What Measures Chinese Monetary Policy?

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Abstract: This paper models the People's Bank of China's operating procedures in a two-stage vector autoregression model to search for a valid good policy indicator for Chinese monetary policy. The model disentangles endogenous components in changes in monetary policy that are driven either by demand for money or the liquidity management needs arising from foreign exchange purchases. There are four main findings. First, the PBC's procedures appear to have changed over time, and hence no single indicator represents Chinese monetary policy well for the 2000-2013 time period. Second, its operating procedure is neither pure interest-rate targeting nor pure reserves targeting, but a mixture. Third, a set of indicators all contain information about the policy stance. It is hence preferred to use a composite measure to measure Chinese monetary policy. Finally, we construct a new composite indicator of the overall policy stance, consistent with our model. A comparison with several existing measurement approaches suggests that the composite indices, rather than individual indicators, perform better in measuring Chinese monetary policy.

Key words: monetary policy, VAR, operating procedures, exogenous (endogenous) components

JEL-Classification: E52, E58

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1. Introduction

Proper measurement of monetary policy is the premise of accurate estimates of policy impact. An indicator is optimal when it is exogenous in the sense that it is not subject to influences of non-policy factors and changes in this indicator reflect shifts in the policy stance only. For decades, studies have been dedicated to a search for such a variable, among which many focus on the case of the Federal Reserve (see, e.g., Bernanke and Mihov 1997, 1998, Boschen and Mills 1995, Brunner and Meltzer 1964, Romer and Romer 1989, 2004). A consensus has emerged that the federal funds rate measures the Fed's monetary policy well under its operating procedure at the normal times. Yet, this conclusion cannot be simply applied to the case of People's Bank of China (PBC) because measurement of monetary policy is regime dependent and apparently, these two central banks are following different operating procedures. Hence, a search for proper measurement of Chinese monetary policy requires an independent study examining details of the PBC's operating procedures.

The main challenge to measure the PBC's monetary policy arises from the fact that the PBC uses multiple policy instruments and none of them can be described as a dominant instrument. All these frequently-applied policy instruments contain information about the PBC's policy. Yet, it is not straightforward how to summarize all policy information into a single indicator. Another challenge is that observed changes in policy instruments are largely endogenous systematic responses to the state of the economy, rather than shifts in the policy stance. For example, the central bank accommodates changes in demand for money to keep the short-run interest rate at its targeted level. In this case, the targeted interest rate remains unchanged and the policy stance is better described as neutral. But focusing on money supply only, one might mistakenly interpret this increase as a monetary easing.[3] It is thus essential to disentangle changes of policy instruments into two parts: systematic responses and exogenous components. Such disentangling requires careful modelling of central banks' response functions. In the case of China, the PBC is designated to take responsibility for various tasks with multiple instruments. Its response behaviour is thus better specified in several response functions, rather than a single one.

[3] Due to its endogeneity nature, money supply is no longer a valid good indicator for monetary policy in many advanced economies.

Several studies address the PBC's policy measurement problem[4], focusing on the challenge that the PBC uses multiple instruments. These studies mainly follow two lines. The first line is the narrative approach, as in Sun (2013), Shu and Ng (2010) and Sun (2014). All these studies use the PBC's documents to infer the information on policy-makers' intentions. Based on this information, the first paper identifies three exogenous contractionary monetary policy episodes[5] while the latter two build a time series to gauge the general monetary policy condition in China as tight, neutral or easy. The second line is to directly consider the PBC's instrument set, as in He and Pauwels (2008) and Xiong (2012). Both papers examine the over-time changes in the PBC's instruments and assign a value to each change. All these indices are then summarized into a single indicator to gauge the overall monetary policy condition (tight, neutral or easy).

All these studies contribute to a better understanding of the measurement problem of the PBC's monetary policy. However, a quick comparison of the policy indices obtained from these two approaches suggests that they do not always attribute the same policy indicator to the PBC's monetary policy: the correlation coefficient between the narrative index (Sun 2014) and the instrument index (Xiong 2012) is only 0.62 for the period of 2000-2010. A consensus on how to measure the PBC's monetary policy is still missing. An overall evaluation of these different indices requires one to look into how the discrepancy arises. Possibly, these indices incorporate different components of changes in policy instruments. It may be insufficient to address the first challenge only. This paper aims to fill this gap. First, we model the PBC's operating procedures and thus decompose changes in policy variables. In so doing, we let the model identify a "clean" indicator, which is independent of other shocks to the reserves market such that its changes are policy induced. Second, with this model we build an overall policy index (including both systematic responses and exogenous components) such that a comparison and evaluation of various existing indices are possible.

To do so, we follow the Bernanke and Mihov's (1997, 1998) method and use a two-stage structural vector autoregression (VAR) model.[6] At the first stage, a VAR model, incorporating two groups of variables (policy and non-policy variables), is estimated. We disentangle policy-sector VAR residuals from those in the non-policy block. At the second stage, those residuals are used in a model that characterizes the PBC's operating procedure. We model demand for and supply of reserves. In particular, we disentangle

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[4] Some studies overlook this measurement problem by gauging the PBC's monetary policy with either a short-term interest rate or some monetary aggregate. Yet, one needs to be cautious as a biased measure might result in some misleading estimates.

[5] Those three episodes are defined as exogenous when the PBC decided for a contractionary shift to fight against higher inflation. The exogeneity comes from the fact that the current inflation is not directly correlated with the level of current and future output, which hence ensures us an unbiased estimate of the policy effect on output even with a simple regression (see Sun 2013).

[6] They use this method to address the measurement problem for the cases of the Bundesbank and the Fed. Later, Cuche (2000) applies this method to a small open economy – Switzerland.

over-time variations in excess reserves, arising from the foreign exchange market interventions that the PBC is engaged in to keep the RMB's exchange rate within its targeted floating range. This model incorporates the PBC's multiple instruments and its liquidity management needs as a result of foreign exchange purchases. We then carry out the following empirical tests with it:

i. Is the PBC targeting a quantity variable, such as excess reserves or total reserves?
ii. Or, is it targeting a price variable, like the money market interest rate or the central bank lending rate?
iii. Or, is it following a hybrid operating procedure (a combination of interest-rate targeting and reserves targeting)?
iv. Has the PBC's operating procedure experienced a structural break during the post-2000 period?

Our main findings include: First, the PBC's procedures appear to have changed over time, and hence no single indicator represents Chinese monetary policy well for the 2000-2013 time period. Second, its operating procedure is neither pure interest-rate targeting nor pure reserves targeting, but better described as a combination. Third, a set of indicators all contain information about the policy stance. It is hence preferred to use a composite measure to measure Chinese monetary policy. Finally, we construct a new composite indicator of the overall stance of policy, consistent with our model. A comparison with several existing measurement approaches suggests that the composite indices, rather than individual indicators, perform better in measuring Chinese monetary policy.

This paper proceeds as follows. Section 2 presents the methodology and provides institutional backgrounds of Chinese monetary policy. Section 3 discusses data issues and presents the estimation results. Section 4 examines implications of individual indicators for the VAR estimation of policy effects. Section 5 presents an overall policy index and compares it with other existing indices. Section 6 concludes.

2. Identifying monetary policy in China

The VAR-based approach is widely applied in identifying the exogenous policy innovations and the subsequent estimation of their impact on the economy (see, among others, Bernanke and Blinder 1992, Christiano, Eichenbaum, and Evans 1999, Sims 1980). A standard VAR model includes several simultaneous equations, which are regressions of the variables of interest on their own lagged terms, and the lagged and contemporaneous terms of the other variables in the system. The reaction of monetary policy to the state of the economy is modelled in the equation for the policy indicator. Then, in an identified

VAR model, the unexplained part of changes in the policy indicator (the error term or the so-called structural innovations in the VAR literature) is interpreted as exogenous policy shocks, which are "changes in a policy variable that are deliberately induced by the central bank actions that could not have been anticipated on the basis of earlier available information" (Hamilton 1997: 80). The estimates of the impact of these structural innovations on output give the effects of monetary policy on the real economy.

This standard VAR approach takes the policy indicator as given, where monetary policy is gauged with the federal funds rate or a quantity variable (such as non-borrowed reserves or M1) as for the U.S. case. This paper differs from this approach in not taking the indicator as a priori. Rather, we search for a variable that could be used as a policy indicator. To do so, we use a two-stage VAR approach proposed by Bernanke and Mihov (1997, 1998), where the PBC's operating procedure is modelled at the second stage. Based on this model, we test various hypotheses on the parameter relationships that we propose based on the assumption that structural innovations to those candidate indicators are exogenous. A good "clean" indicator is exogenous such that changes in it are mainly policy induced.

In the following, we outline this methodology, present the evolution of PBC's operating procedures and propose a structural model of these procedures.

2.1. Methodology

The economy is described in the following structural macroeconomic VAR model given in Eqs. (1)-(2):

$$\boldsymbol{Y}_t = \sum_{i=0}^{k} \boldsymbol{B}_i \boldsymbol{Y}_{t-i} + \sum_{i=0}^{k} \boldsymbol{C}_i \boldsymbol{P}_{t-i} + \boldsymbol{A}^y \boldsymbol{v}_t^y \quad (1)$$

$$\boldsymbol{P}_t = \sum_{i=0}^{k} \boldsymbol{D}_i \boldsymbol{Y}_{t-i} + \sum_{i=0}^{k} \boldsymbol{G}_i \boldsymbol{P}_{t-i} + \boldsymbol{A}^p \boldsymbol{v}_t^p \quad (2)$$

where boldface variables denote vectors or matrices. Variables are classified into two groups – **Y** and **P**, which stand for vectors of macroeconomic (non-policy) variables and policy variables, respectively. These policy variables may all contain information about the policy stance but can also be affected by shocks to other factors. They are our potential candidates for a policy indicator. With this framework, it is possible to model the policy indicator either as a scalar or as a combination of policy variables. The policy indicator can even be modelled to change over time. Such modelling fits the PBC's case well where it uses multiple instruments and its operating procedure can hardly described as a pure interest-rate targeting or pure reserve targeting.

All the variables in the system depend on their own lags, and both contemporaneous values and up to k lags of all other variables. Eq. (1) describes how macroeconomic variables evolve over time. Eq. (2) can be considered as the policy response function of the PBC to the state of economy, where those policy variables are in addition allowed to interrelate with one another. The vectors $\boldsymbol{v}^y$ and $\boldsymbol{v}^p$ are mutually uncorrelated structural error terms. We are particularly interested in structural error terms of policy block, the vector $\boldsymbol{v}^p$, that may include money supply shock v^s, shocks to other policy instruments, shocks to money demand v^d, or whatever disturbances affect the policy indicators.

The estimation is obtained by running simultaneous OLS regressions of the reduced form of the system (1)-(2). Further application of the estimated results relies crucially on whether the structural system (SVAR) can be recovered from the estimated system.[7] In this paper, we combine an ordering assumption with a further structural model to achieve full identification. Our aim is to find a "clean" policy indicator among several candidates. Thus, we avoid to propose many constraints on the contemporaneous relation among policy variables in the first step, which is later identified with an operating-procedure model in the second step. In the first-step VAR model, the recursive ordering constraint is proposed between two blocks of variables – $\boldsymbol{C}_0 = 0$, i.e., policy variables do not affect macro variables contemporaneously. Obviously, using high-frequency data will help assure the plausibility of this assumption. Monthly data are used in this paper. The system (1)-(2) becomes:

$$\begin{pmatrix} \boldsymbol{Y}_t \\ \boldsymbol{P}_t \end{pmatrix} = \sum_{i=1}^{k} \boldsymbol{\Pi}_i \begin{pmatrix} \boldsymbol{Y}_{t-i} \\ \boldsymbol{P}_{t-i} \end{pmatrix} + \begin{pmatrix} \boldsymbol{r}_t^y \\ \boldsymbol{r}_t^p \end{pmatrix} \tag{3}$$

where $\boldsymbol{\Pi}_i$ is the estimated parameter matrix; $(\boldsymbol{r}_t^y\ \boldsymbol{r}_t^p)'$ are reduced-form residuals after the first estimation, which can be linked to structural shocks $(\boldsymbol{v}_t^y\ \boldsymbol{v}_t^p)'$ in Eq. (4):

$$\begin{pmatrix} \boldsymbol{r}_t^y \\ \boldsymbol{r}_t^p \end{pmatrix} = \begin{pmatrix} (\boldsymbol{I}-\boldsymbol{B}_0)^{-1}\boldsymbol{A}^y & 0 \\ (\boldsymbol{I}-\boldsymbol{G}_0)^{-1}\boldsymbol{D}_0[(\boldsymbol{I}-\boldsymbol{B}_0)^{-1}\boldsymbol{A}^y] & (\boldsymbol{I}-\boldsymbol{G}_0)^{-1}\boldsymbol{A}^p \end{pmatrix} \begin{pmatrix} \boldsymbol{v}_t^y \\ \boldsymbol{v}_t^p \end{pmatrix} \tag{4}$$

Let $\boldsymbol{u}_t^p$ be the proportion of the VAR residuals in the policy block that are orthogonal to the residuals in the non-policy block. We can thus write:

$$\boldsymbol{u}_t^p = \boldsymbol{r}_t^p - (\boldsymbol{I}-\boldsymbol{G}_0)^{-1}\boldsymbol{D}_0\boldsymbol{r}_t^y = (\boldsymbol{I}-\boldsymbol{G}_0)^{-1}\boldsymbol{A}^p\boldsymbol{v}_t^p \tag{5}$$

[7] A triangle Cholesky decomposition makes the SVAR exactly identified. Indeed, many studies adopt this identification method. Yet, there are problems with this identification restriction. On the one hand, further application (e.g., impulse responses and variance decomposition) depends on the ordering chosen. On the other hand, some ordering restrictions can be counterintuitive. In particular, it is difficult to decide a recursive ordering among variables in the policy block – **P**, which contains money market variables that are subject to high fluctuation and are easily observed at a high frequency.

As in other standard structural VAR (SVAR) systems, Eq. (5) relates observable VAR-based residuals $\mathbf{u}$ to unobserved structural shocks $\boldsymbol{v}$, which contain the policy shock to be identified in the second step with an operating-procedure model.

The next subsection reviews the PBC's instruments and operating procedures. With this prior information, we specify the model in the innovation form, using $\boldsymbol{u}$ and $\boldsymbol{v}$.

2.2. Instruments and indicators of PBC policy

In China, the PBC was designated exclusively as a central bank in 1984. Since then, the PBC has experienced large changes in its institutional framework and its operating procedures. The first half of this period saw transitional changes with lingering impacts of the planned economy spotted from time to time. Only by the end of 1990s, the PBC's monetary policy regime turned from direct to more indirect control (see Sun 2013). This paper thus focuses on the post-2000 monetary policy regime.

Institutionally, the PBC is far from independent. Monetary policy is widely used in China, together with other policy measures, to fulfil various tasks arising from the different economic development stages. At the moment, the PBC's main tasks include: price stability[8], economic growth, and financial stability. The last task is mainly reflected in exchange rate stability. The managed floating exchange rate regime requires that the PBC be actively engaged in foreign exchange interventions and the subsequent sterilisation operations. In line with these tasks, we decompose changes in policy variables into three parts: 1. Responses to the macroeconomic conditions (output and prices); 2. Liquidity management, including both accommodation to money demand in case of the interest-rate-targeting, and "sterilization" operations; 3. Exogenous (unexpected) changes in the policy variable (i.e., structural innovations to the policy indicator).

The advantage of this decomposition is twofold. First, we can trace our disentanglement procedures clearly. For example, the orthogonalized VAR residuals in the policy block, $\boldsymbol{u}^p$, obtained above, have abstracted Element 1 from others. The task remains for the second stage to identify Element 3 from Element 2. Second, this decomposition would help us compare different policy indicators. The low correlation between the narrative index (Shu and Ng 2010, Sun 2014) and the instrument index (He and Pauwels 2008,

[8] The PBC's mandate is defined in the People's Bank of China Act (promulgated in 1995) as "to maintain the stability of the value of the currency and thereby promote economic growth".

Xiong 2012), as mentioned in the introduction, is apparently due to the fact that these two approaches account different components of changes in policy variables. The instrument index accounts each change in all the policy instruments and hence includes all elements, while the narrative index abstracts the liquidity management part and considers only Element 1 and 3.

The first two elements can be modelled as anticipated or endogenous part of policy, identified in the policy reaction functions. In Element 2 – liquidity management, "sterilization" operations are somewhat China's specific that cannot be found in other monetary policy regimes of advanced economies.[9] However, simply ignoring the implication of this element to our policy indicator is very likely to contaminate the policy indicator as "sterilization" operations say nothing about shifts in the policy stance. Hence, to correctly identify policy shocks, we do need to carefully disentangle exogenous policy shocks from liquidity management.

Element 3 is deliberately induced by the PBC's actions, exogenous and unexpected from the well-defined policy reaction function(s). Using this element to measure monetary policy helps solving the identification problem. With disentangled exogenous shocks, the estimate of dynamic effects of policy changes on the economy can be obtained by simply tracing their impacts on the economy. This is also the standard approach in the literature to gauge the impact of monetary policy. Noticeably, the estimation accuracy crucially relies on the "cleanness" of the policy measure. Hence, it is preferable to measure monetary policy with an indicator that is relatively exogenous.

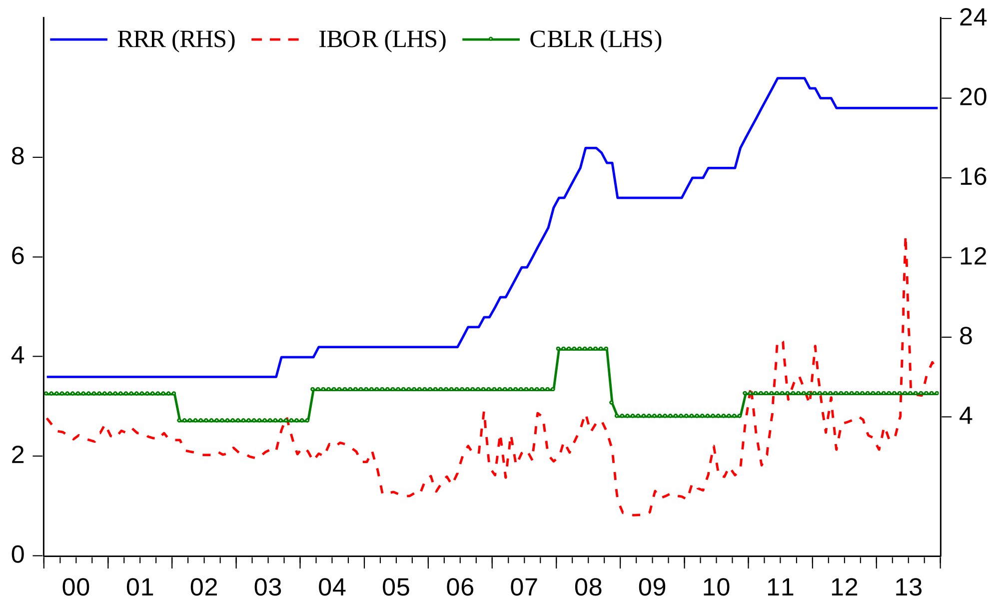
To achieve those above-listed tasks and implement desired changes in the policy stance, the PBC uses various instruments (see Sun 2013), mainly in four ways:

First, the PBC frequently uses open market operations to influence the base money, which include issuing central bank bills (CBB), in addition to conventional repo and reverse repo transactions. Central bank bills are short-term securities issued by the PBC, which were introduced in 2002 to deal with the inadequate supply of government bonds. Through this issuing, the PBC can effectively reduce the money supply. The PBC has used them extensively to offset rises in liquidity in the banking system as a result of the PBC's foreign exchange purchases. Therefore, central bank bills are often referred as sterilization bonds.

[9] For the Fed's and the Bundesbank's cases, the liquidity management is mainly reflected in the accommodation to the liquidity demand.

Second, the PBC frequently adjusts the required reserve ratio, especially since 2007 as the use of central bank bills for the sterilization purpose was "partly constrained by weaker purchasing willingness on the part of commercial banks" (*China Monetary Policy Report 2006 Quarter II*). In mid-2006, the PBC shifted to extensive use of the required reserve ratio, as shown in Fig. 1. This is effective in influencing the money supply.

Figure 1: Policy instruments:
Required reserve ratio, central bank lending rate, interbank offered interest rate

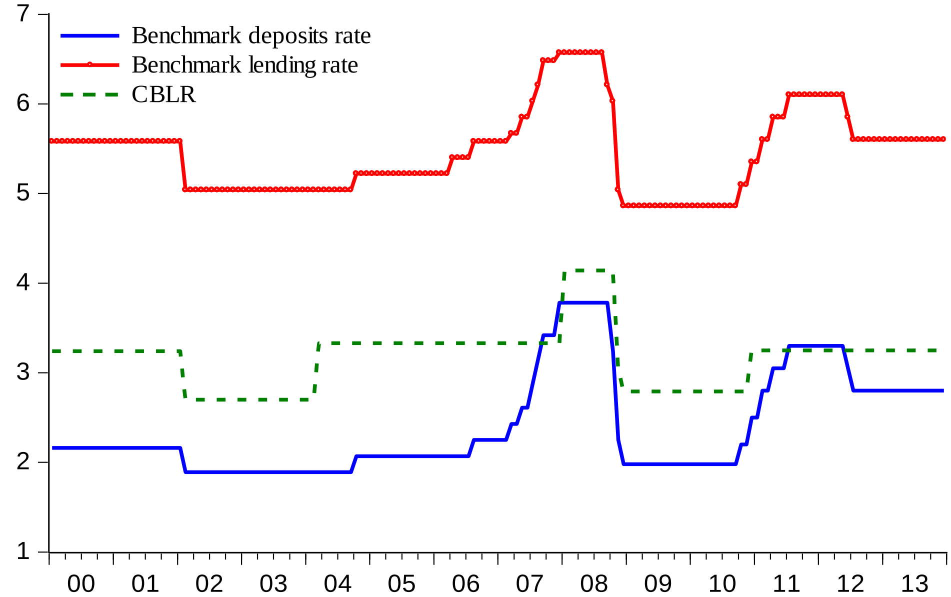


Source: CEIC dataset.

Third, the PBC exerted direct influences on private saving and bank lending by setting the benchmark deposit rates and lending rates (of various maturities), while commercial banks are allowed to adjust interest rates around the benchmark within a limited band.[10] This tool is employed on a discrete basis and has not been intensively used, as indicated by Fig. 2.[11]

[10] Only in July 2013, the benchmark lending rates were abolished. In 2012, the floating band for the lending rate was extended to [0.7, ∞) and that for the deposit rate to (-∞, 1.1]. The lending-rate ceiling and the deposit-rate floor were abolished in 2004.
[11] Researchers refer to this coexistence of the regulated benchmark interest rates and various market interest rates in China as a dual-track interest-rate system. Its implications to transmission mechanisms are well discussed in studies by Chen, Chen and Gerlach (2013) and He and Wang (2012).

Figure 2: Three policy interest rates:
Benchmark deposits rate, benchmark lending rate and central bank lending rate (CBLR)



Source: CEIC dataset.

Fourth, the PBC could affect base money through its borrowing facility (central bank lending) by adjusting the quantity and the rate charged for those loans (the central bank lending rate). Over the most of time, the central bank lending rate was held above the interbank offered interest rate, as shown in Fig. 1. One would expect central bank loans to be very small or close to zero. Yet, this is not the case, presumably because some banks have imperfect access to the interbank loan market, as evidenced in the transaction volume of interbank loan, which used to be very low.[12] In the earlier period, banks relied heavily on central bank lending. The ratio of the borrowed reserves (w.r.t. total reserves) was more than 50% till 2002. Afterwards, this ratio declined steadily to 20% by mid-2006, then to 10% by mid-2008, to today's 6%. Recently, the PBC has tended to use more indirect policy instruments by reducing central bank lending. At the moment, central bank lending, together with rediscount lending, is often used as a tool to improve the structure of bank loans.[13] Slowly, banks have been turning to the money market for loans.

This overview indicates that the PBC still applies multiple policy instruments to achieve various goals, which differs from the standard one-instrument operating procedure[14] that advanced economies adopt.

[12] Only starting with early 2007, the monthly turnover of total interbank loan exceeded 10% of total reserves.
[13] The PBC specifies prerequisites and lends to a particular group of industries or regions. Besides these central bank lending schemes, the PBC uses window guidance as an additional tool to guide bank loans to policy-oriented sectors and regions, such as agriculture, small- and medium-sized enterprises, job creation, less-developed western regions, etc.
[14] That is, those central banks use open market operations with short-term money market rates as the operational target.

Indeed, the PBC's Governor, Zhou, Xiaochuan, described Chinese monetary policy as having always been unconventional (Caixin 2014). Particularly, in China quantitative tools and targets are still playing dominating roles in the implementation of monetary policy. As further pointed out by the PBC's latest official articulation (Zhang and Ji 2012: 186), the PBC "presently adopts M2, the broad money, as the intermediate target of monetary policy. In line with this quantitative intermediate target, the open market operations primarily target excess reserves in financial institutions with due consideration to (interbank lending rate or repo rate in the money market)." The intermediate target, the growth rate of M2, is announced every year (see Sun 2013), while the PBC has "never openly discussed and formally established" the numerical target for these two operating targets – the excess reserve ratio and the money market interest rate (Zhang and Ji 2012: 177). Nevertheless, while implementing monetary policy, the PBC routinely monitors excess reserves and the money market rate.

The managed floating exchange rate regime implies that intensive liquidity management operations are necessary to keep excess reserves under control. This was particularly critical for the period prior to 2013 when China saw continuous trade surplus and piling-up of foreign exchange (FX) reserves. Fig. 3 illustrates the balance sheet of the PBC. A trade surplus forces the PBC to intervene in the foreign exchange market to keep the RMB exchange rate within the managed floating band. The FX purchases (on the assets side) are first reflected in rises of excess reserves on the liabilities side. The resulting excessive liquidity is not always what the PBC desires. The PBC absorbs it through three ways: repo transactions; issuance of central bank bills; increase of the required reserve ratio. First two tools sterilize the effects of FX purchases on the monetary base, while with the last tool, excess reserves will be transferred to required reserves. This results in a change in the composition of total reserves, but an equal rise in the monetary base. This offsetting action differs from the conventional sterilization operation though the PBC has managed to absorb excessive liquidity nevertheless. Some studies refer to this tool as "sterilisation" tool as well (e.g. Zhang and Ji 2012). This paper follows this convention.

The PBC uses all three ways to offset excessive increases in liquidity, though the weight of the these instruments has varied over time. Between 2003 and mid-2006, the PBC relied heavily on central bank bill issuance, while for the post-mid-2006 period, it has leaned more on the required reserve ratio as a routine "sterilisation" tool. The frequent changes in reserve requirements have drawn a lot of attention – they were publicly announced and newsworthy. Nevertheless, these changes are "not necessarily indicative of monetary easing or tightening, but are more related to the management of foreign exchange reserves", as Zhou, Xiaochuan, pointed out (Caixin 2012). This suggests that simply interpreting each change in policy instruments as a policy stance indicator might impair the accuracy of their policy measurement.

Figure 3: Components of the PBC's Balance Sheet

Assets	Liabilities
I. Foreigen assets	1. Reserve money
a. Monetary gold	1.1 Currency issue
b. Foreign exchange (FR)	1.2 Total reserves (TR)
	1.2.1 Required Reserves (RR)
	1.2.2 Excess Reserves (ER)
II. Claims on goverment	2. Bond Issue (CBB)
III. Claims on financial institutions	3. Deposits of government
IV. Other assets	4. Own capital
	5. Other liabilities

Source: Author's summary.

The above analysis suggests that to choose a monetary indicator for China, we could particularly focus on two indicators that the PBC closely observes as operating targets – excess reserves and the money market rate. To find out the right policy indicator, we model Chinese bank reserves market. Our model is in innovation form, considering the PBC's multiple policy instruments and in particular, describing its behaviour in three reaction functions.

Total reserves demand: $u_{TR} = -\alpha u_{IBOR} + \upsilon^{d}$ (6)

Required reserves demand: $u_{RR} = \beta u_{RRR} + \theta(u_{IBOR} - u_{CBLR}) + \upsilon^{RR}$ (7)

(Excess) reserves supply: $u_{ER} = \phi^{d}\upsilon^{d} + \phi^{RR}\upsilon^{RR} + \phi^{RRR}\upsilon^{RRR} + \phi^{i}\upsilon^{i} + \upsilon^{s}$ (8)

Required reserve ratio: $u_{RRR} = \gamma^{d}\upsilon^{d} + \gamma^{RR}\upsilon^{RR} + \gamma^{s}\upsilon^{s} + \gamma^{i}\upsilon^{i} + \upsilon^{RRR}$ (9)

Central bank lending rate: $u_{CBLR} = \tau^{d}\upsilon^{d} + \tau^{RR}\upsilon^{RR} + \tau^{s}\upsilon^{s} + \tau^{RRR}\upsilon^{RRR} + \upsilon^{i}$ (10)

where variables $u's$ indicate (observable) VAR residuals, obtained from the first-step VAR estimates and orthogonalised already; and $\upsilon's$ indicate (unobservable) structural disturbances. TR stands for total reserves, IBOR for the interbank offered rate, RR for required reserves, CBLR for the central bank lending rate, ER for excess reserves, and RRR for the required reserve ratio.

The demand for total reserves is modelled in Eq. (6). It says that a higher overnight money market interest rate (interbank offered rate, u_{IBOR}), which is the borrowing cost on the interbank money market, leads to lower demand for total reserves. The demand shock is denoted υ^d.

Eq. (7) says that required reserves (u_{RR}) change with the required reserve ratio. Furthermore, banks are allowed to borrow from the PBC to meet the reserve requirement. The demand for central bank lending depends on the spread between the money market rate and the central bank lending rate. With this setup, we include central bank lending as part of required reserves.[15] Shock to required reserves is given by υ^{RR}.

Eq. (8) models the policy reaction function as supply of (excess) reserves (u_{ER}) in response to various shocks. The PBC accommodates demand shocks through $\phi^d \upsilon^d$. In addition, the PBC is assumed to adjust the reserves supply in response to shocks to required reserves (υ^{RR}), shocks to the required reserve ratio (υ^{RRR}) and shocks to the central bank lending rate (υ^i). Supply shock is indicated with υ^s.

Another two policy instruments that the PBC uses are the required reserve ratio, u_{RRR}, and the central bank lending rate, u_{CBLR}. Eqs. (9) and (10) describe how the PBC use them in reaction to various shocks. Shocks to the required reserve ratio and the central bank lending rate are indicated with υ^{RRR} and υ^i, respectively.

To solve this system (6)-(10), we first make some simplifying assumptions for Eqs. (9) and (10): $\gamma^i = 0$, $\tau^{RRR} = 0$, $\gamma^{RR} = 0$, and $\tau^d = 0$. The first two assumptions imply that two discrete instruments – the RRR and the CBLR – are contemporaneously orthogonal, i.e., these two policy tools do not respond to each other directly. This seems plausible. The third assumption, $\gamma^{RR} = 0$, implies that the required reserve ratio does not respond to shocks to the demand for required reserves. This is justified because the required reserve ratio is mainly used as a liquidity management tool to deal with excessive liquidity. Moreover, the central bank lending rate is a price tool. It is very likely not to respond to contemporaneous demand shocks. Hence we assume $\tau^d = 0$.

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[15] Our model of the demand for borrowed reserves is in line with Bernanke and Mihov (1998)'s practice where this demand is a function of the spread between the federal funds rate and the Fed's discount rate only. Yet, Christiano, Eichenbaum and Evans (1999) criticize this practice by referring to by Goodfriend (1983), which point out that this interest rate spread is positive and there must exist the non-price rationing at the discount window. Non-price costs rise for banks that borrow from the window too much today as it may reduce their access in the future. Hence, Christiano, Eichenbaum and Evans (1999) model the demand for borrowed reserves to be dependent on non-borrowed reserves as well. However, this criticism does not apply to the PBC's case where quite often, the spread between the money market rate and the central bank lending rate is negative and banks borrow from the PBC as they have imperfect access to the money market, as shown and argued above.

This setup, tracing components of the monetary base (i.e., the mix of required reserves and excess reserves)[16], is thus an improvement to considering the monetary base as a whole. The reason is that a significant proportion of the variation in the monetary base is not policy-induced supply innovations, but the PBC's offsetting transactions following foreign exchange purchases through increasing the required reserve ratio. Using the monetary base as a policy measure would lead to a confounding of exogenous and endogenous innovations. Instead, by using a disaggregate setup, given in Eqs. (6)-(10), we can disentangle liquidity management from exogenous policy shocks.

Using the condition that the supply of excess reserves plus required reserves must equal the total demand for reserves, we solve this model in the form of Eq. (5) ($\mathbf{u} = (\mathbf{I} - \mathbf{G})^{-1}\mathbf{A}\mathbf{v}$), where: $\mathbf{u}' = (u_{TR}\ u_{IBOR}\ u_{ER}\ u_{RRR}\ u_{CBLR})$, $\mathbf{v}' = (v^d\ v^{RR}\ v^s\ v^{RRR}\ v^i)$ and

$$(\mathbf{I} - \mathbf{G})^{-1}\mathbf{A} = \tag{11}$$

$$\begin{pmatrix} \omega[\alpha\left(\phi^d + \beta\gamma^d\right) + \theta] & -\alpha\omega(\theta\tau^{RR} - \phi^{RR} - 1) & -\alpha\omega(\theta\tau^s - \beta\gamma^s - 1) & \alpha\omega(\phi^{RRR} + \beta) & -\alpha\omega(\theta - \phi^i) \\ \omega(1 - \phi^d - \beta\gamma^d) & \omega(\theta\tau^{RR} - \phi^{RR} - 1) & \omega(\theta\tau^s - \beta\gamma^s - 1) & -\omega(\phi^{RRR} + \beta) & \omega(\theta - \phi^i) \\ \phi^d & \phi^{RR} & 1 & \phi^{RRR} & \phi^i \\ \gamma^d & \mathbf{0} & \gamma^s & 1 & \mathbf{0} \\ \mathbf{0} & \tau^{RR} & \tau^s & \mathbf{0} & 1 \end{pmatrix}$$

where $\omega = \frac{1}{\alpha+\theta}$.

We use the generalised method of moments to estimate the model, matching the second moments implied by this model to the covariance matrix of the orthogonalized "policy-sector" VAR residuals.[17] On the right-hand side, there are sixteen unknown parameters (eleven coefficients plus the variances of five structural shocks) to be estimated from fifteen distinct residual variances and covariances (from 5x5 symmetric matrix) on the left-hand side. The model is underidentified by one degree. At least one further identifying restriction is necessary.

[16] Bernanke and Mihov (1997, 1998) and Strongin (1995) model the Fed's operating procedure with special focus on non-borrowed reserves. Our setup traces excess reserves as the PBC is targeting excess reserves, rather than non-borrowed reserves.
[17] Two-stage estimation is not necessarily the only way to solve the whole model. For example, Bagliano and Favero (1998) reproduce the Bernanke and Mihov (1998)'s result by one-stage VAR estimation, where they incorporate the various parameter constraints implied by the second-step operating-procedure model back to the VAR structural parameter matrices. However, the testing power of the one-stage approach is limited and we can hardly apply it to our Chinese case as our operating-procedure model is far more complicated. The advantage with the two-stage approach is that we can directly estimate many key parameters rather than imposing fixed values.

To achieve identification, we impose restrictions on coefficients, based on our theories of different operating procedures. Quite often, these hypotheses imply overidentification of the model given by Eq. (11). We then apply a Hansen-J test to test overidentifying restrictions. We specify a just-identified model as a benchmark as well. We try possibly many different hypotheses that could characterise PBC's operating procedures. They are altogether six:

a. IBOR targeting (interbank-offered-rate targeting);
b. ER targeting (excess-reserves targeting);
c. TR targeting (total-reserves targeting);
d. RRR targeting (required-reserve-ratio targeting);
e. CBLR targeting (central-bank-lending-rate targeting);
f. JI model (just-identification model).

Furthermore, we allow possible regime switches by splitting the whole sample into two and carrying out all these hypotheses tests for subsamples as well. In so doing, we could test whether the PBC's operating procedures have changed over time. Given that the PBC claims to target both excess reserves and money market interest rate (see Zhang and Ji 2012), we can test whether the weight on these two has changed over time.

a. ***Model IBOR (interbank-offered-rate targeting)***. For this model, we impose:

$$1 - \phi^d - \beta\gamma^d = 0, \theta\tau^{RR} - \phi^{RR} - 1 = 0, \phi^{RRR} = 0, \phi^i = 0 \quad (12)$$

The first two restrictions imply that under this operating regime, the PBC adjusts supply of reserves to offset demand shocks to total reserves and required reserves to keep the money market interest rate at its target level. In this way, the IBOR is insulated from demand shocks in the reserves market. The last two assumptions say that the IBOR is allowed to passively adjust (i.e., no changes are made in excess reserves) to innovations in the required reserve ratio and the central bank interest rate. Following these four restrictions, we can write innovations to the IBOR as $u_{IBOR} = \omega[(\theta\tau^s - \beta\gamma^s - 1)\upsilon^s - \beta\nu^{RRR} + \theta\nu^i]$. It indicates that with the IBOR sterilised from demand shocks, the observed changes in this interest rate are those deliberately induced by policy actions, through either reserves supply, or the RRR or the CBLR. This variable will hence be the good "clean" policy indicator that we are searching for.

One of the solutions to the first two restrictions is $\phi^d = 1$, $\phi^{RR} = -1$, $\gamma^d = 0$ and $\tau^{RR} = 0$. These parameter restrictions on ϕ^d and ϕ^{RR} are exactly same as those made by Bernanke and Mihov (1998) for the federal-funds-rate model.

Given that the money market rate is one of the PBC's targets, it is of our interest to test whether this is the case. Furthermore, this test is particularly interesting because some studies try to follow the literature on the Fed's monetary policy by measuring Chinese monetary policy with a short-term interest rate. With this simple model, we can test the validity of this application.

b. ***Model ER (excess-reserves targeting)***. For this model, we impose the restrictions:

$$\phi^d = 0, \phi^{RR} = 0, \phi^{RRR} = 0, \phi^i = 0 \quad (13)$$

It hence follows that $\upsilon^s = u_{ER}$. That is, excess reserves depend only on their own shocks and are not systematically responsive to other reserves-market shocks. This hypothesis implies that changes in excess reserves mainly reflect shifts in the policy stance and excess reserves can measure monetary policy well.

Testing this hypothesis is interesting since the PBC puts particularly emphasis on liquidity management and quantitative targets. In particular, excess reserves are closely related to its intermediate target – the growth rate of M2.

c. ***Model TR (total-reserves targeting)***. For this model, we impose the restrictions:

$$\alpha(\phi^d + \beta\gamma^d) + \theta = 0, \theta\tau^{RR} - \phi^{RR} - 1 = 0, \phi^{RRR} = 0, \phi^i = 0 \quad (14)$$

such that we have $u_{TR} = -\alpha\omega[(\theta\tau^s - \beta\gamma^s - 1)\upsilon^s - \beta\nu^{RRR} + \theta\nu^i]$

The first two restrictions indicate that total reserves are independent of contemporaneous demand shocks. Shocks to the RRR and the CBLR will be reflected in changes in required reserves through nonzero β and θ, respectively, and eventually total reserves. The PBC replies on various policy tools to keep total reserves at the "target".

d. ***Model RRR (required-reserve-ratio targeting)***. For this model, we impose the restrictions:

$$\gamma^d = 0, \ \gamma^s = 0, \phi^i = 0 \quad (15)$$

such that we have $\upsilon^{RRR} = u_{RRR}$.

Can the required reserve ratio or the central bank lending rate, these two discrete policy tools, be the PBC's operating targets? This model and the subsequent one try to answer this question.

The last restriction simplifies the estimation process, assuming that the reserves supply is inactive to innovations to the CBLR. That is, the interaction between these two is one dimension, allowing the CBLR to respond to supply shocks only. It seems to be a right assumption to have a continuous variable not depend on an infrequently-changed discrete variable. The first two restrictions say that the required reserve ratio does not respond to other structural shocks in the reserves market. Changes in this ratio are exogenous and thus could be interpreted as policy shocks.

e. ***Model CBLR (central-bank-lending-rate targeting)***. For this model, we impose the restrictions:

$$\tau^{RR} = 0,\ \tau^{s} = 0, \phi^{RRR} = 0 \tag{16}$$

such that we have $v^{i} = u_{CBLR}$.

The interpretation of these restrictions is analogous to that for the RRR-targeting model.

f. ***Model JI (just-identification model)***. For this model, we impose the restrictions:

$$\alpha = 0, \phi^{RRR} = 0 \tag{17}$$

All these models impose more than one restriction and are overidentified. Alternatively, we could let the model just identified and use it as a benchmark.

To do so, we first make the simplifying assumption that the residual to the central bank lending rate u_{CBLR} is zero. We set the CBLR innovation and the associated parameters τ^{RR}, τ^{s}, and ϕ^{i} to zero. This simplification is out of the concern that the CBLR is an infrequently changed policy rate and may not be well modelled by a linear model.[18] Our system, specified by Eqs. (6)-(10), is now transferred into a 4-equation system, with 12 unknowns and 10 covariances. Hence, two restrictions are necessary to just-identify this simplified system. In line with Bernanke and Mihov's (1998) and Strongin's (1995), we propose $\alpha = 0$, assuming that the short-run demand for total reserves is inelastic. The second restriction, $\phi^{RRR} = 0$, says that excess reserves do not react to innovations in the required reserve ratio.

[18] Bernanke and Mihov (1998) take a similar practice, where the innovation to the discount rate is assumed zero.

3. Data, estimation, and results

We use monthly data for the sample period 2000:1-2013:3.[19] As discussed in Section 2, we include both policy variables and non-policy variables in the VAR. In non-policy sector, vector **Y**, we include industrial production (IP), the consumer price index (CPI) and the producer price index (PPI), all in logarithm. The PPI is included as a proxy of additional information available to the PBC about the future course of inflation and an inclusion of it helps solve the price puzzle. For policy variables, we include total reserves (TR), excess reserves (ER), the required reserve ratio (RRR), the interbank offered rate (IBOR), the central bank lending rate (CBLR).

For the VAR-estimation, we prefer using the level data to the first-difference data. With the level data, we ensure there is no loss of information of the long-run properties of the system. Monthly level data for IP, CPI and PPI are imputed from corresponding time series of growth rates. Appendix A reports our imputation method.

Monthly data for the IBOR (overnight, weighted average), the CBLR (with maturity of less than 20 days) and the RRR[20] are obtained from the CEIC dataset. The data for total reserves are collected from the PBC's balance sheets of various years.[21] Only in 2011, the PBC started to use the conventional definition of reserves that refer to deposits of other depository institutions. Prior to that, the PBC included deposits of other financial corporations (till 2010) and deposits of non-financial corporations (till 2007) into total reserves as well. [22] Accordingly, we modify the data to get a consistent time series, defining total reserves as deposits by other depository corporations at the PBC.

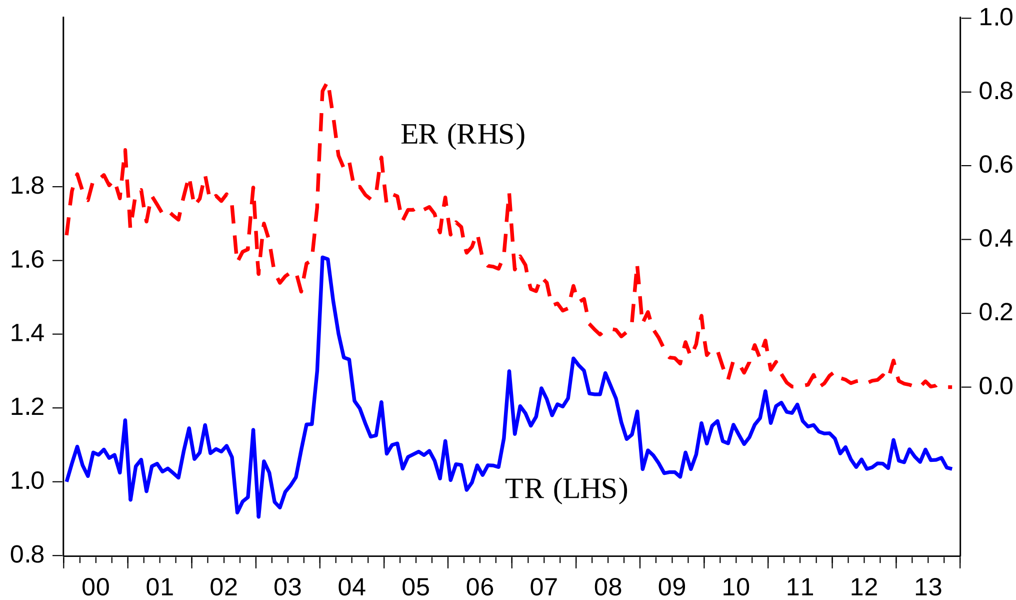
Excess reserves are given by ER = TR – RR = TR – (M2-M0)*RRR. The multiplier base, (M2-M0), gives us a sum of various deposits (i.e., demand, saving and time deposits) that are subject to the reserve

[19] The sample ends before mid-2013, when the money market rate fluctuated dramatically during the currency crunch in China. Exclusion of those months avoids a big structural break at the end of the sample period.
[20] Since Sep. 25 2008, the PBC has been using the differentiated RRR, where the reserve ratio for small- and medium-sized financial institutions (FIs) is set 1-2 percentage points lower than that for large FIs. The CEIC reports the RRR since then as the weighted average with ¾ attributed to that for large FIs. I follow this line and use this weighted average RRR.
[21] The PBC's balance sheets with monthly entries are available from 2000 on.
[22] According to the PBC's Interim Regulations on Statistics and Publication of Money Supply Data (1994), the PBC defines other depository corporations as depository banks (commercial banks, credit cooperatives, etc.) plus special depository institutions (including trust and investment companies, foreign banks and financial companies that are allowed to accept some specific funds as deposits). Financial corporations are defined as other depository corporations plus other financial corporations (such as insurance companies, securities companies and pension funds). Yet, other financial corporations are not subject to the reserve requirement and conventionally, their deposits at the central bank are not included in the base money.

requirement. As presented in Section 2, our identification procedures at the second stage assume linear relations between reserves and interest rates (the IBOR and the CBLR). We thus normalize TR and ER, rather than taking logarithms, by a 12-month moving average of TR.[23]

Fig. 4 presents these two normalized time series. It seems that around mid-2006 the relation between these two variables collapsed. For the period prior to mid-2006, fluctuations in excess reserves were transmitted into changes in total reserves. the correlation coefficient is about 0.8. Afterwards, the fluctuations in excess reserves declined, particularly after 2010. For the post-mid-2006 period, the correlation coefficient between TR and ER is much lower, only 0.35. This time point corresponds roughly to the start of an intensive use of the required reserve ratio to freeze up excessive liquidity. This operation involves transfers of excess reserves to required reserves, which implies that fluctuations in total reserves are more correlated to changes in required reserves. This suggests a possible regime switch around this time.

Figure 4: Total reserves and excess reserves (normalised), 2000-2013



Note: Total reserves and excess reserves are normalised (see text for explanations).
Source: Author's calculation. Data are from the PBC's balance sheets of various years.

Estimation is carried out in two steps. First, we estimate Eq. (3), the reduced form. The "policy-sector" VAR residuals are then disentangled from those in the non-policy block to break the loop of contemporaneous influences between non-policy and policy variables in this dynamic system. The second step is to employ GMM to identify policy innovations net of the PBC's accommodation of the demand

[23] Strongin (1995) and Bernanke and Mihov (1997, 1998) adopt similar procedures.

for money and liquidity management need, based on the model given in Eqs. (6)-(10). This system is not identified. Identifying restrictions, specified in Eqs. (12)-(17) and in line with various operating procedures, are proposed. These restrictions (and hence the proposed operating procedures) are tested with the Hansen-J test.

Table 1 reports parameter estimates for the six models discussed in Section 2, together with standard errors in parentheses. Those identifying restrictions are indicated in boldface. The last column reports *p*-values for the Hansen-J test (the test of the overidentifying restriction). With those greater than 0.05 (highlighted in boldface), we cannot reject the particular model at the 5-percent level of significance. Our review of Chinese monetary history indicates a possible regime switch around mid-2006. Hence, we divide our sample[24] into two subsamples – 2001:1-2006:6 and 2006:7-2013:3; their estimates are reported in the table as well.

[24] The sample for the second stage starts one year later, since the VAR estimation includes twelve lags.

Table 1: Parameter estimates for all models

Sample	Model	Parameter estimates: α	β	θ	ϕ^d	ϕ^{RR}	ϕ^{RRR}	ϕ^i	γ^d	γ^s	τ^{RR}	τ^s	Hansen-J Test (p- values)
2001:1-2013:3													
	IBOR	0.02 (0.18)	0.08 (0.04)	-0.02 (0.04)	0.99 (0.39)	-1.50 (1.03)	**0**	**0**	$\boldsymbol{\frac{1-\phi^d}{\beta}}$	0.06 (2.43)	$\boldsymbol{\frac{1+\phi^{RR}}{\theta}}$	0.30 (3.52)	**0.53**
	ER	0.23 (0.31)	0.12 (0.05)	0.01 (0.05)	**0**	**0**	**0**	**0**	2.41 (3.10)	-4.60 (3.34)	8.62 (6.02)	1.05 (1.47)	**0.19**
	TR	-0.06 (0.09)	0.02 (0.03)	0.05 (0.06)	1.15 (0.15)	-1.00 (0.14)	**0**	**0**	$\boldsymbol{\frac{-(\alpha\phi^d+\theta)}{\alpha\beta}}$	103 (112)	$\boldsymbol{\frac{1+\phi^{RR}}{\theta}}$	-3.00 (6.68)	0.01
	RRR	0.02 (0.03)	0.12 (0.05)	-0.02 (0.03)	1.00 (0.002)	-0.98 (0.33)	-0.12 (0.05)	**0**	**0**	**0**	-1.03 (22)	-67.30 (127)	**0.21**
	CBLR	0.01 (0.05)	0.04 (0.02)	-0.006 (0.05)	1.00 (0.12)	-1.00 (1.03)	**0**	-0.01 (0.05)	0.16 (3.13)	-25.36 (12.3)	**0**	**0**	0.01
	JI	**0**	0.05 (0.02)	0.00 (0.00)	0.99 (0.11)	-1.01 (0.01)	**0**	--	0.24 (2.13)	-19.59 (8.94)	--	--	--
2001:1-2006:6													
	IBOR	0.05 (0.07)	0.03 (0.03)	-0.02 (0.04)	1.12 (0.15)	-1.33 (0.33)	**0**	**0**	$\boldsymbol{\frac{1-\phi^d}{\beta}}$	-0.03 (0.75)	$\boldsymbol{\frac{1+\phi^{RR}}{\theta}}$	-0.62 (2.92)	0.00
	ER	-0.03 (0.05)	0.04 (0.03)	0.05 (0.04)	**0**	**0**	**0**	**0**	13.49 (7.48)	10.88 (5.00)	5.71 (2.51)	0.98 (1.06)	0.005
	TR	-0.01 (0.03)	0.01 (0.02)	0.01 (0.02)	0.94 (0.11)	-1.08 (0.09)	**0**	**0**	$\boldsymbol{\frac{-(\alpha\phi^d+\theta)}{\alpha\beta}}$	442 (2449)	$\boldsymbol{\frac{1+\phi^{RR}}{\theta}}$	-1.44 (1.76)	0.00
	RRR	0.00 (0.01)	0.10 (0.04)	0.00 (0.01)	1.00 (0.00)	-1.00 (0.07)	-0.10 (0.04)	**0**	**0**	**0**	1.05 (13.85)	-260.5 (951)	0.00
	CBLR	0.03 (0.02)	0.01 (0.02)	-0.03 (0.02)	1.07 (0.09)	-1.00 (0.004)	**0**	-0.03 (0.02)	-7.45 (8.98)	-106 (184)	**0**	**0**	0.00
	JI	**0**	0.017 (0.014)	0.00 (0.00)	1.02 (0.14)	-1.00 (0.00)	**0**	--	-0.95 (7.59)	-58.7 (47.1)	--	--	--
2006:7-2013:3													
	IBOR	0.18 (0.11)	0.14 (0.02)	-0.05 (0.02)	-2.54 (1.72)	-8.79 (3.70)	**0**	**0**	$\boldsymbol{\frac{1-\phi^d}{\beta}}$	0.69 (1.75)	$\boldsymbol{\frac{1+\phi^{RR}}{\theta}}$	-5.05 (2.25)	0.00
	ER	0.08 (0.06)	0.08 (0.04)	-0.06 (0.03)	**0**	**0**	**0**	**0**	12.59 (4.12)	-9.43 (3.27)	-12.94 (6.15)	-2.54 (3.21)	**0.05**
	TR	0.54 (0.21)	0.08 (0.03)	-0.09 (0.01)	-0.15 (0.20)	-4.23 (1.65)	**0**	**0**	$\boldsymbol{\frac{-(\alpha\phi^d+\theta)}{\alpha\beta}}$	-7.28 (7.5)	$\boldsymbol{\frac{1+\phi^{RR}}{\theta}}$	24.13 (13.7)	0.01
	RRR	0.02 (0.02)	0.09 (0.04)	-0.03 (0.02)	0.97 (0.04)	-0.97 (0.25)	-0.09 (0.05)	**0**	**0**	**0**	-2.21 (9.25)	-41.6 (30.4)	**0.08**
	CBLR	0.02 (0.05)	0.03 (0.03)	-0.02 (0.05)	0.83 (0.17)	-1.00 (0.01)	**0**	-0.02 (0.05)	6.14 (6.54)	-35.8 (39)	**0**	**0**	0.00
	JI	**0**	0.033 (0.017)	0.00 (0.00)	1.02 (0.08)	-1.00 (0.02)	**0**	--	-0.62 (2.37)	-30.14 (13.6)	--	--	--

Note: The estimates are obtained from an eight-variable VAR (see text for explanations). Standard errors are reported in parentheses. Those parameter estimates that are significantly different from zero at the 5-percent level of significance are highlighted in grey. Parameter restrictions are indicated in boldface. The last column presents *p*-values from Hansen-J tests, with the values in boldface indicating that the restrictions implied by the particular model cannot be rejected at the 5-percent level of significance.
Source: Author's estimation.

We first focus on the parameter estimates. The slope of reserves demand function, α, is found to be small and insignificantly different from zero in most cases. It implies that the demand for reserves is not elastic. This finding is fairly comparable to the U.S. results of Bernanke and Mihov (1998), and seems plausible as Strongin (1995) argues that the short-run demand for total reserves is rigid and inelastic. This argument is further supported by estimates of θ, which is often found to be very small in magnitude and insignificant as well. This, together with $\alpha = 0$, suggests that in China, the demand for reserves is neither sensitive to the money market interest rate nor to the interest-rate spread. This finding lends strong supports to our just-identified model where $\alpha = 0$ is assumed.

The parameter β measures how required reserves changes with the required reserve ratio. It is of the expected sign. For the full sample and the later subsample, it is mostly precisely estimated across models, while for the period 2001:1-2006:6, it is often found to be insignificant. This period corresponds to the regime where the PBC seldom adjusted the required reserve ratio. This lack of variations in the ratio could lead to an insignificant estimate.

The parameter estimates of three functions that describe the PBC's reaction to the reserves-market shocks (see Eqs (8)-(10)) are of our particular interest. In the first behaviour function, given by Eq. (8), describes how the PBC adjusts money supply in response to various shocks in the reserves market. The parameter ϕ^d measures the PBC's propensity to accommodate reserves demand shocks. For the full sample and the earlier subsample, this coefficient is generally estimated to be around one in the models where it is to be identified (in five out of six models), with high statistical significance. This implies something close to full accommodation of reserves demand shocks ($\phi^d = 1$), in support of the interest-rate targeting model. This conclusion gets somehow weaker for the later sub-period, during which accommodation of reserves demand shocks is found to be negative, though insignificant. in the IBOR model and the TR model. Indeed, the Hansen-J test results also suggest that during this period the ER-targeting model is marginally preferred to the IBOR-targeting model. This result is interesting since post-mid-2006 was the period in which the excess reserves ratio declined and slowly became stable (see Fig. 4) due to various efforts that the PBC took to lower this ratio to dredge the monetary transmission channels (the PBC's *China Monetary Policy Report 2008 Quarter II*: 6-8). Our finding seems to support the PBC's efforts, implying that with its increasing ability to influence the quantity of excess reserves, it is more capable of using the excess-reserves targeting procedure, as it has attempted.

The PBC offsets shocks in the reserves market through its response to required reserves shocks as well. This coefficient, ϕ^{RR}, is in most of cases estimated to be negative, significant and close to -1 (with exceptions of two models for the second sub-period). This means that excess reserves decrease almost proportionally with a positive demand shock to required reserves. This is consistent with our interpretation of the PBC's "sterilization" operations.

The estimates of these two parameters, ϕ^{d} and ϕ^{RR}, are of particular importance as they can be used to distinguish the IBOR model from the ER model, which in turn are the PBC's two main operating targets. As discussed in Section 2.2, when $\phi^{d} \rightarrow 1$ and $\phi^{RR} \rightarrow -1$, it suggests strong evidence for the IBOR model, while the case that these two parameters tend towards 0 can be interpreted as supportive evidence for the ER model. So far, our estimates show evidence in favour of the IBOR model in general. This suggests that it is inappropriate to ignore the policy stance information that this short-term interest rate contains by measuring Chinese monetary policy with quantity variables alone (either excess reserves or broader monetary aggregates).

Two parameters, ϕ^{RRR} and ϕ^{i}, measure how the reserves supply is used to react to shocks to other two policy instruments – the required reserve ratio and the central bank lending rate, which the PBC adjusts mainly on a discrete basis. Thus it is very likely that the reserves supply does not respond to the contemporaneous shocks to these two instruments. To identify the system, these two coefficients are often restricted to zero.

The behaviour functions of two discrete policy tools – the required reserve ratio and the central bank lending rate – are identified mainly through the estimates of γ^{s} and τ^{s}, with other parameters restricted either to zero or to some combined relationships. They are found to be of mixed sign and generally not precisely estimated. Nevertheless, it hints that the PBC uses these two policy tools mainly for the liquidity management purpose.

A quick comparison of estimates across periods in Table 1 indicates that that the PBC's operating procedures have changed over time and apparently, no single model is optimal for the 2001-2013 time period. In case of the whole sample, the PBC's policy framework seems to be better described as mix of operating procedures: three models (the IBOR targeting, the ER targeting and the RRR targeting) all have Hansen-J test *p*-values greater than 5%. This implies that changes in excess reserves, the short-term interest rate and the required reserve ratio all contain information about the policy stance. This finding supports the emerging wisdom among many researchers that measuring Chinese monetary policy requires one to consider those variables all (see, among others, Chen, Chen, and Gerlach 2013, He and Pauwels 2008, Shu and Ng 2010, Sun 2013, Xiong 2012). However, in doing so, special attention needs to abstract non-policy induced changes in them, such as accommodation to reserves demand (note that we find almost full accommodation) and liquidity management due to the FX market interventions.

We find this mix of operating procedures for the post-2006 subsample as well, during which two models (the ER targeting and the RRR targeting) cannot be rejected by the Hansen-J tests at the 5-percent level of significance. However, if we focus on the pre-2006 period only, it appears that no model describes the PBC's operating procedure well.

Two models, the TR-targeting model and the CBLR-targeting model, are highly rejected across periods. This result is somehow not surprising. As discussed in Section 2, banks are constrained with limited access to the interbank loan market, in particularly in the early period due to the under-developed money market in China, and hence their borrowing from the PBC is not interest elastic. Furthermore, the central bank lending rate is adjusted only infrequently. Overall, changes in this interest rate seem to contain only limited information about the PBC's policy stance. The TR-targeting model does not perform well, in contrast to the ER-targeting model. The main reason for it is that total reserves, as a sum of required and excess reserves, are likely to rise simply because the PBC raises the required reserve ratio for the "sterilization" purpose. This is typically the case for the post-2006 period. Changes in total reserves hence reflect something other than shifts in the policy stance.

Comparable to the Fed's and the Bundesbank's cases, this methodology seems to perform well in identifying the PBC's operating regime over different periods. We find that the PBC's operating procedure has been changing over time. It is neither pure interest-rate targeting nor pure excess reserves targeting, but better described as a combination. To measure Chinese monetary policy stance, one needs to consider the money market interest rate, excess reserves and the required reserve ratio altogether.

In Table 1, the sample break is determined based on our prior knowledge of Chinese monetary operating procedures. Alternatively, we can use statistical procedures to determine the sample breaks. To do so, we focus on Eq. (8), the PBC's key response function specified in the benchmark just-identified model. We run a Markov regime switching regression of this equation over the full sample, allowing two possible states of freely estimated combination of two parameters ϕ^d and ϕ^{RR}. These two parameters are particularly informative in distinguishing the IBOR-targeting or the ER-targeting model.

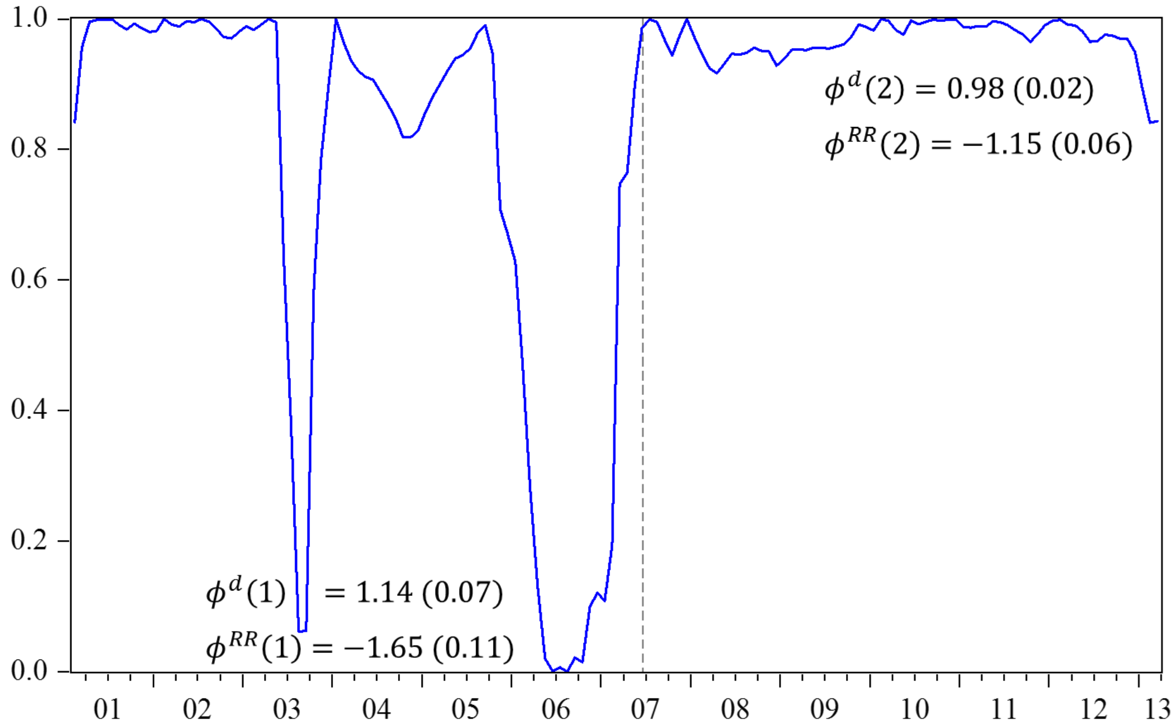
Figure 5 shows the smoothed probability that the operating regime is in the second of the two states at each date, together with the estimates of two parameters ϕ^d and ϕ^{RR} (with standard errors in parentheses) for both regimes.

The smoothed probability indicates that there are regime switches in the pre-2007 period, while the later period is relatively stable. Two short periods (the second half of 2003 and the period of 2005:08 – 2007:06) are found in the first state. The 2003 period is fairly short, corresponding to the time when the PBC, for the first time, raised the required reserve ratio to control the money supply and bank lending after keeping it at 6 percent for about 4 years (See Figure 1). The second period lasts about two years, during which the PBC switched to more intensive use of the required reserve ratio for the "sterilization" purpose. The start of this period also roughly corresponds to the time when we saw a switch of Chinese exchange rate regime – in July 2005, China announced to give up its decade-long dollar peg and switch to a managed floating exchange rate regime.

The two parameters, ϕ^d and ϕ^{RR}, are significant and precisely estimated in both regimes, with values larger in absolute term for the first state. Despite this, qualitatively they are both estimated to be around 1 and -1 or even larger, in support of the interest-rate targeting model or some mixed model. It suggests that regime switches (in PBC's case) do not necessarily imply shifts from a *pure* ER targeting to a *pure* IBOR targeting model.

This analysis shows strong evidence for regime switches, which confirms our previous findings. In particular, it suggests a switch to a relative stable regime around June 2007, which can be used as an alternative break point. We estimate all the six models for pre- and post-mid-2007 subsamples, and obtain qualitatively similar results (available from the author upon request).

Figure 5: Estimated smoothed regime probability of the PBC's operating procedures



Note: The estimates are obtained from running a Markov regime-switching regression of Eq. (8) in the just-identified model (see text for explanations). The figure reports the smoothed probability of the second state at each date, together with the estimates of parameters ϕ^{d} and ϕ^{RR} (with standard errors in parentheses) for both regimes.
Source: Author's estimation.

4. Implications of individual policy indicators for VAR estimation: IBOR, ER or RRR?

For the full sample, we have three indicators that cannot be rejected. Does any of them perform superior in the further application for the estimation of policy effects? To answer this question, we apply the standard VAR approach to examine the implication of various policy indicators for the estimation of policy effects. Each time, we run a four-variable VAR with the same set of non-policy variables as above plus one of three non-rejected indicators – excess reserves, the interbank offered interest rate and the required reserve ratio.

Figure 6 shows, together with 95% percent confidence interval, the accumulated responses of industrial production and the CPI to a one-standard-deviation policy shock, estimated with these three VAR models. A quick comparison of these three columns indicates that industrial production exhibits a qualitatively similar response pattern after a policy shock in all three models.[25] Consistent with the theoretical

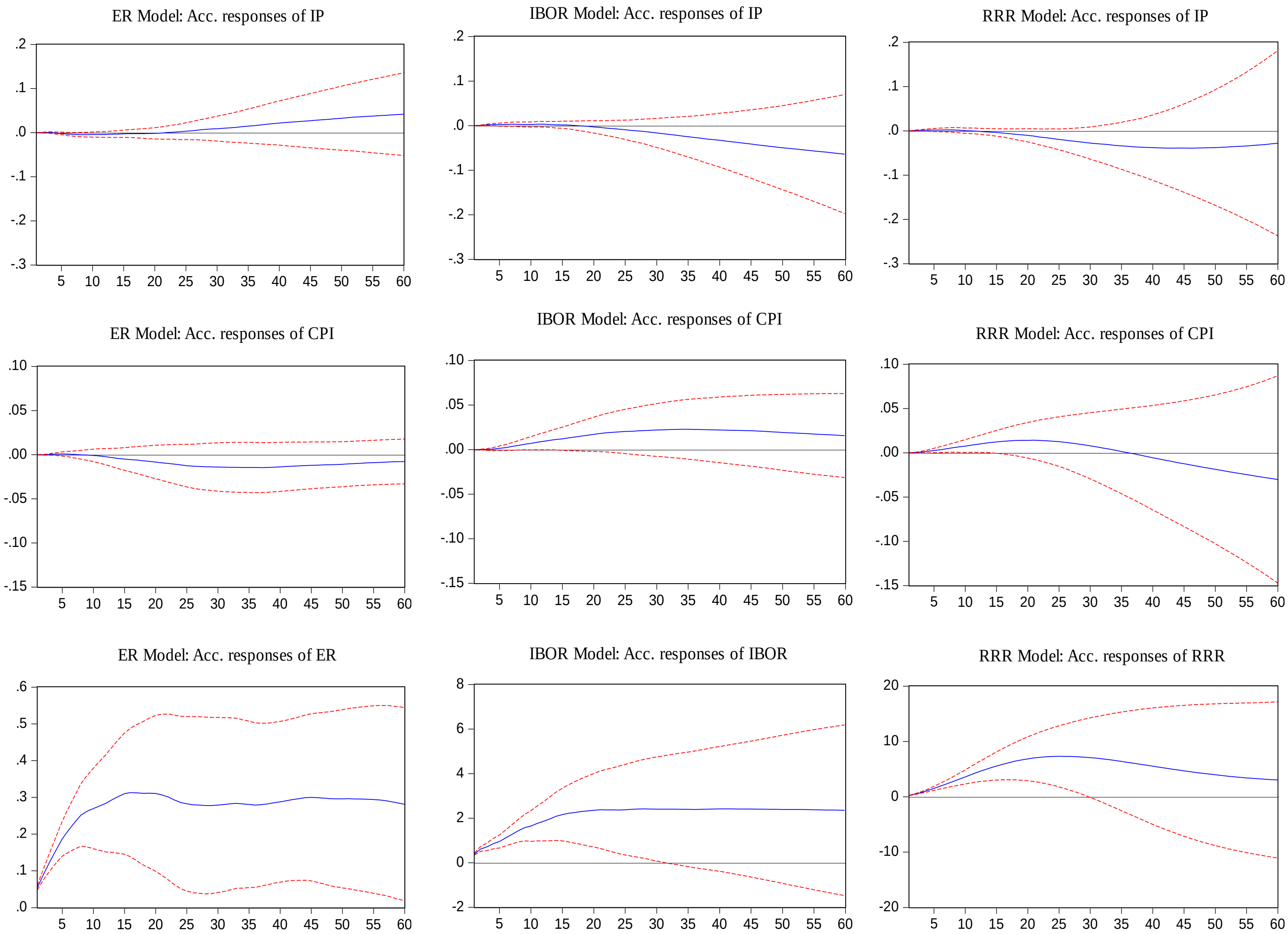
[25] Note that the policy shock described in Column 1 is expansionary while that in both Column 2 and 3 is contractionary.

predication, output responds to a monetary policy shock sluggishly; and after about one year, it starts to fall (rise) following a contractionary (expansionary) policy shock. However, the response of the price level to both excess reserves and the interbank offered interest rate exhibit the “price puzzle”, where a monetary easing (contraction) results in a fall (rise) of the price level. Only in the RRR model, prices decline eventually after a long delay (about three years) following a rise in the required reserve ratio. Yet, the statistical uncertainty about this estimate is large.

Overall, no single indicator performs superior. This exercise is not helpful in distinguishing them.[26] None of these three indicators seems to be sufficient to measure Chinese monetary policy conditions. A correct measure might require a comprehensive consideration of them all.

[26] Needless to say, the potential model misspecification could also be one of the reasons for this unsatisfactory result. As we discussed in Section 2, changes in policy variables contain three-fold information. Our simple VAR model might not be able to abstract the “liquidity management”, in particular. We leave the VAR model selection and other applications to future research.

Figure 6: Accumulated responses of output and prices to a monetary policy shock



Note: Each column presents accumulated responses of the economy to a monetary policy shock, estimated in a four-variable VAR with PPI, IP, CPI plus a monetary policy indicator. This indicator varies across models. The impulse in each model is a one-standard-deviation shock to its policy indicator – either excess reserves or the interbank offered interest rate or the required reserve ratio. Twelve lags of each variable are included in all VARs. The dashed lines mark 95% confidence intervals. Monthly data are used. The sample is 2000:1-2013:3.

Source: Author's estimation.

5. Comparison and evaluation of other policy measures

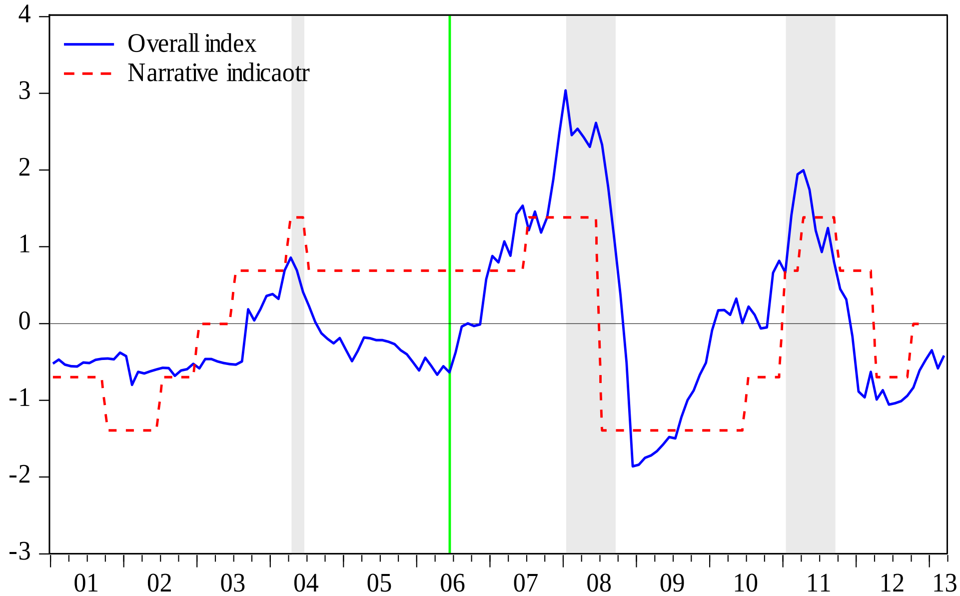
So far, we used two-stage VAR approach to isolate exogenous policy shocks from systematic responses. However, it is also useful to have an index that measures the overall monetary conditions. It thus includes all the changes in monetary policy, both the endogenous (systematic) and the exogenous (unexpected) components. As discussed above, we find that various policy instruments all contain the information about the policy stance. Hence, we consider them all to construct such an overall index as a linear combination of all the variables in the policy block. For an evaluation purpose, we then compare this index with other policy indicators.

To construct this composite indicator, we focus on the vector of variables $\boldsymbol{A}^{-1}(\boldsymbol{I}-\boldsymbol{G})\boldsymbol{P}$. That is, we premultiply $\boldsymbol{P}$, as specified in Eq. (2), by the inverse of the multiplicand of structural shocks such that the orthogonalized VAR innovations to one element (let us call it *p*) correspond to exogenous policy shocks. With our ordering, this *p* is the third element in the vector that corresponds to the line having υ^{s}. Essentially, this ordering does not play any role as our specification models this overall indicator as a linear combination of all policy variables – TR, IBOR, ER, RRR and CBLR. When considering it in combination with various parameter restrictions, this overall index is equivalent to various single indicators as those models suggest. For example, the ER model assumes $\phi^{d}=0$, $\phi^{RR}=0$, $\phi^{RRR}=0$ and $\phi^{i}=0$, which implies that *p* equals excess reserves. Similarly, the IBOR model's restrictions imply that *p* is equivalent to the IBOR, etc.

We compute this overall index and report it in Figure 7. It is smoothed and normalized by subtracting from it a 12-month moving average of its own past values. In so doing, this index is continuous over changes in regime and comparable over time.[27] We define zero as the benchmark for "normal" monetary policy. For comparison reason, we multiply this index with -1 such that positive (negative) values of this index suggest a contractionary (expansionary) monetary policy.

[27] Discontinuity arises in face of a regime shift (e.g., from targeting the interbank offered rate (IBOR) to targeting excess reserves (ER)) as these indicator variables (i.e., the IBOR and ER) are not in comparable units.

Figure 7: An indicator of overall monetary policy stance



Note: The overall index and the Sun (2014) narrative indicator are both normalized. The latter is converted from the initial quarterly-basis series. The vertical green line marks two subsamples. The grey shaded areas are the contractionary episodes, identified by Sun (2013).
Source: Author's estimation and Sun (2013, 2014).

Together with this overall index, in Fig. 7 we also show two narrative-based indicators as mentioned in the introduction – the Sun (2013) contractionary episodes (in grey shaded areas) and the Sun (2014) narrative indicator (the dashed line). The vertical line marks two subsamples. The overall index and the Sun narrative indicator are rescaled to have the same mean. A quick comparison of these three indicators suggests that they conform well to each other, despite of the fact that they are derived from very different methods. Our overall index is moving closely with the Sun (2014) narrative indicator, although the latter is less volatile – both in the whole sample and in subsamples. Their monthly correlation is high – 0.57 for the whole sample – and turning to an even higher value if we focus on subsamples (see Table 2). Three local peaks in our overall index – that is, the maximum tightness periods over the period – coincide with the Sun (2013) contractionary episodes when the PBC took various contractionary measures to rein high inflation.

Table 2 reports various subsample correlations of our overall index of policy stance with two composite indices and three non-rejected policy indicators. The correlation of our overall index with the first composite index – the Sun (2014) narrative indicator – is high, particularly for subsample periods (0.6 and 0.66 respectively). The correlation between our overall index and the Xiong (2012) instrument index is moderate, from 0.34 to 0.41 over different samples.

Table 2: Correlations between the overall index and other measures of monetary policy stance

	Full Sample (2001.01-2013.12)	First-half Sample (2001.01-2006.06)	Second-half Sample (2006.07-2013.12)
Narrative indicator (Sun 2014)	0.57	0.60	0.66
Instrument index (Xiong 2012)	0.36	0.34	0.41
IBOR	0.31	0.04	0.32
ER	0.19	0.04	-0.24
RRR	0.23	0.50	-0.08

Note: The overall index is obtained from an eight-variable VAR (see text for explanations).
Source: Author's estimation.

The correlations of the overall index with individual policy indicators are getting weaker (about 0.2 and 0.3 only for the full sample). It conforms our finding that none of them is sufficient to represent the overall monetary policy condition. For the first subsample, the correlation coefficients of the IBOR and ER with the overall index are close to zero. Over the post-2006 subsample period, only the IBOR has relatively high correlation with the overall index (0.32), while the other two (excess reserves and the required reserve ratio) even have negative correlation with the overall measure. This finding is not totally surprising as for this period, changes in the required reserve ratio and consequently in excess reserves are closely related to the "sterilisation" transactions and quite often, they reflect something rather than shifts in the policy stance.

This comparison suggests that two composite indices have potential to convey policy information and are hence preferable to individual indicators in measuring Chinese monetary policy.

6. Conclusion

The novelty of the paper lies in its extended application of the two-stage VAR approach to China's case. For the first time, it formulates the PBC's multiple "unconventional" policy tools into a simple operating-procedure model. The main findings are fourfold and have been amply discussed. In brief, the PBC's operating procedure has changed over time. It is neither pure interest-rate targeting nor pure reserves targeting, but better described as a combination of two. An instrument-based composite measure of Chinese monetary policy needs to consider three indicators – reserves supply, the money market interest rate and the required reserve ratio.

Appendix A: Imputation of monthly IP, CPI and PPI data

The National Bureau of Statistics of China (NBS) does not publish the original level data. In this appendix, we impute the monthly level data for IP, CPI and PPI from the available time series.

The NBS used to employ an unconventional method to tackle the seasonality problem inherent in the time series data and publish only "YoY" (year-over-year) or "YoY: ytd" (year-over-year: year-to-date) growth rates data.

The "YoY" growth rate of IP, for example, is calculated by comparing IP of the current month over the same period last year. The growth rate for 2011 M_j is thus calculated as

$$g_{IP,2011M_j} = \left(\frac{IP_{2011M_j}}{IP_{2010M_j}} - 1\right) * 100, \text{ with } j = 1, 2, \ldots, 12$$

which gives a percentage change of IP in month M_j over year. In so doing, the time series of the IP growth rate should not contain any seasonal variations, because March of this year, for example, typically has the same number of working days, weather, and other variables that might affect output as March of last year. However, in some years we still find abnormal fluctuations in January or February. It is due to Chinese New Year effects, since the Chinese New Year does not fall in the same month each year (Sun 2013). In 2005, the NBS stopped publishing IP growth for January. Instead, IP in January and February was added up and the growth rate for such an aggregate was calculated and reported for February IP growth.

The "YoY: ytd" growth rate is a percentage change of the variable over year, but cumulated to the date. For example, the growth rate of IP for 2011 M_j is calculated according to the formula

$$G_{IP,2011M_j} = \left(\frac{\sum_{i=1}^{j} IP_{2011M_i}}{\sum_{i=1}^{j} IP_{2010M_i}} - 1\right) * 100, \text{ with } j = 1, 2, \ldots, 12$$

where the growth rate of 2011 M1 is a percentage change of IP in January over year, but the growth rate reported for February is calculated as a percentage change of the sum of IP for the first two months over that sum in 2010; and so on so forth. The data are thus seasonally adjusted. No Chinese New Year effects are found.

Yet, using times series of either "YoY" growth or "YoY: ytd" growth is problematic because they reflect only remote (over-year) change, rather than immediate over-time changes. Moreover, in the VAR literature, the level data are preferred such that we ensure there is no loss of information on the long-run properties of the system.

Recently, the NBS started to publish the "MoM" (month-over-month) growth rates for those variables. Based on those available time series, we impute the level data for IP, CPI and PPI.

IP: Since 2011, the NBS publishes the time series of IP "MoM" growth.[28] To impute the level data, we follow two steps:

1) For the period since 2011-1, we use the "MoM" SA (seasonally adjusted) IP growth (since 2011-2) to impute the IP level data, assuming 2011-1=100.
2) For the period 2000-2010, we use IP (YoY: ytd) rate to impute the IP level data backwards.
3) The imputed time series still exhibits cyclical seasonal movements. It is then seasonally adjusted.

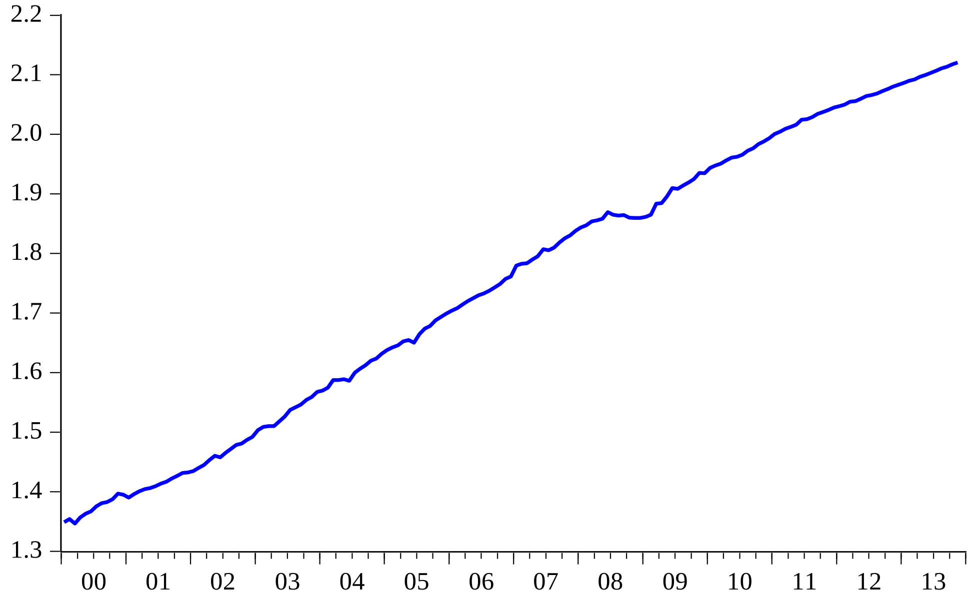
CPI: The time series of CPI "MoM" growth is available since 1995-1. We hence use this time series to impute the CPI level data, with 1998-1 as the base period.

PPI: The time series of PPI "MoM" changes is available since 2003-1. In analogy to IP, we impute PPI level data in two steps, with 2003-1 = 100. For the period 2000-2002, our backwards imputation is based on "YoY" PPI time series.

These three imputed time series (in logarithms) are presented in Figs. A-1 and A-2.

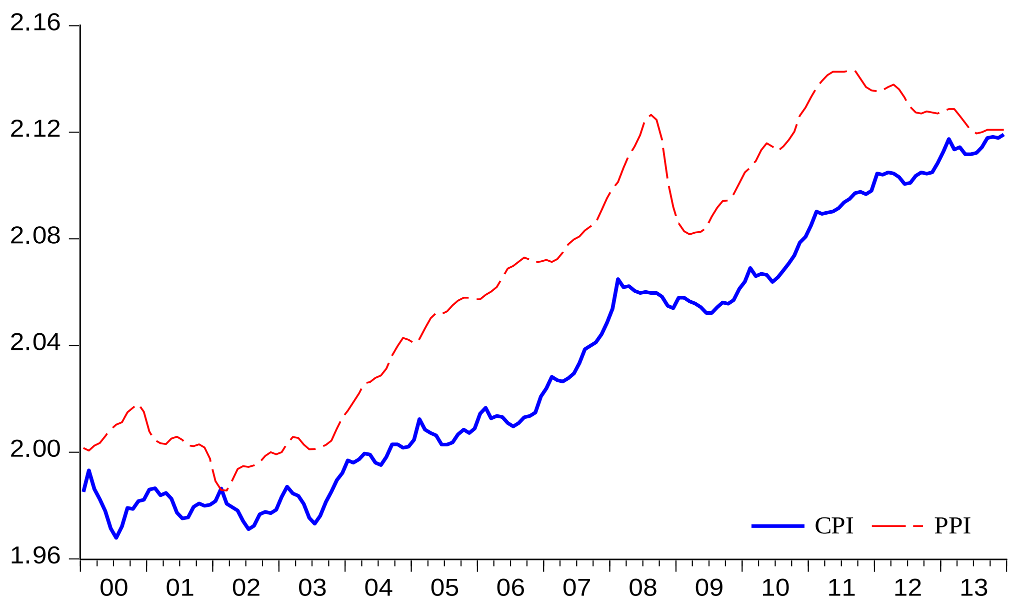
[28] The data source is CEIC. The time series is marked as "Value Added of Industry: MoM: SA".

Figure A-1: Industrial production (SA, in log) (2000-2013)



Note: The level data are imputed by the author, using the CEIC dataset.

Figure A-2: Consumer price index and producer price index (in log) (2000-2013)



Note: The level data are imputed by the author, using the CEIC dataset.

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