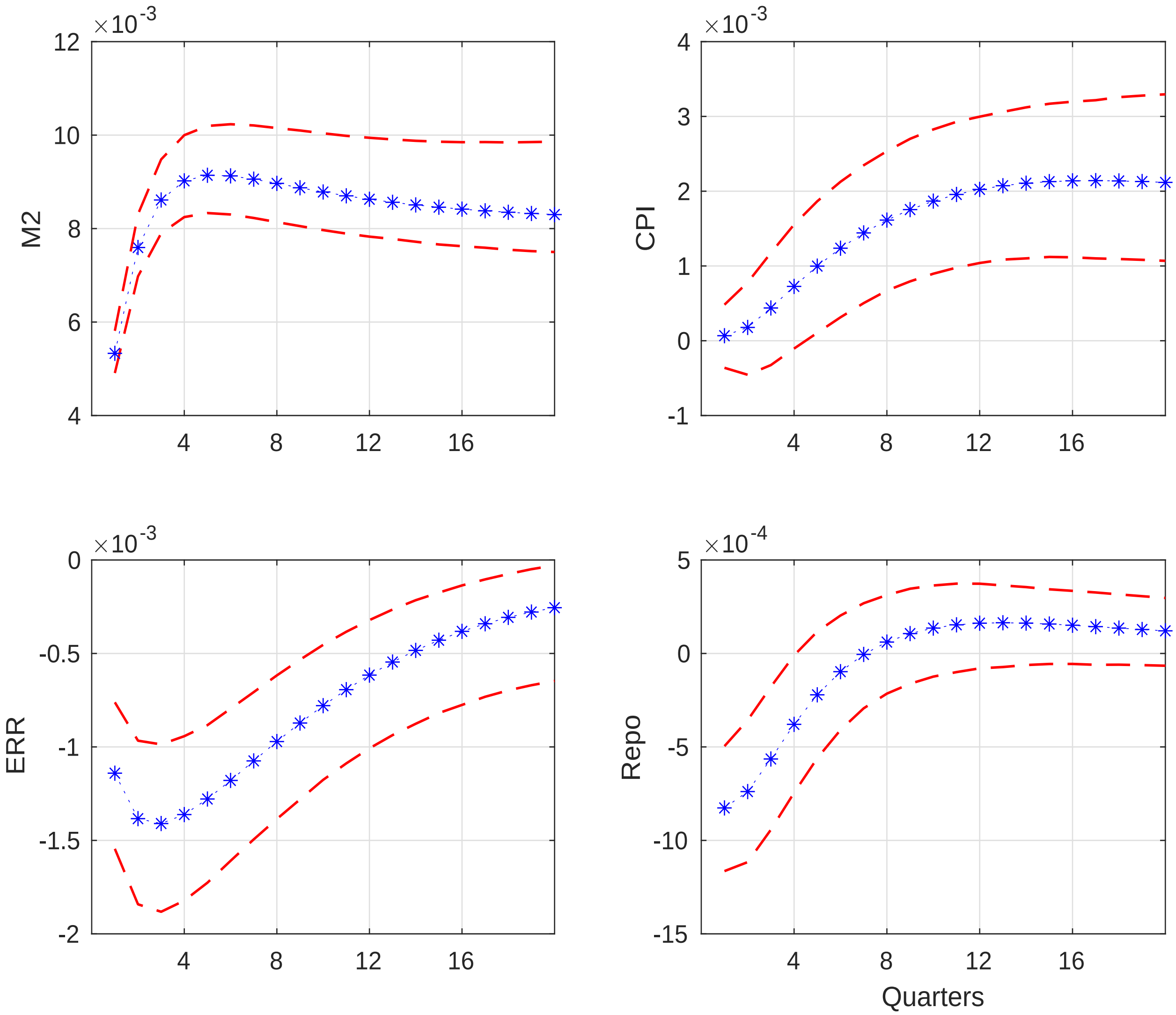

Figure 5. Dynamic responses of various key policy variables to a one-standard-deviation positive monetary policy shock. Asterisk lines represent the estimated responses and dashed lines represent the corresponding .68 probability bands. "ERR" stands for the excess reserves ratio in the banking system, and "Repo" is the 7-day rate for national interbank bond repurchases.

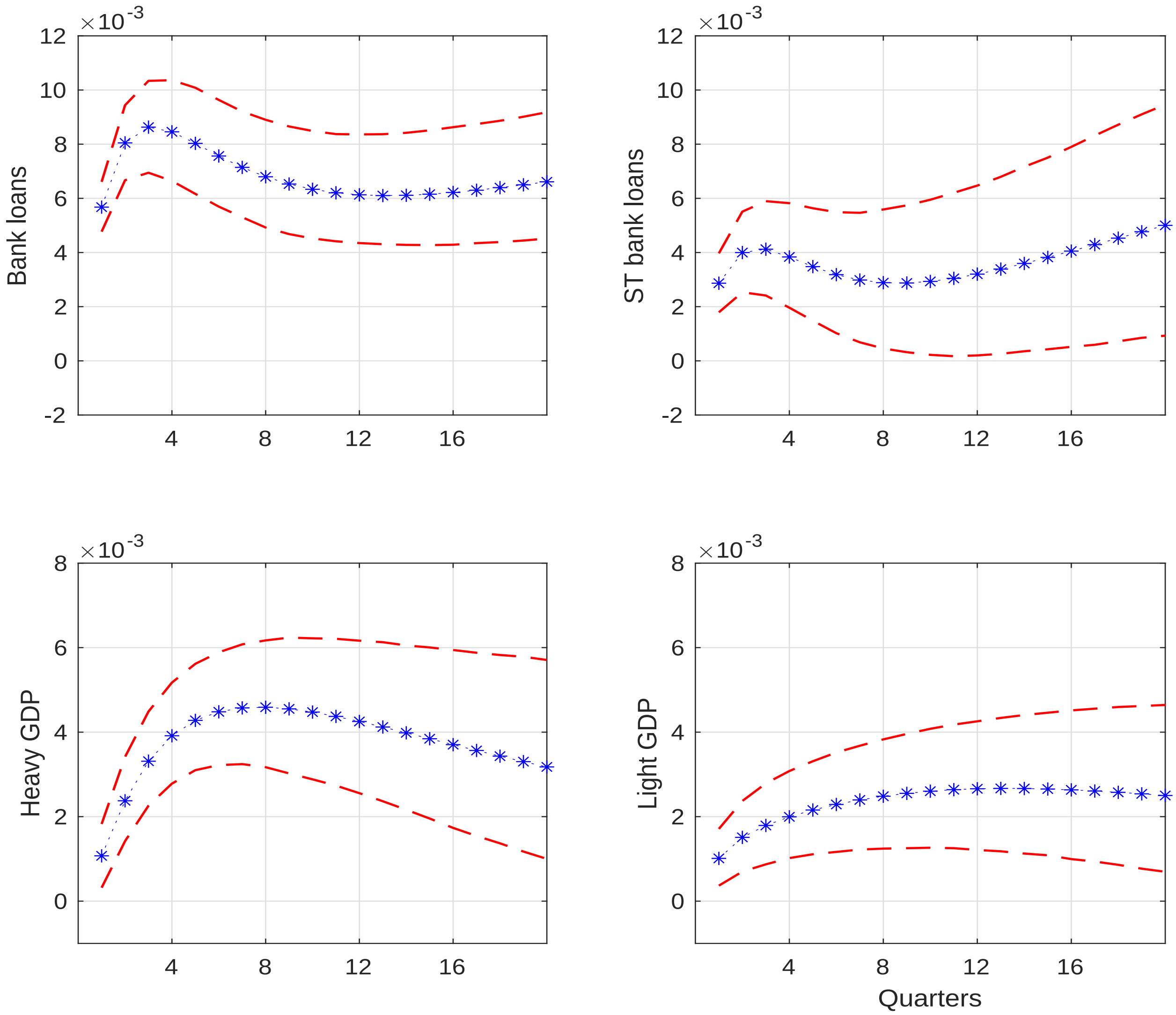

FIGURE 6. Dynamic responses to a one-standard-deviation positive monetary policy shock: (total) bank loans, short term bank loans (ST bank loans), value-added output produced from the heavy sector (Heavy GDP), and value-added output produced from the light sector (Light GDP). Asterisk lines represent the estimated responses and dashed lines represent the corresponding .68 probability bands.

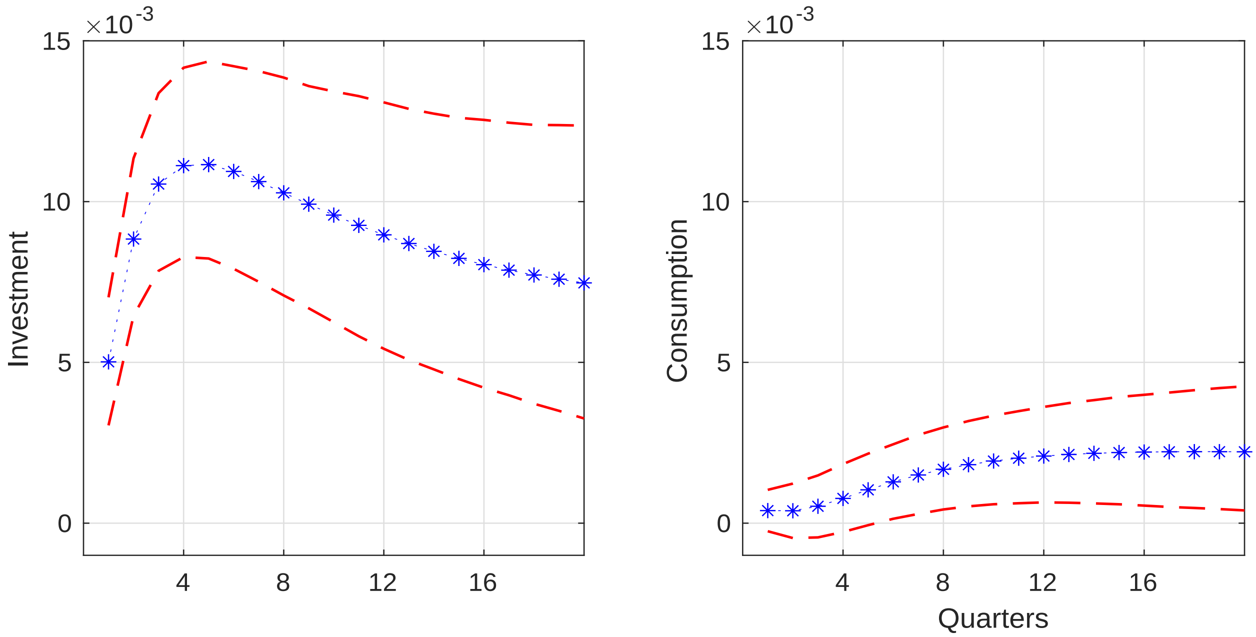

FIGURE 7. Dynamic responses of investment and consumption to a one-standard-deviation positive monetary policy shock. Asterisk lines represent the estimated responses and dashed lines represent the corresponding .68 probability bands.

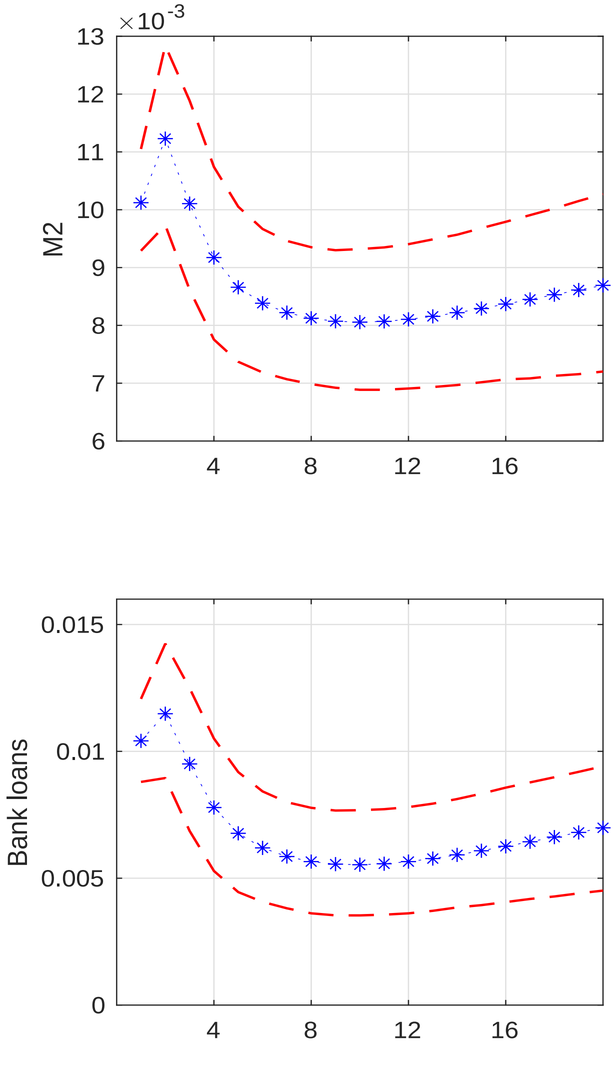

FIGURE 8. Dynamic responses to a one-standard-deviation positive monetary policy shock in the shortfall state. Asterisk lines represent the estimated responses and dashed lines represent the corresponding .68 probability bands.

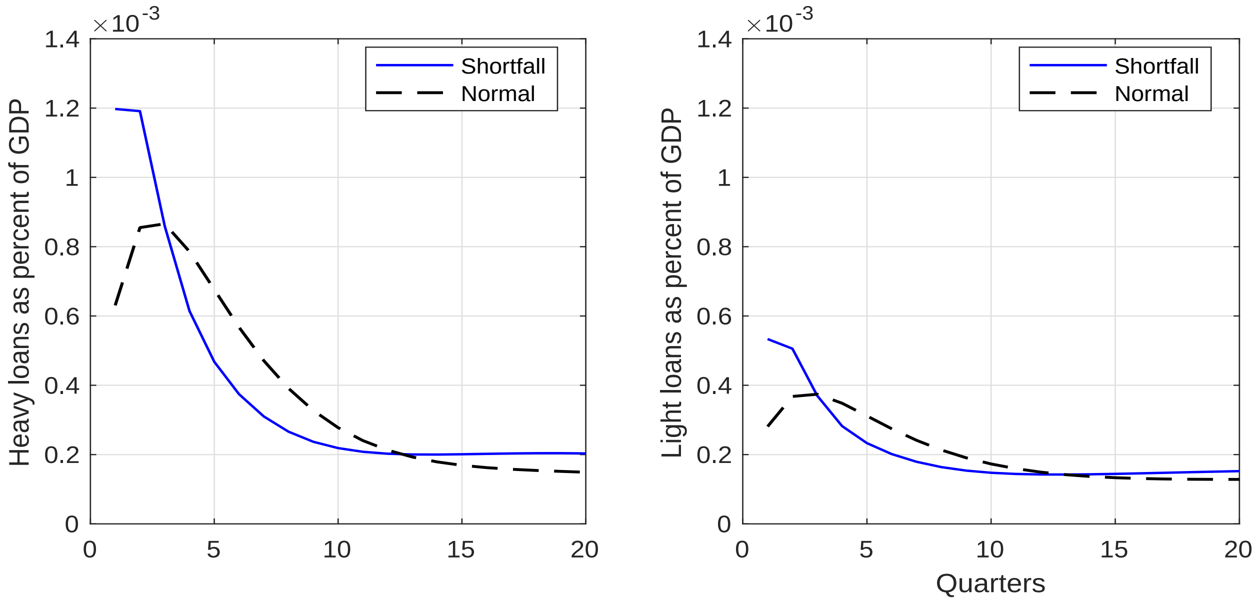

FIGURE 9. Dynamic responses to a one-standard-deviation positive monetary policy shock. "Heavy loans" are newly originated bank credit to fixed investment in the heavy sector. "Light loans" are newly originated bank credit to fixed investment in the light sector.

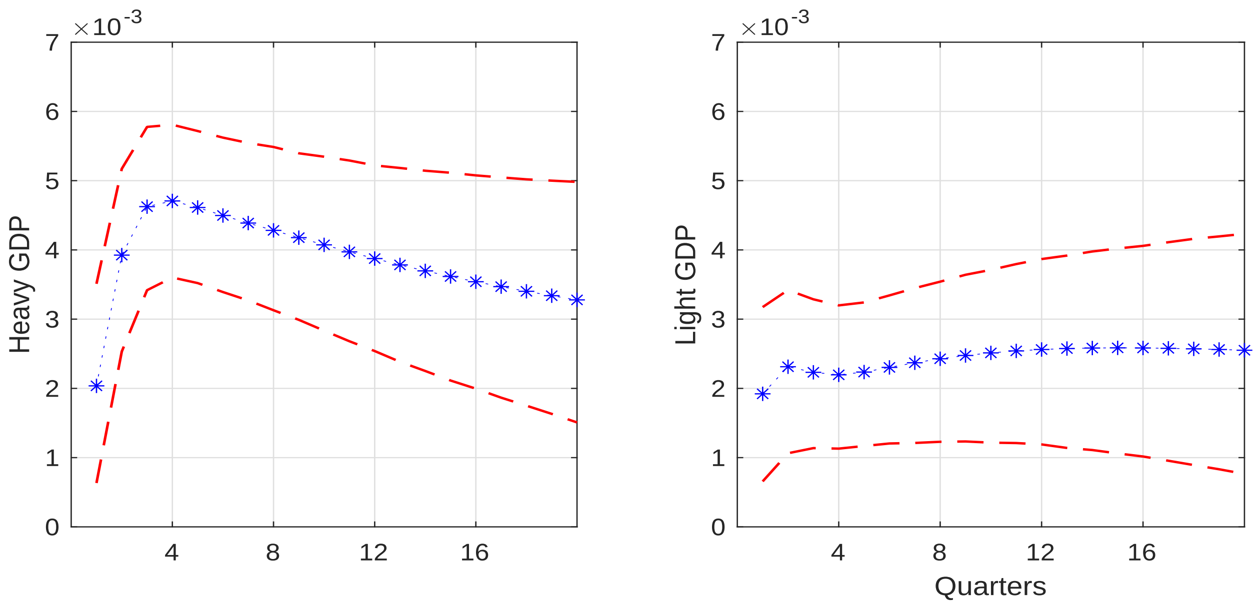

FIGURE 10. Dynamic responses to a one-standard-deviation positive monetary policy shock in the shortfall state. Asterisk lines represent the estimated responses and dashed lines represent the corresponding .68 probability bands.

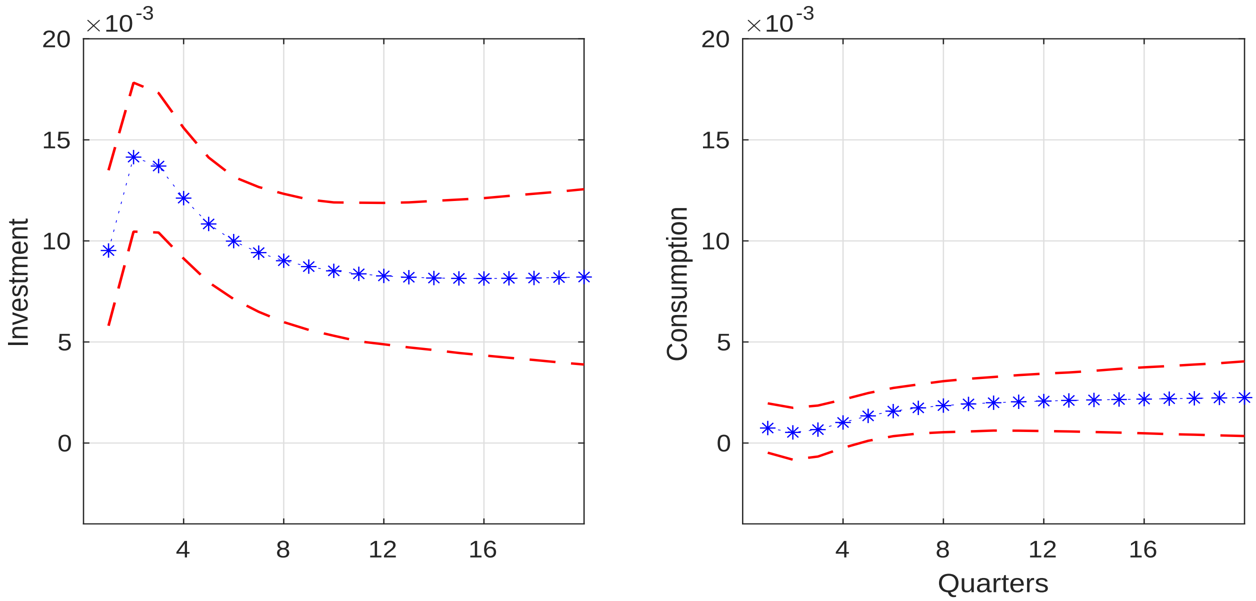

FIGURE 11. Dynamic responses to a one-standard-deviation positive monetary policy shock in the shortfall state. Asterisk lines represent the estimated responses and dashed lines represent the corresponding .68 probability bands.

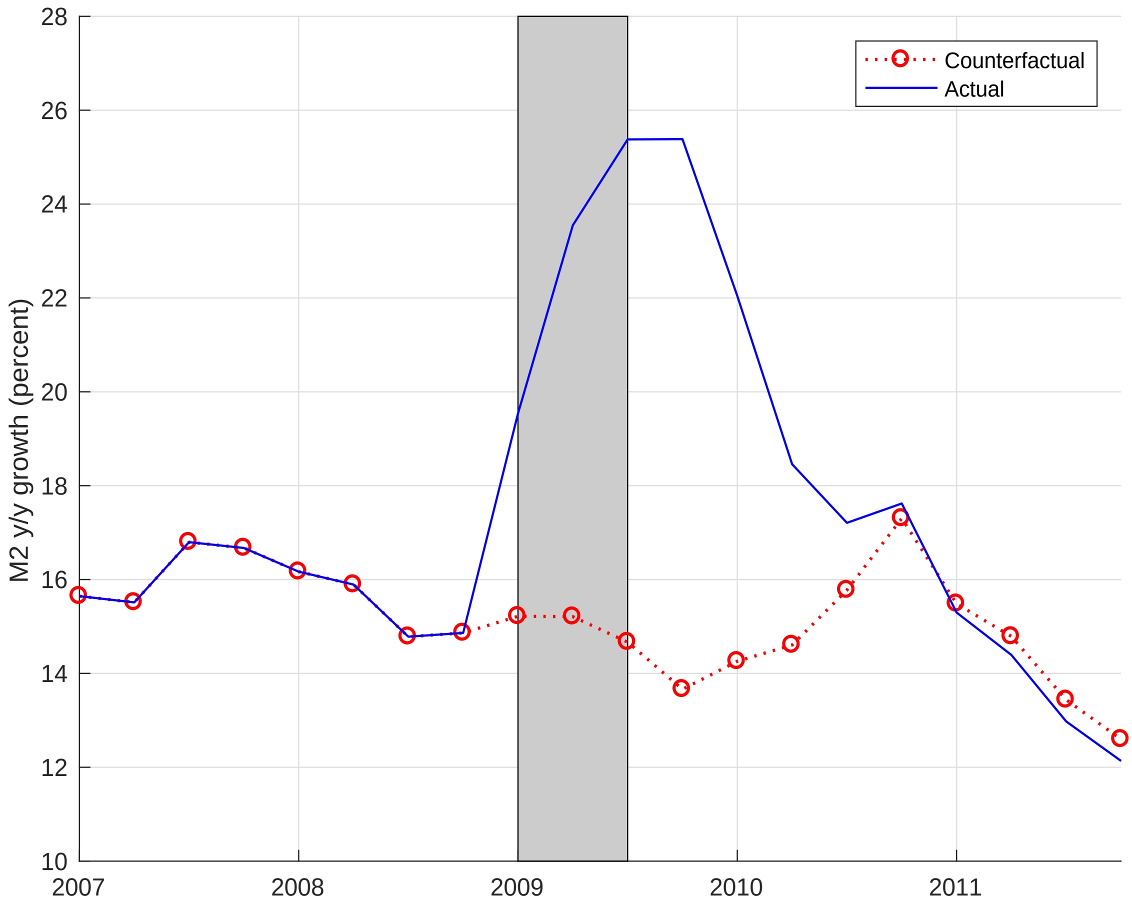

Figure 12. Actual and counterfactual historical paths of M2 year-over-year (y/y) growth rates. The shaded bar marks the period of 2009Q1-2009Q3 during which a switch of monetary policy to more aggressive stimulation is identified by the model. The counterfactual path assumes that monetary policy had not changed during this stimulation period.

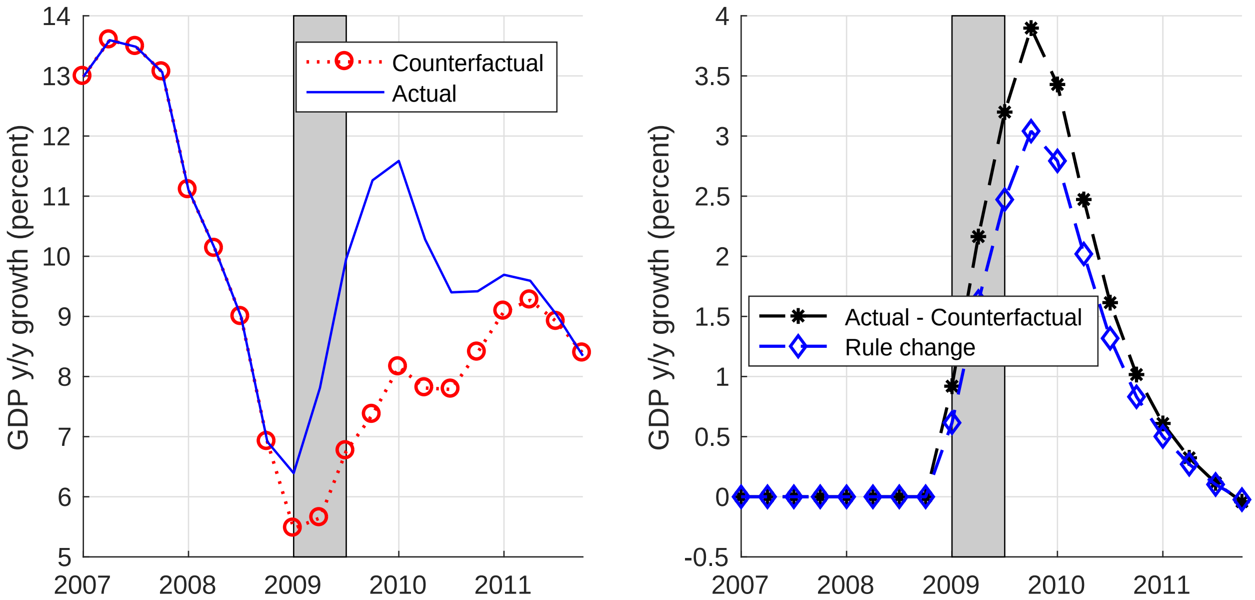

FIGURE 13. Actual and counterfactual historical paths of GDP year-over-year (y/y) growth rates. The shaded bar marks the period of 2009Q1-2009Q3 during which a switch of monetary policy to more aggressive stimulation is identified by the model. The counterfactual path assumes that monetary policy had not changed during this stimulation period. The diamond line in the right panel indicates the contribution from the change of systematic monetary policy alone.

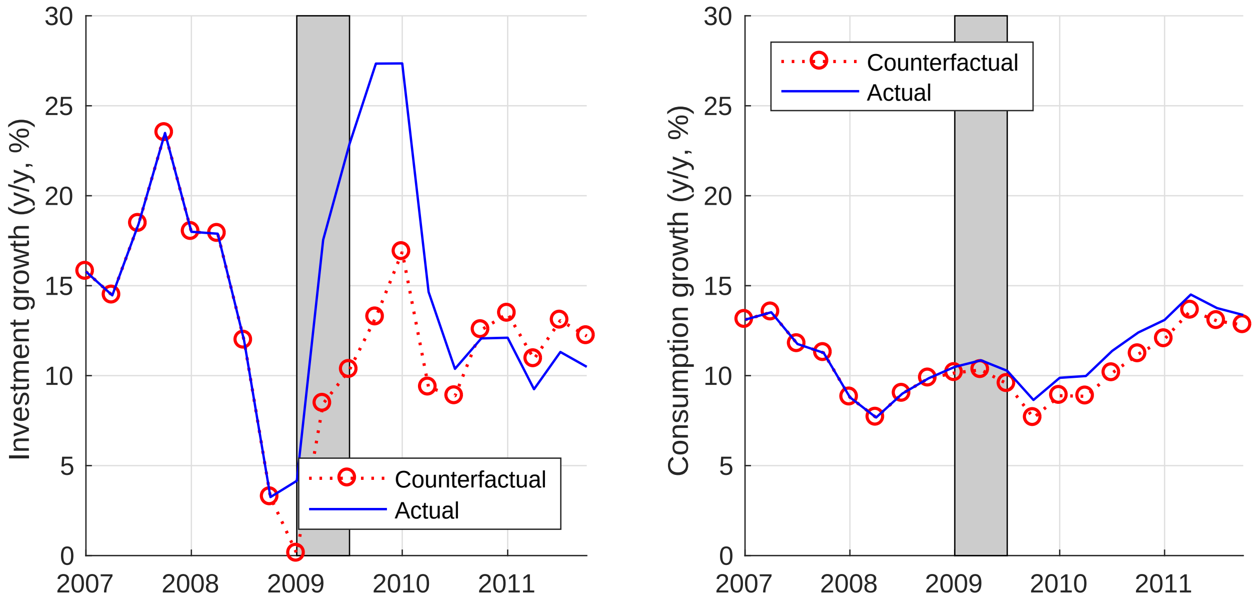

Figure 14. Actual and counterfactual historical paths of year-over-year growth rates of GDP in investment and household consumption. The shaded bar marks the period of 2009Q1-2009Q3 during which a switch of monetary policy to more aggressive stimulation is identified by the model. The counterfactual path assumes that monetary policy had not changed during this stimulation period.

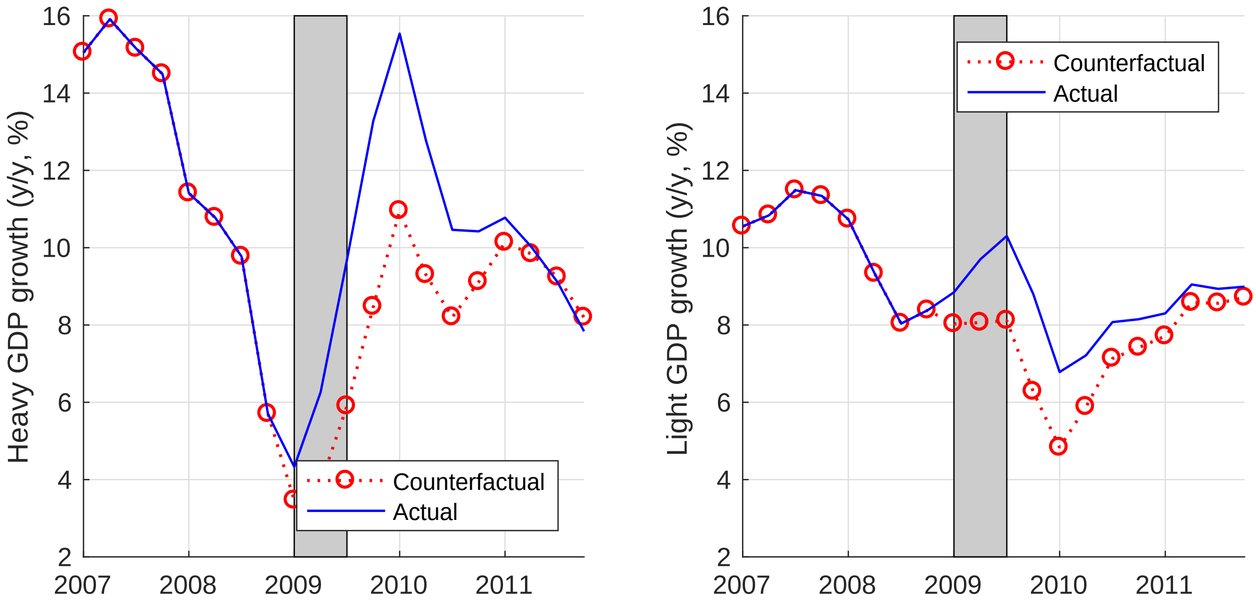

FIGURE 15. Actual and counterfactual historical paths of heavy GDP and light GDP growth rates. The shaded bar marks the period of 2009Q1-2009Q3 during which a switch of monetary policy to more aggressive stimulation is identified by the model. The counterfactual path assumes that monetary policy had not changed during this stimulation period.

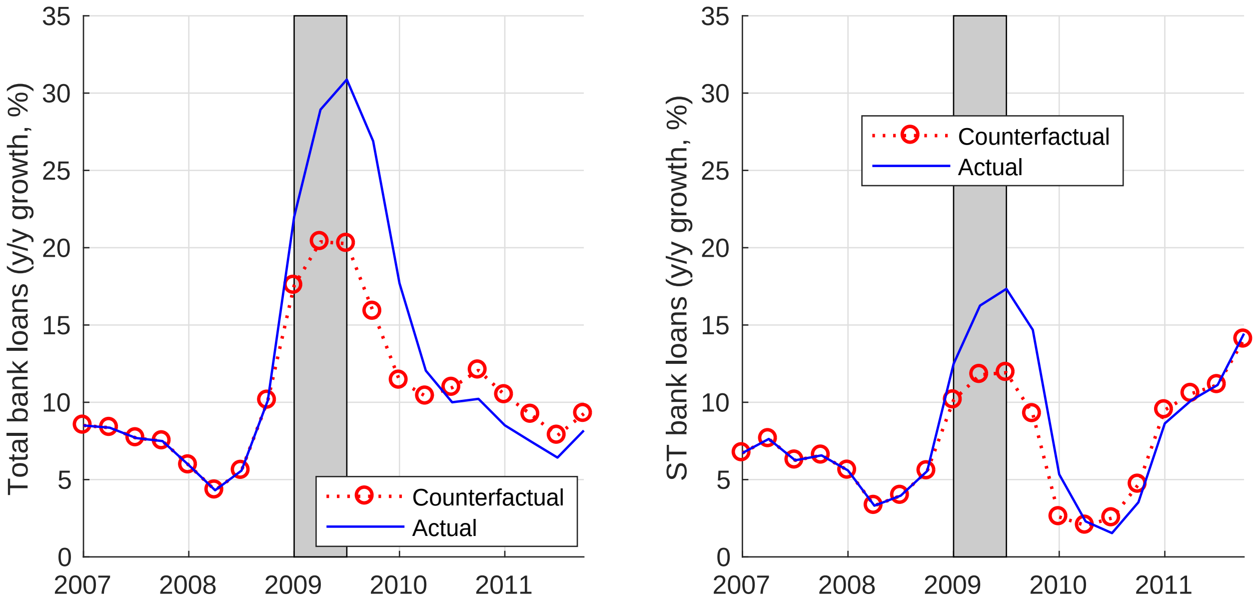

FIGURE 16. Actual and counterfactual historical paths of outstanding bank loans (year-over-year growth rates). The shaded bar marks the period of 2009Q1-2009Q3 during which a switch of monetary policy to more aggressive stimulation is identified by the model. The counterfactual path assumes that monetary policy had not changed during this stimulation period.

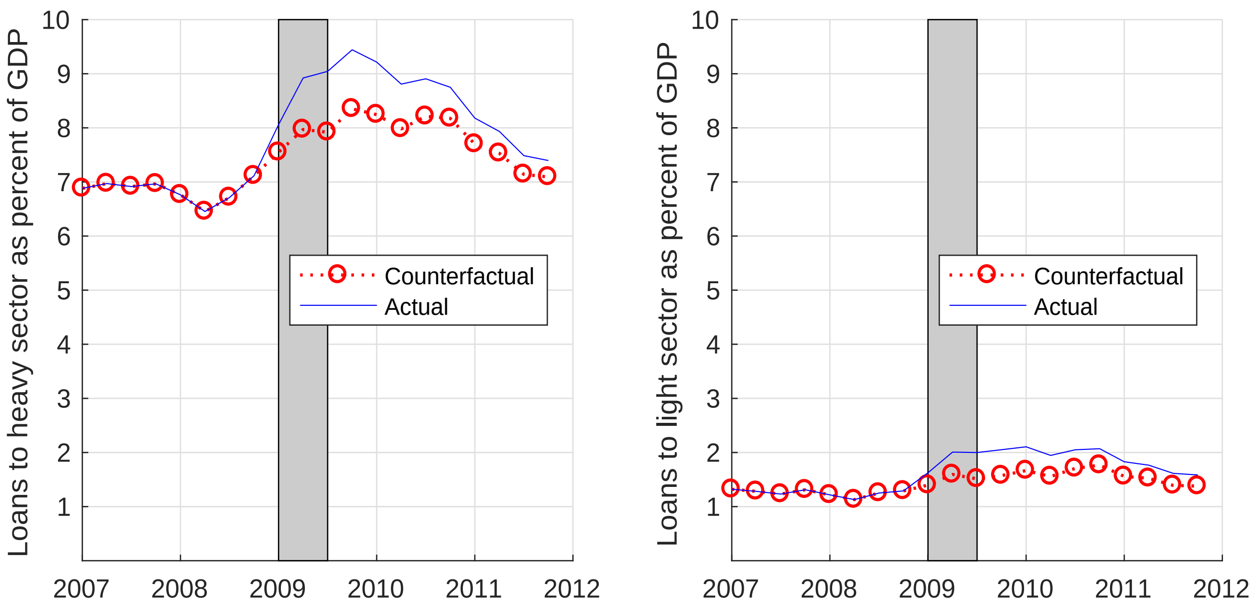

FIGURE 17. Actual and counterfactual historical paths of newly originated loans in percent of GDP. The shaded bar marks the period of 2009Q1-2009Q3 during which a switch of monetary policy to more aggressive stimulation is identified by the model. The counterfactual path assumes that monetary policy had not changed during this stimulation period.

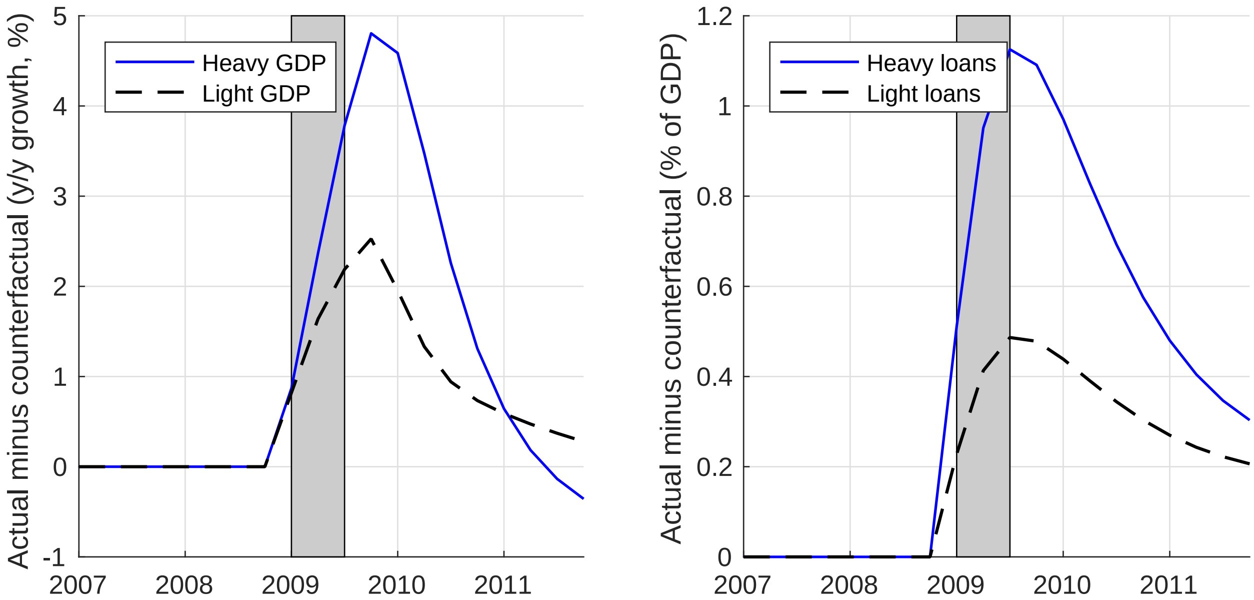

FIGURE 18. Actual and counterfactual historical paths of the two components of GDP (heavy and light) and newly originated loans in percent of GDP. The shaded bar marks the period of 2009Q1-2009Q3 during which a switch of monetary policy to more aggressive stimulation is identified by the model. The counterfactual path assumes that monetary policy had not changed during this stimulation period.

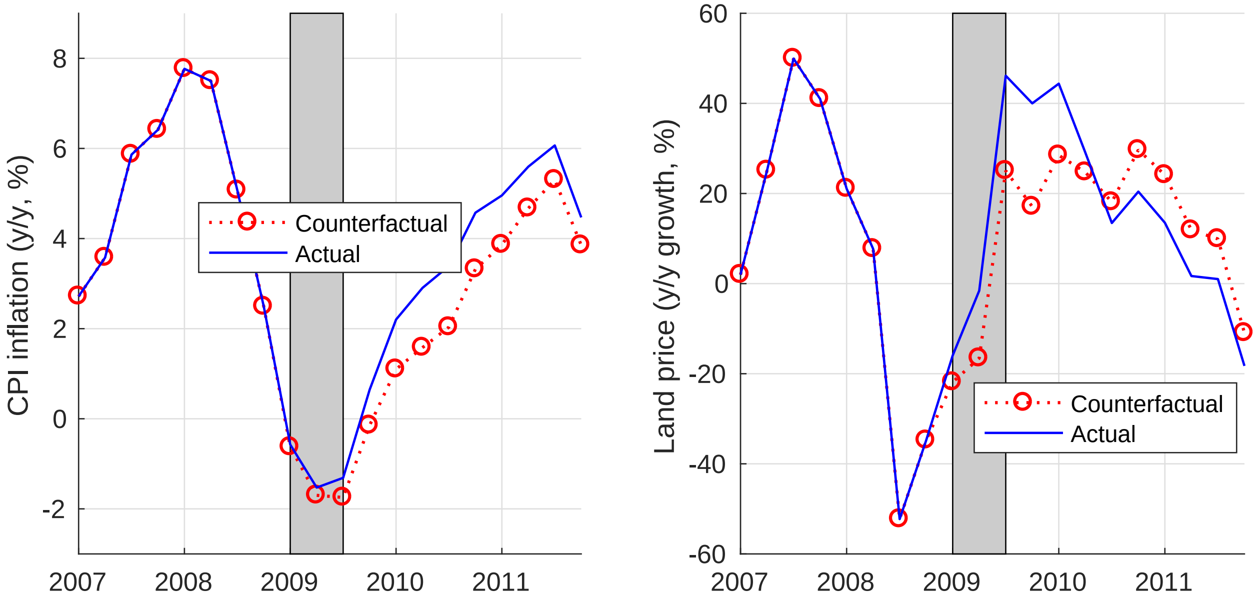

Figure 19. Actual and counterfactual historical paths of year-over-year CPI inflation and *real* land price growth (adjusted by CPI inflation). The shaded bar marks the period of 2009Q1-2009Q3 during which a switch of monetary policy to more aggressive stimulation is identified by the model. The counterfactual path assumes that monetary policy had not changed during this stimulation period.

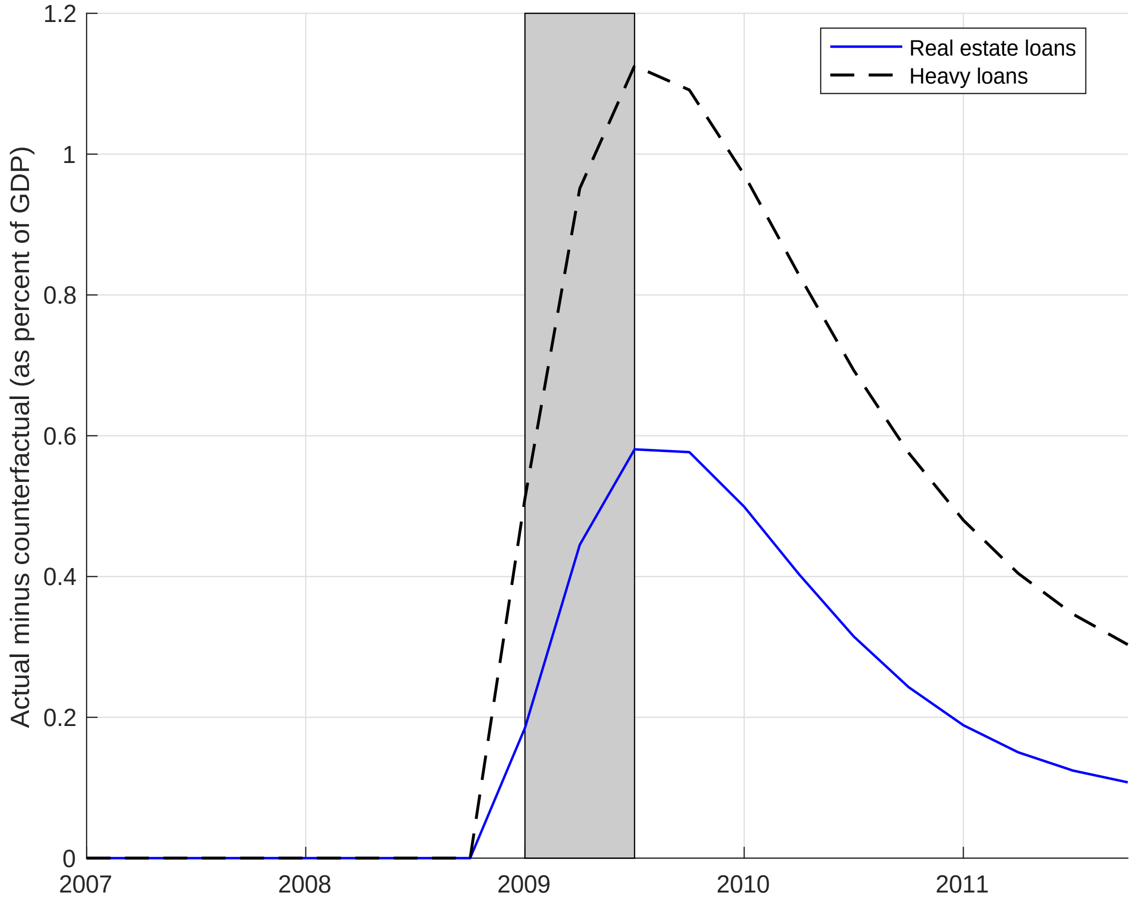

Figure 20. Historical paths of newly originated loans in percent of GDP. "Heavy loans" stands for new loans to the heavy sector and "Real estate loans" stands for new loans to the real estate sector. The shaded bar marks the period of 2009Q1-2009Q3 during which a switch of monetary policy to more aggressive stimulation is identified by the model. The counterfactual path assumes that monetary policy had not changed during this stimulation period.

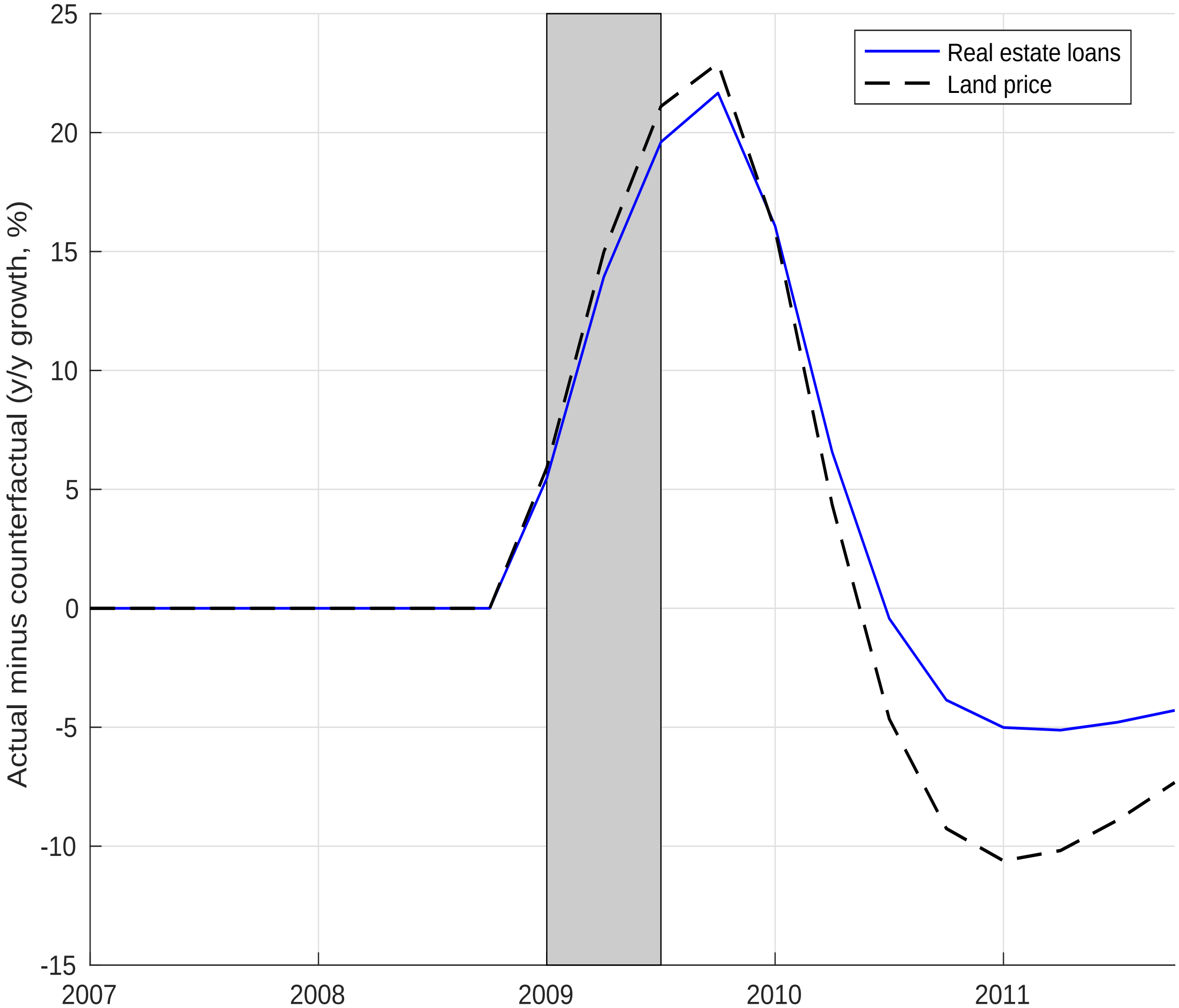

Figure 21. Historical paths of year-over-year growth rates of land price growth and newly originated loans to the real estate. The shaded bar marks the period of 2009Q1-2009Q3 during which a switch of monetary policy to more aggressive stimulation is identified by the model. The counterfactual path assumes that monetary policy had not changed during this stimulation period.

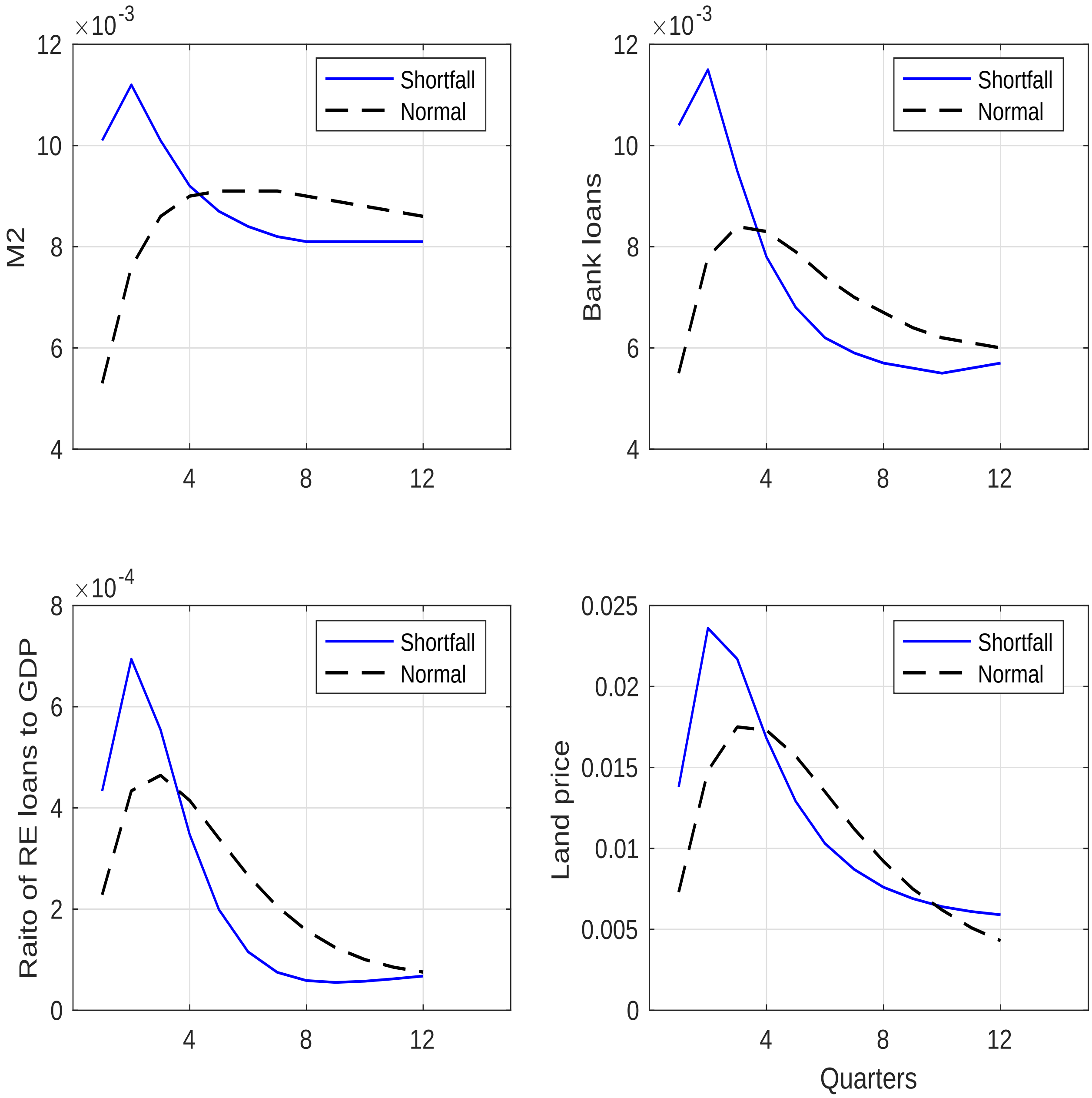

FIGURE 22. Impulse responses of various key macroeconomic variables to an expansionary monetary policy shock in the normal and shortfall states.

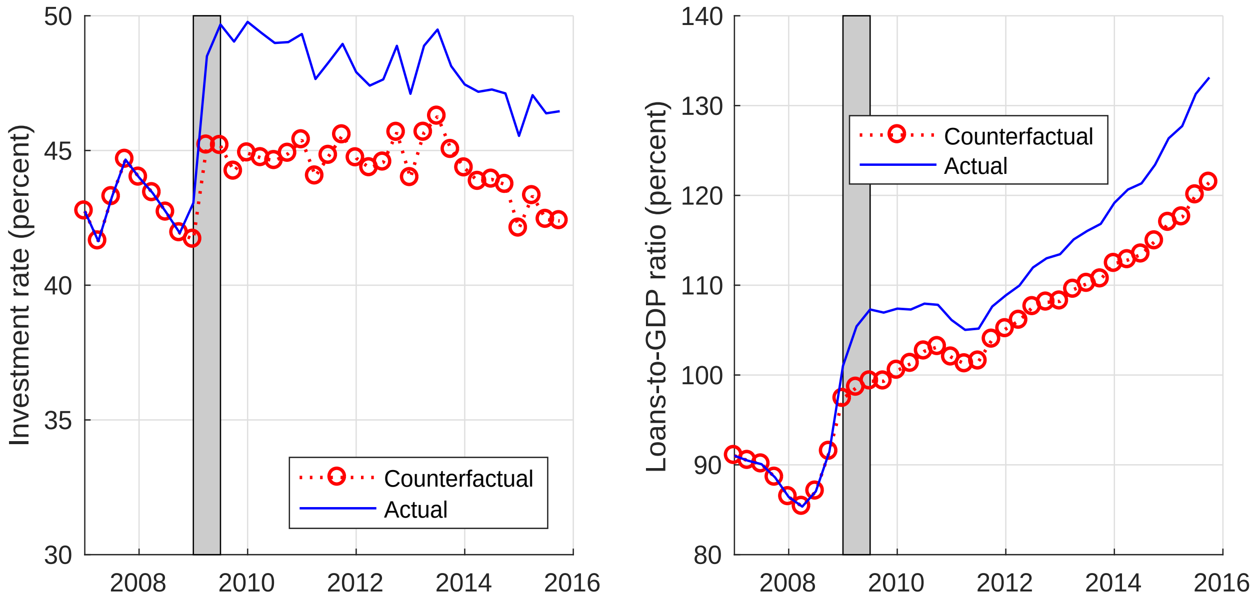

Figure 23. Actual and counterfactual historical paths of the investment-to-GDP ratio and the debt-to-GDP ratio (the ratio of bank loans to GDP). The shaded bar marks the period of 2009Q1-2009Q3 during which a switch of monetary policy to more aggressive stimulation is identified by the model. The counterfactual path assumes that monetary policy had not changed during this stimulation period.

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

Quarter	4	8	12	16	20
	GDP (normal state)				
Benchmark model	13.7	19.5	20.2	18.9	17.1
Benchmark model excl Rs	12.7	18.3	20.1	20.0	18.7
Benchmark model excl FXR	14.7	20.5	21.4	20.3	18.5
Benchmark model excl Rs and FXR	12.8	18.2	20.1	20.1	19.2
	GDP (shortfall state)				
Benchmark model	36.4	44.3	45.0	43.4	40.9
	Benchmark model (normal state)				
CPI	0.4	2.1	4.2	6.0	7.2
Total bank loans	24.6	23.0	22.7	22.8	23.3
ST bank loans	5.8	4.2	3.3	3.0	3.2
Investment	13.4	16.1	15.8	15.0	14.2
Consumption	0.4	1.4	2.4	3.1	3.5

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

Appendix A. Data and Definitions

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 details of constructing all the series except M2, bank loans, ST bank loans, and land prices are described in these two references. The main data sources are China's National Bureau of Statistics, the People's Bank of China, and CEIC. The proc X-12 procedure in the SAS software package is used for seasonal adjustment. 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 Denton (1971).

- **M2**. M2 money supply, quarterly average of the monthly series (RMB billion). For the last monthly observation, we use the level of M2 (CEIC ticker CKSAAC). The 12 monthly observations prior to the last observation are constructed recursively from the month-over-month gross growth rates of CKSAAC each multiplied by a constant adjustment factor. The adjustment factor is chosen so that the 12-month growth rate of the last observed value of our constructed series is equal to the last published 12-month growth rate (CEIC ticker CKSAACA). Once these last 13 observations are determined, we recursively construct the level series back to 1996M4 with the published year-over-year growth rate, back to 1994M12 with the year-over-year growth rate provided by the PBC, and back to 1990M3 with an interpolated year-over-year growth rate derived from the quarterly level of M2 (CEIC ticker CKAAC).
- **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 asset 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.
- **Bank loans**. End-of-quarter financial institution loans outstanding (i.e., the third monthly observation of each quarter, RMB billion). We construct this series all the way back to 1978Q4 prior to seasonal adjustment. The last monthly observation is taken from the CEIC ticker CKSAC. The 12 monthly observations prior to the last observation are constructed recursively from the month-over-month gross growth rates of CKSAC each multiplied by a constant adjustment factor. The adjustment factor is chosen so that 12-month growth rate of the last observed value of our constructed series is equal to the last published 12-month growth rate (CEIC ticker CKSAD). Once these last 13 observations are determined, we recursively construct the level series back to 1997M4 with the published year-over-year growth rates. We then use data from WIND to backcast the series prior to 1997M4, assuming that the ratio of the series from WIND to our series prior to 1997M4 is the same as it is in 1997M4.
- **ST bank loans**. Short-term (ST) bank loans outstanding with the third monthly observation of each quarter (RMB billion). The constructed series goes back to 1994Q1. Multiplying the bank loans series by the ratio of CEIC ticker "CKAHLA–CN: Loan: Short Term" to CEIC ticker "CKSAC–CN: Loan", we construct the monthly level series. The series prior to 1999M1 is extrapolated with the WIND data on short-term bank loans using the same ratio extrapolation method as the construction of the bank loans series.
- **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.
- **Net exports**. Nominal net exports as a percentage of nominal GDP. Annual measure from national domestic product is interpolated by seasonally adjusted 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 product interpolated by fixed-asset investment and deflated by the investment price index. The U.S. counterpart of this series is gross private domestic investment, except our Chinese series includes government and SOE investment.
- **Consumption**. Household consumption based on the expenditure side of national domestic products, interpolated quarterly by retail sales of consumer goods and deflated by the CPI. This series includes consumer durable goods.
- **Heavy GDP**. Value-added output produced by the heavy sector (RMB billion). The heavy sector includes real estate, infrastructure, transportation, telecommunication, and basic industries such as steel, cement, electricity, chemical products, coal,

petroleum processing, and natural gas. The classification of the heavy sector is described in Chang, Chen, Waggoner, and Zha (2016).

- **Light GDP**. Value-added output produced by the light sector (RMB billion). Industries that does not belong to the heavy sector are those in the light sector such as education, health care, scientific research, and environment. The classification of the light sector is described in Chang, Chen, Waggoner, and Zha (2016).
- **Heavy and light loans**. Newly originated loans from financial institutions for investment in both heavy and light sectors (RMB billion). Annual series on heavy, light, and total loans are constructed by aggregating industry-level data on newly originated domestic loans for investment in fixed assets excluding rural households downloaded from the NBS website. Annual total loans are interpolated by a modified measure of seasonally adjusted new quarterly total loans using Fernandez (1981) interpolation adapted by Higgins and Zha (2015). Annual heavy loans are interpolated with the same Fernandez (1981) method jointly using the same quarterly measure of total loans and a modified measure of seasonally adjusted new real estate loans for investment as interpolaters. The two interpolaters are constructed from monthly data originally from the NBS and downloaded from CEIC [tickers COBDPD and CECGB, respectively]. After quarterly aggregation and seasonal adjustment, both interpolaters are modified to add up to their orignal unadjusted annual totals using an intermediate Fernandez (1981) interpolation step as adapted by Higgins and Zha (2015). Newly originated quarterly loans from financial institutions for investment in the light sector is defined as the difference between the interpolated series on total and heavy new domestic loans.
- **Land price**. Wharton/NUS/Tsinghua Chinese residential land price index from Wu, Gyourko, and Deng (2012). The original series, downloaded from Joseph Gyourko's website, is updated through 2016Q2.
- **Real estate loans**. Newly originated bank loans to investment in the real estate sector (RMB billion). The series is constructed by aggregating the monthly series published by the NBS, seasonally adjusting, and interpolating the annual series using the Higgins and Zha (2015) adaptation of Fernandez (1981) interpolation so that the quarterly series aggregates to the annual total.
- **SOE shares of industrial sales and fixed investment**. Constructed with data downloaded from the NBS.

Appendix B. Proof of Proposition 1

For system (4), we first show that the first equation (the monetary policy equation) is identified. According to Theorem 2 of Rubio-Ramírez, Waggoner, and Zha (2010), this equation is identified if the following statement is true: if $\widetilde{Q}\widetilde{A}_{0,t} = \widehat{A}_{0,t}$, where $\widetilde{Q}$ is an orthogonal matrix, and $\widehat{A}_{0,t}$ maintains the form of

$$\begin{bmatrix} \widehat{A}^{11}_{0,t} & \widehat{A}^{12}_{0,t} \\ \widehat{A}^{21}_{0,t} & \widehat{A}^{22}_{0,t} \end{bmatrix} = \begin{bmatrix} \widehat{A}^{11}_{0,t} & \underset{1\times n}{0} \\ \widehat{A}^{21}_{0,t} & \widehat{A}^{22}_{0,t} \end{bmatrix},$$

then $\widetilde{Q}$ must be of the form

$$\begin{bmatrix} \widetilde{Q}^{11} & \widetilde{Q}^{12} \\ \widetilde{Q}^{21} & \widetilde{Q}^{22} \end{bmatrix} = \begin{bmatrix} 1 & \underset{1\times n}{0} \\ \underset{n\times 1}{0} & \widetilde{Q}^{22} \end{bmatrix}. \tag{B.1}$$

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

$$\begin{bmatrix} \widetilde{Q}^{11}\widetilde{A}^{11}_{0,t} + \widetilde{Q}^{12}\widetilde{A}^{21}_{0,t} & \widetilde{Q}^{12}\widetilde{A}^{22}_{0,t} \\ \widetilde{Q}^{21}\widetilde{A}^{11}_{0,t} + \widetilde{Q}^{22}\widetilde{A}^{21}_{0,t} & \widetilde{Q}^{22}\widetilde{A}^{22}_{0,t} \end{bmatrix} = \begin{bmatrix} \widehat{A}^{11}_{0,t} & \underset{1\times n}{0} \\ \widehat{A}^{21}_{0,t} & \widehat{A}^{22}_{0,t} \end{bmatrix}.$$

Since $\widetilde{A}^{22}_{0,t}$ is invertible for the system and $\widetilde{Q}^{12}\widetilde{A}^{22}_{0,t} = 0$, we have $\widetilde{Q}^{12} = 0$. Because $\widetilde{Q}$ is an orthogonal matrix, it must be that $\widetilde{Q}^{21} = 0$ and $\widetilde{Q}^{11} = 1$. This proves (B.1).

We now show that impulse responses of y_t to $\varepsilon_{m,t}$ are invariant to the rotation matrix Q or the ordering of elements in y_t. Note that the rotation matrix Q in subsystem (2) is the same as $\widetilde{Q}^{22}$. Because the first equation of system (3) is identified and the rotation matrix $\widetilde{Q}$ for the whole system satisfies (B.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 (3) 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 C. Proof of Proposition 3

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

$$
\begin{aligned}
\mathrm{LH} \propto & \left|\det(\widetilde{A}_{0,t})\right|^T \exp\left\{-\frac{1}{2}\sum_{t=1}^{T}\sum_{i=1}^{1+n}\left[\tilde{a}^i_{0,t}z_t - \tilde{c}^i_t - \sum_{\ell=1}^{4}\tilde{a}^i_{\ell,t}z_{t-\ell}\right]^2\right\} \\
= & \, \sigma_{m,t}^{-T}\exp\left\{-\frac{1}{2}\sum_{t=1}^{T}\left[\tilde{a}^1_{\ell,t}z_t - \tilde{c}^1_t - \sum_{\ell=1}^{4}\tilde{a}^1_{\ell,t}z_{t-\ell}\right]^2\right\} \times \\
& \left|\det(\widetilde{A}^{22}_{0,t})\right|^T \exp\left\{-\frac{1}{2}\sum_{i=2}^{1+n}\sum_{t=1}^{T}\left[\tilde{a}^i_{0,t}z_t - \tilde{c}^i_t - \sum_{\ell=1}^{4}\tilde{a}^i_{\ell,t}z_{t-\ell}\right]^2\right\}.
\end{aligned}
\tag{C.1}
$$

The first part of the right hand side of (C.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 (4) that the coefficients $\widetilde{A}^{22}_{0,t}$, $\tilde{a}^i_{\ell,t}$, and $\tilde{c}^i_t$ are constant across time for $i = 2, \ldots, 1+n$. Thus, the second term of the right hand side of (C.1) is time invariant and is equivalent to the estimation of the linear VAR system.

Sims and Zha (1998)'s Bayesian prior is designed for the structural form (4), not for the conventional form (3). This important feature ensures that when the prior is applied to the second part of system (4), the posterior probability density function has exactly the same form as the second part of the right hand side of (C.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 $\widetilde{A}^{22}_{0,t} \equiv A_0$, moreover, each equation in the second block of system (C.1) can be estimated independently of other equations.

Appendix D. Role of the external sector

One aspect of monetary policy under discussion focuses on how monetary policy reacts to movements in the exchange rate market. This and many other details are abstracted from the simple policy equation. A natural question is whether the endogenous part of monetary policy encompasses possible reactions to exchange rate movements. If the answer were negative, then our exogenous monetary policy shocks would contain endogenous movements related to the external sector. To test this hypothesis, we regress the estimated monetary policy shock series on the four lags of the foreign exchange rate as well as net exports (as percent of GDP). For completeness, we also regress the estimated endogenous 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

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.

captured by endogenous monetary policy. The identified monetary policy shocks, therefore, are not contaminated by an endogenous response to fluctuations in the RMB exchange rate.

Foreign exchange reserves are a combination of the exchange rate and trade surplus; thus, they have been an important factor for capital control. PBC's sterilization operations by selling central bank bills or raising the reserve requirement ratio to freeze the excess liquidity in the banking system would affect foreign exchange reserves significantly (Chang, Liu, and Spiegel, 2015). But how important are foreign exchange reserves 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 model. 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, confirming that the effects of monetary policy in China work mainly through bank loans to domestic investment, not through the external sector.

In the spirit of the simple Taylor rule (Taylor, 1993), the endogenous component of China's monetary policy is "sufficiently encompassing" to the extent that fluctuations in GDP growth and CPI inflation capture other factors such as net exports and foreign exchange reserves (Taylor, 2000). The Chinese central government's overriding goal is to target *real GDP growth* and promote this growth *beyond the target.* The main task of monetary policy is to help achieve this goal, all else becoming a means to this end.

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