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[1] SUN: People's Bank of China (PBC), sguofeng@pbc.gov.cn, REES: Bank for International Settlements (BIS), daniel.rees@bis.org, We would like to thank Claudio Borio, Michael Chui, Marco Lombardi, Benoit Mojon, Ilhyock Shim, and seminar participants at the Bank for International Settlements for helpful comments and suggestions and Li Wenzhe for outstanding research assistance. In the early stage of the paper, Zhang Xin who formerly worked at the PBC contributed to this paper. The views expressed in this paper are those of the authors and not necessarily those of the PBC or the BIS.

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Contents

1. Introduction

Over the past few decades, China's economy has undergone an extraordinary transformation. As the economy has grown and financial markets have developed, the conduct of monetary policy has also evolved from a quantity-based framework based on controls of monetary and credit aggregates to a market-based system where short- and medium-term interest rates increasingly serve as the primary instruments of monetary policy. This evolution has created a need for tools to evaluate the stance of monetary policy in China. We contribute to this effort by providing estimates of China's natural interest rate.

Several definitions of the natural interest rate exist. Like much of the literature, we define it natural as the real interest rate that would be consistent with output being equal to its potential level and stable inflation over the medium run (Wicksell 1936). According to this definition, the natural interest rate is not necessarily an 'optimal' rate, or the real interest rate that would stabilise output and inflation at any point in time. Instead, it provides a benchmark for assessing whether monetary policy is exerting an expansionary or contractionary influence on the economy. It also serves as a guide to where we might expect real interest rates to settle after temporary cyclical factors have abated.

Because the natural interest rate is not directly observable, we must infer its value from the behaviour of market interest rates and other economic variables. We follow the approach proposed by Laubach and Williams (2003), and work with a semi-structural unobserved components model that links the natural interest rate to the output gap and inflation. We opt for this approach rather than more formal structural approaches, such as that described in Del Negro et al (2017), as the latter involves strong theoretical restrictions that may be inappropriate for a large developing economy undergoing a significant economic transition. For example, this specific methodology would require us to impose stationarity of real interest rates and output growth, which we do not believe are reasonable assumptions for China over recent decades.

Applying the Laubach and Williams framework to Chinese data throws up a number of challenges. Chinese GDP growth varies little from quarter to quarter.[2] In addition, several key Chinese variables have a relatively short data samples. For example, the one-year loan prime rate (LPR), a key policy instrument, did not exist prior to 2013Q4. Short samples and uninformative data make it hard to generate plausible estimates of key latent variables such as the output gap, trend growth or expected inflation.[3] Without these, estimates of the natural interest rate lack credibility.

As well as providing estimates of China's natural interest rate, a key contribution of our paper is to propose a method to estimate the output gap and other unobserved variables using Chinese macroeconomic time series. The key to our approach is to use multiple data sources to form inferences about unobserved latent variables. We use data on GDP, import values, railway freight volumes and the volume of electricity usage as indicators of economic activity, and both the consumer price index (CPI) and producer price index (PPI) as measures of underlying inflation. Individually, each of these measures have drawbacks. For example, GDP growth shows little quarter-to-quarter variation, while railway freight volumes provide little insight into economic activity in the services sector. But by extracting the common component from multiple series, we are able to shed light on the Chinese business cycle and trends in the rates of economic growth and inflation.

Our main result is that China's natural interest rate averaged around 3-5 per cent between 1995 and 2010, but has declined more recently to be about 2 per cent as of 2020. Assuming an annual inflation

[2] See Kerola and Mojon (2021) for a discussion of this issue.

[3] In this paper, we refer to trend growth and potential growth interchangeably.

rate of 2-3 per cent, which is consistent with recent inflation outcomes and the inflation objective laid down by the National People's Congress, this would imply a natural nominal interest rate of around 4- 5 per cent.[4] This is higher than the natural interest rate estimates typically generated for advanced economies, as would be expected given China's higher trend growth rate. However, the decline in our natural interest rate estimates for China seems to be broadly similar to that experienced in other economies.

We now discuss the related literature. Over the past decade, as policy interest rates have declined to unprecedentedly low levels in many economies, a large literature has emerged estimating natural interest rates, typically for advanced economies. Much of this work builds on the contribution of Laubach and Williams (2003), who propose a semi-structural unobserved components model to estimate the natural interest rate for the United States. The estimates presented in the original Laubach and Williams paper suggested that, while the US natural interest rate varied over time, it exhibited no clear drift. However, subsequent updates of the model point to a persistent decline in the natural interest rate, particularly since the mid-2000s (Laubach and Williams 2016).

A number of papers have applied variants of the Laubach and Williams model to other economies. Examples include Pedersen (2015) for Denmark, Holston et al (2017) for Canada, the euro area and the United Kingdom, McCririck and Rees (2017) for Australia, Armelius et al (2018) for Sweden, Han (2019) for Japan and Kuhn et al (2019) for South Africa. Although the precise details of the models and results differ across countries, all of these studies report a decline in their countries' natural interest rate of several percentage points since the early 1990s.

Laubach and Williams (2003, 2016) decompose the natural interest rate into a component determined by the US economy's trend growth rate and a residual component. They conclude that changes in trend growth account for a relatively small share of the decline in the natural interest rate. Papers that have estimated the natural interest rate for other economies typically come to the same conclusion. A number of explanations have been put forward to account for the decline in the residual component. Some papers argue that demographic changes, including slower population growth and a rising old-age dependency ratio, encourage households to save more and firms to invest less, thus lowering the natural interest rate (Carvahlo et al 2016, Gagnon et al 2016, Eggertsson et al 2019). Others point to increased capital flows from emerging to developed economies since the early 2000s (Pescatori and Turranen 2016, Han 2019) or stronger investor preferences for safe assets more recently (Del Negro et al 2017). Still others argue for a role for increased competition and market power in goods and labour markets, or for rising inequality (Rachel and Smith 2016, Farhi and Gourio 2018, Natal and Stoffels 2019). The coincidence of declining natural interest rates in many economies with open capital markets suggests that for these economies the relevant explanatory variables are likely to be global in nature (Del Negro et al 2019, Rachel and Summers (2019).

We contribute to the natural interest rate literature by providing estimates of the natural interest rate for China and showing that it has fallen over the past decade alongside the declines observed in advanced economies. Aside from the intrinsic value of having estimates of the natural interest rate for a large economy like China, the Chinese application is also interesting because for most of our estimation sample, China maintained a relatively closed capital account. This has placed limits on investors' ability to arbitrage away interest rate differentials between China and the rest of the world, and means that China's natural interest rate is more likely to reflect primarily domestic factors. China thus provides us with a laboratory to test competing explanations for the global decline in natural interest rates. For example, the global savings glut explanation for a declining natural interest rate seems at odds with the case of China, which has run current account surpluses for most of our sample and yet still experienced a declining natural interest rate. In contrast, many of China's demographic patterns, including an ageing population,

[4] Specifically, this would correspond to the natural one-year LPR. The natural rate defined in terms of alternative reference rates would need to be adjusted by the average spread between those rates and the LPR rate.

slowing population growth and rising life expectancy, mirror those in other economies. This lends weight to demographic explanations for a declining natural interest rate.

Several previous studies have attempted to estimate the natural interest rate in China. Using Laubach and Williams-style models, Li, Su and Hong (2016) and Li and Su (2016) estimate that China's natural interest rate fluctuated between 0 and 6 per cent between 2004 and 2016. These papers, however, illustrate the difficulties of working with Chinese macroeconomic data. The estimated output gap in Li, Su and Hong (2016) suggests that the Chinese economy was operating above full capacity for the entire period between 2004 and 2016, with the degree of overcapacity exceeding 10 per cent for much of that time. Similarly, the estimates in Li and Su (2016) suggest that monetary policy in China was highly expansionary for their entire sample period. Both sets of estimates are hard to reconcile with the behaviour of inflation which has, if anything, become more stable over the past decade.

A more recent paper by Xu and Jia (2019) estimates the China's natural rate using a variety of models, including a Laubach and Williams-style model and a small DSGE model, over a sample spanning 1995-2018. They recover lower estimates of the natural interest rate, of typically between -4 and 4 per cent. However, because their measure of monetary policy is a shadow interest rate, constructed as a weighted average of M2 growth and the 10-year government bond yield, it is hard to say what these estimates imply for the natural real policy rate. In contrast, our approach provides an estimate of the natural interest rate that (after accounting for inflation expectations) is directly related to the policy interest rates used by the People's Bank of China (PBC) to conduct monetary policy.

The rest of this paper proceeds as follows. Section 2 provides a background to the evolution of monetary policy in China. Section 3 describes the empirical methodology of our core model and accompanying data. Section 4 presents the main results from our empirical analysis. Section 5 presents an alternative simpler model, the results of which are described in Section 6. Section 7 concludes and discusses some policy implications of our results.

2. Monetary Policy in China

Since taking central banking functions in 1984, the PBC has constantly improved its monetary policy framework according to economic and financial developments. From 1984 until the late 1990s, aggregate credit volumes served as both the main intermediate target and, at first, the main instrument of monetary policy. In the late 1990s the PBC placed more emphasis on M2 growth as intermediate target, with the monetary base initially serving as the key unofficial operational target. To better manage financial markets and support the real economy, the PBC experimented with a number of market-oriented instruments, such as open market operations and reserve requirements, achieving some success. Amsted et al (2020) discussed and explained in detail about China's financial systems and the PBC's monetary policy operations, especially in evolutions and recent developments.

In recent years, the PBC endeavoured to advance modern monetary policy framework, improve the anchor of intermediate targets and keep growth of M2 and Aggregate Financing to the Real Economy (AFRE) in line with nominal GDP growth. At the same time, interest rates have come to play an increasingly important role as the key instruments of monetary policy. Yi (2009) reviewed key development of China's market-oriented interest rate reform after economic reform, and systematically explained measures to solve "dual track" problem and respective achievements. At present, the PBC utilises a combination of price- and quantity-based monetary policy instruments, as well as macro-prudential tools. This combination has proved effective in achieving the PBC's key objectives of ensuring price stability and promoting economic growth.

The PBC endeavoured to deepen the market-oriented interest rate reform and smooth monetary policy transmission. To enhance the market-oriented interest rate formation and transmission mechanism, the PBC will improve the central bank policy rate system in which OMO rates act as short-term policy rates and MLF rates as medium-term policy rates, and the PBC will advance the reforms of money market benchmark rates so that market rates are guided to move around policy rates. As China's market-oriented interest rate reform has still been ongoing, commercial banks' loan pricing mainly referred to benchmark lending interest rate at one time (Sun and Luan, 2019) . Under this circumstance, the medium-term policy rates created by the PBC has significant effect on amount and interest rate of commercial bank loans (Sun and Duan, 2016)[5].

The PBC continues to encourage the evolution of the financial system to one where market interest rates play the dominant role. An important step in this process was the launch of the Loan Prime Rate reform in August 2019. As part of this reform, the LPR is now calculated from the actual rates on bank lending to high quality clients and is expressed as a spread to medium-term lending facility rates which are under the PBC's direct control. The LPR serves as the major pricing reference for new loan contracts and hence, unlike benchmark interest rates, directly reflects the supply and demand for funds in the credit markets. Thus, taking the LPR as a pricing reference should help to further encourage market-based interest-rate formation and the transmission of policy rates to lending rates.

Any attempt to estimate the natural interest rate in China must take account of the changes in the structure of financial markets and conduct of monetary policy that have occurred over recent decades. In our view, the absence of market-based mechanisms for credit allocation and loan pricing render estimates of the natural interest rate prior to the mid-1990s essentially meaningless. Hence, we start our estimation in 1995. Even then, we would caution against reading too much into the natural rate estimates in the first few years of our sample as China's financial system marketisation development was not sufficient during this time. It is also necessary to take account of monetary aggregates, given the important role that these played as an instrument and target for monetary policy until the 2010s. To account for this, we include M2 growth in our model, as well as interest rate measures.

3. Empirical Methodology for the Full Model

Our empirical framework is based on the unobserved components model of Laubach and Williams (2003). However, we modify and extend their model in a number of dimensions to account for two challenging aspects of working with Chinese data. The first is that the macroeconomic data samples that we have to work with are short. For example, quarterly GDP and CPI inflation data are available only from the early 1990s, and samples for other series such as the LPR are even shorter. The second challenge relates to measurement. Some series, most notably GDP, are extremely smooth (Figure 1). This makes it hard to extract a meaningful business cycle and, hence to pin down the stance of monetary policy and level of the natural interest rate.

Our solution to these challenges is two-fold. First, we include additional measurement variables to help identify the model's unobserved latent variables. For example, we include consumption, investment, import values, railway freight volumes and electricity production as measures of economic activity, in addition to GDP. Similarly, we include both CPI inflation and PPI inflation to help better identify the inflation expectations that households and firms use to deflate nominal interest rates. Second, we estimate the model using Bayesian methods. This is helpful in addressing the potential weak identification of some parameters and guides the parameter estimates away from values that are sharply at odds with economic theory or evidence for other economies.

[5] See also Sun (1996, 2001, 2015a and 2015b) for a discussions of the role of banks in the monetary policy transmission in China

The core of our model is similar to Laubach and Williams (2003). There is an IS curve that links the state of the business cycle, c_t, to lags of itself and gaps between the real policy interest rate, r_t, and the natural interest rate, r_t^*. In the past, the PBOC used monetary and credit aggregates, rather than short-term nominal interest rates, as the primary tool of monetary policy. Reflecting this, we also include lags of the gap between M2 growth, $\Delta M2_t$, and its trend, $\Delta M2_t^*$, in the IS curve.

$$c_t = \alpha_{c,1}c_{t-1} + \alpha_{c,2}c_{t-2} - \frac{\alpha_{c,3}}{2}\sum_{j=1}^{2}\left(r_{t-j} - r_{t-j}^*\right) + \frac{\alpha_{c,4}}{2}\sum_{j=1}^{2}\left(\Delta M2_{t-j} - \Delta M2_{t-j}^*\right) + \eta_t^c \quad (1)$$

where η_t^c is an uncorrelated error term, which follows a normal distribution with variance σ_c^2.[6]

The model also includes a Phillips curve that links inflation to the business cycle. In principle inflation is observable. However, Chinese inflation series with long time series, such as CPI inflation, are subject to large amounts of volatility driven by idiosyncratic changes in food prices and other items whose prices bear little relationship to broader economic conditions or monetary policy. To account for this, we treat the various observable inflation series as noisy signals of an unobserved variable that we term 'underlying inflation', π_t . This is the inflation measure which appears in the model's Phillips curve and is related to expected or trend inflation, π_t^*, and the lagged business cycle:

$$\pi_t = \frac{1}{4}\pi_{t-1}^* + \alpha_\pi c_{t-1} + \eta_t^\pi \quad (2)$$

We assume that inflation expectations are backward looking and equal to the average of 'underlying inflation' over the past four quarters:

$$\pi_t^* = \pi_{t-1} + \pi_{t-2} + \pi_{t-3} + \pi_{t-4} \quad (3)$$

The natural interest rate, r_t^*, is related to trend GDP growth, g_t, and additional unexplained component, z_t, both of which follow random walk processes:

$$r_t^* = \zeta g_t + z_t \quad (4)$$

$$g_t = g_{t-1} + \eta_t^g \quad (5)$$

$$z_t = z_{t-1} + \eta_t^z \quad (6)$$

We assume that trend M2 growth, $\Delta M2_t^*$, is equal to the sum of trend GDP growth, expected inflation (evaluated in quarterly terms) and a constant:[7]

$$\Delta M2_t^* = \phi^{\Delta \mathrm{M2}^*} + \frac{1}{4}\pi_t^* + g_{t-1} + \eta_t^{\Delta \mathrm{M2}^*} \quad (7)$$

We link the business cycle to seven observable variables: real GDP, nominal consumption, nominal investment, import values, railway freight volumes, electricity production and industrial production. Each of these series is assumed to be correlated with the business cycle, which can be thought of as the common transitory component of the seven series.[8] The individual series, however, also contain an idiosyncratic transitory component and a nonstationary trend component. More formally, the measurement equations for the model's measures of economic activity are:

$$y_t = y_t^* + c_t + \varepsilon_t^y \quad (8)$$

$$cons_t = cons_t^* + \alpha_{cons}c_t + \rho_{cons}(cons_{t-1} - cons_{t-1}^*) + \varepsilon_t^{cons} \quad (9)$$

$$invest_t = invest_t^* + \alpha_{invest}c_t + \rho_{invest}(invest_{t-1} - invest_{t-1}^*) + \varepsilon_t^{invest} \quad (10)$$

$$m_t = m_t^* + \alpha_m c_t + \rho_m(m_{t-1} - m_{t-1}^*) + \varepsilon_t^m \quad (11)$$

6 The error terms on the model's other state variables, denoted by the symbol η, follow a similar process.

7 The constant term allows for persistent differences between the growth rates of M2 and nominal GDP.

8 Note that the activity variables enter the model in log levels. Hence $y_t - y_t^*$ can be interpreted as the output gap – the deviation of the *level* of GDP from its trend. Similarly, c_t is the common transitory component of the *level* of these series.

$$f_t = f_t^* + \alpha_f c_t + \rho_f (f_{t-1} - f_{t-1}^*) + \varepsilon_t^f \tag{12}$$

$$elec_t = elec_t^* + \alpha_e c_t + \rho_e (elec_{t-1} - elec_{t-1}^*) + \varepsilon_t^e \tag{13}$$

$$ip_t = ip_t^* + \alpha_{ip} c_t + \rho_{ip} (ip_{t-1} - ip_{t-1}^*) + \varepsilon_t^{ip} \tag{14}$$

where y_t is the log of real GDP, $cons_t$ is the log of nominal consumption, $invest_t$ is the log of nominal investment, m_t is the log of import values, f_t is the log of railway freight volumes, $elec_t$ is the log of electricity production volumes and ip_t is the log of industrial production. The variables y_t^*, $cons_t^*$, $invest_t^*$, m_t^*, f_t^*, $elec_t^*$ and ip_t^* are unobserved trend levels of GDP, consumption, investment, import values, railway freight, electricity production and industrial production, described in more detail below. The terms ε_t^y, ε_t^{cons}, ε_t^{invest}, ε_t^m, ε_t^f, ε_t^{elec} and ε_t^{ip} are uncorrelated error terms. These could reflect measurement error or simply transitory idiosyncratic changes in the variables.

We set the coefficient on the business cycle in the GDP equation to 1. This is a normalisation that defines the scale of the cycle. However, we estimate the parameters α_{cons}, α_{invest}, α_m, α_f, α_{elec} and α_{ip}, which allow for the possibility that these variables may exhibit more or less cyclical variation than GDP.

The trends in the observed activity variables follow the processes:

$$y_t^* = y_{t-1}^* + g_{t-1} + \eta^{y^*}_t \tag{15}$$

$$cons_t^* = \phi^{cons} + cons_{t-1}^* + \alpha_{cons^*}\left(\frac{1}{4}\pi_{t-1}^* + g_{t-1}\right) + \eta_t^{cons^*} \tag{16}$$

$$invest_t^* = \phi^{invest} + invest_{t-1}^* + \alpha_{invest^*}\left(\frac{1}{4}\pi_{t-1}^* + g_{t-1}\right) + \eta_t^{invest^*} \tag{17}$$

$$m_t^* = \phi^{m^*} + m_{t-1}^* + \alpha_{m^*}\left(\frac{1}{4}\pi_{t-1}^* + g_{t-1}\right) + \eta_t^{m^*} \tag{18}$$

$$f_t^* = \phi^{f^*} + f_{t-1}^* + \alpha_{f^*} g_{t-1} + \eta_t^{f^*} \tag{19}$$

$$elec_t^* = \phi^{elec^*} + elec_{t-1}^* + \alpha_{elec^*} g_{t-1} + \eta_t^{elec^*} \tag{20}$$

$$ip_t^* = \phi^{ip^*} + ip_{t-1}^* + \alpha_{ip^*} g_{t-1} + \eta_t^{ip^*} \tag{21}$$

The real variables – GDP, railway freight, electricity production and industrial production – inherit the drift in trend growth g_{t-1}. The nominal variables, consumption, investment and import values, inherit the drift in trend growth as well as the drift in trend inflation, π_t^*. The constant terms – ϕ^{cons^*}, ϕ^{invest^*} etc. – allow for the possibility of a permanent wedge between the growth rate of the trend variables and the growth rates of GDP and inflation. This could occur, for example, if the income elasticity of consumption was greater than one or if there was a persistent gap between import price inflation and consumer price inflation.

We include two observed measures of inflation: CPI inflation and PPI inflation. We assume that these series provide a noisy signal of underlying inflation, π_t, which is the concept that households use to deflate the nominal policy rate to determine the real interest rate. The measurement equation for CPI inflation is:

$$\pi_t^{CPI} = \pi_t + \alpha_{CPI}(\pi_t - \pi_t^*/4) + \varepsilon_t^{CPI} \tag{22}$$

where the parameter α_{CPI} allows for the possibility that CPI inflation could move more than one-for-one with underlying inflation. The measurement equation for PPI inflation is similar:

$$\pi_t^{PPI} = \phi_{PPI} + \pi_t + \alpha_{PPI}(\pi_t - \pi_t^*/4) + \varepsilon_t^{PPI} \tag{23}$$

with the addition of a constant term, ϕ_{PPI}, to allow for the possibility that PPI inflation could have a different mean to CPI inflation.

We include three nominal interest rate measures in the model: the loan prime rate, the one-year benchmark lending interest rate and the average loan rate. While we believe that the LPR gives the best insight into the conduct of monetary policy, it has only existed since late 2013. The benchmark rate and weighted average lending rate provide an indication of policy interest rate settings prior to that time. Each of the observed interest rates provides a potentially noisy signal of the ex-ante nominal policy interest rate, which is equal to the (unobserved) real interest rate, r_t, plus expected inflation π_t^*. We also allow for permanent wedges, ϕ_{blr} and ϕ_{war}, between the benchmark and weighted other interest rates and the LPR rate.

$$i_t^{lpr} = r_t + \pi_t^* + \varepsilon_t^{lpr} \tag{24}$$

$$i_t^{blr} = \phi_{blr} + r_t + \pi_t^* + \varepsilon_t^{blr} \tag{25}$$

$$i_t^{war} = \phi_{war} + r_t + \pi_t^* + \varepsilon_t^{war} \tag{26}$$

Because r_t is a state variable, we need to assign it a transition equation. We assume that it follows an AR(1) process, with a time varying mean of r_{t-1}^*:

$$r_t = \gamma_r r_{t-1} + (1 - \gamma_r) r_{t-1}^* + \eta_t^r \tag{27}$$

The other observed indicator of the policy stance, M2 growth, is a weighted average of its own lag and the growth in trend M2, as well as a residual.

$$\Delta M2_t = \gamma_{\Delta \mathrm{M2}} \Delta \mathrm{M2}_{\mathrm{t-1}} + (1 - \gamma_{\Delta \mathrm{M2}}) \Delta M2_t^* + \varepsilon_t^{\Delta \mathrm{M2}} \tag{28}$$

Figure 1 plots the observed data series used in estimation.

4. Results for the Full Model

We estimate the model using Bayesian methods over the period from 1995Q2 to 2019Q4. The starting point of sample largely reflects data availability – we use the longest sample for which quarterly CPI inflation data are available. Given the changes in the structure of the Chinese economy and conduct of monetary policy over recent decades, there is a case for restricting the sample even further. Arguing against this, however, is the fact that using a materially shorter sample would be likely to leave us with scarcely one completed business cycle. We end the estimation before the start of the Covid-19 pandemic in early 2020 because the unusually large volatility that occurred in this episode could contaminate the estimates earlier in the sample.[9] A detailed description of data we use in this paper is reported in Appendix A.

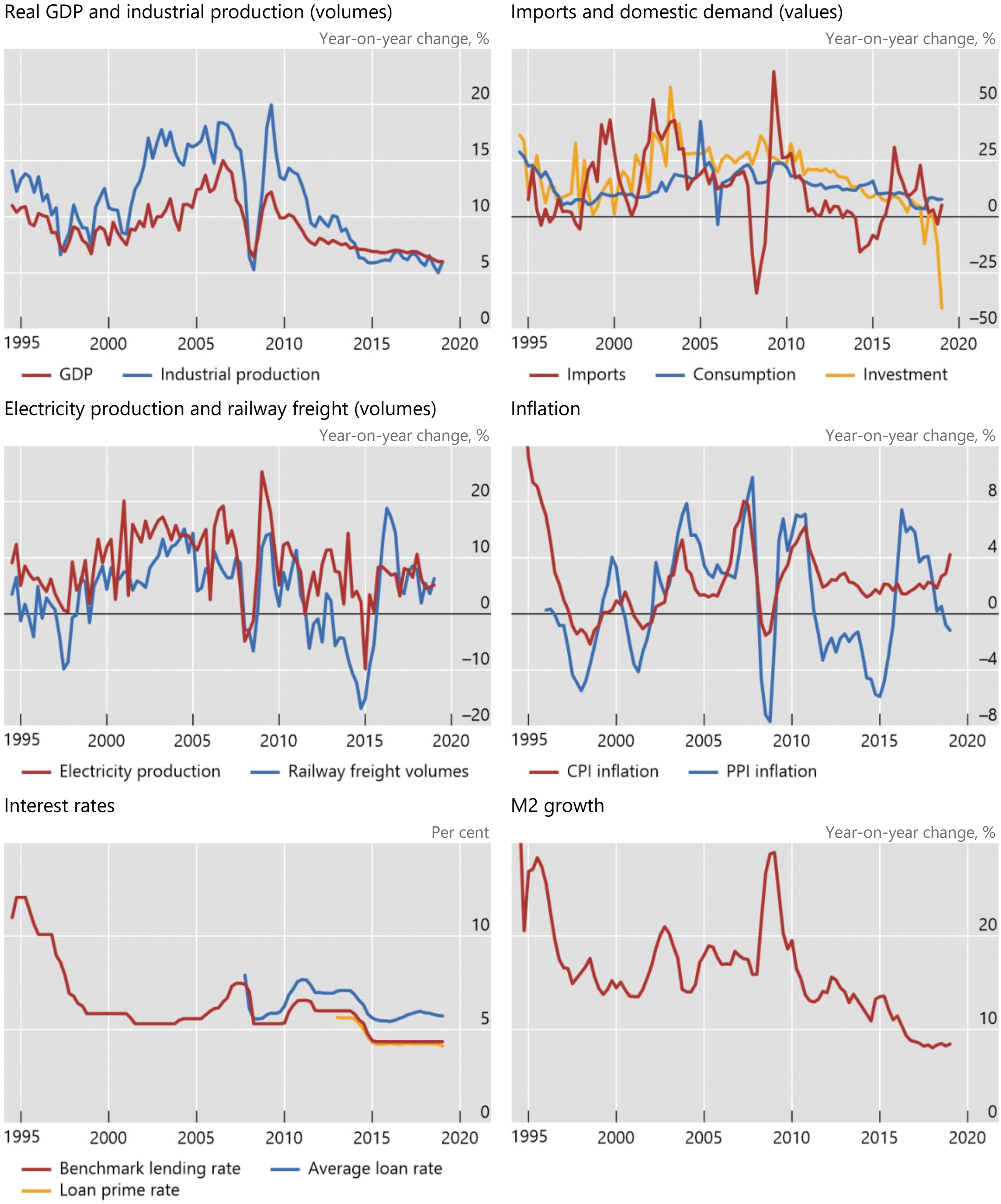
Using Bayesian techniques allow us to combine prior information about the values of the estimated parameters from economic theory and other studies with information from the data. Within that scope, we have tried to make the prior distributions relatively loose (Table 1). For example the priors on the slopes of the IS and Phillips curves, α_{c3}, α_{c4} and α_π have positive mass at zero, meaning that we allow for the possibility that policy interest rates could have no effect on economic activity or inflation in China. Similarly, our prior on the responsiveness of the natural interest rate to trend GDP growth, ζ, allows for the possibility that there is no relationship between the two variables, or that increases in trend growth lower the natural interest rate.

We use the Metropolis-Hastings algorithm to map out the posterior distribution, after using a numerical procedure to locate the mode. We take 200,000 draws from the posterior distribution, dropping an initial 50,000 draws as a burn-in. After estimating the model's parameters, we use the Kalman smoother to construct estimates of the unobserved states, including the natural interest rate, based on the full posterior distribution.

9 See Lenza and Primiceri (2020) for a discussion of the challenges with estimating macroeconomic models over samples including the Covid pandemic.

Data series used in estimation

Figure 1



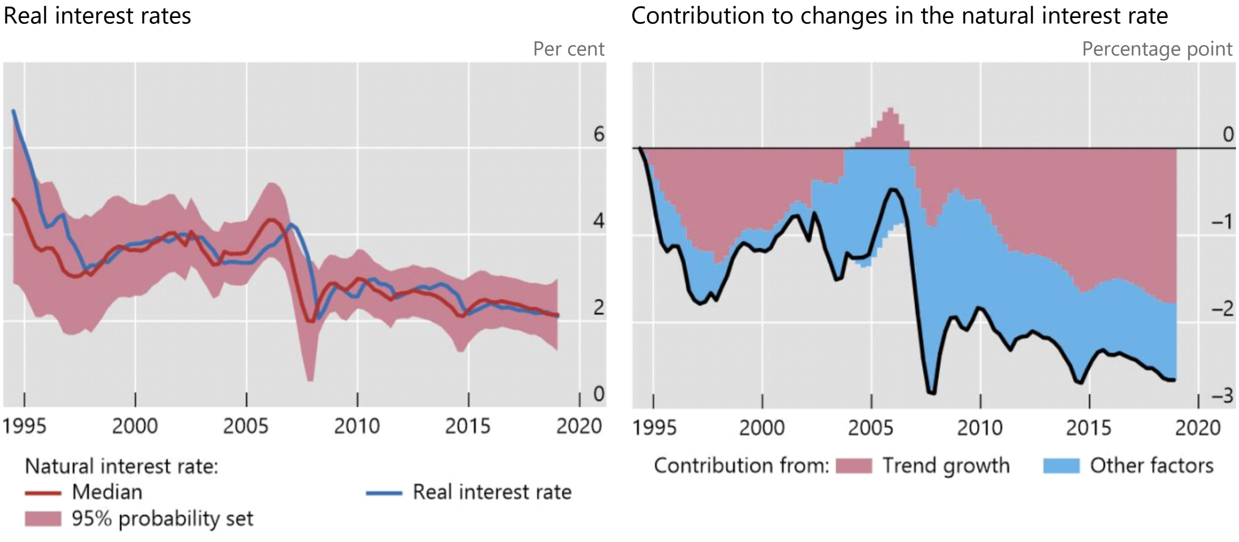
Sources: Wind; National Bureau of Statistics of China; People's Bank of China; authors' calculations.

Table 1 reports the parameter estimates.[10] As suggested by the raw data, import values, railway freight, electricity volumes and industrial production all exhibit a considerably larger response to the business cycle than GDP. The cyclicality of consumption and investment, is broadly similar to that of aggregate GDP.[11] However, the standard deviations of the 'measurement error' shocks to these variables are much larger than for GDP. Investment, import values and railway freight exhibit persistent deviations from their estimated trends. However, deviations of consumption, electricity production and industrial production from their trends are smaller. These results point to the benefit of using multiple measures of economic activity to infer the state of the business cycle. For inflation, both the CPI and PPI exhibit considerably more cyclical variation than underlying inflation. This too highlights the advantages of using multiple variables to infer the true level of underlying inflation.

For the state equations, the estimated slope coefficients, α_{c3}, α_{c4} and α_{π}, are reasonably large, although somewhat imprecisely estimated. The estimated endogenous persistence of the cycle, given by $\alpha_{c1} + \alpha_{c2}$, is lower than estimates for advanced economies, which are typically greater than 0.9. The estimate of the sensitivity of the natural interest rate to changes in trend growth, ζ, of 0.30 is considerably below the estimates for the US in Laubach and Williams (2003, 2016), which are both above 1.0. However, our estimates are consistent with the findings of Lunsford and West (2019) and Borio, Distyatat and Rungcharonkitkul (2019), who argue that the relationship between real interest rates and trend growth is relatively weak over a long sample.

We now turn to the estimates of the model's state variables. Figure 2, left-hand panel shows the model's estimate of the natural interest rate. The solid red line shows the model's point estimate, while the shaded area shows the 95 per cent probability interval around this estimate. The natural interest rate is estimated to have been around 5 per cent at the start of our sample. It declined throughout the late 1990s to around 4 per cent by the turn of the century and remained at about that level until the GFC. It has averaged around 3 per cent in the years since then, although has drifted down more recently and is currently estimated to be a bit above 2 per cent. As is common for other countries, estimates of China's natural interest rate are imprecise; the 95 probability band around the estimates spans 1.5-3 per cent.

The natural interest rate has declined alongside lower trend growth — Figure 2



Sources: Wind; National Bureau of Statistics of China; People's Bank of China; authors' calculations.

[10] We scale some variables by dividing them by 10 to avoid numerical difficulties that can occur from sampling parameters with very different orders of magnitude.

[11] This is to be expected as these variables account for a large part of GDP.

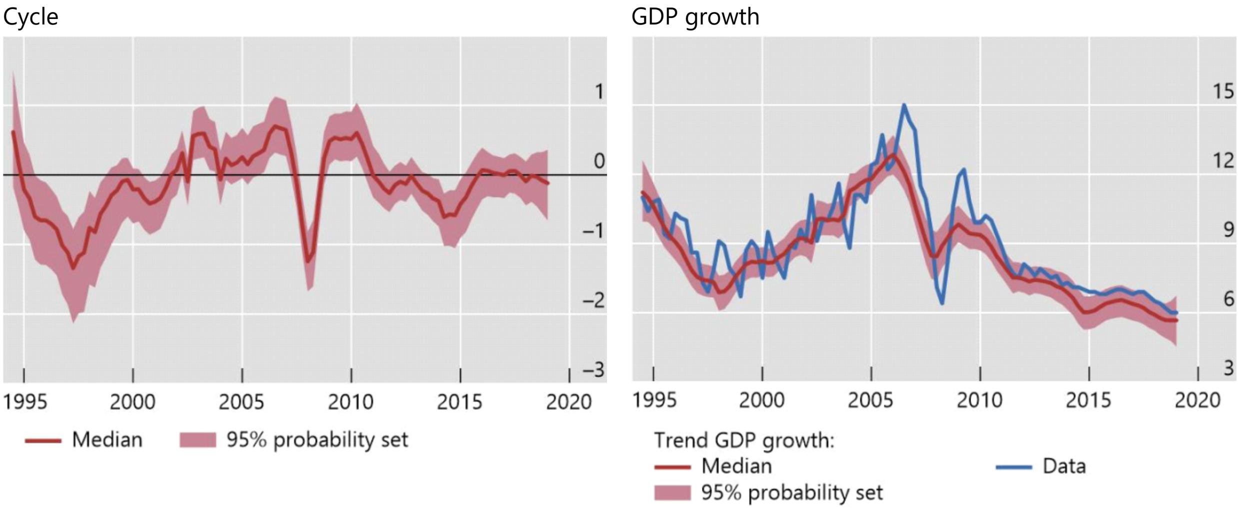
The blue line in Figure 2, left-hand panel plots the model's estimate of the actual real policy rate. The gap between the real and natural interest rate broadly mirrors the evolution of the business cycle (discussed below). The real interest rate was above the natural interest rate in the late 1990s, and slightly below the natural interest rate during the mid-2000s boom. Since 2016, we estimate the real interest rate has been close to the natural interest rate. This is consistent with the PBOC's view that its monetary policy stance has been natural over this period.

In Figure 2, right-hand panel we decompose the estimated changes in the natural interest rate into a contribution from the change in trend growth and a residual component, which accounts for the net effect of all other influences on the natural rate. Since the start of our sample, China's natural rate has declined by about 2½ percentage points. Around 1½ percentage points of the decline reflects a slowdown in trend growth over our sample. Although the estimated coefficient on trend growth in the natural rate equation is fairly small, the large changes in China's trend growth rate over our sample mean that this variable has still had a large influence on the natural interest rate. Changes in trend growth also account for much of the higher-frequency changes in the natural interest rate, such as its decline in the late 1990s. The unexplained component of the natural interest rate declined by 2 percentage points between 1995 and 2009, before increasing by 1 percentage point over the subsequent four years. Since 2015, the unexplained component has been relatively stable.

As well as the natural interest rate, our estimation procedure also produces estimates of other Chinese latent macroeconomic variables. The left-hand panel of Figure 3 shows our estimate of the Chinese business cycle. For the most part, the cycle corresponds to standard accounts of Chinese economic conditions. After experiencing a cyclical downturn in the late 1990s, economic activity in China picked up through the mid-to-late 2000s, likely supported by its entry to the WTO in 2001. Economic activity declined sharply during the Great Financial Crisis (GFC), although the downturn was extremely brief. Between 2012 and 2019, the business cycle was close to zero, except for a small dip around 2015.

Output growth has been close to trend, ensuring a relatively small output gap

In per cent | Figure 3



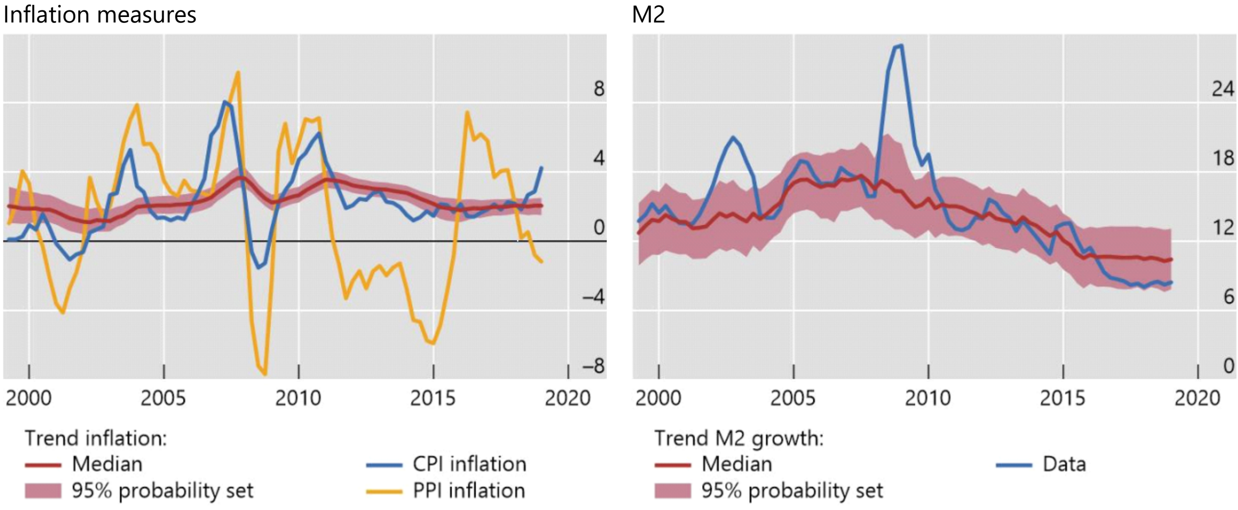
Sources: Wind; National Bureau of Statistics of China; People's Bank of China; authors' calculations.

Figure 3, right-hand panel compares the model's estimate of trend GDP growth for China (red line and shaded area) to actual growth outcomes (blue line). Trend growth increased substantially in the early years of this century, rising from about 7 per cent in the late 1990s to a peak of just over 12 per cent in 2007. Trend growth then experienced a persistent decline to until 2015. Between 2015 and 2019, trend growth was broadly steady at around 6 per cent. Consistent with the relatively small output gap in China for most our estimation sample, actual economic growth has typically been close to its estimated trend.

Figure 4, left-hand panel compares the model's estimates of trend inflation to the year-ended growth rates of CPI and PPI inflation. Trend inflation declined from around 6 per cent at the start of the sample, to around 1 per cent at the turn of the century. Since then, trend inflation has been fairly stable at between 2 and 3 per cent and is estimated to be at the lower end of that range currently. The stability in trend inflation stands in contrast to observed inflation measures, which are considerably more variable.[12] Many of the large movements in these series have been driven by changes in food and energy prices. Our results indicate that transitory changes in these prices have had little impact on inflation expectations in China.

Trend inflation and M2 growth much more stable than observed data

Year-on-year change, in per cent | Figure 4



Sources: Wind; National Bureau of Statistics of China; People's Bank of China; authors' calculations.

One surprising aspect of Figure 2 is the behaviour of the actual and natural interest rates around the GFC. Our estimates suggest that the real policy rate was above the natural interest rate for much of this episode, implying that monetary policy was exerting a contractionary effect on economic activity. This is at odds with most accounts of China's economic policy during the GFC, which point to a substantial economic stimulus. Taking a broader view of monetary policy helps to reconcile these two views. As emphasised in Section 2, up until the early 2010s the PBC used monetary aggregates as well as interest rates to influence the level of economic activity. Figure 4, right-hand panel compares the actual growth rate of M2 to its estimated trend growth rate.[13] Actual M2 growth was clearly above its trend level during the GFC – indeed this is the largest deviation of M2 growth from its trend over the entire estimation sample. Because we estimate that faster M2 growth raises the level of economic activity, this indicates that monetary policy settings were expansionary in this period, although the stimulus came largely through money and credit, rather than interest rates.

[12] CPI inflation has, however, been more stable since 2013 than in the previous part of the sample.

[13] Although M2 enters the model as a quarterly growth rate, we plots its year-ended growth as it is a volatile series and easier to interpret in year-ended terms.

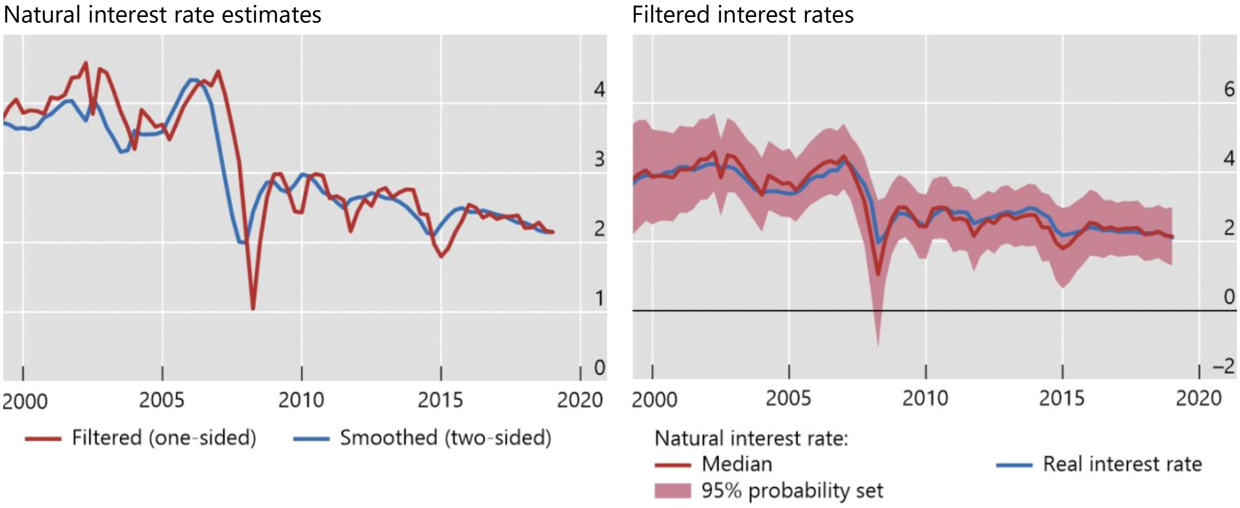
So far, we have reported results describing two-sided (i.e. smoothed) estimates of the model's state variables. These estimates use information from the entire sample to infer the value of the state variables at each point in time. As such, they may overstate the predictability of the natural interest rate and understate the uncertainty around its level in real time. To give a sense of the importance of these concerns, the left panel of Figure 5 left-hand panel compares the smoothed estimates of the natural interest rate to the model's filtered (i.e. one-sided estimates).[14] As one would expect, the filtered estimates lag the real time estimates by a few quarters. For example, with the benefit of hindsight, our model estimates that China's natural interest rate fell temporarily by around 2 percentage points, from 4 per cent to 2 per cent, during 2008. But, with the information available at the time, this decline would not have been apparent until late 2009. Overall, however, the pattern of the two series is similar. This suggests that the model provides a reasonable indication of the natural interest rate in real time. This is also the case for other important state variables, including the output gap, trend inflation and trend GDP growth.

One-sided estimates also provide an alternative interpretation of the stance of monetary policy over our sample. Policymakers do not have the benefit of hindsight when choosing policy settings and must instead work with the information they have at hand. Consequently, one-sided estimates arguably provide a better indication of the stance that policymakers were *trying* to achieve at any point in time. Figure 5, right-hand panel compares the filtered estimates of the natural interest rate, with 95 per cent confidence bands, to the filtered estimate of the actual ex-post real interest rate. The two series track each other closely, and the actual interest rate never lies outside the 95 per cent confidence band of the natural interest rate. This suggests that, given real-time information, the PBC has tracked the natural interest rate fairly closely, even though, with the benefit of hindsight, real interest rates have deviated from their natural level from time-to-time.

Real interest rates have tracked the natural rate when using real-time information

In per cent

Figure 5



Sources: Wind; National Bureau of Statistics of China; People's Bank of China; authors' calculations.

[14] For both the smoothed and filtered lines we plot the median of the posterior distribution of the natural interest rate at each point in time.

Parameter estimates

Table 1

Parameter	Posterior			Prior		
	Mode	Mean	95% prob. interval	Distribution	Mean	Standard deviation
Measurement equations						
ρ_{cons}	0.28	0.37	[0.10-0.92]	B	0.50	0.20
ρ_{invest}	0.97	0.97	[0.93-0.99]	B	0.80	0.10
ρ_m	0.83	0.80	[0.65-0.91]	B	0.50	0.20
ρ_f	0.90	0.84	[0.59-0.95]	B	0.50	0.20
ρ_{elec}	0.23	0.26	[0.09-0.47]	B	0.50	0.20
ρ_{ip}	0.35	0.39	[0.17-0.64]	B	0.50	0.20
ϕ_{ppi}	-0.25	-0.24	[-0.43--0.04]	N	0.00	1.00
ϕ_{blr}	0.19	0.19	[0.14- 0.24]	N	0.00	1.00
ϕ_{alr}	1.21	1.18	[1.07-1.29]	N	0.00	1.00
α_{cons}	0.95	0.87	[-0.22-1.95]	N	1.00	1.00
α_{invest}	1.17	1.40	[-0.13-2.89]	N	1.00	1.00
α_m	7.59	7.30	[5.23-9.49]	N	1.00	2.00
α_f	3.27	3.05	[1.63-4.52]	N	1.00	2.00
α_{elec}	3.69	3.63	[2.01-5.34]	N	1.00	2.00
α_{ip}	1.71	1.82	[1.15-2.52]	N	1.00	1.00
α_{cpi}	3.64	3.89	[2.63-5.31]	N	0.00	4.00
α_{ppi}	7.34	7.54	[5.49-9.79]	N	0.00	4.00
$\gamma_{\Delta M2}$	0.54	0.58	[0.44-0.71]	B	0.50	0.20
State equations						
ϕ_{cons^*}	0.32	0.30	[-0.04-0.64]	N	0.00	1.00
ϕ_{invest^*}	0.68	0.64	[-0.07-1.31]	N	0.00	1.00
ϕ_{m^*}	0.01	-0.16	[-0.91- 0.57]	N	0.00	1.00
ϕ_{f^*}	-1.12	-1.09	[-1.57- -0.63]	N	0.00	1.00
ϕ_{elec^*}	-0.13	-0.10	[-0.41-0.22]	N	0.00	1.00
ϕ_{ip^*}	0.34	0.37	[0.15-0.60]	N	0.00	1.00
$\phi_{\Delta M2^*}$	0.76	0.79	[0.51-1.06]	N	0.00	1.00
α_{cons^*}	1.00	1.00	[0.98-1.02]	N	1.00	0.01
α_{invest^*}	0.99	1.01	[0.93-1.09]	N	1.00	0.05
α_{m^*}	1.00	1.00	[0.92-1.08]	N	1.00	0.05
α_{f^*}	0.99	0.99	[0.91-1.07]	N	1.00	0.05
α_{elec^*}	1.02	1.01	[0.93-1.09]	N	1.00	0.05
α_{ip^*}	1.06	1.06	[0.98-1.14]	N	1.00	0.05
$\alpha_{c1} + \alpha_{c2}$	0.75	0.73	[0.60-0.84]	B	0.70	0.10
α_{c2}	0.25	0.24	[-0.08-0.53]	N	-0.25	0.25
α_{c3}	0.28	0.34	[0.14-0.60]	G	0.60	0.50
α_{c4}	0.16	0.15	[0.07-0.24]	G	0.60	0.50
α_π	0.19	0.20	[0.12-0.29]	G	0.60	0.50
γ	0.76	0.73	[0.62-0.83]	B	0.70	0.10
ζ	0.30	0.32	[0.10-0.57]	N	0.75	0.50

Note: B = Beta, N = Normal, G = Gamma

Parameter estimates

Table 1 cont.

Parameter	Posterior			Prior		
	Mode	Mean	95% prob. interval	Distribution	Mean	Standard deviation
Measurement equations						
σ_y	0.14	0.13	[0.09-0.18]	IG	0.25	1.00
$\sigma_{cons} \times 10$	0.18	0.19	[0.14-0.27]	IG	0.25	0.50
$\sigma_{invest} \times 10$	0.69	0.71	[0.63-0.80]	IG	0.25	0.50
$\sigma_m \times 10$	0.25	0.28	[0.14-0.43]	IG	0.25	0.50
$\sigma_f \times 10$	0.18	0.18	[0.11-0.25]	IG	0.25	0.50
$\sigma_{elec} \times 10$	0.23	0.23	[0.19-0.28]	IG	0.25	0.50
σ_{ip}	0.18	0.22	[0.12-0.35]	IG	0.25	0.50
σ_{cpi}	0.42	0.40	[0.29-0.51]	IG	0.50	1.00
σ_{ppi}	1.04	1.02	[0.85-1.09]	IG	0.50	1.00
σ_{blr}	0.10	0.11	[0.08-0.15]	IG	0.25	0.50
σ_{alr}	0.42	0.42	[0.35-0.50]	IG	0.25	0.50
σ_{lpr}	0.08	0.09	[0.07-0.13]	IG	0.25	0.50
$\sigma_{\Delta M2}$	0.81	0.80	[0.68-0.93]	IG	0.50	1.00
State equations						
σ_c	0.17	0.17	[0.11-0.23]	IG	0.25	0.50
σ_π	0.07	0.08	[0.06-0.10]	IG	0.25	0.50
σ_z	0.23	0.27	[0.15-0.43]	IG	0.25	0.50
σ_r	0.18	0.16	[0.10-0.21]	IG	0.10	0.50
σ_{g^*}	0.14	0.15	[0.12-0.20]	IG	0.25	0.50
σ_{y^*}	0.16	0.17	[0.11-0.24]	IG	0.25	0.50
σ_{cons^*}	1.91	1.83	[0.51-2.45]	IG	0.25	0.50
$\sigma_{invest^*} \times 10$	0.25	0.46	[0.16-1.14]	IG	0.25	0.50
$\sigma_{m^*} \times 10$	0.46	0.44	[0.30-0.56]	IG	0.50	1.00
$\sigma_{f^*} \times 10$	0.22	0.21	[0.13-0.27]	IG	0.25	0.50
$\sigma_{elec^*} \times 10$	0.15	0.17	[0.12-0.22]	IG	0.25	0.50
$\sigma_{ip^*} \times 10$	0.09	0.09	[0.08-0.10]	IG	0.25	0.50
$\sigma_{\Delta M2^*} \times 10$	0.07	0.07	[0.04-0.11]	IG	0.10	0.50

Note: IG = Inverse Gamma

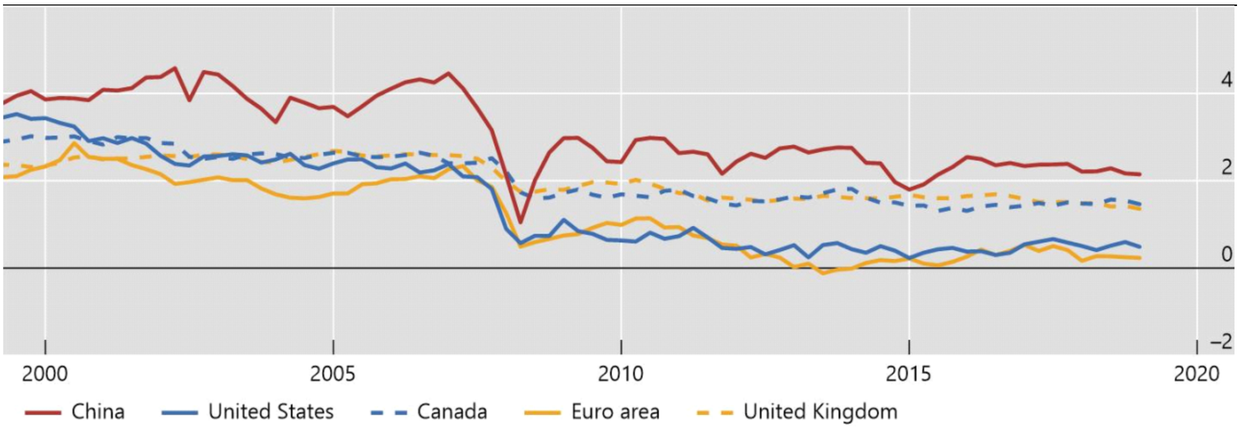
The estimated trend decline in China's natural interest rate mirrors that observed in other economies. To illustrate this, Figure 6 compares our estimate of the natural interest rate in China to the estimates for the United States, Canada, euro area and the United Kingdom produced by Holston et al (2017).[15] Although the level of China's natural interest rate is typically higher than estimates for those countries, it shares a downwards trend over recent decades. The size of the decline in natural interest rate estimates is also similar. A full investigation of the relationship between the natural rate in China and those abroad is beyond the scope of this paper. However, the common trends in the series plotted in Figure 6 suggests that the forces weighing on the natural rate in China could be similar to those overseas.

[15] We plot updated estimates of the Holston et al (2017) model, downloaded from https://www.newyorkfed.org/research/policy/rstar.

The decline in the natural rate in China mirrors that in other economies

Natural interest rates, in per cent

Figure 6



Sources: Holston, Laubach and Williams (2017); authors' calculations.

5. A Simpler Model

As an alternative to the rather complex model described above, we also present results from a simpler set up. This model differs in several important respects from the full model.

First, we use year over year (yoy) growth rates for most variables, other than interest rates, in the simpler model. For example, in the simpler model y_t refers to the yoy growth rate of real output, rather than its log level. Similarly, y_t^* becomes the trend growth rate of real output, rather than the log of trend output. The rationale for this specification is that yoy growth rates are more commonly used in the economic analysis of Chinese data. As such, readers might find a model specified in growth rates easier to interpret than the levels specification used in the full model.

Second, we estimate the simpler model using maximum likelihood (ML), rather than Bayesian approach used in the full model. The ML estimation procedure is a standard feature of most econometric packages, which will make our results easier to replicate.

Third, we work with a more parsimonious specification that is better suited for ML estimation. For example, we link business cycle only to real output, railway freight, and electricity production to distil trend output. We also use only GDP deflator to gauge inflation, rather than the combination of the CPI and PPI.[16] And, we reduce the number of lags of interest rates and M2 growth that appear in the equation for the business cycle and simplify the specification of observed interest rates.

Fourth, we change the specifications of the natural interest rate and trend M2 growth equations. The natural interest rate reacts to change in trend output growth, while trend M2 growth follows classical quantity theory of money.

As we have given detailed rationale for each equation of the full model in Section 3, we present only the equations of the simpler model here, without elaboration on the rationale for each equation.

The simpler model's state equations are:

[16] We also reduced the number of lags of inflation used to determine expected inflation from four to two.

$$c_t = \alpha_1^C c_{t-1} + \alpha_r^C (r_{t-1} - r_{t-1}^*) + \alpha_{M2}^C (\Delta M2_{t-1} - \Delta M2_{t-1}^*) + \eta_t^c \tag{29}$$

$$r_t = \gamma r_{t-1} + (1-\gamma) r_{t-1}^* + \eta_t^r \tag{30}$$

$$r_t^* = \alpha_{r^*} r_{t-1}^* + \zeta y_{t-1}^* - \zeta y_{t-2}^* + \eta_t^z \tag{31}$$

$$\Delta M2_t^* = \phi^{\Delta M2^*} + \pi_t^e + y_{t-1}^* + \eta_t^{\Delta M2^*} \tag{32}$$

$$\Delta M2_{t-1}^* = \Delta M2_{t,-1}^* \tag{33}$$

$$y_t^* = y_{t-1}^* + \eta_t^y \tag{34}$$

$$y_{t-1}^* = y_{t,-1}^* \tag{35}$$

$$f_t^* = \phi^{\mathrm{f}^*} + \alpha_{y^*}^{f^*} y_{t-1}^* + \eta_t^{\mathrm{f}^*} \tag{36}$$

$$elec_t^* = \phi^{\mathrm{elec}^*} + \alpha_{y^*}^{elec^*} y_{t-1}^* + \eta_t^{\mathrm{elec}^*} \tag{37}$$

The simpler model's measurement equations are:

$$\pi_t^{GDP} = \alpha^\pi c_t + \pi_t^e + \eta_t^\pi \tag{38}$$

$$i_t^{lpr} = r_t + \pi_t^e + \varepsilon_t^{lpr} \tag{39}$$

$$i_t^{walr} = \phi^{walr} + r_t + \pi_t^e + \varepsilon_t^{walr} \tag{40}$$

$$\Delta M2_t = \delta \Delta M2_{t-1} + (1-\delta) \Delta M2_{t-1}^* + \varepsilon_t^{\Delta M2} \tag{41}$$

$$y_t = y_t^* + c_t + \varepsilon_t^y \tag{42}$$

$$f_t = \alpha^f c_t + f_t^* + \varepsilon_t^f \tag{43}$$

$$elec_t = \alpha^{elec} c_t + elec_t^* + \varepsilon_t^{elec} \tag{44}$$

6. Results of the Simpler Model

We estimate simpler model using the standard Kalman filter procedure in Stata over the period 1994Q2 to 2019Q4. Table 2 reports the parameter estimates. Most of the estimates have a meaningful sign and value, and several provide insights on the behaviour of China's economy. For example, the cycle reacts positively to higher money growth in the IS curve. On the other hand, some of the results are harder to interpret. For example, the cycle responds positively to the real interest rate gap, which could be an indication of reverse causality. Inflation turns out to be very responsive to the state of the business cycle. When GDP growth accelerates by 1 percentage point, the GDP deflator tends to rise by 1.5 percentage points, which is quite consistent with observations. Trend values of railway freight and electricity production react positively to trend GDP growth, while the actual values of the two react by more than GDP to changes in the business cycle. M2 growth tends to be highly persistent, more so even than interest rates.

Figure 7 plots the estimate of the business cycle and trend growth from the simpler model. The estimates of the cycle (left-hand panel) are in many respects similar to those from the full model. In particular, we observe that economic activity was below capacity during the GFC and again around 2015. Unlike the full model, however, the simpler model suggests that the output gap was larger in the 2015 episode than during the GFC. The estimates of trend growth in the simpler model are more volatile than those from the full model (right-hand panel). However, they also suggest that actual growth has been close to its trend for most of our sample.

Parameter Estimates: Simpler Model			Table 2
Parameter	Coefficient	Parameter	Coefficient
α_1^C	0.822***	$\alpha_{y^*}^{f^*}$	0.452***
	(0.062)		(0.159)
α_r^C	0.002**	ϕ^{elec^*}	-1.087
	(0.001)		(2.146)
α_{M2}^C	-0.013*	$\alpha_{y^*}^{elec^*}$	1.140***
	(0.007)		(0.241)
γ	0.805***	α^{π}	1.549***
	(0.061)		(0.587)
α_{r^*}	0.808***	ϕ^{walr}	0.542***
	(0.076)		(0.065)
ζ	-1.857***	δ	0.910***
	(0.000)		(0.045)
$\phi^{\Delta M2^*}$	3.213*	α^f	14.748***
	(1.843)		(4.769)
ϕ^{f^*}	1.094	α^{elec}	7.281***
	(0.000)		(2.141)

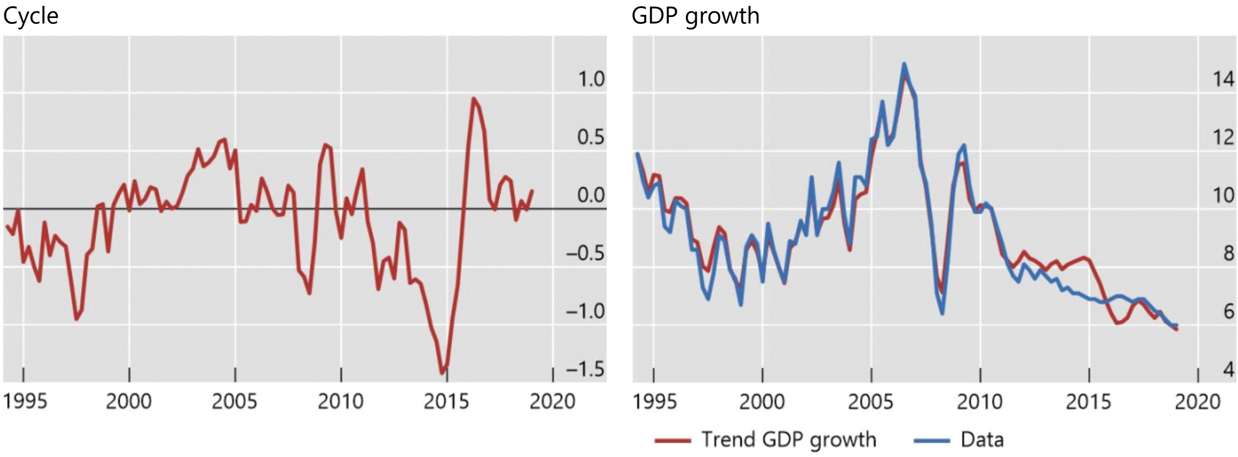
Note: Standard errors in parentheses; *** = p < 0.01, ** = p < 0.05, * = p < 0.1.

Figure 8 plots the estimates of the natural interest rate and trend M2 growth from the simple model against the ex-post real interest rate and M2 growth. The estimates of the natural interest rate from the simple model are considerably more volatile than those from the full model, indicative of the fact that this model suggests a lower sensitivity of macroeconomic aggregates to real interest rates (left-hand panel). Trend M2 growth also varies substantially from quarter to quarter, but has typically been close to actual M2 growth (right-hand panel).

Output growth has been close to trend, ensuring a relatively small output gap

In per cent

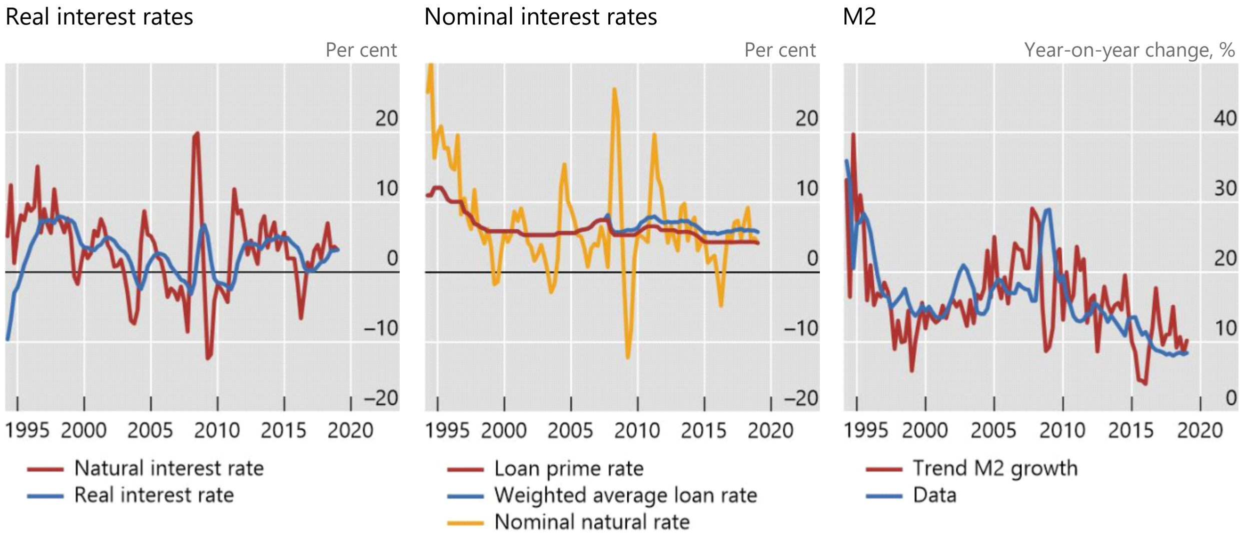
Figure 7



Sources: Wind; National Bureau of Statistics of China; People's Bank of China; authors' calculations.

Figure 8 (centre-panel) compares the estimates of the nominal natural interest rate from the simple model against two nominal market rates – the loan prime rate and weighted average loan rate. Consistent with the volatility of the natural interest rate, this Figure points to considerable deviations of market interest rates from the natural interest rate over the sample. At the same time, it also suggests that the natural nominal interest rate is currently around 4-5 per cent, consistent with the results from the full model. Moreover, at the end of our sample the natural nominal rate was broadly in line with the two market rates.

Interest rates and M2 growth — Figure 8



Sources: Wind; National Bureau of Statistics of China; People's Bank of China; authors' calculations.

7. Conclusion

As the Chinese financial system evolves and its links with overseas economies intensifies, interest rate developments in China will be of increasing importance for macroeconomic conditions in China and globally. We contribute to the understanding of these developments by proposing a framework to estimate the natural interest rate in China. Our framework overcomes the challenges associated with working with Chinese data series by using information from multiple economic indicators to infer the natural interest rate. Individually, many of the data series have limitations. But taken together the estimates that they provide are plausible. In particular, we estimate that the natural real interest rate in China averaged 3-5 per cent between 1995 and 2010, but has subsequently declined and is a bit above 2 per cent as of the end of 2019. Assuming an inflation rate of 2-3 per cent, consistent with the inflation objective, this implies a natural nominal interest rate of around 4-5 per cent.

As the estimation of our full model is somewhat complicated, we also propose a simpler approach of estimating China's natural interest rate that may be of use to practitioners. The estimates of the natural interest rate from this approach vary more from quarter to quarter than those from our full model. But they also indicate that China's nominal natural interest rate is currently around 4-5 per cent.

There are a number of questions that we leave for future research. Our estimates indicate that slightly more than half of the decline in the natural interest rate over our sample reflects a decline in trend growth. However, it is agnostic about the causes of the remaining decline. Better understanding how demographic, financial and other factors have influenced China's natural interest rate would be useful, not least in helping to predict how the natural interest rate might evolve in the future. The decline in our estimate of the natural interest rate in China mirrors that observed in many advanced economies (Holston et al 2017). Further investigation of the links between the natural interest rate in China and natural rates overseas would be a worthwhile exercise, particularly as the linkages between financial conditions in China and those in the rest of the world are likely to expand in the years ahead.

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Annex I: Data sources

All data used in this paper are sourced from National Bureau of Statistics of China (NBS), The People's Bank of China (PBC) and other official government data sources and downloaded from the Wind database.

Real output (GDP)

Real output is published quarterly by the NBS. The data is rebased every five years to reflect price changes and structural factors. Within a given five year interval, the level of real output from quarter to quarter is comparable. The same is not true for output levels calculated using different base years. As the current base year is 2015, after 2016 we use original data from NBS. Before 2015, we use quarterly year over year (yoy) growth rate to re-calculate quarterly GDP. For example, real output in 2015Q1 is calculated by dividing GDP in 2016Q1 by 1 plus the yoy growth rate from 2015Q1 to 2016Q1.

Industrial production

The industrial production index is published monthly by the NBS. The data series is indexed to 100 in 2010. After 2011, we use original downloaded data. Before 2010, we use monthly yoy growth to backcast the industrial production index. Monthly data is aggregated by quarter to get quarterly data.

Consumption, investment, electricity production and railway freight.

Year-to-date (YTD) values of these four variables are published monthly by NBS. Quarterly data are calculated as the differences of adjacent quarterly YTD data.

Import Values

RMB-denominated import value data is published monthly by the General Administration of Customs of the People's Republic of China (GACC). Monthly data is aggregated by quarter to get quarterly data.

Inflation

The NBS publishes monthly CPI and PPI indices, which are adjusted every 5 years. As the current base year is 2015, after 2016 we use original data from NBS. Before 2015, we use monthly yoy growth to calculate the inflation index reading. Monthly data is aggregated by quarter to get quarterly data.

M2 growth

The PBC publishes M2 on a monthly basis, with periodic adjustments. There will be jumps in data if we use original data due to these adjustments. As for inflation, for 2019 we use original broad monetary aggregate from PBC. Before 2019, we use monthly yoy growth to calculate the series. Monthly data is aggregated by quarter to get quarterly data.

Interest rates

The China Foreign Exchange Trade System first published the Loan Prime Rate in October 2013. We aggregate original monthly data to get quarterly data after 2013Q4. For the simpler model, we splice this data with the 1-year benchmark lending rate published by the PBC to backcast the series before 2013Q4. The weighted average loan rate, in turn, starts only in 2008Q3. Prior to that, we splice the series with the 1-year benchmark lending rate. As loan rates were less liberalised in the early years of our sample, this substitution should provide a reasonable approximation to actual borrowing rates over this period.

Seasonal adjustment

We use the JDemetra+ package to seasonally adjust the variables in this paper. We use an automatic model selection procedure to determine the optimal form of seasonal adjustment for each series. We use the longest available sample to conduct the seasonal adjustment.

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