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Qianying Chen, Michael Funke and
Michael Paetz

Market and non-market monetary
policy tools in a calibrated DSGE
model for mainland China



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Market and Non-Market Monetary Policy Tools in a Calibrated DSGE Model for Mainland China

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Abstract

Monetary policy in mainland China differs from conventional central banking in several respects. The central bank regulates retail lending and deposit rates, influences the credit supply via window guidance, and, in recent years has even used the required reserve ratio as a tool for fine-tuning monetary policy. This paper develops a New Keynesian DSGE model to captures China's unconventional monetary policy toolkit. We find that credit quotas are important as the interest-rate corridor distorts the efficient reactions of the economy. Moreover, for China's central bankers the choice of a particular monetary policy tool or a the appropriate combination of instruments depends on the source of the shock.

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1 Introduction

There has been remarkable progress over the past ten years in the specification and estimation of dynamic stochastic general equilibrium (DSGE) models. The recipe for success of DSGE models lies their ability to combine rich structural macro models with novel numerical algorithms and simulation techniques. Woodford (2009) sees an emerging macroeconomic consensus today that embodies five elements: (i) the notion that macroeconomic models should incorporate a coherent set of intertemporal general-equilibrium foundations; (ii) that quantitative policy advice should be based on econometrically validated structural models; (iii) that expectations should be modelled as rational and endogenous with respect to monetary policy; (iv) that real disturbances and nominal rigidities are important sources of short- and medium-run fluctuations; and (v) that monetary policy is effective, especially as a means of controlling inflation.¹

China's monetary policy somewhat defies this consensus in that it employs a wide variety of non-market policy instruments, including the setting of administered deposit and minimum lending rates, as well as quantitative measures such as reserve requirements, lending quotas and "window guidance." China's unconventional approach to monetary policy includes three notable particularities. First, the People's Bank of China (PBoC) not only controls the policy rate, it regulates the retail lending rate and the deposit rate. Second, the PBoC uses non-market tools such as loan quotas and window guidance, which essentially involves telling banks how to do their jobs. Just as window guidance influences the direction of lending, China's quantitative credit quotas are important (at least aspirationally) in regulating the amount of credit. Unfortunately, these quantitative targets can be just as elusive in China as elsewhere: quantitative monetary and credit targets have in recent years almost always exceeded the PBoC's intended limit. Third, the required reserve ratio, rarely invoked as a policy instrument by Western-type central banks, has uniquely become an important tool for the short-run fine-tuning of monetary policy in China over the last decade.

Since the aim of this paper is to shed light on the explicit design of monetary policy over this successful decade, we modify some of the latest DSGE models on banking to fit the Chinese context. So far, this strand of research can be divided into papers that introduce a variety of financial assets with differing returns (e.g. Christiano et al. (2010) or Goodfriend and McCallum (2007)), and those that assume a banking sector under monopolistic competition, resulting in a mark-up of banking interest rates over the policy rate and a sluggish interest rate adjustment (e.g. Gerali et al. (2010)). Our view is that neither of these approaches suit the unconventional monetary policy in China. Following the work of He and Wang (2011) and Chen et al. (2011), who investigate a partial equilibrium model for the banking sector

¹See, for example, the 50 DSGE models collected on the Macro Model Data Base website: <http://www.macromodelbase.com/>.

when credits and interest rates are regulated by the central bank, we implement their partial-equilibrium modelling work in a fully specified DSGE framework to analyze the effect on inflation and output.

The remainder of this paper is organized as follows. The next section illustrates monetary policy in mainland China over the last decade. Section 3 describes the analytical DSGE model, while section 4 presents model calibrations to demonstrate the model's properties. We conclude by applying the modelling tool to study the role of unconventional monetary policy in China. The final section concludes.

2 Monetary policy in mainland China

Officially, the mandate of the PBoC is to maintain currency stability and thereby promote economic growth. In contrast to the central banks in advanced economies, the PBoC has little independence from the central government. Decisions on monetary policy are generally made by the State Council.

To achieve the ultimate target of price stability and economic growth, the PBoC has set up a group of intermediate targets. The main intermediate target is the growth of the money aggregate. In 1994, the PBoC announced the growth of M1 and M2 as the official targets and has published target values ever since.² Another intermediate target is the growth of domestic bank credit, which is released together with the target for aggregate money. The PBoC is also responsible for maintaining the profitability of commercial banks in the Chinese banking system. As a result, the minimal profit margin, i.e. the difference between the highest deposit rate and the lowest lending rate is controlled [Geiger (2006)]. The PBoC also seeks stability of the exchange rate. Up to 2005, the renminbi (RMB) was pegged to the US dollar at a fixed rate. Currently, PBoC uses a managed floating exchange rate regime, i.e. the RMB is allowed to fluctuate within upper and lower bounds of a reference currency basket.

Why does the PBoC set multiple intermediate targets, which, at first glance, seem difficult to achieve simultaneously?

At least part of the explanation is historical. China opted for a gradual approach to transition from a planned economy in which the state allocates resources, distributes goods and sets prices to a market economy where prices are determined by the market. Similarly, the Chinese monetary policy framework has gradually evolved since 1978, when China began its transition to a market economy. The starting point was a system where the PBoC set loan quotas for all economic sectors and allocated credit to enterprises through its central branches in each province. In the 1980s, interest rates were still set by the central bank, but as commercial banks were established, the PBoC turned to setting credit plans for individual commercial banks, leaving room for banks to adjust their lending to reflect economic conditions [Zhang (2011)]. In the late 1990s, the PBoC further relaxed its direct control of

²However, the PBoC stopped publishing targets for M1 in 2007.

credit allocation and moved to indirect management of money supply by setting the M2 growth as a nominal anchor of monetary policy and directing retail lending. Commercial banks gradually gained freedom to set their own interest rates for deposits and loans. The flexibility of the RMB exchange rate gradually increased. Thus, China's economic transition provides the backdrop for the emergence of the PBoC's approach based on multiple intermediate targets, as well as a regulatory and macro-management framework where the central bank uses a broader variety of instruments than its international peers in conducting monetary policy .

The monetary policy instruments used by the PBoC can be grouped into two categories. The first includes market-based instruments. Some are commonly used in the advanced economies such as open market operation and central bank lending; others less so, e.g. the required reserve ratio (RRR).³ The second category is made up of residual non-market based instruments from the planned economy. These include regulated interest rates for deposits and retail lending, as well as window guidance for retail bank lending. RRR and this second group of instruments are actively used by PBoC.

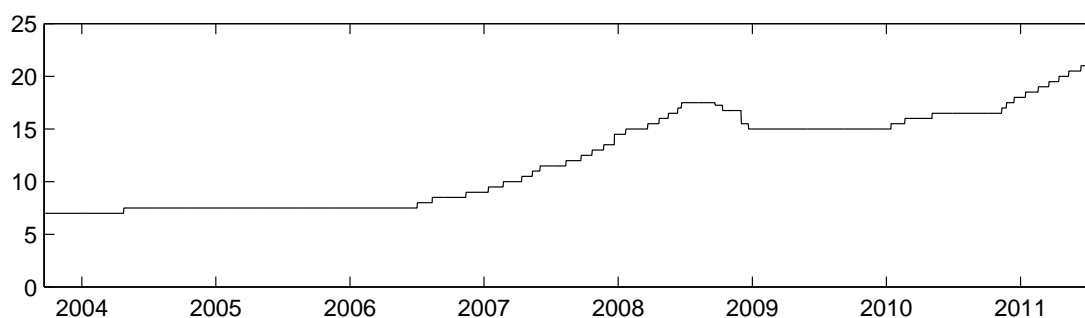
The PBoC has actively used the RRR since the mid-2000s (see Figure 1). In terms of policy adjustment, RRR belongs to the most intensively deployed instruments.⁴ From July 2006 to April 2011, the PBoC adjusted the RRR 33 times, typically in 50-basis-point increments. The RRR level doubled from late 2006 to the end 2008. It currently exceeds 20 % [Ma et al. (2011)], which is very high by international standards. The PBoC introduced in 2004 a differentiated RRR based on an individual bank's capital adequacy and asset quality. In 2011, the PBoC debuted the "dynamic differentiated RRR," which sets the allowed monthly variation for a bank-specific RRR. Increasingly alarmed by economic overheating, the PBoC raised RRRs several times during 2011. Periodic RRR changes have also been used for other policy purposes. For example, RRR changes have been used to sterilize foreign reserve inflows and drain excess liquidity from the system.

The benchmark deposit rate and lending rate (the ceiling interest rates bank pay for deposits and the floor of the rates banks earn from loans, respectively) act as monetary policy instruments as well. Banks are not allowed to attract deposits at a rate exceeding the benchmark deposit rate or lend at a rate below 90 % of the lending rate. The PBoC began its interest rate deregulation in the late 1990s, starting with the interbank lending rates and bond yields, as well as interest rates on foreign currencies. Between 1998 and 2004, the ceiling rate for retail lending was gradually lifted. In October 2004, both the lending rate ceiling and the deposit rate floor were removed. Commercial bank lending rates are presently subject to a

³Kashyap and Stein (2012) recently analyzed the scope of reserve requirements in pursuing two objectives: the inflation-output trade-off and the externalities created by excessive debt issuance. Other important contributions analyzing reserve requirements include Reinhart and Reinhart (1999), Cúrdia and Woodford (2011) and Glocker and Towbin (2012).

⁴The PBoC has greater freedom and tactical discretion in applying RRR changes than adjusting benchmark interest rates, which requires approval of the State Council.

Figure 1: Required Reserve Ratio (%)



Source: CEIC Database

floor, and deposit rates to a ceiling (Figure 2 and Table 1).⁵ The deposit rate ceiling is generally considered binding as actual deposit rates tend to cluster around the benchmark rate [He and Wang (2011)]. It is more difficult to judge if the floor for the lending rate is binding or not. In any case, the PBoC plans to further liberalize the interest rates by gradually phasing out the benchmark deposit and lending rates, i.e. move to a more market-based monetary policy implementation framework.

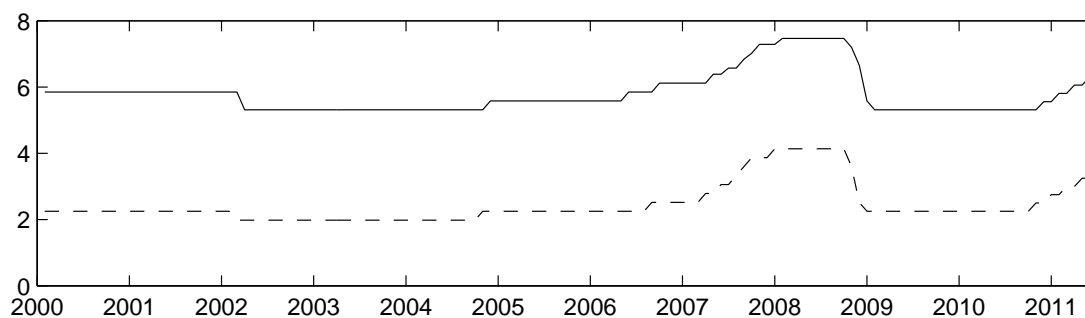
The PBoC also controls bank credit through its administrative window guidance policy on retail bank lending.⁶ This quantity-based non-price instrument is an important tool in the conduct of monetary policy and can be understood as gentle coercion through formal statements or private discussions.⁷ The PBoC regularly reports on its window guidance in its Quarterly Monetary Policy Reports. Under this policy, the PBoC, in cooperation with the China Banking Regulatory Commission (CBRC), persuades banks to lend according to the guideline. The guidance typically covers the level of loan growth and sectors to which bank lending should be directed. Recently, the PBoC has intensified the window guidance policy by laying down quarterly quota for banks. Using window guidance rather than interest rates to steer credit seems natural; China lacks a well-developed money market, making fine-tuning via short-term money market rates impracticable. One reason window guidance is so effective is that the senior personnel in the state-owned banks are appointed by the central government. Diverging from the guidance is likely to be

⁵Mortgage lending is also regulated by the PBoC. Mortgage interest rates have to be adjustable and are linked to the commercial lending rate. Rates are adjusted at the beginning of each year.

⁶The Japanese window guidance policy in the mid-1950s may serve as a template for the current PBoC policy. The Bank of Japan incorporated window guidance into its policy framework when interest rate steering alone proved unsuccessful in curbing a surge in lending. Japanese window guidance measures were abolished in 1991.

⁷Despite its soft image, there has been no case where a commercial bank has refused guidance since the penalty for disobeying window guidance was announced. For example, the China Monetary Policy Report (Quarter Four, 2009) states: "(the PBoC) issued special central bank bills to commercial banks with relatively rapid credit extension to encourage them to pay attention to a stable and proper increase in credit." Also see Laurens and Maino (2009).

Figure 2: 1-year benchmark deposit and lending rates



Solid line: Base lending rate (working capital, 1 year), **Dashed line:** Time deposit interest rate (lump-sum deposit and withdrawal, 1 year).

Source: CEIC Database

Table 1: Share of commercial loans issued at different rates

	Floating downward [90% to 100% of benchmark]	At regulated level [100% benchmark]	Floating upward [above benchmark]
2004	22.02	26.83	51.16
2005	21.67	24.99	53.34
2006	24.71	27.01	48.28
2007	27.6	27.83	44.57
2008	22.89	31.22	45.9
2009	29.53	32.32	38.15
2010	29.76	30.61	39.63

Source: Chen et al. (2011)

costly for bankers concerned about their career path. The PBoC also wields the threat of fining a bank that violates its credit limits. Another reason for steering bank lending is that it is often the main source of funding for Chinese firms. Bank lending accounts for over 70 % of official funding for corporations [Liu and Zhang (2010) and Zhang (2011)]. However, this ratio is declining along with the development of markets for direct finance. Table 2 shows the annual target for new RMB loans and realised loans. The gaps between loan targets and their respective actual values are eye-catching. In five out of six years, actual bank lending exceeded the target level set by the PBoC. In recent years, credit targets have also often been exceeded.⁸

The descriptive evidence presented suggests important interlinkages between various monetary policy instruments. To build a unified theoretical framework for analysis, we incorporate the atypical instruments and monetary policy transmission

⁸Lending surged after lending quotas were abolished in 2009 as part of economic stimulus policies. The move generated abundant liquidity.

Table 2: Target and actual levels of new loans (RMB trillion)

Year	Target	Actual
2005	2.5	2.4
2006	2.5	3.2
2007	2.9	5.3
2008	3.6	5.0
2009	4.6	9.6
2010	7.5	8.0

Source: *China Monetary Policy Report*, PBoC (2005-2010)

channels outlined above in a dynamic macroeconomic framework. This requires a range of enhancements in our DSGE modelling to overcome some specific challenges.⁹

3 The model

We now lay out a medium-scale New Keynesian DSGE model to reflect the Chinese monetary policy framework described above. To our knowledge, this contribution is novel to the literature. To keep the focus on the PBoC's unconventional monetary policy tools, we build a simple two-household closed economy model in the spirit of Iacoviello (2005). Instead of introducing a housing sector, however, we enrich the model with a private banking sector restricted by the guidelines of the central bank.

Following the seminal work of Kiyotaki and Moore (1997) on credit cycles, households are divided into patient and impatient groups. In our model, impatient households are modelled as entrepreneurs and denoted with the superscript E . Impatient households take loans from private banks that, in turn, buy and sell bonds from the central bank and borrow deposits from patient households (denoted with P). Private banks can also trade financial assets with institutional investors in the interbank market. The entrepreneurs in the impatient household group produce intermediate goods to sell in the retail sector. This sector has some monopoly power and sets prices in a staggered manner.

Finally, we describe the problem faced by each economic agent, showing the corresponding optimality conditions and the shocks that perturb these conditions.

⁹A search on Google Scholar finds 147 papers with "Monetary Policy China" in the title over the period 2008-2011. Notably, no studies examine a mixture of price- and quantity-based monetary policy tools in a DSGE context. Instead, China's monetary policy transmission channels are treated as a black box [e.g. Liu and Zhang (2010)]. In other words, earlier studies largely sidestep the thorny issue of assessing a regime that incorporates both price- and quantity-based monetary policy tools. This is a bit surprising given the widespread interest in how China actually implements monetary policy.

Together with market-clearing conditions, these relationships characterize the equilibrium behaviour of the model setup.

3.1 Patient households

A domestic representative patient household is allowed to hold deposits D_t at private banks, which yield a net return of r_t^D . Consequently, a household chooses sequences for consumption (C_t^P), labour supply (N_t) and deposits to maximize

$$\mathbb{E}_0 \left\{ \sum_{t=0}^{\infty} \beta_p^t \mathcal{V}_t \left[\frac{1}{1 - \sigma_P} (C_t^P)^{1 - \sigma_P} - \frac{1}{1 + \varphi} N_t^{1 + \varphi} \right] \right\}, \quad (1)$$

subject to a sequence of dynamic budget constraints (in real terms)

$$C_t^P + D_t = \frac{R_{t-1}^D D_{t-1}}{\Pi_t} + \frac{W_t}{P_t} N_t + F_t^R + F_t^B, \quad (2)$$

where W_t , P_t , F_t^R and F_t^B represent the nominal wage rate, the consumption price index (CPI), and real lump-sum profits received from the retail and the banking sector, respectively.¹⁰ \mathbb{E}_t is the expectation operator at time t . For simplicity we assume that consumption and labour supply are separable in the utility function. Moreover, the gross interest rate on deposits is given by $R_t^D = (1 + r_t^d)$, and the consumer price inflation is defined as $\Pi_t \equiv \frac{P_t}{P_{t-1}}$. The parameters σ_p and φ represent the inverse intertemporal elasticity of substitution with respect to consumption and labour supply, respectively, and β_P is the discount factor of patient households. We also add an intertemporal preference shock $\mathcal{V}_t \equiv \exp(\nu_t)$, reflecting shifts in the marginal utility of consumption.

In equilibrium, the conventional optimality conditions may be stated as (2), the Euler equations, and the optimal labour-leisure decision:

$$\frac{1}{1 + r_t^D} = \beta_p \mathbb{E}_t \left[\left(\frac{C_{t+1}^P}{C_t^P} \right)^{-\sigma_p} \frac{P_t}{P_{t+1}} \frac{\mathcal{V}_{t+1}}{\mathcal{V}_t} \right], \quad (3)$$

$$\frac{W_t}{P_t} = (C_t^P)^{\sigma_p} N_t^\varphi. \quad (4)$$

3.2 Entrepreneurs

Entrepreneurs are essential agents of the model, since they demand bank loans from private banks L_t , which they partly invest to accumulate capital. A representative entrepreneur chooses the amount of consumption (C_t^E), capital (K_t), loans (L_t), labour demand (N_t), and investments (I_t) to maximize

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta_e^t \mathcal{V}_t \frac{1}{1 - \sigma_e} (C_t^E)^{1 - \sigma_e},$$

¹⁰Deposits are measured in real terms, denominated with the consumer price index. Real lump-sum profits are described below.

subject to the following constraints:

$$C_t^E + \frac{W_t}{P_t} N_t + \frac{R_{t-1}^l}{\Pi_t} L_{t-1} + I_t + \mathcal{A}_t = \frac{Y_t}{X_t} + L_t, \quad (5)$$

$$K_t = (1 - \delta) K_{t-1} + I_t, \quad (6)$$

$$Y_t = A_t K_{t-1}^\alpha N_t^{1-\alpha}, \quad (7)$$

where $R_t^l \equiv (1 + r_t^l)$ represents the gross retail lending rate, $A_t \equiv \exp(a_t)$ represents labour-augmenting productivity, and a_t is an exogenous disturbance.¹¹ In addition, Y_t and X_t represent real output and the mark-up of final over intermediate goods.¹² The constraints of entrepreneurs are the usual flow budget constraint (5), the capital accumulation (6), and a Cobb-Douglas production function (7) for intermediate goods. The parameters δ and α represent the depreciation rate for capital and the input share of capital in the production process, respectively. Moreover, convex adjustment costs for installing new capital goods are given by $\mathcal{A}_t \equiv \psi \left(\frac{I_t^l}{K_{t-1} \mathcal{U}_t^I} - \delta \right)^2 \frac{K_{t-1}}{2\delta}$, where $\mathcal{U}_t^I \equiv \exp(u_t^i)$ represents a cost decreasing investment shock. Convex adjustment costs are important in models with sticky prices to prevent implausibly large movements in the capital stock after exogenous shocks.

In equilibrium the dynamics of consumption, capital, investments and labour demand are determined by (5) - (7) and

$$\frac{1}{1 + r_t^l} = \beta_e \mathbb{E}_t \left[\left(\frac{C_{t+1}^E}{C_t^E} \right)^{-\sigma_e} \frac{P_t}{P_{t+1}} \frac{\mathcal{V}_{t+1}}{\mathcal{V}_t} \right], \quad (8)$$

$$\begin{aligned} v_t &= (C_t^E)^{-\sigma_e} \left(\frac{\psi}{\delta} \left(\frac{I_t}{K_{t-1} \mathcal{U}_t^I} - \delta \right) \frac{I_t}{K_{t-1} \mathcal{U}_t^I} - \frac{\psi}{2\delta} \left(\frac{I_t}{K_{t-1} \mathcal{U}_t^I} - \delta \right)^2 \right) \\ &\quad + \beta_e \mathbb{E}_t \left((C_{t+1}^E)^{-\sigma_e} \frac{\alpha Y_{t+1}}{K_t X_{t+1}} + (1 - \delta) v_{t+1} \right), \end{aligned} \quad (9)$$

$$\frac{W_t}{P_t} = (1 - \alpha) \frac{Y_t}{X_t N_t} \quad (10)$$

where the shadow price of capital is given by $v_t \equiv (C_t^E)^{-\sigma_e} \mathcal{V}_t \left[\left(1 + \frac{\psi}{\delta} \left[\frac{I_t}{K_{t-1} \mathcal{U}_t^I} - \delta \right] \right) \right]$. According to (8) the entrepreneur's consumption dynamics follow a similar Euler equation as consumption of patient households does. As emphasized in Iacoviello (2005) equation (9) equalizes the shadow price of capital to the sum of (i) the capital's marginal product next period, (ii) the capital contribution to lower installation costs, and (iii) the shadow value of capital next period. The last optimality condition is a conventional labour demand curve.

¹¹Loans and investments are measured in real terms, denominated with the consumer price index. All other variables and parameters are defined in the same fashion as in section 3.1.

¹²Similar to Bernanke et al. (1999), we assume that retailers purchase the intermediate goods from entrepreneurs at a retail price and transform it into a final good.

3.3 Retailers

For the modelling of a retail sector we one-by-one pick the framework of Bernanke et al. (1999) and Iacoviello (2005), who assume that retailers of mass one have some monopoly power and set prices in a Calvo-staggered manner. Hence, a randomly selected fraction $(1 - \theta)$ adjusts prices while the remaining fraction θ does not adjust. Moreover, only a fraction of $(1 - \tau)$ firms sets prices in a forward-looking way and the remaining fraction τ sets prices according to the recent history of inflation.¹³

All forward-looking entrepreneurs, that reset prices in t , choose the same price P_t^{fl} as they face the same optimization problem. This leads to the conventional price-setting rule in Calvo context:

$$p_t^{fl} = \mu_t + (1 - \beta\theta) \sum_{i=0}^{\infty} (\beta\theta)^i \mathbb{E}_t \left(p_{t+i} - \frac{(1 - \alpha)\mu}{\mu + \alpha} x_{t+i|t} \right), \quad (11)$$

where μ_t captures the time-varying net mark-up of prices over marginal costs costs (i.e. cost-push shock), $x_{t+i|t}$ represents the mark-up of final goods over intermediates in $t + 1$ for a firm set reset prices in t , and μ refers to the equilibrium net mark-up.

Defining the domestic index for the prices newly set in period t (\bar{P}_t^n) as a weighted average of adjusting and non-adjusting firms, and assuming a rule of thumb for the backward-looking price-setters, $p_t^{bl} = p_{t-1}^n + \pi_{t-1}$, where $\pi_t = \ln \left(\frac{P_t}{P_{t-1}} \right)$, the aggregate price level is given by

$$P_t = \left[\theta P_{t-1}^{1-\theta} + (1 - \theta) (\bar{P}_t^n)^{1-\theta} \right]^{\frac{1}{1-\theta}}, \quad (12)$$

$$p_t^n = (1 - \tau) p_t^{fl} + \tau p_t^{bl}, \quad (13)$$

Scattered price adjustment implies that some firms produce below their optimal allocation, causing a distortion in output and reduction in welfare. These welfare losses are directly related to the size of the gap between output in the sticky price model and the level of output that would occur with flexible prices. Finally, we assume that profits $F_t = (1 - 1/X_t) Y_t$ are rebated to patient households.

3.4 Private banks

The banking sector of the model is based on the partial-equilibrium modelling work of He and Wang (2011) and Chen et al. (2011) of a Chinese banking sector and Gerali et al. (2010), who implemented a banking sector in a DSGE framework. More precisely, we embed those ingredients from the first two papers that are needed to analyze Chinese monetary policy into the wholesale banking branch introduced in

¹³In its recent struggle to suppress inflationary pressures, China announced plans to curb price hikes on a range of goods from instant noodles to milk, describing the action as a temporary intervention to stem surging inflation. The government has long set prices for oil and electricity and has pledged to freeze them at current levels. Calvo price-setting therefore also reflects administered prices in China.

Gerali et al. (2010). However, we refrain from introducing banking capital or a retail branch to keep the focus on the transmission of Chinese monetary policy. The banking sector determines the demand function for deposits and excess reserves and the supply function for loans, taking all interest rates as given. The deposit and lending rates are thus market-determined as long as the guidelines of the central bank are not binding.

The intertemporal optimization problem A representative private bank chooses the amount of loans and deposits, excess reserves (E_t) deposited at the central bank, and borrowings from the interbank market. In addition, banks are constrained by the guidelines of the monetary authority. We assume that deviations of actual credits from the target of the central bank (L_t^{cb}) induce costs, given by $\frac{\kappa}{2} (L_t - L_t^{cb})^2$. Moreover, we assume quadratic management costs for loans, deposits, and excess reserves: $\mathcal{C}_t = \frac{1}{2} (c_d [(1 - \eta_t) D_t]^2 + c_l L_t^2 + c_e E_t^2)$. Hence the representative bank seeks to maximize the discounted sum of cash flows

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta_b^t \left\{ \begin{array}{l} (1 + r_t^l) L_t - L_{t+1} + (1 + r_t^e) E_t - E_{t+1} \\ - [(1 + r_t^d) - \eta_t (1 + r_t^r)] D_t + (1 - \eta_t) D_{t+1} - (1 + r_t^{ib}) IB_t \\ + IB_{t+1} - \frac{\kappa}{2} (L_t - L_t^{cb})^2 - \frac{1}{2} (c_d [(1 - \eta_t) D_t]^2 + c_l L_t^2 + c_e E_t^2), \end{array} \right\} \quad (14)$$

subject to a flow budget constraint,

$$IB_t + (1 - \eta_t) D_t = L_t + E_t, \quad (15)$$

where IB_t and η_t represent net borrowings from the interbank market and the required reserve ratio, and r_t^{ib}, r_t^e, r_t^r and β_b represent the interbank interest rate, and the interest rates on excess reserves and minimum reserves, and the banking sector's discount factor, respectively.

By substitution of the bank's budget constraint, the problem can be reduced to a period-by-period maximization of profits,

$$\begin{aligned} F_t^B &\equiv (r_t^l - r_t^{ib}) L_t + (r_t^e - r_t^{ib}) E_t - (r_t^d - \eta_t r_t^r - (1 - \eta_t) r_t^{ib}) D_t \\ &\quad - \frac{\kappa}{2} (L_t - L_t^{cb})^2 - \frac{1}{2} (c_d [(1 - \eta_t) D_t]^2 + c_l L_t^2 + c_e E_t^2), \end{aligned} \quad (16)$$

which are rebated to patient households. In an optimum, the amount of loans, excess reserves, deposits and net borrowings from the interbank market are chosen, so that marginal benefits from these assets are equalized to the opportunity costs of holding them:

$$r_t^l = r_t^{ib} + c_l L_t + \kappa (L_t - L_t^{cb}), \quad (17)$$

$$r_t^e = r_t^{ib} + c_e E_t, \quad (18)$$

$$r_t^d = \eta_t r_t^r + (1 - \eta_t) r_t^{ib} - c_d (1 - \eta_t)^2 D_t. \quad (19)$$

According to (17) and (18) opportunity costs for loans and excess reserves are given by the sum of the interbank rate, management costs and costs for deviating from

the central bank loan target. Equation (19) illustrates that the opportunity costs for deposits depend on a weighted average of the yield on reserves (due to the required reserve ratio), the interbank rate, and the management costs for deposits. To close the banking side of our model, we follow Gerali et al. (2010) and assume, that banks have unlimited access to a lending facility at the central bank. Thus, arbitrage ensures, that the interbank rate equals the policy rate ($r_t^{ib} = r_t$).

PBoC interest rate corridor Loan and deposit rates are restricted by the guidelines of the central bank: $r_t^l \geq r_t^{l,cb}$, $r_t^d \leq r_t^{d,cb}$. For loans, the market rate that would prevail without constraints is derived by equating the private bank's supply of loans (17) to entrepreneur demand, which is implicitly given by (5). Following this logic, market deposit rates are determined by equating the bank's demand for deposits (19) with the household's supply, implicitly given by (2). Technically, due to the restrictions of the monetary authority, the actual lending and deposit rates are given by

$$r_t^l = \max \left(r_t^{l,cb}, r_t^{l,pb} \right), r_t^d = \min \left(r_t^{d,cb}, r_t^{d,pb} \right), \quad (20)$$

where $r_t^{l,pb}$ and $r_t^{d,pb}$ represent the market rates, determined by (17) and (19). These one-sided constraints induce asymmetric business cycle effects that are not fully captured by conventional linear approximation methods. Thus, standard analytical DSGE approaches appear unfit for the analysis of Chinese monetary policy.

3.5 Monetary policy

To tie macroeconomic performance to policy variables and reflect the particularities of Chinese central banking mentioned above, we enhance the description of the conventional monetary policy toolkit.

First, conventional monetary policy follows a Taylor-type rule:

$$r_t = \phi_\pi \pi_t + \phi_y y_t + \phi_r r_{t-1}, \quad (21)$$

where the ϕ 's reflect the preferences of the central bank with respect to inflation and output gap stabilization, and the smoothing of interest rate dynamics, respectively.¹⁴ This rule implies that if inflation and/or output growth rise above (fall below) their baseline levels, then the interest rate is lifted (lowered) at a rate that depends on the coefficient ϕ_r .

Deposit and lending rate guidelines form a corridor around the policy rate. Thus, in terms of deviations from equilibrium the reaction of both rates should be equal. We assume that the central bank sets interest rates according to

$$r_t^{d,cb} = (1 - \phi_r^d) r_t + \phi_r^d r_{t-1}^{d,cb}, \quad (22)$$

¹⁴In the following discussion, all lower-case letters are percentage deviations of their upper-case counterparts, except interest rates, RRR and the inflation rate, which are measured in absolute deviations.

$$r_t^{l,cb} = (1 - \phi_r^l) r_t + \phi_r^l r_{t-1}^{l,cb}, \quad (23)$$

where ϕ_r^l and ϕ_r^d represents preference parameters for smoothing the lending and deposit rate guidelines, respectively.

In addition, the central bank influences the credit supply via window guidance. The use of credit quotas is primarily directed at preventing excessive credit growth. Hence, we assume that the loan targets of the central bank follow a Taylor-type rule of the form

$$l_t^{cb} = - (1 - \phi_l^{cb}) (\phi_l^\pi \pi_t + \phi_l^y y_t) + \phi_l^{cb} l_{t-1}^{cb}. \quad (24)$$

According to (24) loans are restricted to slower growth if inflation or the output gap are positive, in order to cool down the economy. Moreover, ϕ_l^π and ϕ_l^y determine the strength of the reaction with respect to inflation and output, while ϕ_l^{cb} determines the persistence of the reaction, respectively. In a nutshell, the PBoC tries to smooth real activity by smoothing loan growth.¹⁵

For the RRR, we assume a rule that depends on inflation. By including inflation in the policy rule, the PBoC is assumed to endogenously adjust the RRR according to:

$$\eta_t = (1 - \phi_\eta^\eta) \phi_\eta^\pi \pi_t + \phi_\eta^\eta \eta_{t-1}. \quad (25)$$

Finally, we assume that the interest rates on excess reserves and required reserves passively follow the policy rate: $r_t^e = r_t^r = r_t$. Equations (21) - (25) describing the essence of Chinese monetary policy close the circle, giving us a complete model. At the same time, equations (21) - (25) clearly deviate from the policy rule which is assumed in almost all variants of existing DSGE models.

3.6 The linearized model

The equations describing the behaviour of households, firms, and the PBoC combine to form a nonlinear system describing the model's equilibrium. By applying a market clearing condition ($Y_t = C_t^E + C_t^P + I_t$), the complete linearised model can be described by the following equations:

$$\begin{aligned} y_t &= \gamma_{ce} c_t^e + \gamma_{cp} c_t^p + \gamma_i i_t, \\ c_t^p &= \mathbb{E}_t c_{t+1}^p - \sigma_p^{-1} (r_t^d - \mathbb{E}_t \pi_{t+1} - (1 - \rho_{\nu^p}) \nu_t^p), \\ \omega_t &= \sigma_p c_t^p + \varphi n_t, \\ c_t^e &= \mathbb{E}_t c_{t+1}^e - \sigma_e (r_t^l \mathbb{E}_t \pi_{t+1} + \mathbb{E}_t \Delta \nu_{t+1}), \end{aligned}$$

¹⁵A particular adverse effect of window guidance deserved mention. The occurrence of credit rationing with a failure in the functioning of interest rate adjustments is undesirable in terms of the efficiency of capital allocation across Chinese firms. In the presence of lending limits, banks may keep lending to large state-owned enterprises while curtailing lending to efficient private firms. This resource misallocation lowers aggregate total factor productivity (TFP). Hsieh and Klenow (2009) have calculated manufacturing TFP gains of 30%-50% in China in capital and labour were hypothetically reallocated to equalize marginal products.

$$\begin{aligned}
\gamma_c^e c_t^e &= \frac{1}{1+\mu} (y_t - x_t) + \gamma_l l_t - \frac{1-\alpha}{1+\mu} (w_t + n_t) - R^L \gamma_l (r_{t-1}^l - \pi_t + l_{t-1}) - \gamma_t i_t, \\
k_t &= (1-\delta) k_{t-1} + \delta i_t, \\
i_t &= u_t^i + k_{t-1} + \beta_e (i_{t+1} - \mathbb{E}_t u_{t+1}^i - k_t) + \frac{1-\beta_e(1-\delta)}{\psi} (y_{t+1} - x_{t+1} - k_t) \\
&\quad + \frac{\sigma}{\psi} (c_t^e - \mathbb{E}_t c_{t+1}^e - (1-\rho_\nu^e) \nu_t^e), \\
y_t &= a_t + \alpha k_t + (1-\alpha) n_t, \\
\omega_t &= y_t - n_t - x_t, \\
\pi_t &= \Phi (\theta \beta_p \mathbb{E}_t \pi_{t+1} + \tau \pi_{t-1}) - \lambda x_t + u_t^\pi, \\
R^L r_t^l &= R r_t - \kappa L l_t^{cb} + (c_l + \kappa) L l_t, \\
R^D r_t^d &= [R^r - R + 2c_d D (1-\eta)] \eta_t + \eta R^R r_t^r + (1-\eta) R r_t - c_d (1-\eta)^2 D d_t, \\
R^E r_t^e &= R r_t + c_e E e_t, \\
\gamma_l l_t &= (1-\eta) \gamma_d d_t - \gamma_D \eta_t - \gamma_e e_t,
\end{aligned}$$

where $\lambda = (1-\tau)(1-\theta)(1-\beta_p\theta)\Phi$, $\Phi = (\theta + \tau[1-\theta(1-\beta_p)])^{-1}$, and $u_t^\pi = \lambda\mu_t$ represents a cost-push shock. All variables without time index represent equilibrium values and all γ_j 's represent equilibrium fractions of variable J over GDP.¹⁶ The model is closed by the monetary policy reaction functions described in (21) - (25). All real variables are measured in percentage deviations from equilibrium, the inflation rate, all interest rates and the required reserve ratio are measured in absolute deviations from equilibrium.

The model presented above yields a fully state-contingent plan for the agents' choice variables. It introduces modern analytical tools built on microeconomic foundations and agents' intertemporal choices to allow formal analysis of Chinese monetary policy.¹⁷

4 Model calibration and simulations

4.1 Calibration

To simulate the DSGE model, we need to cross the minefield of calibration. As methodological issues related to calibration are not the focus of this paper, we take a pragmatic stance. Parameter values are specified on a quarterly model. Some parameters are relatively inconsequential, others central. We set discount

¹⁶Details on the derivation of equilibrium values are given in Appendix A.

¹⁷Despite the dominance of the DSGE modelling approach in the business cycle literature, various authors have recently expressed concerns about the DSGE straightjacket [see, for example, Caballero (2010), Fuster et al. (2010), Manski (2011) and Pesaran and Smith (2011)]. One criticism is that complex policy decision making with various nested instruments in a DSGE framework raises difficulties. In contrast, the model presented above shows that the DSGE framework possesses a high degree of adaptability to account for a decidedly different and unique monetary policy design and to address questions that policymakers confront in practice.

factors of patient households and entrepreneurs to $\beta_p = 0.995$ and $\beta_e = 0.985$, which correspond to equilibrium annual net interest rates of 2% and 6%, respectively. As illustrated in Figure 2, these values are in line with empirical observations over the last years. As shown in the appendix, the cost parameters and the remaining interest rates on required and excess reserves pin down the equilibrium policy rate. Hence, we calibrate those parameters to imply plausible steady state interest rates: $c_l = c_e = 1$, $c_d = 2$, and $R^E = R^R = 1.009$. This results in an annualised net policy rate of 3.36% in equilibrium. This calibration also ensures a positive steady-state value for excess reserves, which is below the equilibrium amount of loans deposited at the central bank as required reserves. We calibrate the RRR to 10% in line with the actual RRR of recent years (see Figure 1).

For most other parameters we use a standard calibration. We set the intertemporal elasticities of substitution in both sectors to $\sigma_p = \sigma_e = 1$, which refers to the case of logarithmic utility. Moreover, the inverse of the Frisch elasticity is set to $\varphi = 1/3$. Such a value is in line with microeconomic estimates of e.g. MaCurdy (1981). For firms, we assume a fraction of backward-looking price setters of $\tau = 0.2$, and calibrate the Calvo parameter to $\theta = 0.75$, implying an average adjustment of prices every year. To ensure a high equilibrium investment share (a typical feature of the Chinese economy), we set the output elasticity of capital to $\alpha = 0.5$, and the steady state net mark-up to $\mu = 10\%$, resulting in a steady state investment share of 45%.¹⁸ On the investment side, we follow Iacoviello (2005) and set the depreciation rate of capital and the adjustment cost parameter to values of $\delta = 0.03$ and $\psi = 2$. The equilibrium deposit-to-output ratio is set to 0.5 to ensure that the entrepreneurs' steady state consumption-to-output ratio is positive.¹⁹

While the GMM estimations of Mehrotra et al. (2011) result in a standard value for ϕ_π of 1.34, Fan et al. (2011) estimate this parameter to a value below 1. We believe that the monetary policy rate is used rather passively, and set $\phi_\pi = 1.01$, $\phi_y = 0$ and $\phi_r = 0.5$, which ensures the stability of the system due to an inflation coefficient greater than one (Taylor principle). This also reflects our concern, that the PBoC uses the additional policy instruments described below for the goal of stabilizing prices.

Next, we turn to the calibration of the unconventional monetary policy tool block. We start with the smoothing parameters of the benchmark deposit and lending rates, which are set to $\phi_r^l = \phi_r^d = 0.7$. This ensures that the guidelines of the PBoC slowly follow the policy rule. Concerning window guidance, we assume that the PBoC has a small preference for smoothing the targets. We therefore fix the reaction parameters of the policy rule to $\phi_l^{cb} = 0.2$, $\phi_l^\pi = 50$, and $\phi_l^y = 5$. The ease and tightness of window guidance is determined by κ . To clarify the impact of the

¹⁸The high share of capital in the production process is also in line with estimations from Heshmati and Kumbhakar (2010).

¹⁹Since the entrepreneurs in our model mainly invest, the share of investments in national income is very high, and consequential the consumption share is very low.

private bank's costs on deviating from loan targets, we simulate the model for a value of $\kappa = 50$. The parameters of the RRR rule, are set to $\phi_\eta^\eta = 0.6$ and $\phi_\eta^\pi = 10$, which ensures a smooth increase in the RRR from 10% to 20% in response to an annual increase in inflation of around 10%.

4.2 Impulse Response Functions

A sense of the properties of the model can be gained from looking at the impulse responses (IRFs) of the model, i.e. the manner in which macroeconomic variables respond to the shocks within the model. For this purpose, we add four exogenous driving forces to the model:

$$a_t = \rho_{t-1}^a a_{t-1} + \varepsilon_t^a, \quad (26)$$

$$u_t^\pi = \rho_i u_{t-1}^\pi + \varepsilon_t^\pi, \quad (27)$$

$$v_t^p = \rho_\nu + \varepsilon_t^\nu, \quad (28)$$

$$u_t^i = \rho_i u_{t-1}^i + \varepsilon_t^i, \quad (29)$$

where all innovations $\varepsilon_t^j \stackrel{i.i.d.}{\sim} \mathcal{N}(0, \sigma_j^2)$. These shocks are the conventional DSGE model shocks used in numerous publications: the productivity shock (26), the cost-push shock (27), the preference shock (28), and the investment shock (29). For the IRFs, we calibrate the standard deviation of these shocks such that they lead to a comparable effect on inflation at impacts of $\sigma_\pi = 0.1, \sigma_a = 2.5, \sigma_\nu = 3.5$ and $\sigma_i = 18$. The AR(1)-parameters are all set to $\rho_j = 0.7$. In the simulation exercise below, we evaluate the performance of the various monetary policy tools under different assumptions for standard deviation.

For the implementation of the PBoC's restrictions with respect to the loan and deposit rates, we employ the algorithm first used by Holden (2010). The beauty of this method is that it allows us to study the impact of inequality constraints with a method that does not require computationally intensive calculations. A detailed description of this algorithm can be found in Holden and Paetz (2012). The method is based on the introduction of shadow price shocks that hit a zero-bounded variable in subsequent periods. The tricky here is to find the size of these shocks that hits the bounded equation when the constraint would otherwise be violated. Since these shocks are known for all agents, this solution method is consistent with a rational expectations solution of the model.²⁰

To use this procedure we first introduce two auxiliary variables bounded by zero:

$$\tilde{r}_t^l = r_t^{l,pb} - r_t^{l,cb} \geq 0, \quad (30)$$

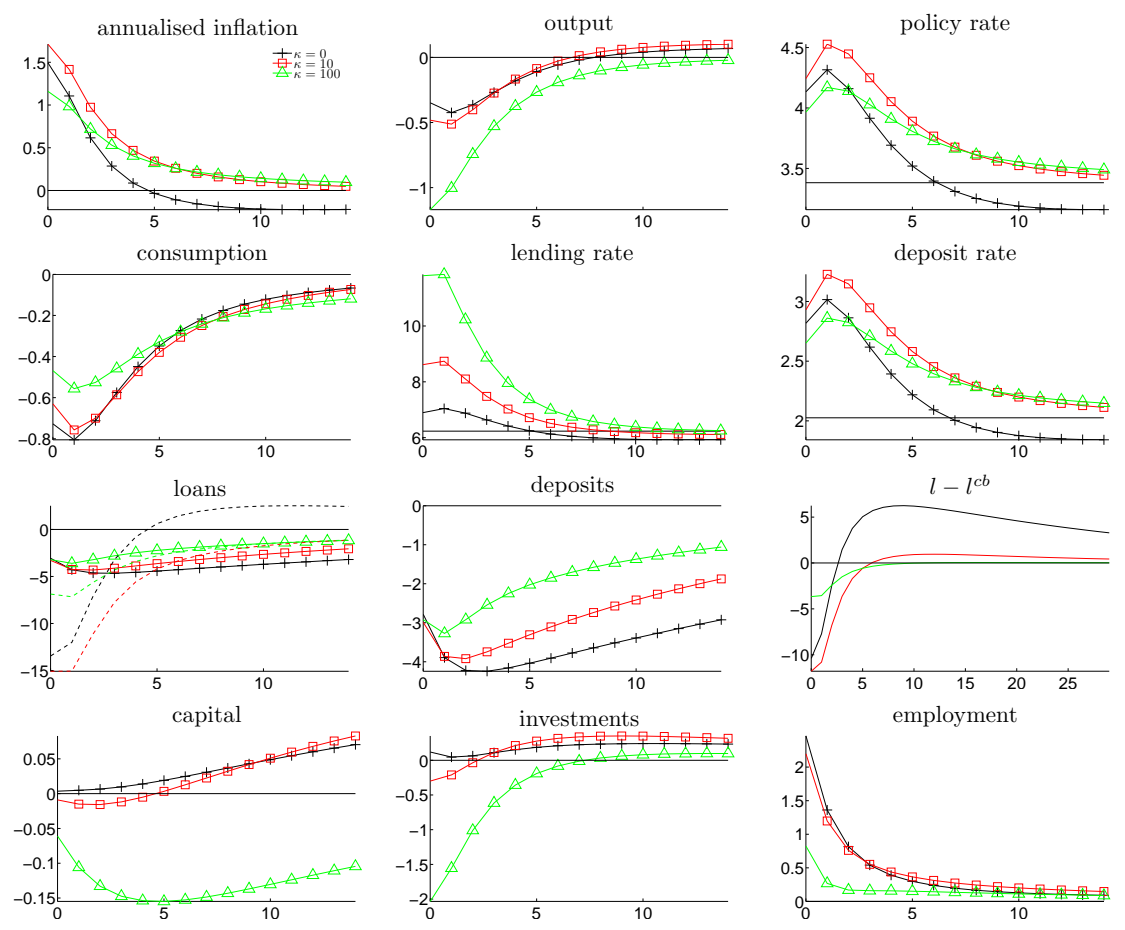
$$\tilde{r}_t^d = r_t^{d,cb} - r_t^{d,pb} \geq 0. \quad (31)$$

Following (30) and (31), $\tilde{r}_t^l = 0$ ($\tilde{r}_t^d = 0$), if $r_t^{l,pb} < r_t^{l,cb}$ ($r_t^{d,pb} > r_t^{d,cb}$). Thus, lending and deposit rates are then simply determined by $r_t^l = r_t^{l,cb} + \tilde{r}_t^l$ and $r_t^d = r_t^{d,cb} - \tilde{r}_t^d$.

²⁰Details on the algorithm are given in Appendix B.

To clarify the impact of the cost parameter κ , Figure 3 illustrates the transmission mechanism of window guidance in case of a negative productivity shock for $\kappa = 0, 10, 100$.²¹ The fall in productivity increases prices, calling for a higher policy rate, which is accompanied by a fall in output. When window guidance becomes more binding (κ increases) the credit targets of the central bank imply higher implicit costs. To compensate for these costs, the private banking sector increases the spread between lending and deposit rates. This implies loans get closer to their target values. Investments and output also fall as higher lending rates increase credit costs for firms, which, in turn, dampens the increase in inflation. By observing the loan quotas of the central bank (represented by dashed lines), we see that the guidelines are less restrictive when κ increases, due to the dampening effect on inflation.

Figure 3: The Impact of Window Guidance, Negative Productivity Shock



Note: All real variables are measured in percentage deviations from equilibrium, the inflation rate and all interest rates are annualised and measured in percent.

Overall, window guidance back by a stiff penalty cost drives bank loans to a target level set by the central bank, typically within a year. If the target loan level

²¹All IRFs are calculated over a 3-year forecast horizon. This is because the Chinese economy already moves so far from its original steady state in that time as to make approximation errors problematic.

is different from the actual loan level without such policy, banks adjust their retail lending by changing the spread between the loan rate and deposit rate. If they have to reduce loans to match the guided level, they increase the loan rate. On one hand, the increase in the interest rate spread compensates for the cost of deviating from the target loan level. On the other hand, the higher loan rate discourages lending and investment in subsequent periods. Thus, when banks have to increase bank lending, they cut loan rates in order to stimulate borrowing. Although imposing window guidance can directly affect the loan level, imposing window guidance brings in extra volatility to lending rates and the interest rate spread.

We now analyze the performance of the various different monetary policy tools of the PBoC with respect to the shocks described above. The model simulations are meant as descriptions of how agents and policymakers in China actually behave. As such, they do not necessarily have a normative interpretation. In what follows, we show IRFs for the benchmark scenario (BM) using policy rate only, a scenario that additionally uses a Taylor rule for required reserves (RRR), a scenario that additionally uses window guidance (WG), a scenario that additionally uses the interest rate corridor (IR) and a scenario that uses all these policy tools at once.²²

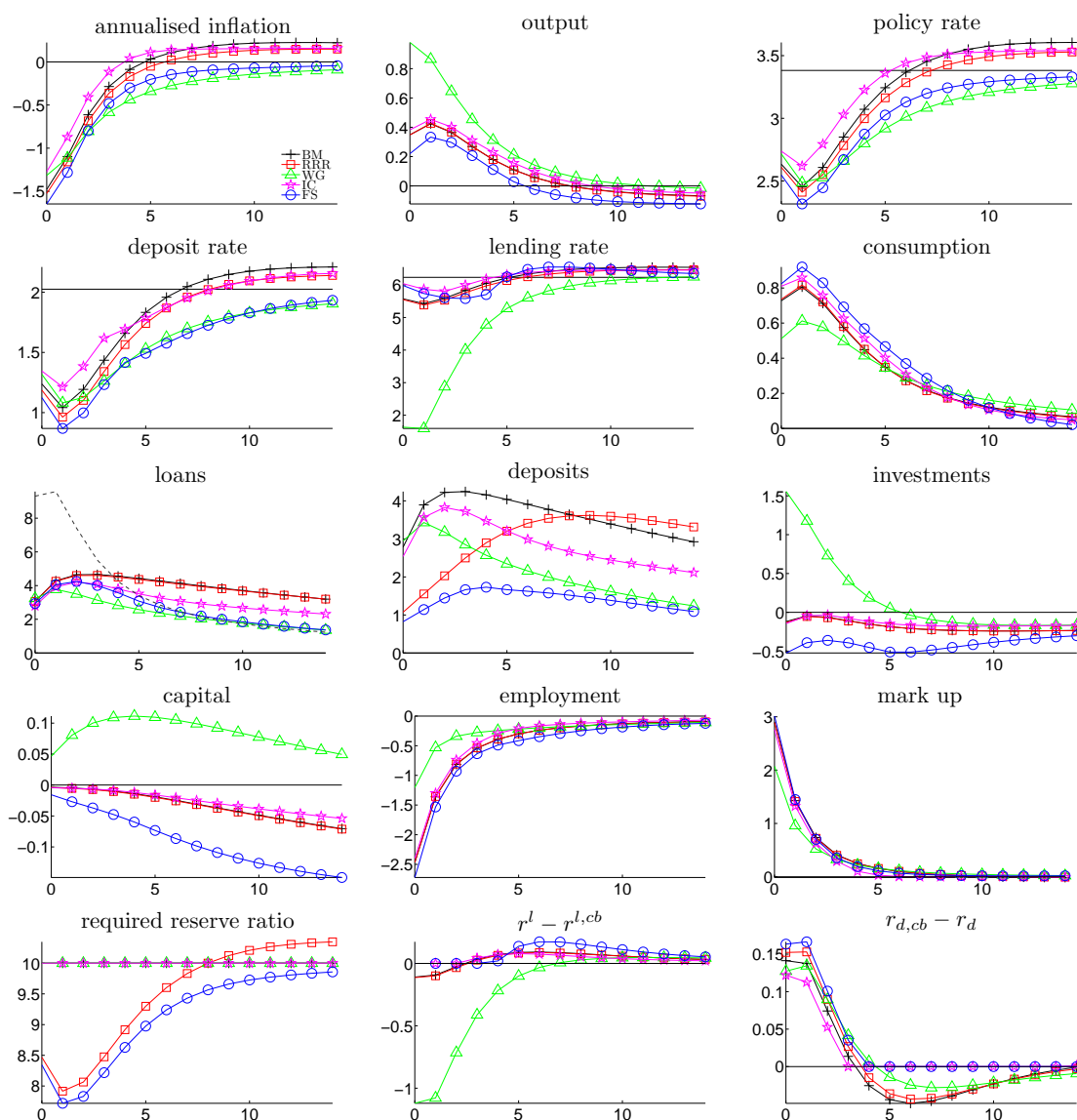
Productivity shock The dynamics of the model following a positive productivity shock are illustrated in Figure 4. Interpretation of the benchmark reactions is straightforward. A productivity shock decreases costs and boosts production, so prices fall and the output gap becomes positive. Higher income and lower interest rate generate a boom in consumption. Higher productivity enables firms to produce more with less input factors, so the demand for employment and investment goods decreases. Higher income also increases deposits, while lower lending rates increase borrowing by entrepreneurs to finance consumption. To analyze the transmission channels of the different additional policy tools, we compare the different IRFs against each other. With respect to inflation, we observe that the use of the RRR as a policy tool initially increases the rate of decrease in inflation but leads to less overshooting in the medium run. The lower RRR of 8% primarily leads to a small increase in deposits and loans. The results for "Chinese Quantitative Easing" can be studied via the window guidance scenario.²³ Here, the dashed grey line in the graph of the loan dynamics shows the loan targets of the central bank. The monetary authority wants to increase credits to induce a boom that returns inflation to equilibrium. In the medium term, both policies smooth the inflation dynamics.

The last two graphs in the last row indicate when the guidelines of the central bank bind. The lending rate floor prevent banks from further lowering their lending rates, so fewer loans are issued. As a results, banks demand fewer deposits from

²²Note that due to the constrained reactions of lending and deposit rates, the dynamics of positive and negative shocks differ.

²³The term "Chinese Quantitative Easing" conveys a completely different meaning from the standard term "Quantitative Easing" as statutory credit targets are relaxed.

Figure 4: Positive Productivity Shock



Note: All real variables are measured in percentage deviations from equilibrium, the inflation rate and all interest rates are annualized and measured in percent, the RRR is measured in percent. **BM:** unconstrained Taylor rule scenario, **RRR:** BM plus RRR policy, **WG:** BM plus window guidance, **IC:** BM plus interest rate corridor, **FS:** Full scenario using all policy tools.

households, reducing the rate of growth of the deposit stock. The fall in household savings implies an increase in consumption. Whether the additional use of lending rate floor can increase investment depends on whether the slowdown in bank lending supports additional production to keep up with the additional consumption demand. In our model, entrepreneurs are able to finance their production out of their own income, so investment grows faster initially and declines in a slower pace later on. The lending rate floor drives up the inflation rate more quickly in the short run.

Finally, the full scenario with all policy instruments represents a combination of all IRFs and shows a lower volatility than the benchmark. Although the impact on

inflation is small, the overall reduction of the Chinese monetary policy toolkit seems to be non-negligible. Moreover, window guidance seems to be the most effective policy tool in terms of the decreasing inflation volatility.

Cost-push shock In Figure 5, the IRFs of a conventional cost-push shock are illustrated. The supply-side increase in inflation implies an increase in the policy rate, and consequently declines in income, consumption, investment, capital and employment. The higher real interest rate makes saving more attractive, so deposits increase. Moreover, entrepreneurs borrow to compensate for their lower incomes.

The unconventional monetary policy tools differ strongly in their impact on the dynamics following a cost-push shock, but all have a dampening effect on inflation. At impact, the interest rate corridor leads to a small increase in inflation, but from the second quarter onwards this effect is reversed. Interestingly, the dampening effect of the interest rate corridor does not imply as strong a downturn in the output gap at impact as one might expect due to the well-known output-inflation trade-off in New Keynesian models. Again, window guidance seems to be the most effective weapon against inflation, but comes at costs of a much stronger recession.

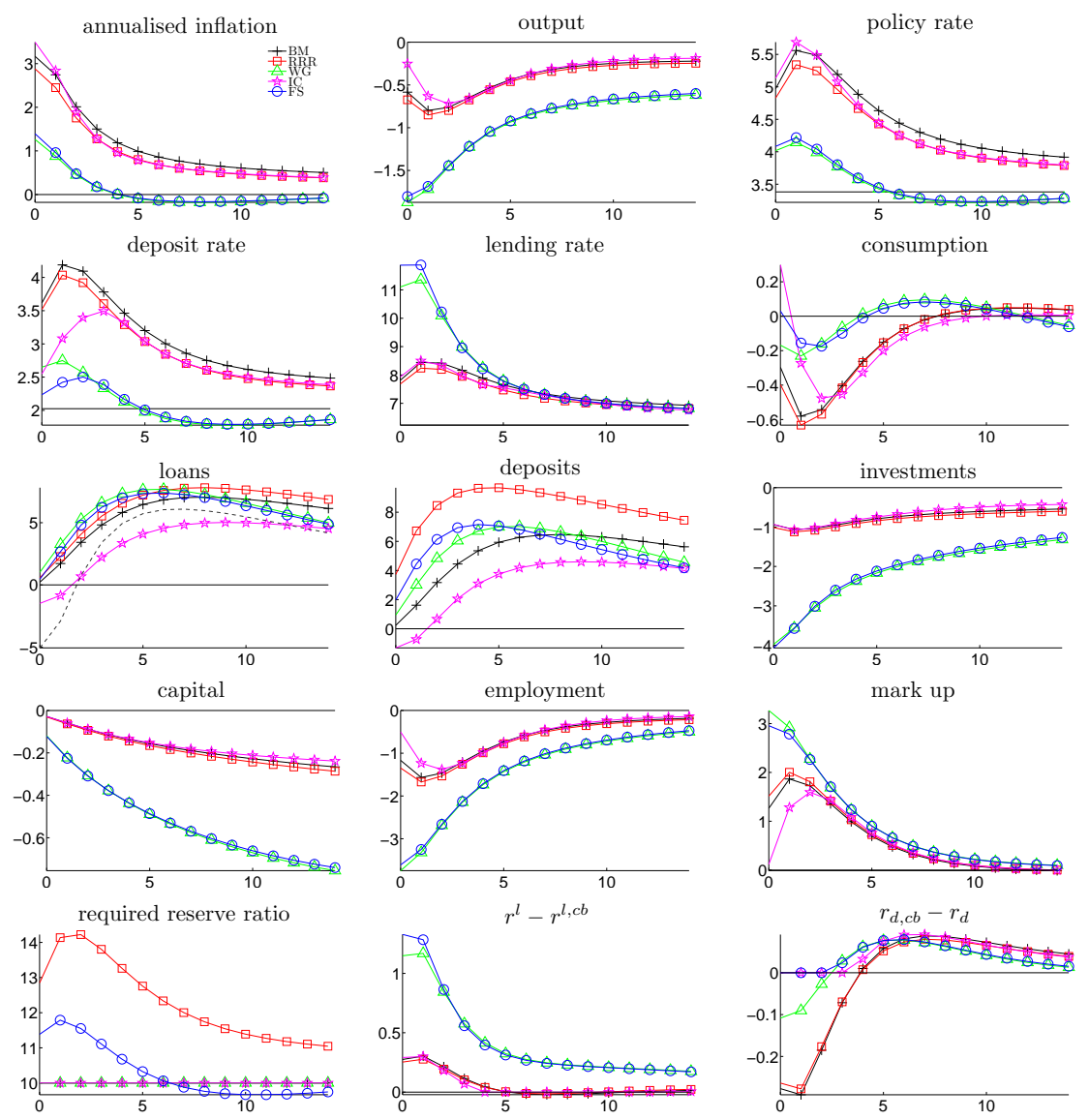
Preference shock The preference shock shown in Figure 6 can be interpreted as a typical demand-side shock in the sense that households and entrepreneurs suddenly increase their current consumption. This shock leads to a boom in the economy with rising consumption, production, employment, investment and inflation. The central bank wants to tighten its monetary stance to discourage consumption and investment to cool the economy.

To deal with the overheating, the PBoC tightens policy by selling central bank bills and raising all interest rates. The deposit rate ceiling keeps the deposit rate from rising, and thus prevent it from attracting more funds. Consequently, there are less deposits available for lending and less credit available for investment. It is harder to constrain consumption, so consumption falls less. The overall impact on investment depends on the combined effect of higher consumption and less bank lending. Given our calibration, the higher demand from additional consumption is insufficient to offset the reduced availability of credit, so investment drops more sharply under interest-rate regulation.

The main role of the interest-rate regulation is to enlarge the tightening impact on investment and mitigate the impact on consumption. Since investment plays a dominant role in Chinese GDP, an increase in real production and employment is smaller in the short run under interest-rate regulation. Moreover, interest-rate regulation implies that inflation will stay below equilibrium much longer. Hence, interest-rate regulation increases the volatility of inflation. Moreover, the policy rate follows the inflation process.

By observing the other policy tools of the Chinese central bank, we see that they have widely different impacts on the dynamics of the economy. Analogous to the effect in the case of a productivity shock, an RRR-focused policy leads to an initial

Figure 5: Positive cost-push shock

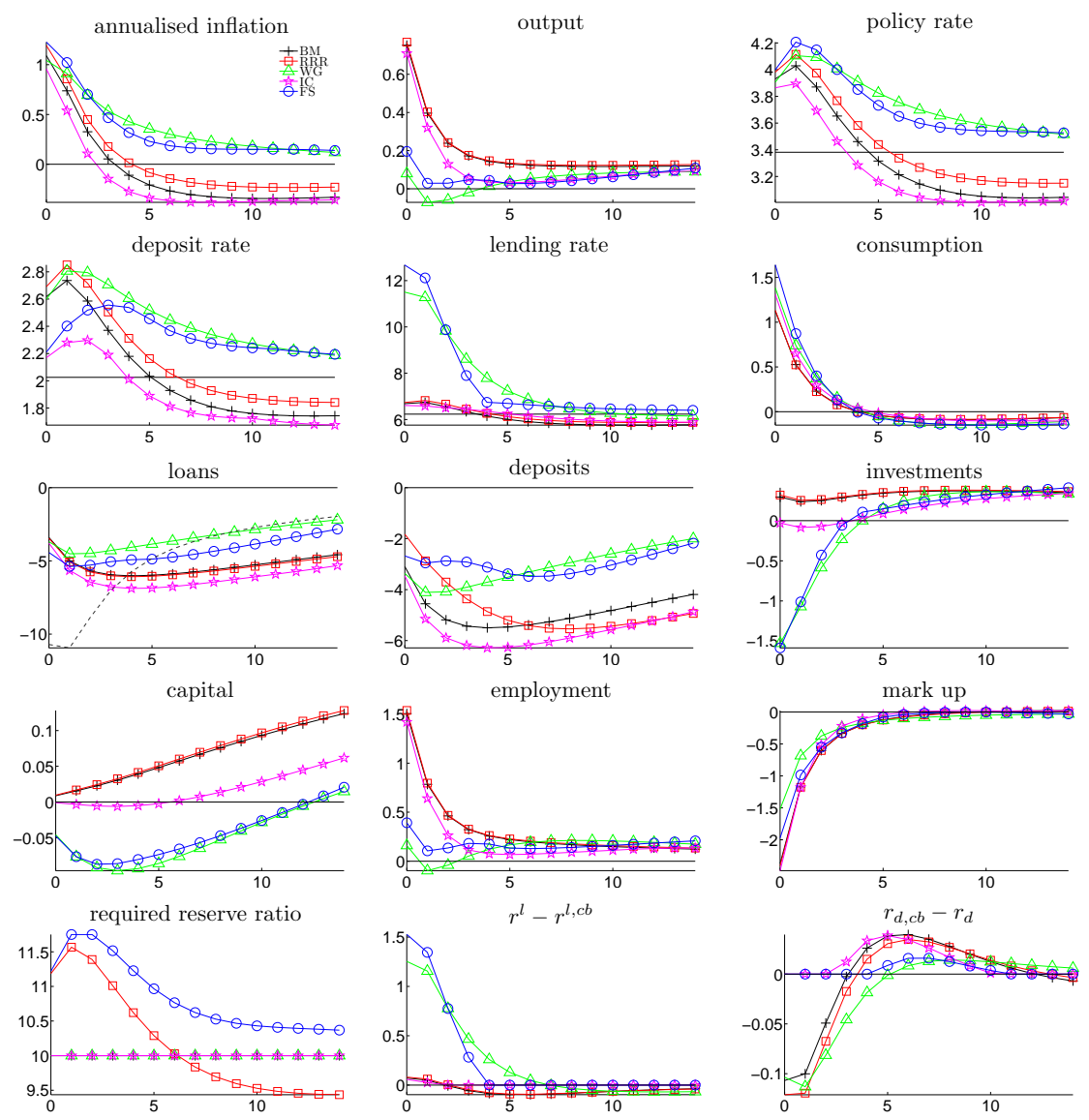


Note: All real variables are measured in percentage deviations from equilibrium, the inflation rate and all interest rates are annualized and measured in percent, the RRR is measured in percent. **BM:** unconstrained Taylor rule scenario, **RRR:** BM plus RRR policy, **WG:** BM plus window guidance, **IC:** BM plus interest rate corridor, **FS:** Full scenario using all policy tools.

increase of inflation, but less undershooting in the medium term. For the interest rate corridor, the opposite is the case. In the full scenario, we see a small effect at impact and a much smoother return to equilibrium. Credit quotas in the case of a preference shock not only smooth the inflation dynamics but also strongly decrease the output volatility, making this instrument very attractive. In addition, credit quotas overcome the negative effects of the interest rate corridor.

Investment shock The responses to a positive investment shock is given in Figure 7. By lowering adjustment costs, this shock induces a boom in investment,

Figure 6: Positive preference shock

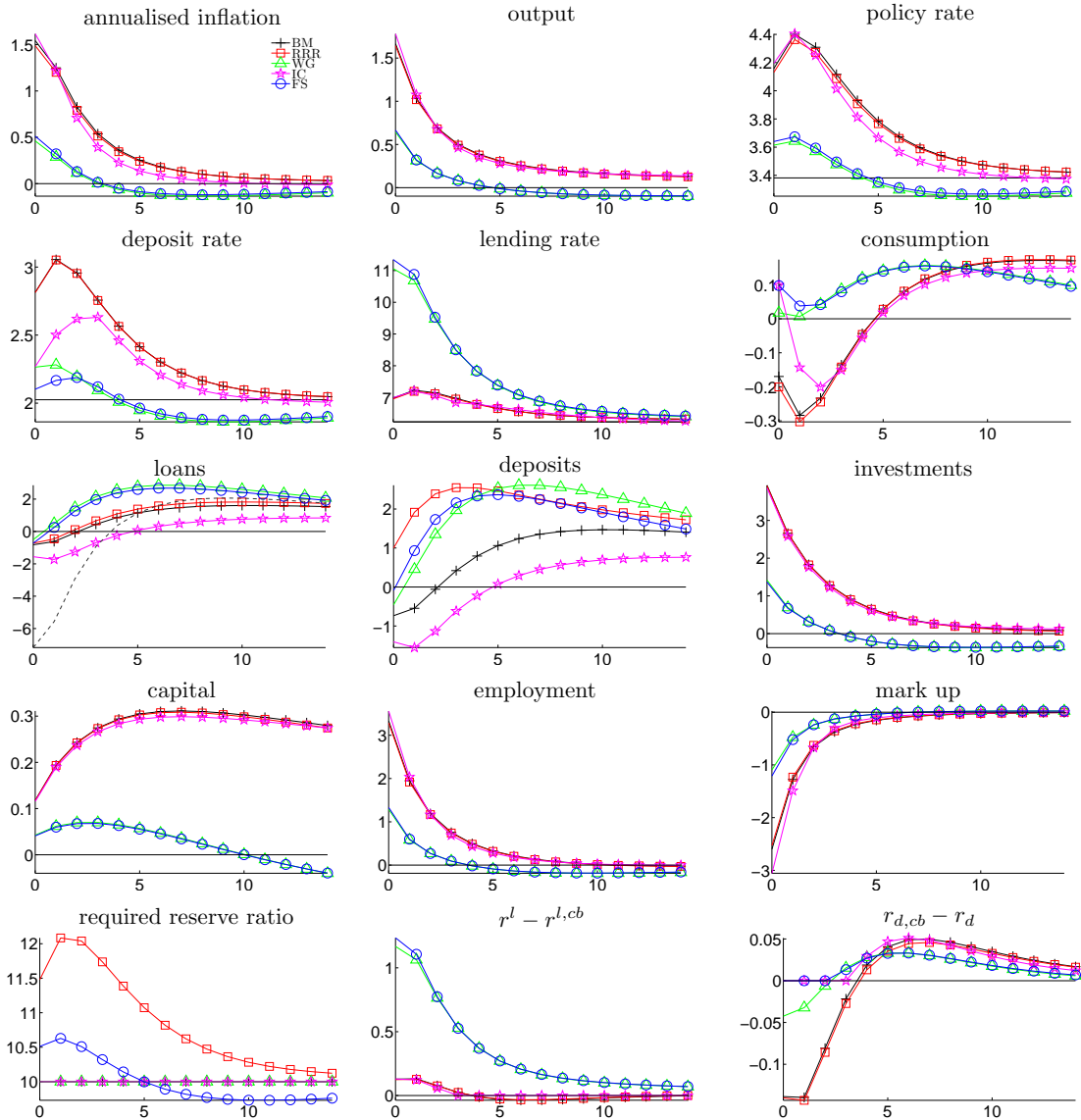


Note: All real variables are measured in percentage deviations from equilibrium, the inflation rate and all interest rates are annualized and measured in percent, the RRR is measured in percent. **BM:** unconstrained Taylor rule scenario, **RRR:** BM plus RRR policy, **WG:** BM plus window guidance, **IC:** BM plus interest rate corridor, **FS:** Full scenario using all policy tools.

accompanied by rising output, employment, capital and inflation. When the central bank increases the interest rate, consumption falls at impact and increases when the policy rate returns to equilibrium. Since entrepreneurs finance their investment first by reducing consumption, loans initially decrease slightly, but become positive from the third quarter onwards.

Concerning the unconventional tools of the PBoC, the RRR policy leads to a reduction at impact and in the medium term, while the interest rate corridor leads to a higher inflation rate at impact. Both effects are rather small compared to the strong declines in inflation and output under window guidance.

Figure 7: Positive investment shock



Note: All real variables are measured in percentage deviations from equilibrium, the inflation rate and all interest rates are annualized and measured in percent, the RRR is measured in percent. **BM:** unconstrained Taylor rule scenario, **RRR:** BM plus RRR policy, **WG:** BM plus window guidance, **IC:** BM plus interest rate corridor, **FS:** Full scenario using all policy tools.

4.3 Simulations

To fully evaluate the Chinese policy toolkit, we simulate the model corresponding to a random draw of shocks. We then compute the variances from these simulations to compare the various policy scenarios. We simulate the model for 1000 periods and ignore the first 100. To get a first impression of the model dynamics, we set the shock sizes to $\sigma_\pi = 0.03$, $\sigma_a = 0.8$, $\sigma_\nu = 1$ and $\sigma_i = 6$, which is roughly one third of the values used for the IRFs. We evaluate the impact of each shock separately below. The resulting simulation paths for 175 quarters are given in Figures 8 and

9. Although we used the same draw of random shocks to compare the outcomes of the different policy types, the dynamics differ substantially. In particular, the interest rate corridor can have a tremendous impact on the dynamics and seems to introduce a strong path dependency. This generates not only the typical fluctuations at business cycle frequencies but also more long-lasting waves.²⁴ Analyzing the full scenario, however, we conclude that window guidance offsets the negative impact of the interest rate corridor. Moreover, the graphs show that window guidance is accompanied by a highly volatile lending rate; the increasing costs of deviating from central bank loan targets are counteracted by higher lending rates.

In our DSGE models, monetary policy tries to minimize welfare losses by eliminating the output fluctuations caused by nominal frictions.²⁵ Table 3 compares the volatility of the model's variables for our baseline scenario, which uses the calibration above, and for each shock separately. The sacrifice ratio (SR) in the last row is defined as the percentage-point reduction in inflation divided by the percentage-point increase in output (compared to the benchmark scenario). Hence, a higher positive value indicates a better inflation-output trade-off. Negative values for the sacrifice ratio reflect the fact that both inflation and output volatility move in the same direction. Note that this holds for both increases and decreases. In addition to the six scenarios shown in Figure 8 and 9, we also present the variances for our mixed scenarios.

The table offers several insights. As suggested by the IRFs shown above, using the RRR and window guidance as additional monetary policy tools reduces the volatility of inflation. However, the interest rate corridor tends to increase inflation and output volatility, accompanied by a strong increase in the volatility of loans and deposits. In terms of dealing with inflation, window guidance appears the most effective tool, but comes at a cost of higher output volatility.²⁶ In contrast, the RRR is less effective, but much more attractive with respect to its inflation-output trade off. Our mixed scenarios illustrate that window guidance can completely offset the negative impact of the interest rate corridor. This also leads to a respectable inflation performance in the full scenario, but again comes at a high cost in terms of output volatility.

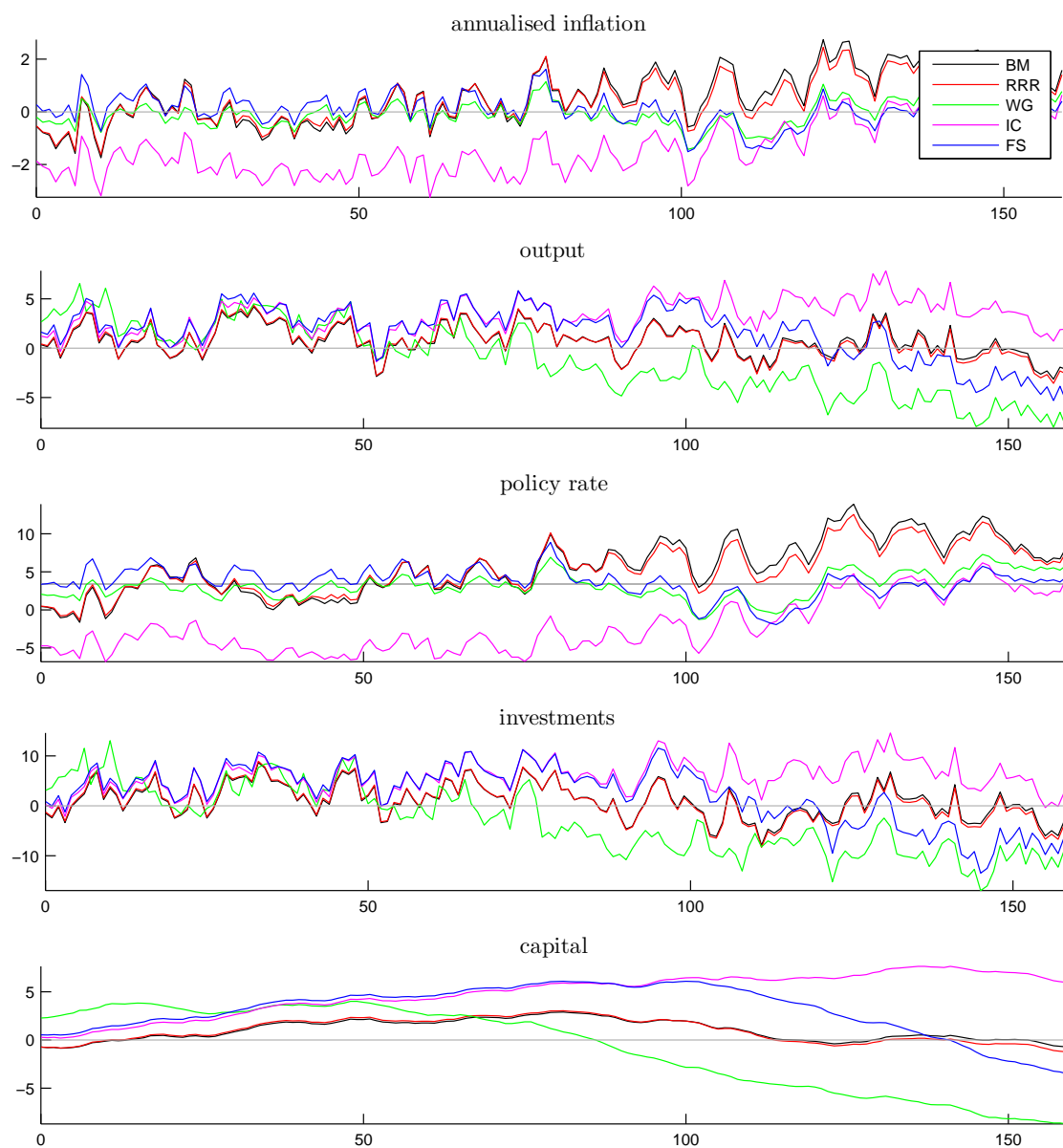
Analyzing our single shock scenarios illustrates that the shock source is somewhat determinative of the appropriate policy tools. In the case of investment and prefer-

²⁴Note that interest rates and the RRR hit the zero lower bound (ZLB) in some periods. Since our focus is not the analysis of a ZLB restriction and the assumption of a positive inflation target would prevent the ZLB to be hit so often, we do not discuss the implications here.

²⁵In the literature on optimal monetary policy, a representative household is typically considered so there are no conflicts of interest among households. In the modelling framework of this paper, however, there are two distinct types of households: borrowers and savers. They presumably have different preferences over what constitutes optimal monetary policy. Analyzing this conflict of interest among households is beyond the scope of the paper.

²⁶In an estimated housing market DSGE model, Peng (2012) also concludes that China's countercyclical credit policy plays a crucial role in stabilising the economy.

Figure 8: Simulations of the model

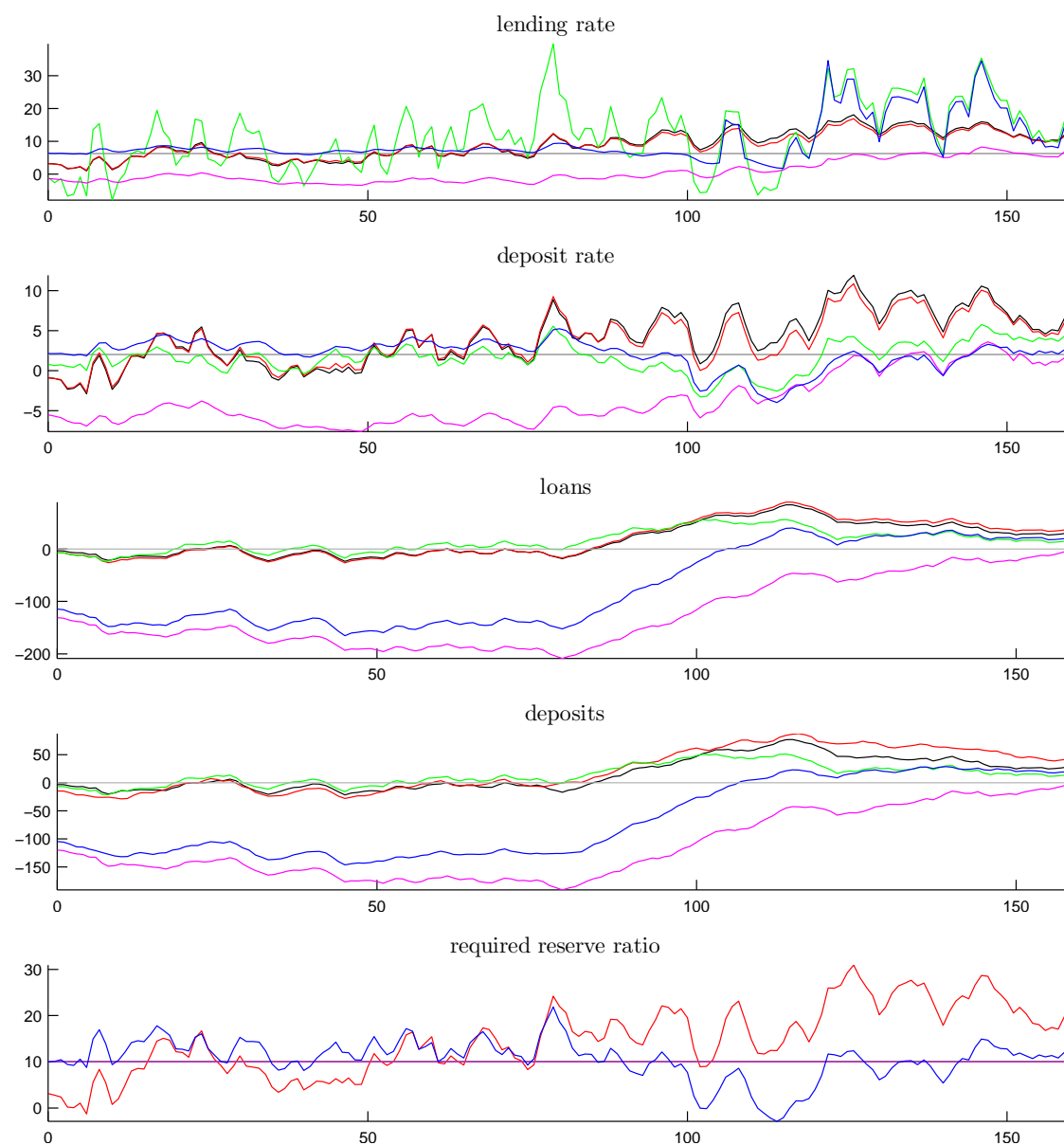


Note: All real variables are measured in percentage deviations from equilibrium, the inflation rate and all interest rates are annualized and measured in percent, the RRR is measured in percent. **BM:** unconstrained Taylor rule scenario, **RRR:** BM plus RRR policy, **WG:** BM plus window guidance, **IC:** BM plus interest rate corridor, **FS:** Full scenario using all policy tools.

ence shocks, for example, window guidance is exceptionally successful and tends to decrease both output and inflation. In the case of cost-push and productivity shocks, window guidance is less attractive than RRR policy. RRR policy, in turn, lowers inflation and output volatility for an investment shock. The results suggest that window guidance is more useful for the demand-side shocks as output and inflation both increase, and stricter credit guidelines dampen both variables.

These simulations help explain why the PBoC keeps so many policy instruments. Credit control seems unavoidable in the presence of a deposit and lending rate floor.

Figure 9: Simulations of the model II



Note: All real variables are measured in percentage deviations from equilibrium, the inflation rate and all interest rates are annualized and measured in percent, the RRR is measured in percent. **BM:** unconstrained Taylor rule scenario, **RRR:** BM plus RRR policy, **WG:** BM plus window guidance, **IC:** BM plus interest rate corridor, **FS:** Full scenario using all policy tools.

If the PBoC modifies its open market operations (OMO) and changes the RRR, and at the same time adjusts the deposit rate ceiling and the lending rate floor, it runs a high risk of raising controlled rates too much or too little. Policymakers don't know how much the deposit rate might rise if they allow banks to raise rates freely. These actions have unfavourable impacts on bank lending and investment, and make ex-post credit control to correct lending volumes and levels of investment unavoidable.

Interest-rate regulation distorts the impact of OMO on consumption and savings,

Table 3: Variances of selected variables under different policy scenarios

	Baseline Scenario								Productivity Shock ($\sigma_a = 0.8$)								Cost-Push Shock ($\sigma_\pi = 0.03$)							
	BM	RRR	WG	IC	RWG	RIC	IWG	FS	BM	RRR	WG	IC	RWG	RIC	IWG	FS	BM	RRR	WG	IC	RWG	RIC	IWG	FS
II	0.94	0.85	0.51	1.05	0.48	0.89	0.59	0.57	0.32	0.32	0.30	0.76	0.29	0.59	0.32	0.31	0.78	0.68	0.30	1.84	0.28	1.41	0.37	0.35
Y	1.90	1.97	2.92	2.37	2.90	2.43	3.13	3.12	0.56	0.58	0.91	1.17	0.89	1.24	1.15	1.16	1.30	1.45	2.80	2.70	2.82	2.92	3.08	3.12
R	0.83	0.75	0.45	0.97	0.42	0.81	0.50	0.48	0.27	0.26	0.26	0.76	0.25	0.57	0.26	0.25	0.70	0.60	0.27	1.83	0.24	1.39	0.31	0.29
R^D	0.81	0.76	0.48	0.88	0.46	0.72	0.45	0.44	0.28	0.28	0.28	0.72	0.28	0.54	0.22	0.22	0.67	0.59	0.27	1.76	0.25	1.32	0.26	0.24
R^L	0.90	0.82	2.48	0.97	2.42	0.80	1.59	1.55	0.28	0.26	1.15	0.77	1.10	0.58	0.47	0.45	0.78	0.69	1.28	1.85	1.26	1.42	0.70	0.67
RRR	0.00	7.05	0.00	0.00	3.96	7.74	0.00	4.48	0.00	2.43	0.00	0.00	2.36	5.63	0.00	2.34	0.00	5.72	0.00	0.00	2.24	13.65	0.00	2.73
C	1.51	1.55	1.79	1.70	1.78	1.73	2.10	2.09	0.92	0.93	0.76	0.93	0.79	0.94	0.94	0.95	0.81	0.90	1.36	1.38	1.37	1.49	1.74	1.75
I	3.85	3.95	5.67	4.44	5.61	4.53	5.71	5.68	0.75	0.78	1.29	1.88	1.21	2.02	1.88	1.88	2.08	2.32	5.34	4.44	5.35	4.79	5.03	5.08
K	1.67	1.83	3.29	2.78	3.27	2.92	4.13	4.12	0.62	0.66	0.22	1.74	0.20	1.87	1.75	1.75	1.56	1.79	3.31	4.13	3.33	4.46	4.48	4.54
W/P	1.76	1.82	2.17	2.06	2.16	2.12	2.56	2.55	0.53	0.55	0.55	0.80	0.56	0.83	0.85	0.86	1.28	1.40	1.99	1.92	2.00	2.07	2.39	2.41
N	3.57	3.60	3.79	3.49	3.79	3.53	3.78	3.77	1.74	1.74	0.85	1.69	0.87	1.73	1.82	1.81	1.73	1.86	3.79	1.84	3.79	1.96	2.67	2.68
L	22.11	23.95	17.47	57.27	16.98	61.58	49.39	49.87	9.92	9.99	5.56	57.33	5.14	61.32	29.62	30.31	15.60	17.77	14.00	125.96	14.11	133.49	64.75	66.64
D	20.23	26.05	15.95	52.38	14.56	62.85	45.11	45.08	9.07	8.93	5.06	52.44	2.33	61.88	27.05	27.06	14.29	21.40	12.79	115.22	13.35	136.73	59.16	61.79
SR		1.18	0.41	-0.24	0.45	0.08	0.28	0.30		0.29	0.06	-0.72	0.10	-0.39	0.01	0.02		0.67	0.32	-0.76	0.33	-0.39	0.23	0.23
Preference Shock ($\sigma_\nu = 1$)								Investment Shock ($\sigma_i = 6$)																
BM	RRR	WG	IC	RWG	RIC	IWG	FS	BM	RRR	WG	IC	RWG	RIC	IWG	FS									
II	0.29	0.26	0.24	1.98	0.23	1.42	0.29	0.29	0.33	0.32	0.11	0.75	0.10	0.59	0.19	0.19								
Y	0.74	0.79	0.32	2.88	0.31	3.00	1.47	1.43	1.34	1.31	0.57	1.49	0.57	1.51	1.44	1.45								
R	0.26	0.23	0.22	2.00	0.21	1.43	0.24	0.24	0.28	0.27	0.09	0.73	0.09	0.57	0.16	0.16								
R^D	0.24	0.23	0.24	2.00	0.24	1.43	0.22	0.21	0.28	0.28	0.10	0.70	0.10	0.53	0.14	0.13								
R^L	0.31	0.26	1.16	2.00	1.12	1.43	0.38	0.35	0.28	0.27	1.15	0.74	1.15	0.57	0.60	0.60								
RRR	0.00	2.11	0.00	0.00	1.95	14.19	0.00	2.26	0.00	2.48	0.00	0.00	0.79	5.55	0.00	1.47								
C	0.78	0.80	0.93	1.53	0.90	1.61	1.15	1.14	0.56	0.57	0.34	0.61	0.34	0.62	0.69	0.69								
I	1.10	1.18	1.35	4.77	1.28	4.95	2.36	2.30	3.15	3.13	1.31	3.39	1.30	3.42	3.16	3.17								
K	0.90	0.98	0.45	4.72	0.43	4.92	2.28	2.22	0.91	0.87	0.53	1.38	0.53	1.46	1.69	1.71								
W/P	1.07	1.09	0.93	1.92	0.90	2.02	1.49	1.48	0.76	0.73	0.41	0.85	0.41	0.84	0.79	0.80								
N	1.02	1.04	0.41	1.25	0.40	1.31	1.16	1.15	2.43	2.39	0.94	2.50	0.93	2.48	2.06	2.06								
L	12.82	13.27	7.41	151.05	7.01	153.41	58.61	59.10	4.59	5.12	5.69	54.20	5.53	57.67	31.10	31.70								
D	11.72	12.86	6.75	138.16	4.39	155.94	53.54	53.17	4.20	5.92	5.19	49.58	4.74	58.53	28.41	28.69								
SR		0.53	-0.10	-0.80	-0.13	-0.50	0.00	0.00		-0.47	-0.29	-2.72	-0.29	-0.51	-10.67	1.24								

Note: **BM:** unconstrained Taylor rule scenario, **RRR:** BM plus RRR policy, **WG:** BM plus window guidance, **IC:** BM plus interest rate corridor, **RWG:** RRR plus WG, **RIC:** RRR plus IC, **IWG:** IC plus WG, **FS:** Full scenario using all policy tools.

and biases the signal of the monetary stance sent by the central bank bill yield. Interest-rate regulation can both strengthen and weaken the OMO impact on output and inflation in the short run, depending on e.g. the nature of the shock, the importance of bank financing in investment, the relative contribution of investment and consumption in inflation. Moreover, using interest rate regulation in tandem with OMO leads to additional volatility in output and inflation in general.

RRR strengthens the OMO impact on interest rates and consumption, and RRR can be viewed as a close substitute for OMO if two conditions hold. First, the interest rate for required reserve is equivalent to the central bank bill yield/interbank rate. Second, banking lending is the main financing channel. Both of these conditions apply in our model.

The ultimate impact of window guidance on consumption and output depends on the source of shocks. Window guidance reduces the volatility under the preference shock and investment shock scenarios, while increasing it under the productivity and costs-push shock scenarios. Window guidance is able to offset the impact of interest rate regulation on loans under some shocks, including the positive productivity shock. A high lending target with severe punishment pushes the deposits and loans suppressed by the deposit rate ceiling. However, the net benefit of using such combination depends on two factors. First, you need to make a good guess of the appropriate lending level without the presence of interest rate regulation. Second, it is the nature of the shock that determines whether the higher volatility of investment ultimately leads to higher volatility for output and employment.

5 Summary and Conclusions

The Chinese transition process since the beginning of the 1980s has transformed China from a centrally planned economy into a mixed market economy. Chinese GDP per capita has risen eight-fold, transforming China into the world's second-largest economy. Furthermore, the global financial crisis has accelerated the shift of power to Asia. This makes economic research on China imperative for understanding the world economy.

The set of monetary policy tools used in mainland China is different from the conventional monetary policy frameworks found in advanced economies. Hence, this paper attempts to build a unified conceptual modelling framework that captures these non-conventional monetary policy instruments such as required reserve ratios, window guidance and constraints on retail rates of private banks. Our analysis shows that a dynamic New Keynesian DSGE model emphasizing the dependence of current choices on expected future outcomes can be extended to investigate and evaluate such policies with respect to their inflation-output trade-off. The model simulations indicate that China's current non-conventional monetary policy toolkit represents a versatile, yet fragile, work of art. The various policy tools interrelate, augment and intensify each other.

Our findings suggest the source of the shock is crucial in evaluating the performance of these policy tools. We find, for example, that credit quotas are quite effective in reducing inflation and highly attractive in the case of demand-side shocks as they can reduce both output and inflation. On the other hand, window guidance comes at a high cost in terms of reduced output and employment in the case of supply-side shocks. Moreover, since the interest rate corridor is likely to distort the efficient reactions of the economy, window guidance seems unavoidable. The impact of the RRR is small, but attractive in terms of its inflation-output trade-off. While the DSGE model is a stylized representation of the Chinese economy, it provides a disciplined approach to real-life issues facing policymakers.

Modelling of Chinese monetary policy in a DSGE model is an uncharted area of monetary economics. Despite its promise in concrete policymaking, no author has yet explored the topic. Beyond its interest to specialists in DSGE modelling, this assessment should also be of interest to a wider audience of macroeconomists and policymakers.

Appendix

A Equilibrium

For the derivation of equilibrium values, we need to calibrate the gross equilibrium interest rates on required reserves and excess reserves, as well as the equilibrium required reserve ratio. These values determine the equilibrium policy rate and the amount of excess reserves, loans and deposits. We also need to calibrate the equilibrium deposit-to-output ratio to solve for all remaining equilibrium values. In the following, we explain the derivation of all other equilibrium values.

Assume a zero-inflation steady state implies $R^D = \beta_p^{-1}$ and $R^L = \beta_e^{-1}$ via the Euler equations of patient households and entrepreneurs. The equilibrium value of loans, deposits and excess reserves can be determined by the first-order conditions of the private banking sector:

$$L = \frac{R^L - R}{c_l}, \quad (\text{A.1})$$

$$D = \frac{\eta R^r + (1 - \eta) R - R^D}{(1 - \eta)^2 c_d}, \quad (\text{A.2})$$

$$E = \frac{R^E - R}{c_e}, \quad (\text{A.3})$$

Next we use $(1 - \eta) D = L + E$ to determine the equilibrium policy rate:²⁷

$$R = \frac{c_d c_e R^L + c_d c_l R^E}{c_l c_e + c_d c_e + c_d c_l} + \frac{c_l c_e (R^D - \eta R^r)}{(1 - \eta) (c_l c_e + c_d c_e + c_d c_l)}. \quad (\text{A.4})$$

²⁷Note that the net position in the interbank market for the whole banking sector needs to be zero.

By setting the equilibrium interest rates on required reserves to the deposit rate, the equilibrium policy rate converges to a cost-weighted average of the rate on deposits, excess reserves and loans: $R = \frac{c_d c_e R^L + c_d c_l R^E c_l c_e R^D}{c_l c_e + c_d c_e + c_d c_l}$.

Due to the monopoly power of firms, the gross mark-up in equilibrium must be equal to $(1 + \mu)$. Since $W/P = (1 - \alpha)(Y/XN)$, it follows that the steady state fraction of the real wage bill is given by

$$\frac{WN}{PY} = \frac{1 - \alpha}{1 + \mu}. \quad (\text{A.5})$$

Moreover, steady state capital is given by $I = \delta K$, and the shadow value of capital (9) determines the equilibrium share of investments to be

$$\frac{I}{Y} = \delta \frac{K}{Y} = \beta_e \frac{\alpha}{1 + \mu}. \quad (\text{A.6})$$

To derive the equilibrium share of entrepreneurial consumption in national income, we first derive the equilibrium national income shares of loans and excess reserves. Therefore, we divide (A.1) and (A.3) by (A.2), yielding the loan-to-deposit and the excess reserves-to-deposits ratios, respectively, and multiply those values by the calibrated value of the deposit-to-output ratio. Using (A.5) with the entrepreneur's budget constraint gives:

$$\frac{C^E}{Y} = (1 - R^L) \frac{L}{Y} + \frac{\alpha}{1 + \mu} - \frac{I}{Y}. \quad (\text{A.7})$$

Finally, the patient household's equilibrium share of consumption can be derived, using the market clearing condition:

$$\frac{C^P}{Y} = 1 - \frac{C^E}{Y} - \frac{I}{Y}. \quad (\text{A.8})$$

B Simulating Models with Inequality Constraints

To ensure, that the auxiliary variables are bounded, we add a sum of "shadow price" shocks to (30) and (31): $\sum_{s=0}^{T-1} \epsilon_{s,t-s}^{SP}$, where T represents the number of periods after which we believe the constraint no longer binds. The shock terms are $\epsilon_{s,t}^{SP} \stackrel{i.i.d.}{\sim} \mathcal{N}(0,1)$, if $t = 0$ and zero otherwise. Consequently, when simulating the model $\epsilon_{s,t-s}^{SP} = 1$, if (and only if) $s = t$.²⁸ Next, we simulate the model for each shock $\epsilon_{s,\cdot}^{SP}$ and save these responses consecutively as column vectors in a matrix M . To derive the impulse responses under bounded interest rates, we then solve the following optimization problem:

$$\alpha^* = \arg \min [\alpha' (m + v + M^* \alpha)] = \arg \min \left[\alpha' (m + v) + \frac{1}{2} \alpha' (M^* + M^{*'}) \alpha \right],$$

²⁸Note that each shock is known in period 0, but hits the equation in period s . Hence, these shocks are consistent with a rational expectations solution of the model.

subject to $\alpha \geq 0$ and $v + M^*\alpha \geq 0$, where M^* is the upper square $T \times T$ submatrix of M , and m is the steady state of the bounded variable (which is zero in our model), and v is the vector of the unconstrained impulse response of the bounded variable. The resulting α determines the linear combination of shocks $\left(\sum_{s=0}^{t=T-1} \alpha_{s+1}^* \epsilon_{s,t-s}^{SP,j}\right)$ exactly the size needed to push the bounded variable back to zero whenever the bound is hit. Since $\alpha^{*'}(m + v + M^*\alpha^*) = 0$, either $\alpha_{s+1}^* = 0$ (implying a zero weight to $\epsilon_{s,t-s}^{SP,j}$) or the bound is binding in period s . The impulse responses for each variable i of the model are now simply given by $v_i + M_i\alpha^*$, where v_i and M_i are the corresponding unconstrained impulse responses and the impulse responses matrix of i , respectively. In order to simulate the model for two constraints, we modify the Holden (2010) optimization problem slightly. Consider, for example, bounded variables 1 and 2. We first introduce a "shadow price" shock for each bounded variable. Let v_1 and v_2 be the unconstrained responses of the two variables of interest, m_1 and m_2 be the steady state vectors, and $M_{i,j}^*$ be the matrix of the responses of variable i to the shadow price shock of variable j . We now to solve for

$$\alpha^* \equiv [\alpha_1^{*'} \quad \alpha_2^{*'}] = \arg \min [\alpha_1' \quad \alpha_2'] \left[\begin{bmatrix} m_1 + v_1 \\ m_2 + v_2 \end{bmatrix} + \begin{bmatrix} M_{1,1}^* & M_{1,2}^* \\ M_{2,1}^* & M_{2,2}^* \end{bmatrix} \begin{bmatrix} \alpha_1 \\ \alpha_2 \end{bmatrix} \right], \quad (\text{A.9})$$

where $M_{i,j}^*$ is the upper square $T \times T$ submatrix of $M_{i,j}$. The reaction of the bounded variables are now given by $v_1 + M_{1,1}\alpha_1^* + M_{1,2}\alpha_2^*$ and $v_2 + M_{2,1}\alpha_1^* + M_{2,2}\alpha_2^*$. The impulse responses for a variable k can now be derived in the same fashion by $v_k + M_{k,1}\alpha_1^* + M_{k,2}\alpha_2^*$, where $M_{k,j}$ represents the matrix of unconstrained responses for k to a shadow price shock corresponding to j .

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