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Article — Published Version

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Economic Record

Provided in Cooperation with:

John Wiley & Sons

Suggested Citation: Funke, Michael; Tsang, Andrew (2021) : The Direction and Intensity of China's Monetary Policy: A Dynamic Factor Modelling Approach, Economic Record, ISSN 1475-4932, Wiley, Hoboken, NJ, Vol. 97, Iss. 316, pp. 100-122, <https://doi.org/10.1111/1475-4932.12576>

This Version is available at:

<https://hdl.handle.net/10419/233739>

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The Direction and Intensity of China's Monetary Policy: A Dynamic Factor Modelling Approach*

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The recent update of the People's Bank of China's monetary policy framework establishes a corridor system of interest rates. We employ a dynamic factor modelling approach to derive an indicator of China's monetary policy stance. The approach is based on the notion that co-movements in several monetary policy instruments have a common element that can be captured by a single underlying, unobserved component. To clarify and interpret the derived index, we employ a baseline dynamic stochastic general equilibrium (DSGE) model that can be solved analytically and allows tracing of the expansionary and contractionary on-and-off phases of Chinese monetary policy.

Highlights

- We construct an indicator of China's monetary policy stance
- The indicator is estimated by dynamic factor modelling approach
- We trace the monetary policy stance by using a DSGE model and the indicator

*We thank four anonymous reviewers and the editor for helpful comments made on an earlier draft of this paper. A previous version of the paper was published as a Bank of Finland BOFIT Discussion Paper (No. 8/2019) (<https://helda.helsinki.fi/bof/handle/123456789/16109>). The views expressed herein are those of the authors only and do not necessarily reflect the views of the Bank of Finland. The usual disclaimer applies. Open access funding enabled and organized by Projekt DEAL.

JEL classifications: C54, E32, E52, E58, E61

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1. Introduction

Since the People's Bank of China (PBoC) began to function exclusively as a Central Bank in 1984, numerous changes to its approach to monetary policy have taken place. China's monetary policy framework has gradually moved away from a financial system resting on preset deposit and lending rates, as well as 'window guidance' lending quotas, to a more market-based regime with money growth as the main intermediate target. As part of this transition, short-term interest rates, open-market operations (OMO), short-term liquidity operations (SLO) and medium-term lending facilities have gained increasing importance in the monetary policy toolbox.¹

Understanding the objectives and formulation of PBoC monetary policy is complicated by the fact that China's monetary policy is in a state of flux as the PBoC struggles with its conflicted objectives of cutting back risky lending while ensuring that money keeps flowing into the economy. Moreover, the PBoC is not independent, but institutionally subordinate to the State

¹ For a detailed discussion of monetary policy in China across decades, see Sun (2015).

Council, Beijing's equivalent of a cabinet, and ultimately the Communist Party of China (CPC). The State Council signs off on all important PBoC measures, occasionally going so far as to approve the wording of Central Bank announcements.

Before the full liberalisation of interest rates, the PBoC directly controlled the funding costs of bank borrowers and saving returns of depositors by adjusting benchmark interest rates. Pricing power today is in the hands of commercial banks. While the PBoC renamed benchmark interest rates as 'reference rates' to guide public expectations, their real influence on lending and deposit rates has weakened and officials downplay their significance.² Instead, the PBoC has recently shifted to a multi-instrument mix of liquidity tools and pricing signals to achieve its competing policy goals. This hybrid monetary policy framework forces PBoC watchers and market participants, including international investors, to monitor several fronts simultaneously as they try to discern the stance of Chinese monetary policy.

Given China's multi-instrument monetary policy toolkit, this paper presents a new method to measure China's monetary policy stance. While there has been a great deal of literature chronicling individual tools, less attention has been paid to estimating an overall indicator for the monetary policy stance. An exception is Girardin *et al.* (2014, 2017). Building on the instrument-set approach of He and Pauwels (2008), Xiong (2012) and Sun (2015), they construct a weighted-average measure of the PBoC's monetary policy stance using price, quantitative and administrative measures. However, the above-mentioned recent reorientation of China's monetary policy is not included in the analysis. Shu and Ng (2010) and Sun (2013, 2018) have employed the narrative approach propounded by Romer and Romer (1989). It entails a mapping of the qualitative discussions in policy records to a quantitative scale by assigning a number indicating the degree of easing or tightening of policy stance. With this approach, the quantitative interpretations of policy statements in terms of such indices are subjective, and therefore debatable.

Against this background, we measure Chinese monetary policy using a dynamic factor model

(DFM) from May 2012 to December 2018 on a monthly basis, taking account of the PBoC's current multiple instrument toolkit. This is a novel way to construct a tractable and timely measure of China's monetary policy stance. As a second contribution, we study the monetary transmission via the dynamic effects of monetary policy shocks on the aggregate economy. To this end we adopt a dynamic stochastic general equilibrium (DSGE) modelling approach.

The paper is structured as follows. Section II describes how the PBoC influences money market conditions. Section III describes our dataset, presents our DFM and discusses the empirical result. Subsequently, we assess our derived monetary stance indicator against various benchmarks. Section IV presents an estimated baseline DSGE model using the derived monetary stance indicator. A graphical evaluation of the DSGE model allows us to evaluate the stance of monetary policy over time and the various macroeconomic impacts. Finally, section V concludes with a summary of the main messages, policy issues and future directions for research.

II. The Evolution of China's Multiple Instrument Monetary Framework

In this section we provide the relevant institutional background that helps understand the key elements of how the PBoC's monetary policy is conducted. After wrapping up its decades-long process of interest rate liberalisation in late 2015, the PBoC updated its monetary policy framework to include a corridor system of interest rates. The basic principle of the corridor system is as follows: the Central Bank provides a lending facility tool (the upper bound of the corridor) and a deposit facility tool (the lower bound of the corridor) to form an interbank interest rate corridor, while the PBoC's interest rate target is somewhere within the corridor. The interest rate target is a new anchor in China's financial system much such as benchmark short-term interest rates in North America and Europe. Under this system, the new policy target is the pledged seven-day interbank market rate. The rates of the standing lending facility (SLF) constitute the upper bound of the corridor.³ The pledged seven-day interbank

² See <https://www.bloomberg.com/news/articles/2018-06-14/china-s-evolving-toolkit-to-manage-monetary-policy-quicktake>.

³ The new policy has not been completely successful. Part of the reason is that the SLF is only available for larger lenders. The seven-day repo rate has surged beyond the SLF lending rate with the same maturity on several occasions.

market rate applies to all financial institutions (including the non-bank financial institutions authorised to trade) in the interbank market without restrictions on the bond securities used as collateral for the repo. The medium-term lending facility (MLF), launched in 2014, allows the PBoC to provide funds with longer maturities and stabilise market expectations with maturities ranging from three months to a year. The range of acceptable collateral includes government bonds and notes, local government debt and highly rated loans of small companies. As Chinese financial markets still lack depth, MLFs also help improve rate transmission by setting borrowing costs at the long end of the curve.

The PBoC has created tools similar to the MLF to offer funding to various banks in different scenarios. Besides the tools of SLO and contingent reserve allowance (CRA), China recently introduced the pledged supplementary lending (PSL) program to fund investment by the nation's three policy banks. The PSL was introduced to guide long-term interest rates and money supply. Selected policy banks are injected with funds so that they can provide loans to specific sectors. Until now only the China Development Bank, the Agricultural Development Bank of China and the Export–Import Bank of China have received this facility. The SLO, introduced in 2013, was aimed at relaxing the market pressure in the event of sudden tightening of money market conditions. The SLO tool has not been used since 2016. The CRA is a new tool for providing temporary liquidity to banks during the Chinese New Year, when there is usually a cash shortage. It was used once in 2018, and it could be used again if needed. Finally, by setting the interest rate it pays on excess reserves, the PBoC effectively marks the lower bound of the interbank interest rate corridor.

The PBoC uses various instruments to steer the corridor system. In practice, it conducts monetary policy by scaling the size of its OMO or adjusting the SLF and MLF rates. OMO mostly involve repurchase or reverse repurchase agreements. Repurchase operations remove liquidity from the system as the PBoC sells short-term bonds to commercial banks. The opposite is the reverse repurchase agreement, that is, buying up the repurchase contracts. These operations give the PBoC control over the money supply and interest rates on a short-term basis. For this reason, short-term interest rate signals have gained importance.

Figure 1 shows the development of the interest rate corridor system. The corridor is currently asymmetric and the PBoC is gradually narrowing the range of the interest rate corridor.

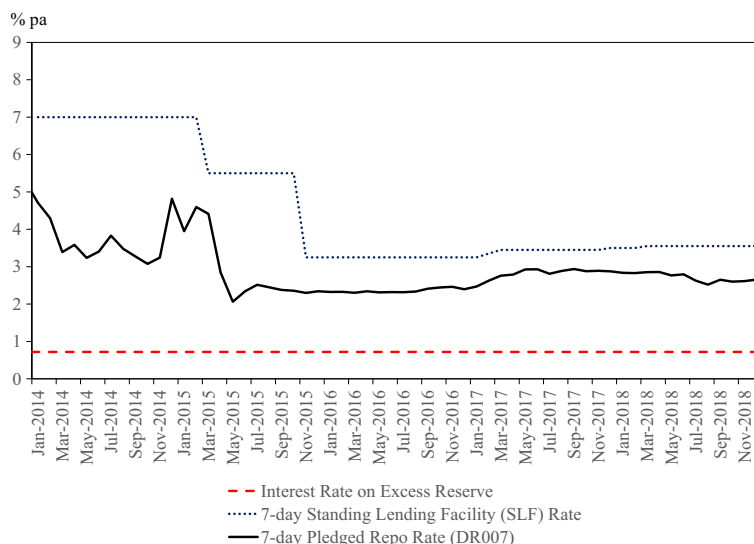
Although the described policy shifts are works in progress, a growing body of literature (e.g., Fernald *et al.*, 2014; Chen *et al.*, 2017) suggests that monetary policy transmission in China has started to resemble that of advanced economies. There has been a reorientation of monetary policy away from the use of quantity targets to one where the PBoC manages a key short-term interest rate. The IMF (2017, p. 34) arrived in 2017 at the tentative verdict that 'the conduct of [China's] monetary policy increasingly resembles a standard interest-rate-based framework'. Kamber and Mohanty (2018) confirm this in their examination of movements in one-year interest rate swap (IRS) contracts based on the interbank seven-day repo rate to measure market expectations of the PBoC's future monetary policy.

The reserve requirement ratio is a quantity-based monetary policy instrument used actively by the PBoC. While the reserve requirement ratio is usually considered a prudential measure to ensure lenders can handle customer withdrawals, its importance in China lies with money supply management, especially in dealing with the country's persistent current account surpluses.⁴ The adjustment of the reserve requirement ratio can unleash or lock up huge amounts of liquidity. Thus, this traditional monetary policy tool has become a powerful weapon in the PBoC's arsenal. In particular, the authorities can resort to the reserve requirement ratio tool in times of market stress to give a clear and strong policy signal to the market. It is worth noting that the reserve requirement ratio has actively been used as a

⁴ Although China has introduced a managed floating exchange rate regime in July 2005, the PBoC has intervened nonetheless in the foreign exchange markets. To neutralise ensuing fluctuations of the domestic money supply caused by changes in foreign reserves, the PBoC has implemented various sterilisation policies. Important elements of this policy are Central Bank bills absorbing changes of bank reserves caused by the PBoC's interventions and adjustments of the reserve requirement ratio. Various studies have shed a light on the sterilisation effectiveness in China. While these studies employ diverse methodologies, there is a consensus that the PBoC has kept control of domestic monetary policy objectives (e.g., Yang, 2016; Wang *et al.*, 2019).

FIGURE 1

Implementation of China's Interest Rate Corridor System. [Colour figure can be viewed at wileyonlinelibrary.com]



Note: The seven-day pledged repo rate for financial institutions authorised to trade in the interbank market (R007) is used before 2015. Sources: People's Bank of China (PBoC) and National Interbank Funding Center.

macro-prudential policy instrument (Wang and Sun, 2013).

Finally, the PBoC occasionally still provides window guidance to commercial banks. The quantity-based window guidance tool relies on moral suasion rather than hard rules to pressure banks to adjust the amount and pace of credit supply until a set credit growth target is met. Window guidance may also be used to optimise the credit structure by moderating banks' allocation of credit to sectors and regions in line with policy objectives.⁵

Whether one describes China's current monetary policy framework as hybrid or hodgepodge, it is clear that the market-based reforms described above have brought Chinese monetary policy closer to the norms in developed markets. But it is also clear that the multiple-instrument monetary policy framework in its current state remains opaque and hinders assessment of the prevailing policy stance.

⁵ The IMF (2016, p. 14) has proposed terminating credit targets through window guidance, unless they are used to achieve macroprudential policy objectives.

III. Set-up of the Dynamic Factor Model

We propose a two-step approach to measure and evaluate China's monetary policy stance. In this section, we set up a DFM to estimate an indicator of China's monetary policy stance. Section IV below will employ the derived indicator to estimate a baseline DSGE model to evaluate the impacts of Chinese monetary policy over time.

(i) Methodology

DFMs are used in applied econometrics to quantify unobserved variables. Such models are particularly valuable in business-cycle analyses (e.g., Forni & Reichlin, 1998; Eickmeier, 2007; Ritschl, Sarferaz & Uebele, 2016), forecasting (e.g., Stock & Watson, 2002a, 2002b) and nowcasting the state of an economy (e.g., Banbura *et al.*, 2013). The numerical procedures used in such models smooth over missing values, and therefore deal with the ragged or jagged edge problem. The procedure is helpful when individual indicators have different signs.

The unobserved monetary policy stance is based on the notion that the co-movements in different monetary policy instruments have a common element that can be captured by a single underlying, unobservable variable.

We have verified the number of factors underlying the variables that is one by standard procedures undertaken in explorative factor analysis. Among these are the test procedures in Bai and Ng (2002), Onatski (2010) and Ahn and Horenstein (2013). The DFM in first differences is specified as follows:

$$\Delta I_{i,t} = \beta_i \Delta M_t + e_{i,t} \quad (1)$$

$$\Delta M_t = \varphi_1 \Delta M_{t-1} + \varphi_2 \Delta M_{t-2} + u_t \quad (2)$$

$$e_{i,t} = \rho_{i,1} e_{i,t-1} + \rho_{i,2} e_{i,t-2} + v_{i,t} \quad (3)$$

where Δ is the first-difference operator; M_t is the unobserved common component at time t ; I_i ($i = 1, \dots, 5$) are the five monetary policy instruments; β_i are the factor loadings; $u_t \sim \text{i.i.d. } N(0, \sigma_u^2)$; and $v_{i,t} \sim \text{i.i.d. } N(0, \sigma_i^2)$.⁶

It is well known that the dynamic properties of time-series models may depend on the AR lag order of the model fitted to the data. Therefore, an important preliminary step in empirical studies is to select the order of the autoregression. A common strategy in empirical studies is to determine the optimal lag-order by means of information criteria. The Akaike information criterion (AIC), the Bayesian information criterion (or Schwarz criterion, BIC) and the likelihood ratio test were used to choose among alternative specifications of the model.

The estimation results in Table 1 illustrate that the two information criteria give different answers. Given these conflicting results, an AR(2) specification was chosen based on the Ljung–Box Q test for autocorrelation to check the i.i.d. assumption for the estimated residuals of each observable variable in the measurement equation.⁷

⁶ The model used is an exact first-generation DFM. This means that the idiosyncratic components are assumed to be cross-sectionally and serially uncorrelated. In contrast, in approximate DFMs, the idiosyncratic components are allowed to be weakly correlated in both the cross-section and time domains. See Stock and Watson (2016) for more details on the various generations of DFMs.

⁷ The AR order itself typically is of no economic interest. It matters only to the extent that it affects the shape of the derived indicator. Appendix S2 in the additional supporting information we therefore address the sensitivity of our monetary stance indicator to the chosen AR lag order. The estimation results for the alternative AR(1) specification of the factor model show that the extracted factor is almost identical to the AR(2) specification when using the same $I_{i,t}$ variables.

The diagnostic tests indicate that the AR(2) specification is adequate for all equations.

The common factor M_t is referred to as the dynamic factor. An essential feature of the factor model is that the common factor and the factor loadings are unobservable. Despite the resemblance, equations (1) – (3) do not correspond to a multivariate regression model. We assume that every monetary policy indicator $I_{i,t}$ is a weakly stationary process that has at least finite second-order moments, and perform unit root tests to support this. On top of this, as suggested by Stock and Watson (1991), the differenced series are also demeaned. The state-space representation contains a measurement equation (signal equation), which links observed variables to latent states, and a state equation, which describes how the states evolve over time. In the state-space model, the measurement equation is written as:

$$\begin{bmatrix} \Delta I_{1,t} \\ \Delta I_{2,t} \\ \Delta I_{3,t} \\ \Delta I_{4,t} \\ \Delta I_{5,t} \end{bmatrix} = \begin{bmatrix} \beta_1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ \beta_2 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ \beta_3 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ \beta_4 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ \beta_5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \Delta M_t \\ \Delta M_{t-1} \\ e_{1,t} \\ e_{1,t-1} \\ e_{2,t} \\ e_{2,t-1} \\ e_{3,t} \\ e_{3,t-1} \\ e_{4,t} \\ e_{4,t-1} \\ e_{5,t} \\ e_{5,t-1} \end{bmatrix}, \quad (4)$$

and the state equation is:

$$\begin{bmatrix} \Delta M_t \\ \Delta M_{t-1} \\ e_{1,t} \\ e_{1,t-1} \\ e_{2,t} \\ e_{2,t-1} \\ e_{3,t} \\ e_{3,t-1} \\ e_{4,t} \\ e_{4,t-1} \\ e_{5,t} \\ e_{5,t-1} \end{bmatrix} = \begin{bmatrix} \varphi_1 & \varphi_2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \rho_{1,1} & \rho_{1,2} & \dots & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 0 & \dots & \rho_{5,1} & \rho_{5,2} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \Delta M_{t-1} \\ \Delta M_{t-2} \\ e_{1,t-1} \\ e_{1,t-2} \\ e_{2,t-1} \\ e_{2,t-2} \\ e_{3,t-1} \\ e_{3,t-2} \\ e_{4,t-1} \\ e_{4,t-2} \\ e_{5,t-1} \\ e_{5,t-2} \end{bmatrix} + \begin{bmatrix} u_t \\ 0 \\ v_{1,t} \\ 0 \\ v_{2,t} \\ 0 \\ v_{3,t} \\ 0 \\ v_{4,t} \\ 0 \\ v_{5,t} \\ 0 \end{bmatrix} \quad (5)$$

A fast, versatile estimation procedure involves four steps. First, the parameters of the DFM in equations (4) and (5) are estimated using the maximum likelihood estimation (MLE) method

TABLE 1
Model Selection

Lag	Akaike information criterion (AIC)	Bayesian information criterion (BIC)	Likelihood ratio test
0	-1.081	-0.783	–
1	-1.435	-0.959*	40.322*
2	-1.440	-0.785	12.403
3	-1.545	-0.712	20.430
4	-1.559	-0.546	13.066
5	-1.486	-0.295	6.195
6	-1.606*	-0.236	21.571
7	-1.420	0.128	2.829
8	-1.123	0.604	11.768
9	-1.396	0.510	33.792
10	-1.246	0.838	0.044

Note: Values shown in bold and asterisked indicate the optimal lag length selected by the respective criterion.

based on the predicted error decomposition.⁸ Following Stock and Watson (1991), the normalisation is applied as the variance of the residuals for the factor (ΔM_t), that is, $\text{var}(u_t)$, is set to be 1 in the estimation. Second, the current state of the unobserved common factor, that is, the change in monetary policy stance index (ΔM_t), is obtained by applying a Kalman filter to the estimated DFM.⁹ Third, the monetary policy stance (M_t) is calculated by accumulating the estimated series of ΔM_t , assuming the initial value of M_t is zero at $t=0$.¹⁰ Finally, the monetary policy stance is scaled, such that all the index values are between -2 and 2. By construction, we obtain:

⁸ As an alternative, Doz *et al.* (2012) demonstrate that the space spanned by the factors may be directly and consistently estimated by quasi-maximum likelihood using the Kalman filter. If the procedure is iterated, it is equivalent to the expectation-maximisation (EM) algorithm.

⁹ Harvey (1989) shows that for a stationary transition equation, the Kalman gain approaches a steady-state Kalman gain as $t \rightarrow \infty$. See Harvey (1989) and Durbin and Koopman (2012) for thorough treatments.

¹⁰ An alternative method would be to estimate M_t long, with ΔM_t as part of the state space model (Chauvet, 1998). For the revised state-space model, as suggested by Chauvet (1998), see Appendix S3 in the additional supporting information. The indicator is consistent with the existing one.

$$\left(\frac{M_t - \frac{M^{\max} + M^{\min}}{2}}{M^{\max} - M^{\min}} \right) \times 4 \quad (6)$$

This min-max scaling facilitates comparison with other indicators in the literature (e.g., Sun, 2018; McMahon *et al.*, 2018).¹¹

Overall, the advantages of the DFM approach are its intuitiveness and the incorporation of dimension reduction and variable selection into a single model. Given the idiosyncratic components are assumed to be orthogonal to the factors, the noise in a given variable that is not part of systematic monetary policy could be eliminated. Moreover, the framework can indicate the respective weights of the input variables, thereby enabling an understanding of the algorithmically determined input-output relationship.

(ii) Data Description and Results

A five-variable DFM on monthly frequency is used to extract the monetary policy stance. These five variables summarise the monetary policy tools used by the PBoC: the seven-day pledged repo rate (DR007); the required reserve ratio (RRR); the PBoC's OMO, including the SLF, rediscount and relending, etc.; the MLF; and the PSL. The data for the seven-day pledged repo rate are taken from the National Interbank Funding Center. All other data have been released by the PBoC. Table 2 summarises these five variables.

The seven-day pledged repo rate for depository institutions in the interbank market (DR007) is used for the interest-rate variable in the model, as this is the PBoC's likely policy target.¹² Although the PBoC has yet to introduce an official policy interest rate in China, the seven-day repo rate is the main indicator for PBoC's target interest rate in its OMO. Since 2012, the PBoC has injected liquidity through its OMO with reverse repos. It introduced the seven-day

¹¹ The level of the index indicates the relative strength over the sample period. If the index is zero in a given month, it does not imply necessarily that the PBoC has assumed a neutral policy stance.

¹² The DR007 interest rate only encompasses sovereign bonds, which includes government bonds, Central Bank bills and the bonds issued by policy banks as collateral. In the case of R007 operations, collateral is not restricted to sovereign bonds.

TABLE 2
Variables Included in the Dynamic Factor Model

Variable	Data description
Changes in the seven-day pledged repo rate	Change in the monthly average of the seven-day pledged repo rate for depository institutions in the interbank market (DR007). Since this rate was first published on 5 December 2014, changes in the seven-day pledged repo rate for financial institutions authorised to trade in the interbank market (R007) are used for the period before 2015
Changes in the required reserve ratio (RRR)	Changes in the required reserve ratio (RRR, within the month). Since a different RRR has been applied to different sizes of banks since September 2008, the overall RRR for the banking sector is estimated as: 75%*RRR for large banks + 25%*RRR for small and medium-sized banks This formula is also used by the CEIC
Net open-market operations (OMO) withdrawal/total loans ($t-1$)	Net amount of funds reduced through the PBoC's OMO from the banking sector (net amount during the month). The net amount of funds withdrawn in other items in the Central Bank's claims on the banking sector, such as standing lending facility (SLF), rediscount, relending, etc., is also included. The variable is calculated by subtracting the monthly change in the Central Bank's claims on the banking sector by the net medium-term lending facility (MLF) withdrawal and the net pledged supplemental lending (PSL) during the month. The variable is normalised by lagged total loans and seasonally adjusted.
Net medium-term lending facility (MLF) withdrawal/total loans ($t-1$)	Net amount of funds withdrawn through the PBoC's MLF from the banking sector (net amount during the month). Before the introduction of the MLF in September 2014, the value is zero for this variable. The variable is normalised by lagged total loans and seasonally adjusted
Net pledged supplemental lending (PSL) withdrawal/total loans ($t-1$)	Net amount of funds withdrawn through the PBoC's PSL from the banking sector (net amount during the month). Before the introduction of the PSL in April 2014, the value is zero for this variable. The variable is normalised by lagged total loans and seasonally adjusted

reverse repo in May 2012. In parallel, the PBoC started to relax its control on the lending and deposit lending rate of commercial banks in June 2012. All controls were lifted in October 2015. This fits in with PBoC's roll-out of the pledged seven-day interbank market rate as its new monetary policy target.¹³ The DR007 series are available from 15 December 2014. To extend the estimation period, we have employed the similar, but longer, series of seven-day pledged repo rate for all financial institutions authorised to trade in the interbank market (R007) between May 2012 and December 2014.

Why were these five instruments chosen? And why are some other instruments not taken into account in the index construction? For example, the standing lending facilities (SLF), CRA, SLO, the targeted medium-term lending facility (TMLF), the temporary lending facility (TLF),

and relending and rediscounting would be conceivable indicators of monetary policy. Table 3 provides an additional rationale for choosing the five monetary policy instruments to construct the index from a different angle.

Among the five different the loan facilities in Figure 3, OMO, MLF and PSL were the three most important facilities in terms of the amount. Table 3 further shows that these facilities were the most frequently used instruments during the sample period. Further information can be obtained by comparing instruments with comparable characteristics. For example, both OMO and SLF are similar short-term facilities, but the use of the latter operations was only 6% of the former. In addition, relending and rediscounting and some 'new' or 'temporary' tools such as SLO, CRA and TMLF were not frequently used (the first TMLF operation was made in January 2019). Against this background, the effects of these rarely used instruments have been included in the calculation of the variable OMO.

¹³ The same assessment is also conveyed by McMahon *et al.* (2018).

TABLE 3
Frequency of Use of Different Monetary Policy Instruments

<i>Monetary policy instruments</i>	<i>Number of operations between May 2012 and December 2018</i>
Changes in the seven-day repo rate in the People's Bank of China's (PBoC) reverse repo operations	25
Changes in the required reserve ratio (RRR)	9
Open-market operations (OMO)	819
Standing lending facility (SLF)	49
Relending and rediscounting	27
Medium-term lending facility (MLF)	63
Pledged supplementary lending (PSL)	52

Figure 2 compares these interest rates to the Shanghai interbank offered rate (SHIBOR). All time series are aligned.¹⁴

The RRR and PBoC's fund injection/withdrawal tools are the PBoC's quantitative policy instruments. Positive (negative) changes in the PBoC's claims on commercial banks (in the balance sheet of the PBoC) can be treated as the PBoC's fund injection into (withdrawal from) the banking sector. The OMO, MLF and PSL are fairly important fund injection/withdrawal tools for the PBoC, so all three measures are included as factors in our DFM. All fund withdrawal series are normalised by the level of total loans at the end of the previous month to ensure the stationarity of the series. Furthermore, because the PBoC always injects funds before the Chinese New Year and withdraws funds thereafter, all indicators are seasonally adjusted. The temporal profiles and the interaction of the different quantitative instruments are shown in Figures 3 and 4, respectively.

Figure 5 shows the indicator, based on our DFM, with discernible turning points in the monetary policy strategy marked with red circles.¹⁵ Higher (lower) values of the indicator

represent a monetary policy tightening (easing). The levels indicate the relative strength.¹⁶

From Figure 5, we can comfortably divide monetary policy stance into four subperiods, two tightening periods (May 2012–January 2015 and April 2016–March 2018) and two easing periods (February 2015–March 2016 and April 2018–December 2018). During the tightening periods, the bid rate for the seven-day reverse repo increased, the RRR remained unchanged and the average monthly fund injections by the PBoC were reduced. During the easing periods, the repo rate and the RRR fell, and the average monthly fund injections by the PBoC increased to over 0.4% of total loans (see Table 4 for details). The turning points of the indicator capture the major policy changes quite precisely.

(iii) Assessment of the Monetary Policy Stance Indicator against Various Benchmarks

As there is no unanimity in the literature on the best way to construct an indicator of China's multiple instrument monetary policy stance, we compare our derived comprehensive indicator against other indices proposed in the literature.

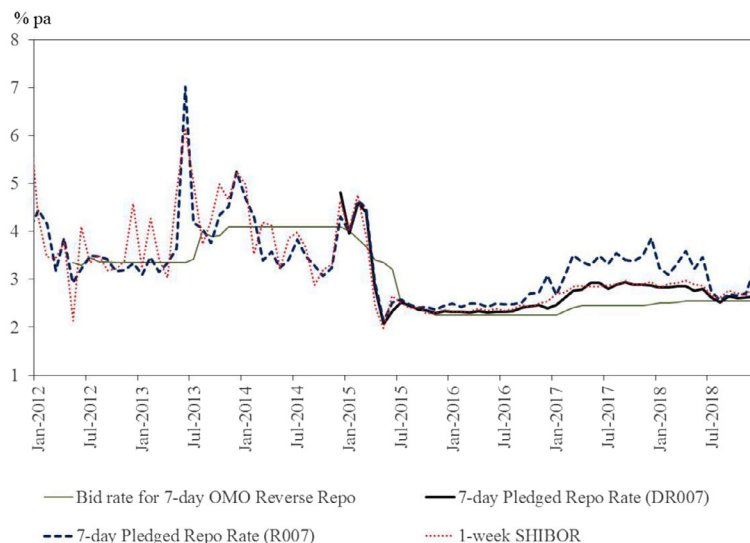
¹⁴ Figure 2 might raise suspicions that the interest rate series exhibit a structural break in the mean. This would affect the estimation of the factor when using the Kalman filtering algorithm. Therefore, we have tested for structural breaks by employing structural break tests with a known and unknown break date. The null hypothesis of no structural break cannot be rejected. For the corresponding test results, see Appendix S4 in the additional supporting information.

¹⁵ For the complete factor model estimation results, see Appendix S1 in the additional supporting information.

¹⁶ As mentioned above, the PBoC introduced a corridor system of interest rates in the monetary policy framework in autumn 2015. This ultimately means that the relative importance of different monetary policy instruments has changed over time. This raises the question of how robust the methodology is when applied to the subsample as of October 2015. The estimation shown in Appendix S5 in the additional supporting information illustrate that the subsample estimates as of October 2015 are almost congruent with the full sample estimates. In addition, the comparison of individual series used to estimate the changes of monetary policy and the changes in the indicator is shown in Appendix S6 in the additional supporting information.

FIGURE 2

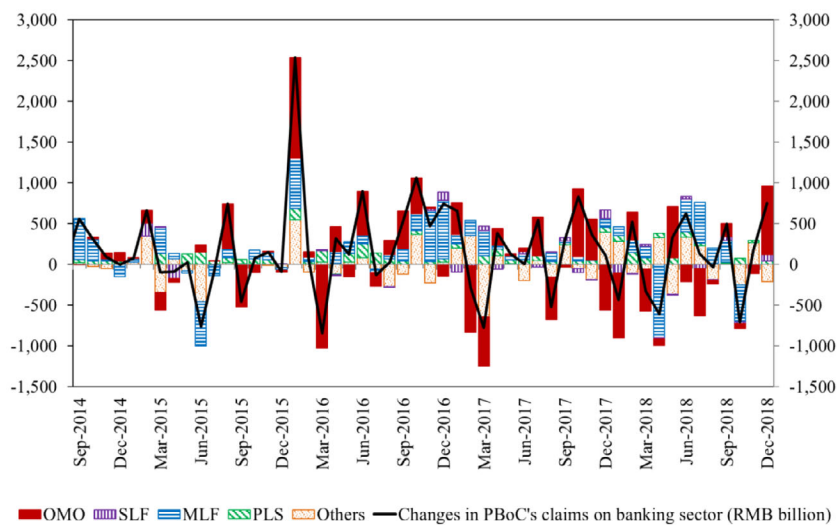
Chinese Policy Interest Rates Relevant to Monetary Policy. [Colour figure can be viewed at wileyonlinelibrary.com]



Sources: People's Bank of China (PBoC) and National Interbank Funding Center.

FIGURE 3

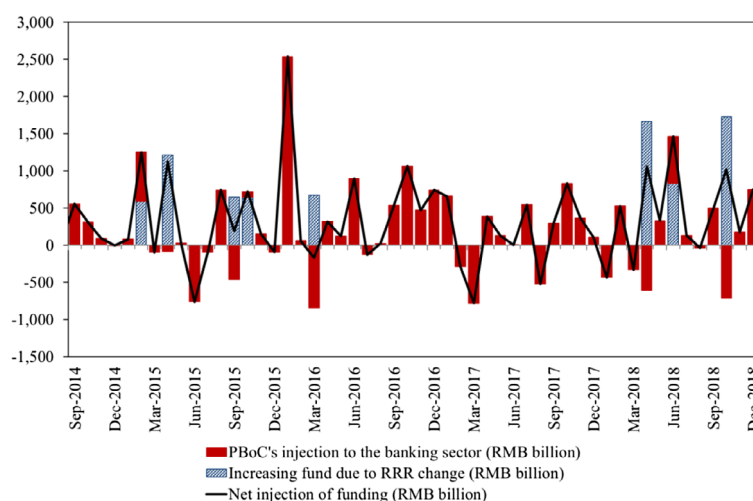
People's Bank of China (PBoC) Fund Injection and Monetary Policy Tool Selection. [Colour figure can be viewed at wileyonlinelibrary.com]



Note: Positive (negative) values represent PBoC fund injections (withdrawals). Values are RMB billions. Source: PBoC

FIGURE 4

Quantitative Monetary Policy Tools: Required Reserve Ratio (RRR) and People's Bank of China (PBoC) Fund Injections.
 [Colour figure can be viewed at wileyonlinelibrary.com]



Source: PBoC.

Special attention is paid to the Chinese monetary shock indicator recently developed by Kamber and Mohanty (2018), as well as the narrative indicators suggested by McMahon *et al.* (2018) and Sun (2018).

We start by addressing important methodological differences. Our indicator and the alternative indicators of McMahon *et al.* (2018) and Sun (2018) are *monetary stance measures*. Monetary policy stance should not be conflated with monetary policy shocks. The PBoC can respond to incoming news about output and inflation by changing its policy stance, but shifts in its policy stance can also affect agent expectations about future trends in the economy. To separate the surprise component from the expected component, we must control for the variation in economic fundamentals to which the monetary policy endogenously responds. A simple way to obtain unexpected changes is to fit a VAR model to the variables, with the residuals representing the unexpected monetary policy shock. This clarification is important because the indicator of Kamber and Mohanty (2018) is a monetary surprise indicator.

In Kamber and Mohanty (2018) the impact of monetary policy surprise is measured by the daily change in the nearest closing price of one-year IRS for the seven-day pledged repo rate (R007) after the time of policy announcement. To compare the monthly DFM-based monetary policy stance indicator with the

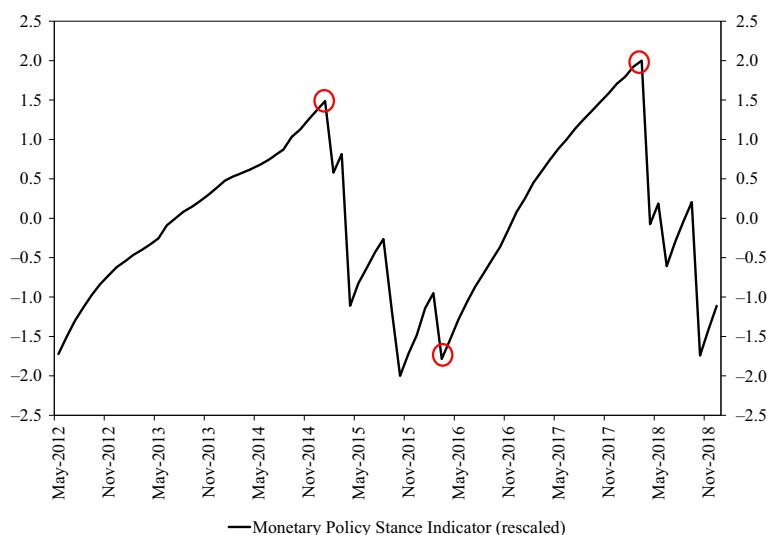
cumulative effects of the monetary policy surprises, the monthly average of the one-year IRS for the seven-day pledged repo rate is used to proxy the cumulative effects of the monetary policy surprise during the month. To this end, the one-year IRS time series for the seven-day pledged repo rate is downloaded from Bloomberg.¹⁷

Figure 6 compares the DFM-based indicator with the movement of the monthly average of the one-year IRS for the seven-day pledged repo rate. Overall, the movements of the two series are very similar despite the methodological differences. The only significant discrepancy occurred between June 2013 and April 2014, where a sharp jump appears in the series of one-year IRS for the seven-day pledged repo rate. Although the one-year IRS for the seven-day pledged repo rate largely reflects the cumulative effects of the monetary policy surprise, it also reflects the market expectation and sentiment to the liquidity condition in the market. The sharp jump in the

¹⁷ Both the data in Kamber and Mohanty (2018) and our data for the one-year IRS for the seven-day pledged repo rate are downloaded from Bloomberg. The replication exercise yields minor differences for about one-third of the observations. For details, see Appendix S7 in the additional supporting information.

FIGURE 5

Dynamic factor model (DFM)-Based Indicator of the Chinese Monetary Policy Stance. [Colour figure can be viewed at wileyonlinelibrary.com]



Note: Rising values for the indicator represents monetary tightening, while a falling value implies easing. The red circle marks the major turning points of the indicator; the details of the turning points are shown in Table 4. For the estimation results, see Appendix S1 in the additional supporting information.

series of one-year IRS for the seven-day pledged repo rate in June 2013 was partly due to a special situation in the interbank liquidity market. Although monetary policy remained unchanged during this period (no changes in benchmark lending interest rate and RRR), liquidity in the interbank market dried up in June 2013. The PBoC asserts that the shortage of liquidity in the interbank market was triggered by several special factors at the time. These included stronger market expectations of an unconventional monetary policy unwinding in the US, a slowdown of foreign exchange inflows and large cash withdrawals ahead of the holidays, and anticipated corporate tax payments (PBoC, Quarterly Monetary Policy Report 2013 Q4, p.7). In the first half of 2014, interbank liquidity market improved significantly and the effects from these special factors evaporated.¹⁸

Figure 7 compares our DFM-based indicator with the two quarterly narrative indicators of

McMahon *et al.* (2018) and Sun (2018) and the monthly instrument-based indicator of Sun (2015). Since the narrative indices only include a few values, we see little variation in monetary policy. Another low-plausibility impression conveyed is that the direction and intensity of Chinese monetary policy has remained unchanged for years. This applies particularly to the narrative indicator of McMahon *et al.* (2018), which employs information in the quarterly PBoC's monetary policy reports to capture policy changes. Unfortunately, wording used in the Central Bank's published statements often suggest an unchanged policy. During the sample period, the only variation of the narrative indicator of McMahon *et al.* (2018) is seen in the PBoC's characterisation of the interest rates hikes in 2017Q1.

Sun (2018) uses more information in the quarterly PBoC's monetary policy reports to construct her narrative indicators. The immediate consequence is that the indicator has somewhat greater variability. Sun's indicator differs from our DFM indicator in two ways. First, there is a different turning point for the monetary policy change in 2014–15. Between April 2014 and January 2015, both the repo rate and RRR did

¹⁸ For an analysis of the interest rate fall in the first half of 2014, see the PBOC's Quarterly Monetary Policy Report 2014 Q2, pp. 21–22.

TABLE 4
People's Bank of China (PBoC) Monetary Policy Actions, Monetary Policy Turning Points based on the Dynamic Factor Model (DFM) and Other Indicators

Period	PBoC policy actions	DFM-based turning points	Comments on DFM-based turning points	Starting points in McMahon et al. (2018)	Starting points in Sun (2018)
May 2012–January 2015 (tightening)	Between May 2012 and late January 2015, the bid rate for the seven-day reverse repo increased by 80 basis points, although the PBoC lowered the benchmark lending interest rate three times by 96 basis points between June 2012 and November 2014. After lowering the required reserve ratio (RRR) in mid-May 2012, the PBoC did not change the RRR at all during this period. <i>Average monthly fund injection: 0.08% of total loans</i>	January 2015	The turning point was just at the first fall in the bid rate for the seven-day reverse repo, and just before the next fall in the RRR. It captures the end of the tightening period quite well	April 2011 (tighter)	April 2012 (easier) January 2013 (tighter) April 2014 (easier)
February 2015–March 2016 (easing)	Between late January 2015 and March 2016, the bid rate for the seven-day reverse repo dropped by 185 basis points. Meanwhile, between March 2015 and October 2015, the PBoC lowered the benchmark interest rate five times by 125 basis points. Since October 2015, the PBoC has removed all the controls on the interest rates of the commercial banks. Also, after October 2015, the PBoC did not release the benchmark lending interest rate again. Between February 2015 and March 2016, the PBoC lowered the RRR five times by 3 percentage points. <i>Average monthly fund injection: 0.45% of total loans</i>	March 2016	The turning point matched with the final fall in the RRR, and captures the end of the easing period quite well		
April 2016–March 2018 (tightening)	Between February 2017 and March 2018, the bid rate for the seven-day reverse repo increased by 30 basis points. The RRR did not change during this period. <i>Average monthly fund injection: 0.22% of total loans</i>	March 2018	The turning point was just before the next fall in the RRR, and captures the end of the tightening period quite well	January 2017 (tighter)	January 2017 (tighter)

TABLE 4
(continued)

Period	PBoC policy actions	DFM-based turning points	Comments on DFM-based turning points	Starting points in McMahon et al. (2018)	Starting points in Sun (2018)
April 2018–December 2018 (easing)	The bid rate for the seven-day reverse repo remained unchanged during this period. Between April 2018 and October 2018, the PBoC lowered the RRR three times by a total of 2.5 percentage points. <i>Average monthly fund injection: 0.46% of total loans</i>				April 2018 (easier)

Note: In the cases of McMahon *et al.* (2018) and Sun (2018), tighter/easier compare the current monetary policy stance against the previous period.

not fall until February 2015. Also, the seven-day pledged repo rate rose in late 2014. Sun's indicator therefore provides a leading signal for easing. The second difference appears in 2017Q1. Sun's indicator puts the arrival of tightening in 2017Q1, while the turning point in our DFM-based indicator was already in March 2016. The RRR fell in March 2016, and there was no change in the RRR from April 2016 to March 2018. Although the bid rate for the seven-day reverse repo started to increase in February 2017, the PBoC's policy target, seven-day pledged repo rate (DR007), had increased since April 2016. In other words, the turning point of the DFM-based indicator aligns with the final drop in the RRR and the beginning of the rise in the seven-day pledged repo rate.

The Sun (2015) indicator is broadly in line with the DFM indicator. However, an outlier exists in June 2013. This has been generated by the decline in liquidity in the interbank market in June 2013. Since the overnight Chibor interest rate is one of the components in Sun's index, this abnormal one-off situation is strongly reflected in the indicator. The drop in the Sun index in spring 2014 represents the subsequent countermovement and therefore again is a special effect.

In the next section we will explore the usefulness of the data-rich DFM measure of the Chinese monetary policy stance using a DSGE model.

IV. Temporal Evolution of Monetary Policy through the Lens of a Small-Scale DSGE Model

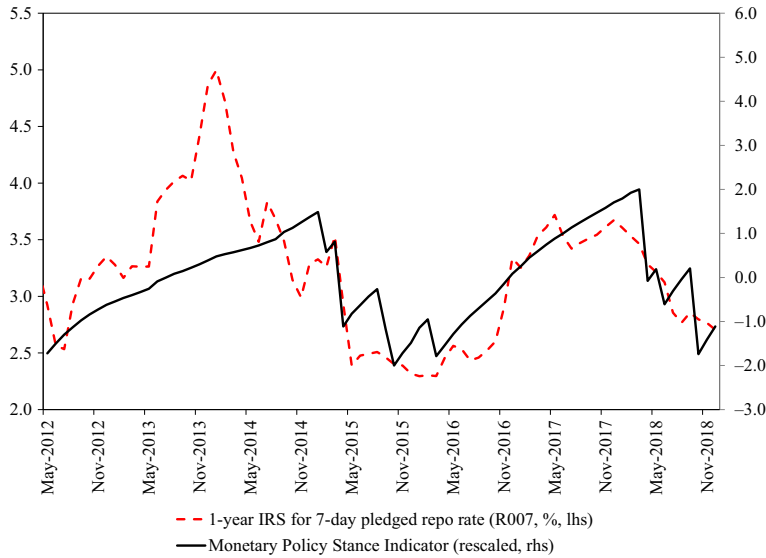
Pushing our analysis further, we employ the derived monetary stance indicator in an estimated standard DSGE model to examine what might prompt the PBoC to change or hold its monetary policy stance, as well as to clarify the effects of monetary policy impulses on such things as the output gap and consumer price index (CPI) inflation.

For evaluation, we employ the simple, analytically tractable DSGE model of Ireland (2004, 2011) and Jones and Kulish (2016) derived via explicit aggregation of the micro-level behaviour of individuals and firms.¹⁹ A distinctive feature is

¹⁹ Of course, several features of the highly stylised DSGE framework are open to dispute and controversy. For example, some complexity in the real world, such as the special role of bank credit and various administrative instruments (e.g., window guidance), as well as the complex link between banks and the shadow banking system, will be missed. For DSGE-based analyses of China's window guidance policy and the shadow banking–monetary policy nexus, see Chen *et al.* (2020) and Chen *et al.* (2018), respectively.

FIGURE 6

Monetary Policy Surprise versus Monetary Policy Stance. [Colour figure can be viewed at wileyonlinelibrary.com]



Note: The impact of monetary policy surprise is measured by the monthly average of the one-year interest rate swap (IRS) for the seven-day pledged repo rate (Kamber and Mohanty, 2018). Sources: Bloomberg and authors' calculation.

the mapping of non-stationary macroeconomic time series into a stationary model. Rather than assuming the actual data follow stationary deviations around deterministic trends, the data are modelled as containing drifting random walks. The implication is that stationarity is induced via differencing rather than detrending.

We start with a brief sketch of the theoretical DSGE model, the central paradigm of New Keynesian economics, and then transform the model into a supply and demand curve, relating inflation to output growth. The graphical representation of the estimated workhorse model illustrates how the underlying structural shocks have moved Chinese aggregate demand and supply simultaneously over time. This graphical device facilitates tracking of changes in monetary policy highlighted in Figure 5 in the inflation-output growth space. The ingredients that characterise this linearised DSGE model are:

$$\hat{x}_t = E_t \hat{x}_{t+1} - (\hat{r}_t - E_t \hat{\pi}_{t+1}) + (1 - \omega)(1 - \rho_a) \hat{a}_t \quad (7)$$

$$\pi_t = \pi + \beta E_t \hat{\pi}_{t+1} + \psi \hat{x}_t - \hat{e}_t \quad (8)$$

$$\hat{r}_t = \hat{r}_{t-1} + \rho_\pi (\pi_t - \pi) + \rho_g (g_t - g) + \rho_x \hat{x}_t + e_{r,t} \quad (9)$$

$$\hat{x}_t = \hat{y}_t - \omega \hat{a}_t \quad (10)$$

$$g_t = g + \hat{y}_t - \hat{y}_{t-1} + \hat{z}_t \quad (11)$$

$$\hat{a}_t = \rho_a \hat{a}_{t-1} + \varepsilon_{a,t} \quad (12)$$

$$\hat{e}_t = \rho_e \hat{e}_{t-1} + \varepsilon_{e,t} \quad (13)$$

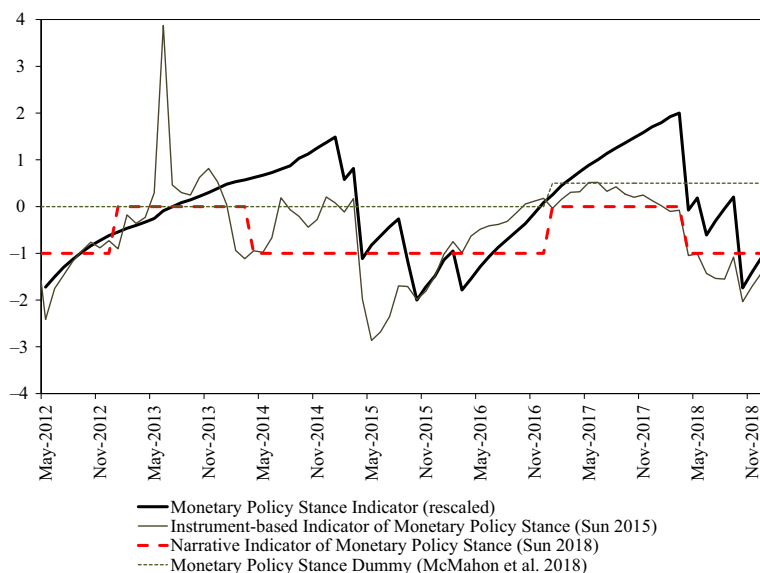
$$\hat{z}_t = \varepsilon_{z,t} \quad (14)$$

where tildes ('^') denote logged deviations of variables from steady-state values;²⁰ \hat{y}_t denotes the logged deviation of output from its steady state; \hat{x}_t is the deviation of the output gap from its

²⁰ The modelling approach stays within the realm of linearised DSGE models. Global solution methods and higher order expansions have recently gained ground as the zero lower bound has hit (e.g., Schmitt-Grohé and Uribe, 2004). In the case of China, the non-linearities triggered by the zero lower bound are not currently relevant.

FIGURE 7

Dynamic factor model (DFM)-Based Monetary Policy Indicator versus Various Monetary Policy Stance Indicators.
[Colour figure can be viewed at wileyonlinelibrary.com]



Note: The published monthly instrument-based monetary stance series in Sun (2015) ends in March 2013. We have extended the series until the end of 2018 by applying the method and estimates used by Sun. The published quarterly monetary stance dummy series in Sun (2018) ends in 2014Q4, but for updated values, see <https://sites.google.com/site/rongrongsun2013/sun-mp-ind>. As the quarterly monetary stance dummy series in McMahon *et al.* (2018) end in 2018Q1, we extend the index to the end of 2018 by applying the method described in McMahon *et al.*

steady state; \hat{r}_t is the deviation of the monetary policy stance derived above from its steady state; $\hat{\pi}_t$ is the deviation of the one-period inflation rate from its steady state; and E is the usual expectation operator.

The model consists of three key equations: an investment–saving (IS) equation, a New Keynesian Phillips Curve and a Taylor rule. The IS equation and the Phillips curve include the one-step-ahead expectations operator are therefore forward-looking. Equation (7) is derived from the representative household's Euler equation. Monetary shocks are transmitted to the real sector through changes in monetary policy stance. A tighter monetary policy stance raises the cost of agents to bring forward future consumption by borrowing, while increasing the return on saving. This direct effect drives the impact of policy. Equation (8) represents the economy's Phillips curve, positively relating inflation to the output gap. The parameter ψ is decreasing in the output cost that intermediate goods producing firms face when changing prices. The PBoC's reaction

function is given by equation (9) with the PBoC adjusting the stance of monetary policy in response to inflation, output growth and the output gap. The ρ_i parameters ($i = \pi, g$) denote elasticities. The inclusion of \hat{r}_{t-1} as an input into the reaction function allows for the gradual adjustment of policy to demand and technology shocks. Equation (10) defines the output gap; equation (11) defines output growth. The output gap is the logarithm of the ratio of actual output to capacity output. Capacity output is defined as the efficient level of output, which is equivalent to the level of output chosen by a benevolent social planner.

Movements in the main macroeconomic variables are the result of four types of (exogenous) stochastic disturbances: preference shocks \hat{a}_t , monetary policy shocks $e_{r,t}$, cost-push shocks \hat{e}_t and total factor productivity shocks $\varepsilon_{z,t}$. The monetary policy shock is assumed to be i.i.d. $N(0, \sigma_r^2)$. The latter three shocks evolve according to AR(1) processes. For the AR(1) persistence parameters of the preference shock (\hat{a}_t) and the

cost shock (\hat{e}_t) the assumption $\rho_i < 1, i = \hat{a}_t, \hat{e}_t$ applies. In other words, the shocks are stationary. On the contrary, the total factor productivity shock is non-stationary and evolves as a drifting random walk. This induces similar behaviour in the model's endogenous variables.

Solving the model can be accomplished by using a numerical gradient procedure. Deviating therefrom we employ a more analytically oriented procedure. The methodology followed here consists of evaluating the implied aggregate demand and aggregate supply curves in the inflation-output growth space. Formally, the (π_t, g_t) space defined with the linear supply curve is given as:

$$\pi_t = \psi g_t + \hat{s}_t + (\pi - \psi g), \quad (15)$$

where:

$$\hat{s}_t = \beta E_t \hat{\pi}_{t+1} + \psi \hat{y}_{t-1} - \psi \hat{z}_t - \omega \psi \hat{a}_t - \hat{e}_t. \quad (16)$$

The slope of the aggregate supply curve (15) depends on the degree of price stickiness. In the special case of flexible prices given by $\psi \rightarrow \infty$, the supply curve is vertical. Conversely, for rigid prices given by $\psi \rightarrow 0$, the supply curve flattens. Rearranging the relationship between output and inflation gives us the aggregate demand curve:

$$\pi_t = -\left(\frac{1 + \rho_g + \rho_x}{\rho_\pi}\right) g_t + \hat{d}_t + \left(\pi + \frac{1 + \rho_g + \rho_x}{\rho_\pi} g\right), \quad (17)$$

where:

$$\begin{aligned} \hat{d}_t = & -\frac{1}{\rho_\pi} \hat{r}_{t-1} + \frac{1}{\rho_\pi} E_t \hat{x}_{t+1} + \frac{1}{\rho_\pi} E_t \hat{\pi}_{t+1} \\ & - \left(\frac{1 + \rho_x}{\rho_\pi}\right) \hat{y}_{t-1} + \left(\frac{1 + \rho_x}{\rho_\pi}\right) \hat{z}_t \\ & + \frac{\omega(1 + \rho_x) + (1 - \omega)(1 - \rho_a)}{\rho_\pi} \hat{a}_t - \frac{1}{\rho_\pi} e_{r,t}. \end{aligned} \quad (18)$$

The slope of the aggregate demand curve (17) depends upon the parameters of the monetary policy reaction function. A greater response of the PBoC to deviations from target, ρ_π , flattens the curve. Stronger responses to output growth, ρ_g , and the output gap, ρ_x , steepen the aggregate

demand curve. The reduced-form representation of (15) and (17) in terms of the structural disturbances is given by:

$$\begin{bmatrix} \pi_t \\ g_t \end{bmatrix} = \begin{bmatrix} 1 \\ 1 + \rho_g + \psi \rho_\pi + \rho_x \end{bmatrix} \begin{bmatrix} \pi(1 + \rho_g + \psi \rho_\pi + \rho_x) + \psi \rho_\pi \hat{d}_t + (1 + \rho_g + \rho_x) \hat{s}_t \\ g(1 + \rho_g + \psi \rho_\pi + \rho_x) + \rho_\pi \hat{d}_t - \rho_\pi \hat{s}_t \end{bmatrix}. \quad (19)$$

Equation (19) facilitates a clear way of understanding how π_t and g_t respond to structural shocks dynamically. For that reason, the environment presented above encompasses the essential elements necessary for a quantitative analysis of monetary policy. At any point in time, the economy can be characterised by the intersection of the aggregate demand curve (17) and the aggregate supply curve (15) in the inflation-output growth space (π_t, g_t) . The structural analysis of the Chinese growth dynamics is a by-product. In other words, using the estimated shocks allows us to track the response of the Chinese economy to monetary policy shocks.

Under the assumption that output and aggregate prices contain drifting random walks, g_t and π_t are stationary; the additional assumption of stationarity for r_t is all that is necessary to proceed with the empirical analysis. Based on the above model, we employ seasonally adjusted quarterly data on real gross domestic product (GDP) growth and CPI inflation and our derived monetary stance indicator to estimate the DSGE model and generate aggregate demand and aggregate supply curves for China. The estimation sample is 2012Q3–2018Q4. The chosen shapes and parameters of the prior distributions are reported in Table 5.²¹

Bayesian estimation methods have gained ground as a highly attractive alternative to classical methods in the field of DSGE models. Unlike the frequentist approach, the Bayesian approach uses both information from the available data and prior knowledge to provide posterior estimates. Metropolis–Hastings Markov chain Monte Carlo (MCMC) methods are employed to generate random samples for the purpose of numerical evaluation of the posterior

²¹ Results are robust against more or less diffuse priors, provided they are independent distributions.

distributions. What makes MCMC methods so useful is that they can generate representative parameter-value combinations from the posterior distribution without computing the integral in Bayes' rule. For a comprehensive treatment of MCMC techniques, with further references, see Gelman *et al.* (2003) and Robert and Casella (2004). For a detailed treatment of Bayesian estimation of DSGE models, see Fernandez-Villaverde (2010). The estimation of the Bayesian DSGE model here was performed with the Dynare software package (<https://www.dynare.org>). Although assured theoretically under mild assumptions, the convergence of MCMC simulations to the target distribution is not guaranteed for any finite sample. Monitoring and diagnosing convergence is therefore necessary to decide whether the simulations provide sufficiently correct results. We assess the chains convergence using methods based on Brooks and Gelman (1998).

Following Ireland (2004) and Jones and Kulish (2016), we apply the benchmark values $\beta = 0.99$, $\psi = 0.1$ and $\omega = 0.06$.²² The Bayesian estimates for the model parameters are presented in Table 6.

The posterior probability densities for some of the important model parameters that are calculated by updating the prior probabilities using Bayes' theorem are available in Appendix S8 in the additional supporting information. One can think of the posterior probability as a mixture of the prior and the data, that is, an adjustment on prior probability. The graphs indicate that despite the small sample size, the posterior is by all means data driven.

As a further model assessment, Figure 8 shows the estimated Chinese aggregate demand and aggregate supply curves at the steady state. The evolution of the economy in the inflation–output growth space can be described by the intersection of the aggregate supply and demand schedules at each point in time. A shock will shift the curves, which over time revert towards the steady state. The estimated slopes of the aggregate demand and the aggregate supply curves are -8.3 and 0.1 , respectively, which implies that the aggregate

²² As results to be used for policy analysis in principle should be reasonably robust to a different prior specification, we also estimate the model with the prior of a much steeper aggregate supply curves ($\psi = 0.9$). We found that there is little difference with respect to the benchmark prior case.

TABLE 5
Priors for Bayesian Estimates of the Dynamic Stochastic General Equilibrium (DSGE) Model for China

Parameter	Distribution
ρ_a	Beta (0.85,0.05)
ρ_e	Beta (0.30,0.10)
ρ_π	Normal (0.40,0.10)
ρ_g	Normal (0.60,0.10)
ρ_x	Normal (0.40,0.05)
σ_a	Inverse Gamma (0.1,0.01)
σ_e	Inverse Gamma (0.1,0.01)
σ_z	Inverse Gamma (0.1,0.01)
σ_r	Inverse Gamma (0.1,0.01)

TABLE 6
Bayesian Estimates of the Baseline Dynamic Stochastic General Equilibrium (DSGE) Model for China

Parameter	Estimate	SE
ρ_a	0.9798	0.0049
ρ_e	0.1030	0.0427
ρ_π	0.2721	0.0840
ρ_g	1.0049	0.0797
ρ_x	0.2599	0.0345
σ_a	0.0919	0.0084
σ_e	0.0819	0.0066
σ_z	0.0919	0.0082
σ_r	0.0813	0.0065

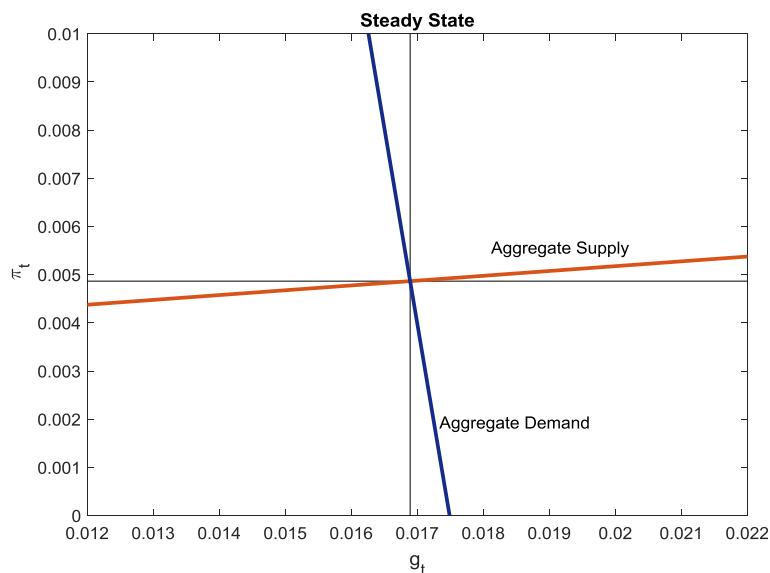
Note: Estimates for the parameters are the posterior modes.

supply curve is relatively flat. A direct consequence of this is the importance of demand shocks for GDP fluctuations.²³

While the supply and demand curves at steady state in Figure 8 characterise the structure of the economy over the entire sample period, the performance of the Chinese economy in specific historical episodes is perhaps of greater interest. For this purpose, we trace out the underlying supply and demand curves for selected subperiods to explore whether the DSGE model simulations provide any pointer to the usability of the derived index for the analysis of monetary policy

²³ Unlike an aggregate demand and supply model with backward-looking expectations, a shock in a model with forward-looking agents shifts both the aggregate demand and aggregate supply curves by affecting expectations.

FIGURE 8
Aggregate Demand and Aggregate Supply Curves at the Steady State. [Colour figure can be viewed at wileyonlinelibrary.com]



decisions in real time. As shown in Figure 5, the DFM yields several turning points in the monetary policy stance (highlighted red circles).

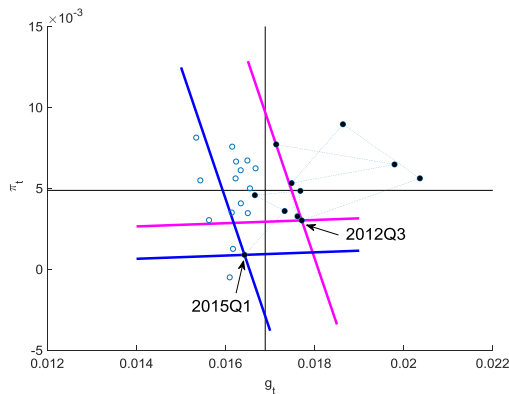
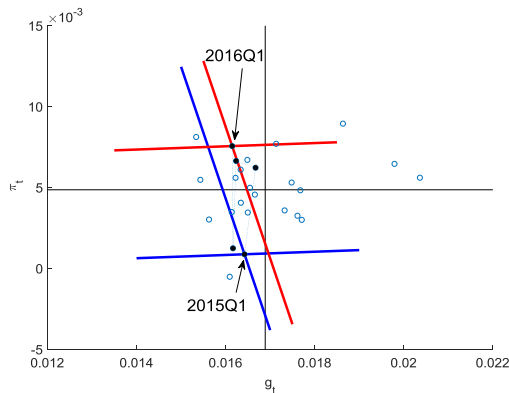
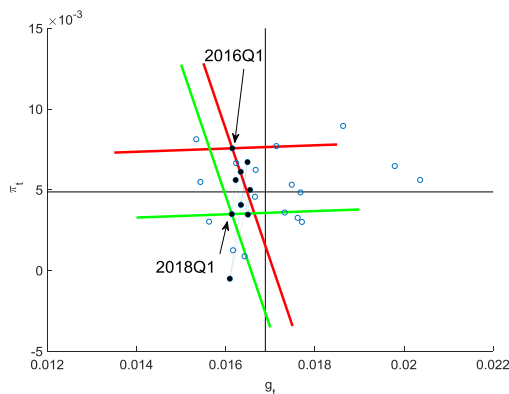
The three panels in Figure 9 present the movements of the derived aggregate demand and supply curves for three subperiods: 2012Q3–2015Q1, 2015Q1–2016Q1 and 2016Q1–2018Q1. As a supplement to Figure 9, the decomposition of the aggregate demand curve and the aggregate supply curve by various shock components at the corresponding turning points are shown in Appendix S9 in the additional supporting information.

The supply and demand curves at these respective starting points provide an indication of the initial economic situation. A comparison of this initial economic situation with the altered orientation of the PBoC's monetary policy stance provides indications of the Chinese monetary policy reaction function. Shifts in the curves give clues about the effects of the time-varying monetary policy impulses. How did the supply and demand curve behave over the sample period? At quick glance at Figure 9 gives two immediate

impressions. First, the shifts in the two curves were caused by the coincidence in time of several shocks of various natures with the corresponding mix changing substantially over time. Second, the relative contribution of each shock varies across the three subperiods. It is impossible to pick two subperiods with a similar profile.

Several observations deserve note. Subperiod (i) of Figure 9 shows that the starting position in 2012 was characterised by higher growth rates and rising inflation rates. Looking at Figure 5, this prompted the PBoC to impose a tighter monetary policy stance. The Chinese authorities aimed to rein in credit growth that had grown at alarming rates in 2010–14. China also took steps to open up its financial markets and the capital account.

The second subperiod (ii) in Figure 9 shows a very different economic situation at the beginning of 2015. Weakening global demand has caused Chinese growth to slow, with China's industrial growth decelerating significantly from 10% per annum to around 6% after the second half of 2014. In addition, there is a significant decline in inflation, driven largely by declining commodity

(i) 2012Q3–2015Q1**(ii) 2015Q1–2016Q1****(iii) 2016Q1–2018Q1****FIGURE 9**

Aggregate Demand and Aggregate Supply Curves for 2012Q3–2018Q4: (i) 2012Q3–2015Q1; (ii) 2015Q1–2016Q1; and (iii) 2016Q1–2018Q1.

Note: In each panel the derived aggregate demand and supply curves at the beginning and the end of the subperiod are shown in the inflation-output growth space. The black points with dotted lines show the movement of the intersection of the aggregate supply and demand schedules at each point in time during the subperiod. [Colour figure can be viewed at wileyonlinelibrary.com]

prices. As shown in Figure 5, the immediate consequence was a softening in the stance of monetary policy. In other words, the PBoC injected a short-term monetary boost to halt the downward spiral.²⁴

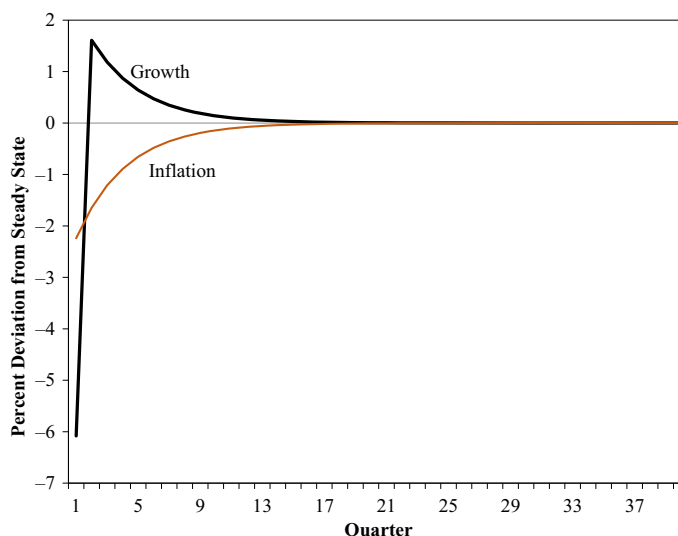
In the third panel (iii) of Figure 9, we see a turnaround in monetary policy towards a more restrictive monetary policy that begins in mid-2016. This is manifested in the increase of the latent monetary stance index (Figure 5). Some of this reflects the stabilisation of financial markets after the turmoil of late 2015 and early 2016. China again confronts the necessity of deleveraging to avert the risk of excessive lending.

A different economic situation emerged in spring 2018. Economists ceased to celebrate the emergence of a broad synchronised global growth upsurge on news of a trade war between China and the US.²⁵ In an era of interconnected markets and global supply chains, the trade conflict had

²⁴ In addition to monetary policy, expansionary fiscal policy also contributed to a shift in the aggregate demand curve. Officially, China's fiscal deficit expanded only modestly in 2015 and 2016, but the government is adept at using off-budget financing vehicles, primarily at the local government level, to borrow and direct funds to projects. The IMF (2018, p. 82) estimates that China's 'augmented' budget deficit, which includes such tactics, rose to around 68% of GDP in 2017, while government debt narrowly defined was 37% of GDP in 2017. This strengthens the view that Chinese policy objective has been pro-growth.

²⁵ Throughout 2018, the US unleashed a wave of tariffs against its largest trading partners, including China, Canada, the European Union and Mexico. Even India was affected, particularly by tariffs on steel and aluminium. For an up-to-date tariff guide, see <https://piie.com/blogs/trade-investment-policy-watch/trump-trade-war-china-date-guide>. The policy has triggered retaliation. China raised tariffs by 25 percentage points on similar amounts of imports from the US on the same dates that the US tariffs came into force.

FIGURE 10
Impulse Responses to Monetary Policy Shocks in the Estimated Dynamic Stochastic General Equilibrium (DSGE) model. [Colour figure can be viewed at wileyonlinelibrary.com]



widespread repercussions. Global manufacturing activity slowed and economies especially reliant on trade, such as China, suffered. As expected, the model captures the declining growth momentum apparent in panel (iii) of Figure 9 as a contractionary supply effect. At the time of writing, the trade conflict remains unresolved. The expected monetary easing of the Central Bank was not long in coming and became effective at the beginning of 2018.

In summary, the graphical evaluation of the structural DSGE model in Figure 9 illustrates the countercyclical orientation of Chinese monetary policy. Whenever growth has slowed in the past, the PBoC has reliably responded with expansionary monetary policies and a strong nudge to commercial banks to increase lending. This applies at least in the absence of overt inflationary pressures. The significant parameters ρ_π and ρ_g in the Taylor-type reaction function of the PBoC confirm this assessment.

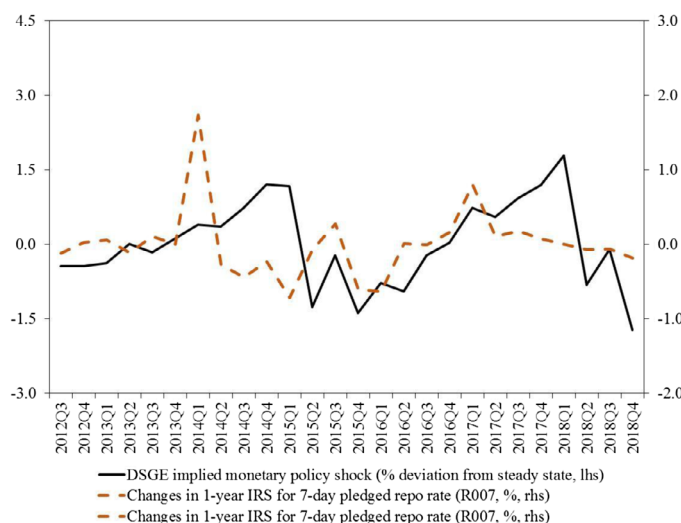
Several modelling results are not very surprising, but the fact that they have been obtained with a plain-vanilla DSGE model estimated with the aid of our monetary policy index derived above allows us to see them as supporting evidence for

the empirical relevance of the dynamic factor monetary policy stance indicator.

Finally, two more graphical evaluations of the DSGE model will be presented. As a first step we evaluate the impact of a contractionary monetary policy shocks on inflation and output in the estimated DSGE model and provide a discussion of relative magnitudes to link the modelling results to the existing literature on monetary policy transmission in China. The impulse responses in Figure 10 are qualitatively similar to the findings of Zhang (2009, p. 480). From a quantitative perspective, however, they differ. More precisely, our estimates show a larger impact on output growth and a smaller impact on inflation. This difference is not entirely unexpected. The growth rates in Zhang's sample period of 1993–2007 were noticeably higher and have been more stable since then.

Finally, we compare the DSGE implied monetary policy shocks with the one-dimensional monetary policy surprises from Kamber and Mohanty (2018). Despite certain differences, a similarity between the two time series in Figure 11 based upon different empirical methodologies is evident. The differences between the

FIGURE 11
*Comparison of Alternative Monetary Policy Shock Measures. [Colour figure can be viewed at
 wileyonlinelibrary.com]*



Note: Changes in the quarterly average of the one-year interest rate swap (IRS) for the seven-day pledged repo rate is used as a proxy for the monetary policy shocks (Kamber and Mohanty, 2018). *Sources:* Bloomberg and authors' calculation.

two time series are due to the one-dimensional consideration of a single interest rate shock versus the unexpected component of the multidimensional DFM index.

V. Conclusions

Given China's growing importance to the global economy, understanding the Chinese monetary policy toolkit and how the PBoC conducts monetary policy has attracted growing interest. The financial markets, in particular, eagerly seek timely information on Chinese monetary policy. The problem is not the information about monetary policy measures per se, but difficulty in interpreting China's monetary objectives. A particular difficulty lies in the fact that China's current multi-instrument policy design complicates reading of the PBoC's signals. Against this background, our monthly index offers a practical yet rigorous measure of the Chinese monetary policy stance. It strikes a balance between broad-based complexity and transparent simplicity. We hope this dataset and the periodically performed updates can be useful for monitoring and evaluating the PBoC's monetary policy in future. We also hope this dataset and future updates will

enable a deeper understanding of the mechanisms related to China's macroeconomic policies.

The PBoC recently began to sell short-term securities in Hong Kong, signalling the creation of a separate 'offshore' monetary policy. This reform measure could pave the way for a regular programme allowing the PBoC to better manage RMB liquidity outside mainland China and to keep the on- and offshore exchange rates in a narrow range. Given the offshore focus of these OMO, we have not included this tool in our onshore index and leave a more detailed analysis of this innovation for future research.

Looking ahead, the further opening of the capital account is an important issue that could have consequences for Chinese monetary policy. The idea of having monetary policy autonomy, exchange rate stability and financial market openness all at once would be attractive to any policymaker, but it is also an elusive goal. According to the trilemma facing Central Banks, no monetary authority can obtain all three at once.²⁶ China is no

²⁶ See Rey (2016) for a comprehensive analysis of the trilemma.

exception. Indeed, with growing international capital flows, this impossible trinity will become increasingly relevant for China. While it is possible to achieve desired levels of two out of the three attributes, it is impossible to achieve simultaneously the desired levels for all three. Consequently, the choice of exchange rate regime must be made in conjunction with the choices on monetary policy autonomy and financial market openness. It can be presumed that for China, maintaining monetary policy management appropriate for its specific cyclical and structural conditions is an important policy goal. It remains to be seen how the Chinese institutional set-up, the policy objectives and the instrument mix evolve.

Acknowledgements

Open access funding enabled and organized by Projekt DEAL.

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. Parameter estimates of dynamic factor model of monetary policy stance indicator.

Appendix S2. Estimation results for the AR(1) specification of the factor model.

Appendix S3. Estimating M_t along with ΔM_t as part of the state space model (Chauvet, 1998).

Appendix S4. Structural break tests.

Appendix S5. Subsample Analysis.

Appendix S6. Plot of the individual series used to estimate the indicator for comparison.

Appendix S7. Replication of monetary policy shocks described in Kamber and Mohanty (2018).

Appendix S8. Comparison between prior and posterior distributions of model parameters using density plots.

Appendix S9. Decomposition of Chinese aggregate demand and aggregate supply, 2012Q3–2018Q1.

Appendix S10. China Monetary Policy Stance Index Data.

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