Sterilized Intervention and Optimal Chinese Monetary Policy

Wukuang Cun*
University of Southern California - Dornsife INET

Jie Li †
Central University of Finance and Economics

August 15, 2016

Abstract

China’s central bank had been actively intervening its foreign exchange markets to prevent sharp appreciation of Chinese Yuan. At the same time, “central bank bills”, a type of short-term central bank debt, were issued to absorb the increase of monetary base caused by intervention, which should have effectively neutralized the effects of intervention if money multiplier were invariant. However, both M2 and bank credit had significantly increased during the sterilized intervention period, regardless of monetary base being kept unaffected, implying an increase in money multiplier. We reproduce these facts in a calibrated DSGE model where central bank bills, issued as sterilization tools, are held by banks as liquidity management instruments. As banks’ holdings of central bank bills increase, they hold less excess reserves, leading to a higher money multiplier and expansions of banks’ balance sheets. The same DSGE framework allows us to study the optimal choice of monetary policy instruments given China’s current exchange rate regime. Comparing to open market operation, raising required reserve ratio, which directly freezes the increase in monetary base caused by intervention, can be more effective for stabilizing the economy. When the central bank is allowed to use reserve requirement as an additional policy instrument, the fluctuations in macro-economic variables are significantly reduced.

JEL Classification: F31, E51, E52

Keywords: Currency Intervention, Sterilization, Reserve Requirement, Monetary Policy, China

*University of Southern California - Dornsife INET, email: wcun@usc.edu.
†Corresponding author, Central University of Finance and Economics, email: jieli.cn@gmail.com.
We thank Roberto Chang, Todd Keister, and seminar participants in Rutgers University, Xiamen University, Shanghai University of Finance and Economic, and Southwestern University of Finance and Economics and conference participants in 2013 ASSA annual meeting in San Diego for their valuable comments. Financial support from Key Project sponsored by China Ministry of Education (Project #: 14JZD016), China National Science Fund (Project #: 61272193) and CUFE Youth Innovation Fund is greatly acknowledged. All errors remain ours.
1 Introduction

Since the early 2000s, the growing balance of payments (BOP) surplus via current and capital accounts have put great upward pressure on the value of the domestic currency in China. To prevent sharp appreciation of Chinese Yuan, the People’s Bank of China (PBOC, China’s central bank) had been actively intervening foreign exchange market by purchasing foreign assets, and thus accumulated massive amounts of international reserves (see Figure 1). When the PBOC purchases foreign assets, an equivalent amount of base money is released, which puts great expansionary pressure on China’s economy. To neutralize the expansionary effects of currency intervention, the PBOC issues central bank bills, a type of short-term central bank debt, to absorb the increase in monetary base caused by intervention. As estimated by Ouyang, Rajan and Willett (2010), monetary sterilization in China was virtually complete in the sense that monetary base was almost kept unaffected.

Complete sterilization, which kept monetary base unaffected by currency intervention, should have largely neutralized the effects of intervention if money multiplier were invariant. However, both broad money (M2) and bank credit had increased significantly during the sterilized intervention period even if monetary base was kept unaffected, which implies an increase in money multiplier (see Figure 3). In this paper, we ask to what extent open market operation (OMO) can neutralize the effects of intervention. In addition, given China’s current external policy regimes, what would be the optimal monetary policy instrument for the PBOC?

Central bank bills, issued as sterilization instruments, are very liquid in the interbank market. During the sterilized intervention period, the volume of central bank bill transaction in the interbank bond market increased significantly. In 2008, the share of central bank bill transaction in the total transactions in the interbank bond market reached 40% (see Figure 2). In addition, central bank bills has the highest turnover rate among all the assets transacted in the interbank bond market. In fact, central bank bills can be good substitutes for excess reserves for banks’ liquidity management. As banks’ holdings of central bank bills increase, they hold less excess reserves, leading to a higher

---

1 Immediate appreciation of domestic currency might not top the China’s policy response list, due to either the worries of losing export competitiveness (Reinhart and Calvo, 2002) or eagerness for international reserve hoarding (Ghosh, Ostry and Tsangarides, 2012).
2 The officially stated objective of the PBOC is to “maintain the stability of the value of its currency and therefore promote economic growth”, which indicates that two most important objectives of the PBOC are stabilizing nominal exchange rate and controlling domestic inflation.
3 According to Burdekin and Siklos (2008), China even over-sterilized reserve accumulation.
4 Schularick and Taylor (2012) documented the divergence between money and credit growth in the past century with particular emphasis on how credit booms, rather than monetary expansion, leads to financial crises.
5 The most typical method of sterilization (in a narrow sense) is open market operations. In a broad sense, any activity of central bank that is aimed to neutralize the effects of intervention can be considered as sterilization.
money multiplier and expansions of banks’ balance sheets. Comparing to open market operation (OMO), raising required reserve ratio (RRR), which directly freezes the increase in monetary base caused by intervention, can be more effective in countering the effects of intervention. Since 2008, the PBOC gradually stopped to issue new central bank bills, and started to use required reserve ratio (RRR) as an stabilization tool, which may well reflect the PBOC’s awareness of the benefits of RRR policy (see Figure 4).

We reproduce these facts in a calibrated DSGE model with Chinese characteristics. Our model highlights the roles of liquid assets, i.e. excess reserves and central bank bills, in banks’ liquidity management, and the role of central bank in supplying liquid assets. In the model, all the funds are channelled through banks. Banks raise deposits from households and extend loans to firms. After loans are extended, a random fraction of the bank’s deposits are transferred out from the bank. Only liquid assets, i.e. excess reserves and central bank bills, can be used to settle the transfer. If a bank does not have enough liquid assets, its reserves fall below the required level. In this case, the bank has to pay a penalty. Thus, the amount of loan a bank can lend is constrained by the amount of liquid assets it holds. Currency intervention increases the total amount of liquid assets (i.e. central bank bills and reserve money) available for banks and is potentially expansionary.

Open market operation only replaces one liquid asset (reserve money) with the other (central bank bills) without changing the total of them two. Thus, the effectiveness of open market operation depends on the extent to which central bank bills are substitutable for reserve money for banks. In an extreme case where they are perfect substitutes, Modigliani-Miller theorem for open market operations (Wallace, 1981) holds, and monetary sterilization has no effect. To capture the difference between reserves and central bank bills, we follow Andolfatto and Williamson (2015) and assume that reserve money can be used to settle a wider array of transactions than can central bank bills. Thus, selling central bank bills has some contractionary effects, but the effects can be limited.

Our model deviates from the standard “bank lending channel” view by introducing the liquidity management of banks. The standard “bank lending channel” view follows the money multiplier in textbook, which suggests that the creation of deposits and loans is constrained by reserve requirement, and changes in monetary base directly affect the amount of lending banks can do. According their view, complete sterilization, which ensures that currency intervention do not affect monetary base, should be able to largely neutralize the impacts of intervention. However, in our model, excess reserve and central bank bills are substitutable for liquidity management purpose, and excess re-

---

6China’s financial markets are less developed compared with its banking system and a large portion of funds are channeled through banks.

7For example, when funds is transferred from one bank to another, this transaction can be settled with either bank reserves or central bank bills. However, if funds is withdrawn by a household from ATM, it can only be settled with bank reserves (vault cash).
serve ratio decrease as banks’ holdings of central bank bills increases. Thus, sterilized intervention, which increases banks’ holdings of central bank bills, endogenously raises the money multiplier and leads to expansions of banks’ balance sheets.

In our model, the balance sheet of central bank is explicitly modeled. In the model, central bank holds foreign assets and issues both reserve money and central bank bills. Under fixed exchange rate regime, the excess supply (demand) of foreign assets is absorbed by central bank, and external imbalance directly translates into changes in central bank’s balance sheet. In our setup, external shock can affect the domestic economy by changing the size of the central bank’s balance sheet.

In the model, nominal exchange rate is fixed by the central bank and capital account is assumed to be closed. Following Chang, Liu and Spiegel (2015), households are allowed to hold both domestic and foreign deposits, while foreign investors are not allowed to hold domestic assets. However, there is a cost for households to adjust the composition of their portfolio, which leads to a wedge in the uncovered interest rate parity (UIP) condition. Thus, changes in the spread between domestic and foreign interest rates will only lead to finite capital flows.

The model is calibrated using macroeconomic and interbank bond market data of China. We use the calibrated model to examine the stabilization performance of the central bank under different monetary policy regimes.

To help understand the decoupling between monetary base and broad money (M2) in China during the sterilized intervention period (2000-2006), we examine the impulse responses of several key macroeconomic variables following two positive external shocks, i.e. an increase in exports demand and a decrease in foreign interest rate. We assume that the central bank conducts open market operation to fix the nominal monetary base, which we think well reflects the PBOC’s policy stance during 2000-2006 (see Figure 3). We find that money multiplier and bank credit increase significantly as expected following a positive external shock. Positive external shocks put upward pressure on the value of domestic currency. Since nominal exchange rate is fixed, BOP surpluses are absorbed by the central bank, leading to increases in the monetary base. To fix the monetary base, the central bank issues central bank bills to sterilize its intervention. With more holdings of central bank bills, banks hold less excess reserves, leading to a higher money multiplier and expansions of banks’ balance sheet.

Then, we use the same framework to study the optimal choice of monetary policy instruments and the accordingly optimal policy rules. We consider two external shocks, i.e. an exports demand shock and a foreign interest rate shock. We assume that the central bank potentially has accesses
to two different monetary policy instruments, i.e. open market operation (OMO) and reserve requirement ratio (RRR). When the central bank conducts open market operation or adjusts required reserve ratio, it has to follow a Taylor-style rule. We consider two monetary policy regimes. Under the first regime, the central bank can only conduct open market operation while the required reserve ratio being fixed. Under the second regime, the central bank has accesses to both monetary policy instruments. For each case, policy reaction coefficients are chosen to minimize a simple quadratic loss function of the central bank.

We find that by allowing the central bank to adjust required reserve ratio according to economic conditions, the volatilities of macro-economic variables significantly decreased. To help understand how RRR policy helps stabilize the economy, we examine the impulse responses of the key macro variables under the two monetary policy regimes. As expected, when the central bank has accesses to both policy instruments, it sells less central bank bills and raises required reserve ratio instead in responding to a positive external shock. In this case, money multiplier and bank credit increase less following the shock. Since open market operation only replaces one liquid assets with the other while raising RRR can directly freeze the excess liquid assets, the central bank switches from OMO to RRR when it is allowed to do so.

Related Literature.

Traditional monetary policy literatures focus on the interest channel of monetary transmission; however, we focus on the role of banking system. In macroeconomics, the role of banking system in the transmission of monetary policy was less studied. Only until recently, economists started to explicitly incorporate banking sector into DSGE models, such as Curdia and Woodford (2009), Gerali et al. (2010) and Ennis (2014). In this paper, we explicitly modeled the banking sector and focus on the liquidity management of banks. However, we focus on an economy with Chinese characteristics. In particular, we study how sterilized intervention shifts the supply of bank credit by changing the amount of liquid assets available for banks and the optimal choice of monetary policy instruments given China’s current external policy regime.

Our paper is also related the literatures that study the role of central bank in supplying liquid assets. After the recent global crisis broke out, central banks in developed economies had expanded their balance sheets to unprecedented levels due to their large scale asset purchases. Motivated by

---

8 Exception is Bernanke and Blinder (1988)

9 Classical literature that study liquidity management include Holmstrom and Tirole (1998), and bank run literatures, such as, Diamond and Dybvig (1983), Allen and Gale (1998), Ennis and Keister (2009). However, Ennis (2014), Bianchi and Bigio (2014) and Gertler and Kiyotaki (2015) are the first ones which introduce the liquidity management of banks into general equilibrium models. In addition, Kashyap and Stein (2000) studies the liquidity holdings of individual banks and find empirical evidence for the bank lending channel.
these dramatic changes in central banks’ balance sheets, some of the recent studies delve into the role of public liabilities in the economy, and the role of central bank in managing the supply of outside liquidity. To shed lights on these issues, Williamson (2012) and Andolfatto and Williamson (2015) have constructed models in which public liabilities functions as exchange medium, and Ennis (2014) and Bianchi and Bigio (2014) focus on their roles in the liquidity management of banks.

Our paper also emphasizes the role of public liabilities, but in very different context. Since early 2000s, China’s central bank had been significantly expanding its balance sheet (Figure 1) as results of its currency intervention. This dramatically increased the amount of central bank liabilities, i.e. bank reserves and central bank bills, which are liquidity management instruments for banks. In this context, we study what are the optimal choice of monetary policy instruments and the accordingly optimal policy rules for central bank to counter the inflationary effects of its currency intervention.

Our work is also closely related to the analysis of credit booms’ association with capital inflows and exchange rate regimes. There is ample evidence showing that capital inflows increase before the peak of credit booms (Mendoza and Terrones, 2012). In addition, Magud, Reinhart and Vesperoni (2012) has shown that capital inflows can lead to more credit growth in economies with less flexible exchange rate regimes and attributes the credit expansion to increasing monetary bases from partial sterilization.

The rest of the paper is structured as follows. Section 2 reviews the currency intervention and monetary policy of the PBOC. We set up the model in Section 3, followed by the calibration of the model in Section 4 and empirical applications in Section 5. The final section concludes the paper.

2 Currency Intervention and Monetary Policy in China

2.1 Currency Intervention and Monetary Sterilization

Since early 2000s, China’s foreign exchange market intervention has greatly changed the balance sheet of the PBOC. As shown in Figure 1, the PBOC’s holdings of foreign assets (i.e. foreign reserves and gold) have been aggressively increasing since 2000. In addition, the composition of the PBOC’s assets was significantly changed. Foreign assets accounted for only 40% of the PBOC’s assets in 2000, but 84% in 2013. Obviously, the fast expansion of the PBOC’s balance sheet was mainly due to its active currency intervention.
When purchasing foreign assets, the PBOC releases equivalent amount of base money, which could put expansionary pressure on the economy. To neutralize the effects of its currency intervention, the PBOC mainly depends on two monetary tools, open market operation (OMO) in the early 2000s, and required reserve ratio (RRR) in the late 2000s.

In the early 2000s, the PBOC had been mainly using OMO to sterilize its currency intervention. Since 2002, the PBOC started to issue central bank bills as a new form of open market operation due to its limited holdings of government bond. The total outstanding central bank bills reached 4 trillion Yuan at the end of 2006, which accounted for about 25% of the PBOC’s total liabilities. During this period, reserve money, however, increased only moderately and its share in the PBOC’s total liabilities decreased from 92% to 56%. (Figure 1)

2.2 Transactions of Central Bank Bills in Interbank Bond Market

The central bank bills, issued as sterilization instruments, are very liquid in the interbank bond market. The left panel of Figure 2 shows the size of central bank bill transactions (including spot and repurchase transactions) in the interbank bond market. The right panel of Figure 2 shows the share of central bank bill transaction in the total transactions in the interbank bond market.

\[\text{Equation}\]

---

\[\text{In China, the interbank bond market is much more developed than the interbank unsecured lending market. Due to various limitations of current legal and institutional infrastructure, secured borrowing (repurchase transaction in interbank bond market) is more accessible than unsecured interbank borrowing for most financial intermediaries. Chinese economists even suggest that the PBOC use the interbank repo rate (REPOR) rather than the interest rate of unsecured interbank borrowing, i.e. Shanghai InterBank Offered Rate (SHIBOR), as the target rate in conducting monetary policy.}\]
Figure 1: The Balance Sheet of PBOC
As is shown, central bank bill transaction had been increasing during the sterilized intervention period (2000-2006), and started to decrease after 2008, as the PBOC gradually stopped the issuance of new central bank bills since 2007 (Figure 1). Central bank bills are an important type of liquid assets transacted in the interbank bond market. The share of central bank bill transaction in the total transactions in the interbank bond market reached 38% in 2008, which is larger than the share of government bond transaction by 30%.

In addition, central bank bills have the highest turnover rate among liquid assets transacted in the interbank bond market. During 2000-2013, the average annual turnover rate of central bank bills is around 8, while the turnover rates of government bonds and financial bonds\(^{11}\) are around 4 and 6 respectively.

### 2.3 Decoupling of Monetary Base and M2

Central bank bills are very liquid in the interbank market, which can be ideal tools for banks’ liquidity management. In this sense, central bank bills are good substitutes for excess bank reserves. As banks hold more central bank bills, they may decrease their holdings of excessive bank reserves. This may increase monetary multiplier, decoupling broad money from monetary base. The PBOC’s

\(^{11}\)They are mainly bonds issued by Chinese policy banks.
sterilized intervention (2000-2006) may thus contributed to the expansions of bank credit and M2 in China during the same period.

As shown in Figure 3, during the sterilized intervention period, M2 had significantly increased (by around 160%), while base money has only increased by around 90%. The divergence between broad money (M2) and base money implies an increase in money multiplier. Given the fact that the required reserve ratio had been actually increasing during this period (Figure 4), excess reserve ratio should have decreased during the sterilization period. The blue line (dash-dot) shows the projected M2 for fixed excess reserve ratio, i.e. the amount of M2 banks would have if excess reserve ratio were kept at its 2000 level, given the actual levels of bank reserves and required reserve ratio. As it shows, the significant positive gap between the actual and projected M2 indicates a drop in excess reserve ratio.

2.4 Required Reserve Ratio Management

Since 2007, the PBOC started to actively adjust reserve required ratio and use it as stabilization tool. Reserve required ratio had been adjusted only around 0.7 times per year during 2000-2006, but around 5 times per year during 2007-2013. In 2007 alone, it had been adjusted 10 times by the
Figure 4: Required Reserve Ratio of China

The PBOC started to actively adjust reserve required ratio and use it as a stabilization tool since 2007. Reserve required ratio had been adjusted 5 times per year on average during 2007-2013. In 2007 alone, it had been adjusted 10 times by the PBOC.

After 2006, the PBOC gradually stopped to issue new central bank bills to sterilize its currency intervention, and as a result, reserve money has significantly increased by around 300% during 2007-2013 (Figure 1). Instead, the PBOC counters the expansionary pressure from currency intervention by raising required reserve ratio. As shown in Figure 4, RRR was raised only from 6% to 9% during the sterilized intervention period 2000-2006, but from 9% to 22% during 2007-2013.

The switch from monetary sterilization to RRR management well reflected the PBOC’s awareness of the ineffectiveness of sterilization, and also could be a response to the increased sterilization costs. After 2008, the Federal Reserve Bank of the US has been keeping the short term interest rates near zero. The three-month interest rates on the US Treasury Bills drops below the three-month interest rate on China’s central bank bills, which increased the “quasi-fiscal loss” of currency sterilization (Chang, Liu and Spiegel, 2015). In addition to the ineffectiveness of sterilization, which is our main focus in this paper, the increased sterilization costs could be another reason that makes the PBOC switch from monetary sterilization to RRR management.
3 The Model

We consider a global economy with two countries, i.e. home and foreign country. We focus on the problems of the home country and assume that the foreign country is passive.

The home country is populated by two groups: patient households and impatient entrepreneurs. The discount factor of households is lower than that of entrepreneurs. Households save, consume and supply labor. Entrepreneurs consume, produce whole sale intermediate goods using capital and labor, hold capital goods, and borrow against the value of their capital stock.

The heterogeneity in discount factor determines positive financial flows from patient households and impatient entrepreneurs in equilibrium. All the funds are channeled through banks. Banks raises deposits from households and extend loans to entrepreneurs. In addition, banks hold liquid assets, i.e. excess bank reserves and central bank bills, as part of their liquidity management. The spread between the interest rates for loan and deposit positively depends on banks’ liquidity management cost, which in turn depends on their holdings of liquid assets relative to the size of their deposits. However, bank reserves can be used in a wider array of transactions than can central bank bills.

The final good is produced by combing domestic goods and foreign goods. To introduce price stickiness, we assume that the production process of domestic goods is as follows. Retailers buy whole sale intermediate goods from entrepreneurs, differentiate them into retail intermediate goods, and sell them to domestic goods producers, which assemble retail intermediate goods using a CES technology. The markets for retail intermediate goods are monopolistically competitive. Retailers set price for their own products to maximize their profits subject price adjustment cost. In addition, to introduce wage stickiness, we assume that there are labor market intermediaries which buy labors from households at a competitive price and sell them in monopolistically competitive markets.

To capture China’s capital account regime, we assume that households can hold both domestic bank deposits and foreign assets, while foreign investors are not allowed to hold domestic assets. However, households are subject to a portfolio adjustment cost when they change their portfolio shares of domestic and foreign assets. Due to the imperfect substitutions between domestic and foreign assets, the model allows for deviations from uncovered interest rate parity (UIP).

Central bank holds foreign assets and issues bank reserves and central bank bills. Central bank adopts fixed exchange rate regime and conduct currency intervention to keep the nominal exchange rate at its target. The excess supply (demand) of foreign assets are absorbed by the central bank,
which changes the size of central bank’s balance sheet. In the benchmark model, central bank is only allowed to conduct open market operation, which changes the shares of reserves and central bank bills in its total liability. In the an extension of this model, we allow central bank to adjust required reserve ratio in responding to changes in economic conditions, and examine its implications for economic stabilization.

3.1 Households

Households lives for infinite periods, and consume final goods and supply labor. The preference of household \( i \) is given by

\[
E_t \sum_{t=0}^{\infty} \beta^t \left\{ \log \left( C_t(i) - \chi C_{t-1}(i) \right) - \psi \frac{N_t(i)^{1+\iota}}{1+\iota} \right\} 
\]

where \( C_t(i) \) and \( N_t(i) \) are the consumption and the labor supply of household \( i \) in period \( t \), \( \beta \in (0, 1) \) is the subjective discount factor, \( \chi \in (0, 1) \) is the habit coefficient, \( \psi \) is the relative weight of leisure in the utility function, and \( \iota \) is the inverse Frisch elasticity of labor supply.

Households hold domestic deposits \( D_t(i) \), foreign assest \( F_{ht}(i) \). The budget constraint of household is given by

\[
C_t(i) + \frac{D_t(i)}{P_t} + (1 + \Gamma_t) \frac{e_t F_{ht}(i)}{P_t} \leq w_t^H N_t(i) + \frac{D_{t-1}(i) R_{t-1}^D}{P_t} + \frac{e_t F_{h,t-1}(i) R_{t-1}^*}{P_t} + \Pi_t + T_t 
\]

where

\[
\Gamma_t = \Gamma \left( \frac{D_t}{D_t + e_t F_{ht}} - \bar{\varphi} \right)
\]

Here, \( P_t \) is the domestic price level, \( e_t \) is the nominal exchange rate, \( w_t^H \) is the price of labor faced by households, \( R_t^D \) and \( R_t^* \) are the nominal interest rates paid on \( D_t(i) \) and \( F_{ht}(i) \), \( \Pi_t \) and \( T_t \) are the lump sum transfer from household owned firms and the public sector, \( \Gamma_t \) is the portfolio adjustment costs, and \( \bar{\varphi} \) is the steady state share of domestic deposits in the total value of households’ assets.

Define \( \varphi_t \equiv D_t/(D_t + e_t F_{ht}) \) to be the aggregate share of domestic deposits in the total value of households’ assets in period \( t \), which is taken as given by individual household. We assume that the portfolio adjustment cost function \( \Gamma(.) \) has \( \Gamma(0) \geq 0 \) and \( \Gamma'(0) > 0 \).

Let \( \lambda_t \) denote the Lagrangian multiplier for the budget constraint (2). The optimal choice of
labor supply implies
\[ w^H_t = \frac{\psi_N(j)^t}{\lambda_t} \quad (4) \]

Let \( \pi_t = P_t/P_{t-1} \) denote the inflation rate. The optimal choice of \( D_t(i) \) and \( F_{ht}(i) \) implies
\[ 1 = \beta E_t \left( \frac{\lambda_{t+1} R^D_t}{\lambda_t \pi_{t+1}} \right) \quad (5) \]
\[ 1 + \Gamma_t = \beta E_t \left( \frac{\lambda_{t+1} R^*_t}{\lambda_t \pi_{t+1}} e_{t+1} \right) \quad (6) \]

By linearizing both sides and combing the above two equations, we can obtain the generalized UIP (uncovered interest parity) condition:\textsuperscript{12}
\[ \hat{R}^D_t - \hat{R}^*_t = E_t \Delta \hat{e}_{t+1} + \Gamma'(0) \hat{\varphi} \hat{\varphi}_t \quad (7) \]

In the presence of portfolio adjustment costs, changes in the difference between domestic and foreign interest rates only lead to finite changes in the households’ optimal share of domestic deposits.

### 3.2 Labor Market

We assume that there are labor market intermediaries which buy wholesale labors from households at a competitive price \( w^H_t \) and sell them in a monopolistically competitive market. Labors sold by different intermediaries are considered to have different types. There are competitive labor packers who assemble them in a CES aggregator and sell the homogeneous labor to the entrepreneurs.

The individual labor intermediary takes as given the wage level \( W^s_t \) and labor packers’ demand function and chooses a price \( W^s_t(i) \) to maximizes its expected discounted dividend flows subject to quadratic price adjustment costs. Thus, labor intermediaries solve the following problem
\[
\max_{W^s_t(i)} E_t \sum_{k=0}^{+\infty} \beta^k \left( \frac{\lambda_{t+k}}{\lambda_t} \right) \left\{ \left( \frac{W^s_{t+k}(i)}{P_{t+k}} - w^H_t \right) N_{t+k}(i) - \frac{\Omega_{w}}{2} \left( \frac{W^s_{t+k}(i)}{\pi w W^s_{t+k-1}(i)} - 1 \right)^2 \left( \frac{W^s_{t+k}}{P_{t+k}} \right) N_{t+k} \right\}
\]

where \( N_t(i) \) is the demand for labor sold by intermediary \( i \) which is given by
\[ N_t(i) = \left( \frac{W^s_t(i)}{W^s_t} \right)^{-\theta_w} N_t \quad (8) \]

\textsuperscript{12}In the absence of portfolio adjustment costs \( \Gamma_t \), the above equation corresponds to the standard UIP condition.
The wage level $W^s_t$ is related to $W^s_t(i)$ by $W^s_t = \left[ \int_0^1 W^s_t(i)^{1-\theta_w} di \right]^{1/\theta_w}$. Here, $\theta_w$ is the elasticity of substitution between different labors and $\Omega_w$ governs the size of price adjustment costs.

In a symmetric equilibrium with $W^s_t(i)$ for all $i$, the optimal pricing rule is implied

$$w^H_t = \left( \frac{\theta_w - 1}{\theta_w} + \frac{\Omega_w}{\theta_w} \left[ \left( \frac{\pi^w_{t+1}}{\pi^w_t} - 1 \right) \frac{\pi^w_t}{\pi^w_{t+1}} - \beta E_t \left( \frac{\lambda_{t+1}}{\lambda_t} \right) \left( \frac{N_{t+1}}{N_t} \right) \frac{w^H_{t+1}}{w^H_t} \left( \frac{\pi^w_{t+1}}{\pi^w_t} - 1 \right) \frac{\pi^w_{t+1}}{\pi^w_t} \right] \right) w^E_t$$

(9)

where $w^E_t \equiv \frac{W^s_t}{P_t}$ is the real wage rate faced by entrepreneurs. In the absence of price adjustment costs, the real cost of labor $w^H_t$ would be equal to the inverse markup times the real wage rate $w^E_t$.

3.3 Entrepreneurs

Entrepreneurs live for infinite periods. The preference of entrepreneurs is given by

$$E \sum_{t=0}^{\infty} \beta^t_e \log(C_t^e)$$

(10)

where $C_t^e$ denotes the entrepreneur’s consumption in period $t$. Entrepreneurs’ discount factor, $\beta_e$, is assumed to be lower than that of households, $\beta$, such that they are always borrowers in equilibrium.

Entrepreneurs produce whole sale intermediate goods, denoted by $Y^w_t$, using a Cobb-Douglas production technology which combines labor $N_t$ and capital $K_t$:

$$Y^w_t = e^{z^\alpha_t} K^\eta_t N^{1-\eta}_t$$

(11)

where $z^\alpha_t$ is the productivity shock.

Entrepreneurs hold capital $K_t$ and borrow loans from banks, denoted by $L_t$. The entrepreneur’s budget constraint is thus given by

$$C^e_t + w^E_t N_t + \frac{R^L_t L_{t-1}}{P^L_t} + q_t K_{t+1} \leq m_c Y^w_t + \frac{L_t}{P_t} + q_t (1 - \delta) K_t$$

(12)

where $m_c \equiv P^w_t / P_t$ denotes the relative price of whole sale intermediate goods in terms of final goods, $w^E_t$ is the real price of labor faced by entrepreneurs, $R^L_t$ is the nominal interest rate on loans, $q_t$ is the real price of physical capital, and $\delta$ is the depreciation rate of capital.
We assume that the amount the entrepreneur can borrow from banks is constrained by his holdings of physical capital:

\[ \frac{R_t L_t}{P_t} \leq \nu E_t \left[ q_{t+1} \pi_{t+1}(1 - \delta) \right] K_{t+1} \]  

(13)

where \( \nu \) is the loan-to-value ratio.

A representative entrepreneur chooses consumption \( C_t^e \), capital stock \( K_{t+1} \), labor input \( N_t \), and loan borrowed from bank \( L_t \), to maximize her life time utility (10), subject to production technology (11), budget constraint (12) and borrowing constraint (13).

Let \( \lambda^e_t \) and \( \mu_t \) denote the Lagrangian multipliers associated with budget constraint (12) and borrowing constraint (13) respectively. The optimal labor demand is given by

\[ w_t^E = (1 - \eta) mc_t \frac{Y_t^{w}}{N_t} \]  

(14)

The optimal choices of \( L_t \) and \( K_t \) imply

\[ 1 = \beta E_t \left( \frac{\lambda^e_{t+1}}{\lambda^e_t} \frac{R_t^L}{\pi_{t+1}} \right) + \mu_t \frac{R_t^L}{P_t} \]  

(15)

\[ q_t = \beta E_t \left[ \frac{\lambda^e_{t+1}}{\lambda^e_t} \left( mc_{t+1} \frac{Y_t^{w}}{K_{t+1}} + (1 - \delta)q_{t+1} \right) \right] + \mu_t \nu E_t \left[ q_{t+1} \pi_{t+1}(1 - \delta) \right] \]  

(16)

### 3.4 Retailers

We assume that there are retailers who buy whole sale intermediate goods from entrepreneurs at a competitive price \( mc_t \) and then transform it into retail intermediate goods \( Y_t^{d}(i) \) and sell them to domestic goods producers. Domestic good producers produce domestic goods \( Y_t^{d} \) using a CES aggregation technology.

The individual retailer chooses the price of her own retail goods \( P_t^{d}(i) \) to maximizes her expected life time profits subject to a quadratic price adjustment cost. The optimization problem of retailer \( i \) is thus given by

\[ \max_{P_t^{d}(i)} E_t \sum_{k=0}^{+\infty} \beta^k \left( \frac{\lambda_{t+k}}{\lambda_t} \right) \left\{ \left( \frac{P_{t+k}^{d}(i)}{P_{t+k}} - mc_t \right) Y_t^{d}(i) - \frac{\Omega_p}{2} \left( \frac{P_{t+k}^{d}(i)}{\pi_d \pi_{t+k-1}^{d}(i)} - 1 \right)^2 \frac{P_{t+k}^{d}(i)}{P_{t+k}} Y_{t+k}^{d} \right\} \]
where $Y^d_t(i)$ is the demand for the intermediate good $i$ which is given by

$$Y^d_t(i) = \left( \frac{P^d_t(i)}{P^d_t} \right)^{-\theta_p} Y^d_t$$

(17)

Here, the price level of domestic goods $P^d_t$ is related to the prices of retail intermediate goods $P^d_t(i)$ by

$$P^d_t = \left[ \int_0^1 P^d_t(i)^{1-\theta_p} di \right]^{\frac{1}{1-\theta_p}}$$

$\theta_p > 1$ governs the elasticity of substitution between differentiated retail intermediate goods, and $\Omega_p$ represents the size of price adjustment cost.

In a symmetric equilibrium where $P^d_t(i) = P^d_t$ for all $i$, the optimal price setting decision implies

$$mc_t = \left\{ \frac{\theta - 1}{\theta} + \frac{\Omega_p}{\theta} \left[ \left( \frac{\pi^d_t}{\pi^d} - 1 \right) \frac{\pi^d_t}{\pi^d} - \beta E_t \left( \frac{\lambda_{t+1}}{\lambda_t} \right) \left( \frac{Y^{d+1}_t}{Y^d_t} \right) \left( \frac{q^{d+1}_t}{q^d_t} \right) \frac{\pi^{d+1}_t - 1}{\pi^d_t - 1} \right] \right\} q^d_t$$

(18)

where $q^d_t \equiv P^d_t/P_t$ denotes the real price of domestic goods. In the absence of price adjustment cost, the marginal cost of domestic goods production $mc_t$ would be equal to its price $q^d_t$ times the inverse markup.

### 3.5 Final Goods Producers

Final goods producers produce final goods, denoted by $Y_t$, by combining domestic goods, denoted by $Y^d_t$, and foreign goods, denoted by $Y^f_t$. The production technology is given by

$$Y_t = \tilde{\alpha} \left( Y^d_t \right)^\alpha \left( Y^f_t \right)^{1-\alpha}$$

(19)

where $\tilde{\alpha} = (\alpha)^{-\alpha}(1-\alpha)^{-(1-\alpha)}$.

Let $P^d_t$ be the price of domestic good, and $P^f_t$ be the price of foreign goods in foreign currency. Let $e_t$ be the nominal exchange rate. The demand for domestic and foreign goods are given by

$$Y^d_t = \alpha \left( \frac{P^d_t}{P_t} \right)^{-1} Y_t$$

(20)

$$Y^f_t = (1-\alpha) \left( \frac{e_t P^f_t}{P_t} \right)^{-1} Y_t$$

(21)
3.6 Capital Goods Producers

Capital goods producers produce capital goods using final goods. They have a linear technology and face an adjustment cost. The cost to produce a unit of new capital goods is $1 - \frac{\Omega_t}{2} \left( \frac{I_t}{I_{t-1}} - 1 \right)^2$. Capital goods producers choose inputs $I_t$ and take price $q_t$ as given to maximize the expected lifetime profits. Their objective function is given by:

$$E_t \sum_{k=0}^{+\infty} \beta^k \left( \frac{\lambda_{t+k}}{\lambda_t} \right) \left\{ q_{t+k} \left[ 1 - \frac{\Omega_t}{2} \left( \frac{I_{t+k}}{I_{t+k-1}} - 1 \right)^2 \right] - 1 \right\} I_{t+k}$$

The first order condition is given by:

$$q_t \left[ 1 - \frac{\Omega_t}{2} \left( \frac{I_t}{I_{t-1}} - 1 \right)^2 - \Omega_t \left( \frac{I_t}{I_{t-1}} - 1 \right) \left( \frac{I_t}{I_{t-1}} \right) - \beta E_t \Omega_t \left( \frac{\lambda_{t+1}}{\lambda_t} \right) \left( \frac{I_{t+1}}{I_t} - 1 \right) \left( \frac{I_{t+1}}{I_t} \right)^2 q_{t+1} \right] = 1$$

Here, $\Omega_t$ measures the size of investment adjustment cost. In the absence of investment adjustment cost, the real price of new capital $q_t$ is always equal to one.

3.7 Banking Sector

We assume that all the funds are channeled via banks. Banks can invest on three assets, which are loans, denoted by $L_t$, central bank bills, denoted by $B_t$, and excessive bank reserves, denoted by $E_t$. The sources of funds are household deposit, denoted by $D_t$. Let $rr_t$ be the required reserve-deposit ratio. The balance sheet of a bank is thus given by:

$$(1 - rr_t)D_t = L_t + B_t + E_t \tag{23}$$

Banks do not accumulate any net worth. They deliver all the profits they earned in each period to households as dividends. Let $R_t^L, R_t^B, R_t^E$, and $R_t^D$ be the interest rates for loans, central bank bills, bank reserves, and domestic deposits. Bank chooses $L_t, E_t, B_t$ and $D_t$ to maximize its profits, which is given by

$$\Pi_t^b = R_t^L L_t + R_t^B B_t + R_t^E E_t - (R_t^D - rr_t R_t^E)D_t - \phi_t D_t \tag{24}$$

where $\phi_t$ is the liquidity management cost for deposits which is endogenously determined.

**Liquidity Management.** Each period is divided into three stages, which are lending stage, liquidity management stage, and balancing stage. In the lending stage, banks raise deposits and
Liquidity Management of Banks in Period $t$

<table>
<thead>
<tr>
<th>Stage One:</th>
<th>Stage Two:</th>
<th>Stage Three:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lending Stage</td>
<td>Liquidity Management Stage</td>
<td>Balancing Stage</td>
</tr>
<tr>
<td>Raises deposits $D_t$ and Lend $L_t$. Chooses $E_t$ and $B_t$</td>
<td>A fraction $\omega$ of $D_t$ is transferred to other banks. Liquid assets are used to settle the transaction.</td>
<td>Bank receives $\omega D_t$ deposit inflows. The initial distribution of deposits is recovered.</td>
</tr>
</tbody>
</table>

build its investment portfolio. In the liquidity management stage, a idiosyncratic shock hits banks, and a fraction $\omega$ of its deposits are transferred to other banks. Here, $\omega$ is i.i.d. across banks and over time, which has mean $\mu_\omega$ and variance $\sigma_\omega^2$. When $\mu_\omega = 0$, the liquidity shock only redistribute deposit across banks, but do not change the total size of deposits in the banking system. When $\mu_\omega > 0$, there is net outflow of funds from the banking system. In the balancing stage, deposits that flowed out in the second stage return to the bank. Thus, the bank gets $\omega D_t$ units of deposits back in the third stage. As results, the initial cross-sectional distribution of deposits is recovered in the third stage.

We assume that loan are illiquid and banks cannot do unsecured borrowing from each other. Thus, the deposit transfer across banks has to be settled with liquid assets, i.e. bank reserves and central bank bills. Banks can use bank reserve to make a payment, or use central bank bills to do a repo transaction. The inner period repo rate has to be one in equilibrium. Following Andolfatto and Williamson (2015), we assume that bank reserves can be used in a wider array of transactions than can central bank bills. When deposits are transferred out of a bank, the bank has to decrease its liquid assets by the same amount in order to settle the transaction. With probability $\gamma$, the bank can only use bank reserves to settle the transaction; with probability $1 - \gamma$, both bank reserves and central bank bills can be used to settle the transaction. If the bank does not have enough liquid assets, its reserve falls below the required level. In this case, the bank has to pay a penalty which equals a fraction $\tau$ of the amount of transfer that could not be settled with the bank’s holdings of central bank bills and excess reserves.

Let $\bar{\omega}_1$ ($\bar{\omega}_2$) denote the maximum levels of deposit outflows that can be settled with the excess reserves $E_t$ (the excess reserves and central bank bills $E_t + B_t$). They are given by

$$
\bar{\omega}_1 = \frac{E_t}{D_t} \quad \text{and} \quad \bar{\omega}_2 = \frac{E_t + B_t}{D_t} \quad (25)
$$

\footnote{The unsecured interbank borrowing is undeveloped in China.}

\footnote{For example, when funds is transfered from one bank to another, this transaction can be settled with either bank reserves or central bank bills. However, if funds is withdrawn by a household from ATM, it can only be settled with bank reserves (vault cash).}
Thus, the expected liquidity manage cost for the bank is given by

\[
\phi_t = \tau \left[ \gamma \int_{\bar{\omega}_1t}^{1} (\omega - \bar{\omega}_1t) \, dF(\omega) + (1 - \gamma) \int_{\bar{\omega}_2t}^{1} (\omega - \bar{\omega}_2t) \, dF(\omega) \right]
\] (26)

**Profits Maximization.** The optimal choice of \(L_t, E_t, B_t\) and \(D_t\) implies

\[
R^L_t - R_t = \tau (1 - \gamma) H(\bar{\omega}_2t)
\] (27)

\[
R^L_t - R^E_t = \tau \left[ \gamma H(\bar{\omega}_1t) + (1 - \gamma)H(\bar{\omega}_2t) \right]
\] (28)

\[
(1 - r_t)R^L_t + rr_t R^E_t - R^D_t = \tau \left[ \gamma G(\bar{\omega}_1t) + (1 - \gamma)G(\bar{\omega}_2t) \right]
\] (29)

where

\[
H(\bar{\omega}_it) = 1 - F(\bar{\omega}_it) \quad \text{and} \quad G(\bar{\omega}_it) = \int_{\bar{\omega}_it}^{1} \omega dF(\omega) \quad \text{for} \quad i = 1, 2
\] (30)

**Open Market Operation.** Note that open market operation (OMO) which replaces excess bank reserves \(E_t\) with \(B_t\) only changes \(\bar{\omega}_1t\); however, it has no effect on \(\bar{\omega}_2t\). As shown in (27)-(29), OMO tends to lower the liquidity management cost and narrow the interest rate spreads. However, the extent to which OMO can affect the interest spreads depends on the value of \(\gamma\). In an extreme case, where \(\gamma = 0\), OMO has no effect at all and the Modigliani-Miller Theorem for OMO holds.

### 3.8 External Sector

**Exports.** Final goods \(Y_t\) are exported to foreign economy. Let \(X_t\) denote the amount of final goods that are exported. We assume that the foreign demand for domestic final goods is given by:

\[
X_t = \left( \frac{P_t}{c_t P^f_t} \right)^{-\xi} X_t
\] (31)

where \(P^f_t\) is assumed to be constant and normalized to one, and \(X_t\) follows the following stochastic process

\[
\log X_t = (1 - \rho_x) \log \bar{X} + \rho_x \log X_{t-1} + \sigma_x \varepsilon^x_t
\] (32)

Here, \(\rho_x\) is the persistence parameter, \(\sigma_x\) is the standard deviation of foreign demand shock, and \(\varepsilon^x_t\) is i.i.d over time and has a standard normal distribution.

**Foreign Interest Rate.** We assume that foreign interest rate is exogenously determined and
follows the following stochastic process

$$\log R_t^* = (1 - \rho_r) \log R_t^* + \rho_r \log R_{t-1}^* + \sigma_r \varepsilon_t^r$$  \hspace{1cm} (33)$$

where $\rho_r$ is the persistence parameter, $\sigma_r$ is the standard deviation of foreign interest rate shock, and $\varepsilon_t^r$ is i.i.d over time and has a standard normal distribution.

**Balance of Payment.** Let $F_t$ denote the total foreign assets held by the country, i.e. both the private and the public sector. The current account surplus expressed in real term is thus given by

$$CA_t = X_t - \left(\frac{e_t P_t^f}{P_t} \right) Y_t^f + \frac{e_t (R_{t-1}^* - 1) F_{t-1}}{P_t}$$  \hspace{1cm} (34)$$

Since we assume that only domestic households can hold foreign assets, while foreign households do not hold domestic assets. Thus, the capital inflows should be equal to the decrease in the foreign assets held by households. The capital account surplus is thus given by

$$KA_t = \frac{e_t (F_{h,t-1} R_{t-1}^* - F_{ht})}{P_t}$$  \hspace{1cm} (35)$$

3.9 Central Bank

The central bank holds foreign assets while issuing bank reserves and central bank bills. Let $F_{ct}$ be the foreign assets held by the central bank, $M_t$ be the nominal amount of bank reserves, $B_t$ be the nominal amount of central bank bills. Let $T_t$ denote the nominal tax revenue. The flow of funds constraint of the public sector is thus given by

$$e_t \left(F_{ct} - R_{t-1}^* F_{c,t-1}\right) = B_t - R_t^B B_{t-1} + M_t - R_t^E M_{t-1} + T_t$$  \hspace{1cm} (36)$$

We assume that the tax $T_t$ is just enough to cover the interest payment made by the central bank, i.e. $T_t = (R_{t-1}^B - 1) B_{t-1} + (R_{t-1}^E - 1) M_{t-1} - e_t (R_{t-1}^* - 1) F_{c,t-1}$.

We assume that the central bank keeps the interest rate on reserves constant, i.e. $R_t^E = R^E$.

**Currency Intervention.** The central bank adopts a fixed exchange rate regime, i.e. $e_t = \bar{e}$. The central bank intervenes the foreign exchange market accordingly to fix the nominal exchange.
The excessive supply (demand) of foreign assets is then absorbed the central bank. Thus, we have

\[
e_t \left( F_{ct} - R_{t-1}^* F_{ct-1} \right) \frac{P_t}{P_t} = CA_t + KA_t
\]  

Open Market Operation. In the benchmark case, we assume that the central bank can only conduct OMO according to one of the following two policy rules. The first rule is an interest rate targeting rule, which allows the policy rate \( R_t \) to respond to inflation and output. The policy rate is the rate at which the central bank is willing to discount any amount of central bank bills (before the realization of liquidity shock). Note that central bank bill is an one-period short-term debt in our setup. The arbitrage between the market for central bank bills and the central bank’s discount window ensures that \( R_t = R_t^B \) in equilibrium. The interest rate rule is given by

\[
\hat{R}_t = \phi_{rp} \hat{\pi}_t + \phi_{ry} \hat{Y}_t
\]  

where \( \phi_{rp} \) and \( \phi_{ry} \) represent the central bank’s preference for inflation and output stabilization.

The second rule is an monetary base targeting rule, which allows the nominal monetary base \( \hat{M}_t \) to respond to inflation and output.

\[
\hat{M}_t = \phi_{mp} \hat{\pi}_t + \phi_{my} \hat{Y}_t
\]  

where \( \phi_{mp} \) and \( \phi_{my} \) represent the central bank’s preference for inflation and output stabilization. In the case where \( \phi_{mp} = \phi_{my} = 0 \), the central bank just fixes the nominal monetary base.

Required Reserve Ratio. In an extension of the model, we allow the central bank to set the required reserve ratio (RRR) according to a simple Taylor-style rule:

\[
\hat{r}_t = \phi_{rep} \hat{\pi}_t + \phi_{rey} \hat{Y}_t
\]  

where \( \phi_{rep} \) and \( \phi_{rey} \) represent the central bank’s preference for inflation and output stabilization.
3.10 Market Clearing and Equilibrium

The market clearing conditions for final goods, domestic goods, labor and foreign assets are

\[ Y_t = C_t + C^e_t + I_t + X_t + Adj_t \]  \hspace{1cm} (41)

\[ Y^d_t = \int_0^1 Y^d_t(i) \, di \]  \hspace{1cm} (42)

\[ N_t = \int_0^1 N_t(i) \, di \]  \hspace{1cm} (43)

\[ F_t = F_{ct} + F_{ht} \]  \hspace{1cm} (44)

\[ M_t = E_t + rr_t D_t \]  \hspace{1cm} (45)

where Adj includes all the real adjustment costs.

Given the government policy and the world economy conditions, an equilibrium of the model is characterized by a sequence of prices \( \{P_t, P^d_t, P^w_t, w^H_t, w^E_t, q_t, R^D_t, R^B_t, R^L_t\} \) and aggregate quantities \( \{C_t, C^e_t, Y_t, Y^d_t, Y^f_t, X_t, K_t, I_t, N_t, D_t, B_t, M_t, F_{ht}, F_{ct}, F_t\} \), and also individual prices \( \{W^s_t(i), P^d_t(i)\} \) and quantities \( \{Y^d_t(i), N_t(i)\} \) for each retailer and labor market intermediary such that (i) taking all the prices as given, the allocation solves the utility maximization problems of households and entrepreneurs and the profits maximization problem of retailers, labor intermediaries, capital goods producers, and banks, and (ii) markets for final goods, intermediate goods, capital goods, deposits, loans, bank reserves, central bank bills, and foreign assets clear.

4 Calibration

The values of calibrated parameters are presented in Table 1. The parameters are divided into five groups, which include the parameters in utility function, those in the production function, those that characterize rigidities, those that characterize financial frictions, and those that are related to international trade.

For parameters in the utility function, the subject discount rate for households \( \beta \) is set to 0.99. The subjective discount rate of entrepreneurs \( \beta^e \) is set to 0.98 to ensure that the annual loan rate at steady state is around 6%. The relative weight of leisure in utility function is calibrated as \( \psi = 12 \) so that the working time is roughly 40% of total time endowment. The habit formation coefficient \( \chi \) is set to 0.5.
For the parameters in the production function, the depreciation rate of capital $\delta$ is set to 0.03. To ensure a high investment rate in steady state, which is a typical characteristic of China, capital share $\eta$ is set to 0.5. Thus, the saving rate at steady state is around 45%.

For the rigidity parameters, the elasticity of substitution between different retail goods $\theta_p$ is set to 10 which yields a mark-up around 0.11. The price adjustment cost $\Omega_p$ is set to 60 so that the model is in line with a Calvo pricing model with a duration of price contracts of four quarters. The elasticity of substitution between different labor $\theta_w$ and the wage adjustment cost $\Omega_w$ are set to 5 and 100 respectively, which is consistent with the estimate by Gerali et al. (2010). The investment adjustment cost $\Omega_i$ is set to 2 so that the inverse elasticity of investment to capital price is around 2, which consists with Iacoviello (2005). The steady state share of domestic assets $\bar{\varphi}$ and portfolio adjustment cost $\Gamma'(0)$ are set to 0.9 and 0.6, which is in line with the estimate by Chang, Liu and Spiegel (2015).

For the parameters in the external sector, the share of domestic goods is set to 0.8 so that the import-to-GDP ratio is 80% in the steady state which consists with Chinese data between 1990-2009. Following Chang, Liu and Spiegel (2015), we set the elasticity of foreign demand for Chinese goods to 1.5.

For the parameters in the banking sector, the liquidity shock $\omega$ is assumed to follow a Logistic distribution, which is consistent with the estimate by Bianchi and Bigio (2014) which uses data of US banks. The mean of the liquidity shock $\mu_w$ is set to 0. Thus the total amount of deposits in the whole banking system is unaffected by the liquidity shock. The values of the penalty rate for bank overdraft $\tau$, the share of transfer that only can be settled by reserve money $\gamma$, and the standard deviation of liquidity shock $\sigma_\omega$ are chosen to hit the following three targets: (i) a steady state excess reserve ration of 0.04; (ii) a steady state loan-to-deposit ratio of 0.73; and (ii) a steady state ratio of central bank bill transaction to deposit of 0.05 (quarterly). These targets are consistent with Chinese interbank data during the complete sterilization period.

For the exogenous processes, we set the persistences of both shocks, $\rho_x$ and $\rho_r$, to 0.9, and set their standard deviations, $\sigma_x$ and $\sigma_r$, to 0.01.
<table>
<thead>
<tr>
<th>Parameters</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preferences</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\beta$</td>
<td>subjective discount rate (households)</td>
<td>0.99</td>
</tr>
<tr>
<td>$\beta^e$</td>
<td>subjective discount rate (entrepreneurs)</td>
<td>0.98</td>
</tr>
<tr>
<td>$\psi$</td>
<td>weight of leisure in utility function</td>
<td>12</td>
</tr>
<tr>
<td>$\iota$</td>
<td>inverse Frisch elasticity</td>
<td>2</td>
</tr>
<tr>
<td>$\chi$</td>
<td>habit formation coefficient</td>
<td>0.5</td>
</tr>
<tr>
<td>Technologies</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\eta$</td>
<td>capital share in production function</td>
<td>0.5</td>
</tr>
<tr>
<td>$\delta$</td>
<td>quarterly capital depreciation rate</td>
<td>0.03</td>
</tr>
<tr>
<td>Rigidities</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\theta_p$</td>
<td>elasticity of substitution between differentiated goods</td>
<td>11</td>
</tr>
<tr>
<td>$\theta_w$</td>
<td>elasticity of substitution between differentiated labor</td>
<td>5</td>
</tr>
<tr>
<td>$\Omega_p$</td>
<td>price adjustment cost</td>
<td>60</td>
</tr>
<tr>
<td>$\Omega_w$</td>
<td>wage adjustment cost</td>
<td>100</td>
</tr>
<tr>
<td>$\Omega_i$</td>
<td>investment adjustment cost</td>
<td>2</td>
</tr>
<tr>
<td>Portfolio Adjustment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Gamma'(0)$</td>
<td>steady state portfolio adjustment cost</td>
<td>0.6</td>
</tr>
<tr>
<td>$\bar{\varphi}$</td>
<td>steady state share of domestic assets</td>
<td>0.9</td>
</tr>
<tr>
<td>Financial Sector</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\nu$</td>
<td>loan-to-value ratio</td>
<td>0.55</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>share of transfer can only be settled with reserves</td>
<td>0.2</td>
</tr>
<tr>
<td>$\mu_\omega$</td>
<td>mean of liquidity shock $\omega$</td>
<td>0</td>
</tr>
<tr>
<td>$\sigma_\omega$</td>
<td>std. of liquidity shock $\omega$</td>
<td>0.215</td>
</tr>
<tr>
<td>$\tau$</td>
<td>penalty rate if reserve fall below the required level</td>
<td>0.0325</td>
</tr>
<tr>
<td>External Sector</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\xi$</td>
<td>elasticity of foreign demand for domestic goods</td>
<td>1.5</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>share of domestic goods</td>
<td>0.8</td>
</tr>
<tr>
<td>$R^*$</td>
<td>steady state foreign interest rate</td>
<td>1</td>
</tr>
<tr>
<td>Monetary Policy (Benchmark)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\phi_{rp}$</td>
<td>response coefficient to inflation in interest rate</td>
<td>1.5</td>
</tr>
<tr>
<td>$\phi_{ry}$</td>
<td>response coefficient to output growth</td>
<td>0.5</td>
</tr>
<tr>
<td>$\bar{r}r$</td>
<td>steady state required reserve ratio</td>
<td>0.08</td>
</tr>
<tr>
<td>$\bar{R}^E$</td>
<td>steady state interest rates on bank reserves</td>
<td>1.005</td>
</tr>
<tr>
<td>Exogenous Processes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\rho_x$</td>
<td>persistence of export demand shock</td>
<td>0.9</td>
</tr>
<tr>
<td>$\rho_r$</td>
<td>persistence of foreign interest rate shock</td>
<td>0.9</td>
</tr>
<tr>
<td>$\sigma_x$</td>
<td>std of export demand shock</td>
<td>0.01</td>
</tr>
<tr>
<td>$\sigma_r$</td>
<td>std of foreign interest rate shock</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Table 1: Parameter Calibration
5 Optimal Monetary Policy

In this section, we examine the central bank’s stabilization performance under different monetary policy regimes. We focus on export demand shock and foreign interest rate shock, which are two common external shocks China faces.

5.1 Why Can’t Complete Sterilization Sterilizes Completely?

In this subsection, we assume that the central bank conducts monetary policy by fixing nominal monetary base, i.e. \( M_t = \bar{M} \). We think this well reflects the PBOC’s monetary policy stance during the complete sterilization period 2000-2006. Even though the PBOC’s currency intervention during this period was completely sterilized, broad money (M2) and bank credit have increased significantly during this period, implying a rise in money multiplier and a decoupling of base money and broad money. In this section, we examine the dynamic responses of macro variables to external shocks, and investigate how the decoupling of base money and broad money happens.

First, consider the effects of a positive export demand shock. Fig.5 shows the dynamics of the model in response to the shock. An increase in export demand increases export and put upward pressure on the domestic currency. Since the nominal exchange rate is fixed, the excess supply of foreign assets is absorbed by the central bank. To keep its monetary base, currency intervention is sterilized by the central bank, which leads to very persistent increases in the stock of central bank bills. Central bank bills are substitutes for excess bank reserves for banks’ liquidity management. As banks’ holdings of central bank bills increases, they lower their excess reserve ratios leading to increases in money multiplier.

As results, bank credit rises even if the monetary base is kept fixed by the central bank. The spread between lending and deposit rates decreases due to the declines in the liquidity management costs. Thus, complete sterilization cannot sterilize completely since the issuance of central bank bills, i.e. the sterilization instruments, has expansionary effects as well. The expansions in banking sector boosts aggregate demand, which raises output and inflation. As domestic inflation increases, real exchange rate appreciates since nominal exchange rate is fixed. This tends to decrease current account surplus and partially offset the expansionary effects of export demand shock.

Second, consider the effects of a decrease in foreign interest rate. Fig.6 shows the dynamics of the model in response to the shock. An decrease in foreign interest rate triggers capital inflows. In
the presence of portfolio adjustment cost, this only leads to a finite amount of capital inflow, which put upward pressure on the domestic currency. Sterilized intervention increases banks’ holdings of central bank bills, which facilitates banks’ liquidity management leading to credit expansion as in the previous case. The expansion of banking sector raises aggregate demand and thus output and inflation. Under fixed exchange rate regime, inflation implies an appreciation in domestic currency which worsens the currency account alleviating the expansionary effects of the shock.
Figure 5: Impulse responses to an increase in export demand (Fixed nominal monetary base)
Figure 6: Impulse responses to a decrease in foreign interest rate (Fixed nominal monetary base)
5.2 Optimal Monetary Policy

The PBOC potentially has access to two monetary policy instruments, which are open market operation (OMO) and required reserve ratio (RRR). Since 2007, the PBOC started to actively adjust RRR and use it as a stabilization tool. In this section, we use the calibrated model to examine the implications of different combinations of monetary policy instruments. In particular, we examine to what extent the stabilization performance of the central bank can be enhanced if it is allowed to use require reserve ratio (RRR) as an additional monetary policy instrument.

For this purpose, we compare the central bank’s stabilization performance under the following two policy regimes. Firstly, we assume that the central bank can only conduct OMO following a simple Taylor-style rule. Then, we allow the central bank to use both OMO and RRR according to simple Taylor-style rules.

The stabilization performance is measured by an exogenous given quadratic loss function. It is given by

$$L = E \left( \hat{\pi}_t^2 + \lambda_y \hat{Y}_t^2 + \lambda_{ca} \left( \frac{CA_t}{\bar{Y}} \right)^2 \right)$$

(46)

where $CA_t/\bar{Y}$ denotes the current account surplus normalized by steady state output. An alternative way to specify the objective of the central bank is to assume that it maximizes households’ welfare implied by utility function. However, most central banks receive mandates from governments which they have to fulfill. Central bank’s loss function can be based on government’s mandate rather than the model-consistent welfare function (Adolfson et al., 2011). Furthermore, by including the volatility of current account surplus in the loss function, we intend to approximate the fact that the PBOC wants to avoid abrupt fluctuations in current account to protect China’s export sector. We assume equal weights and set $\lambda_y$ and $\lambda_{ca}$ to one.

Table 2 shows the standard deviations of the key macro variables and the values of loss function under different policy combinations. The first two columns show the standard deviations and the values of loss function when the central bank only has access to OMO and follows (i) a standard Taylor rule and (ii) an optimized interest rate rule in which policy reaction coefficients are chosen to minimize the central bank’s loss function. The next two columns show the standard deviations of the same variables and the values of loss function when the central bank has access to both OMO and RRR, and follows (i) a combination of standard Taylor rule and optimized RRR policy rule and (ii) a jointly optimized interest rate rule and RRR policy rule.
### Policy Rules

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Taylor Rule</th>
<th>Optimal R Rule</th>
<th>Taylor+Optimal RRR</th>
<th>Joint Optimal Rules</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\phi_{\lambda}$</td>
<td>1.50</td>
<td>1.75</td>
<td>1.50</td>
<td>0.30</td>
</tr>
<tr>
<td>$\phi_{\sigma}$</td>
<td>0.50</td>
<td>0.59</td>
<td>0.50</td>
<td>0.89</td>
</tr>
<tr>
<td>$\phi_{\lambda}$</td>
<td>-</td>
<td>-</td>
<td>$-2.18 \times 10^2$</td>
<td>$-0.14 \times 10^3$</td>
</tr>
<tr>
<td>$\phi_{\lambda}$</td>
<td>-</td>
<td>-</td>
<td>$1.74 \times 10^3$</td>
<td>$0.58 \times 10^3$</td>
</tr>
</tbody>
</table>

**Stand Deviation ($\times 10^{-3}$)**

| | | | | |
|---|---|---|---|
| $\hat{Y}$ | 5.9 | 5.1 | 0.8 | 1.4 |
| $\hat{\pi}$ | 1.6 | 1.6 | 0.4 | 0.6 |
| $\hat{N}$ | 7.9 | 5.8 | 1.6 | 2.2 |
| $\hat{L}$ | 17.1 | 20.4 | 5.8 | 5.0 |
| $\hat{q}$ | 10.9 | 13.5 | 7.0 | 6.5 |
| $\hat{CA}/\hat{Y}$ | 3.0 | 3.8 | 3.9 | 3.6 |

**Loss Function ($\times 10^{-3}$)**

| | | | | |
|---|---|---|---|
| | 4.7 | 4.4 | 1.6 | 1.5 |

Table 2: Standard Deviations under Different Policies

By allowing the central bank to adjust required reserve ratio according to economic conditions, its stabilization performance is greatly enhanced. In particular, the standard deviations of output and loan dropped significantly, which indicates that required reserve ratio is quite powerful in terms of stabilizing bank credit. Under fixed exchange rate regime, the size of central bank’s balance sheet is affected by external shocks. After a positive external shock, the central bank expands its balance sheet to absorb the excess supply of foreign assets in order to keep its nominal exchange rate at the target. As results, the total amount of liquid assets (i.e. bank reserves and central bank bills) increases. Open market operation only changes the composition of these liquid assets while have no effect on their size. In contrast, raising require reserve ratio can directly freeze these excess liquid assets. Thus, RRR policy helps stabilize credit by stabilizing the amount of liquid assets available to banks.

Under the optimal RRR rules, required reserve ratio increases with output growth and decreases with inflation. An increase in output growth calls for a policy tightening by raising required reserve ratio. However, required reserve ratio seems not serve to stabilize inflation as its reaction coefficient to inflation is negative. Actually, to mitigate the fluctuations in the real amounts of liquid assets available to banks, a lower required reserve ratio is called for to release liquid assets to banks when the economy experiences an inflation.

In addition, the central bank’s over all stabilization performance is enhanced by switching from (i) the combination of Tylor rule and optimized RRR rule to (ii) the join optimal rules. However, not all the deviations are decreased. Actually, the standard deviation of current account surplus
decreases, while that of inflation increases. When the economy faces exports demand shock, there could be a trade off between inflation and exports stabilization. After a positive exports demand shock, demand for domestic goods increases and domestic price rises. Under fixed exchange rate regime, domestic inflation implies an appreciation of real exchange rate, which tends to reduce and thus stabilize the exports. In this case, the central bank may not be able to achieve inflation and exports stabilization at the same time. Thus, the joint optimal rule better balances this trade-off and thus enhances the central bank’s over-all stabilization performance.

The Underlying Mechanism. To investigate how RRR policy helps stabilize the economy, we compare the impulse responses of key macro economic variables to external shocks under different monetary policy regimes.

We consider the effects of a positive export shock and a decrease in foreign interest rate. Fig.7 and Fig.8 display the impulse responses of the key macro variables following the two external shocks under different monetary policy regimes. The blue (solid) line shows the responses of those variables when the central bank only has access to open market operation and follows an optimal interest rule. The red (dashed) line shows the responses when the central bank has accesses to both open market operation and reserve requirement policy, and follows joint optimal interest rules. We compare the central bank’s stabilization performances under the two monetary policy regimes, and investigate how required reserve ratio policy helps stabilize the economy.

The central bank’s stabilization performance is significantly enhanced when it is allowed to use required reserve ratio as an additional policy tool. With respect to credit stabilization, the central bank’s performance is dramatically improved. However, with respect to inflation stabilization, the central bank’s performance is improved less.

A positive external shock (i.e. an increase in exports demand or a decrease in foreign interest rate) increases aggregate demand and raises output and inflation. At the same time, the central bank’s monetary base is expanded due to the BOP surplus.

Under the optimal interest rate rule (blue-solid line), the policy rate increases to stabilize the economy. Since the central bank only has access to open market operation, it issues more central bank bills to push policy rate up to the target. As shown in Fig.7 and Fig.8, the amount of central bank bills rises sharply after the shock hits. However, central bank bills are substitutes for excess bank reserves for liquidity management purpose. As banks' holdings of central bank bills increase, they reduce holdings of excess reserves, which leads to increases in money multiplier and can offset the effects of contractionary monetary policy.
Under the joint optimal rules (red-dashed line), both the policy rate and the required reserve ratio are raised to stabilize the economy. In this case, the central bank raises required reserve ratio to freeze the increase of monetary base caused by its intervention, and thus issues less central bank bills. As results, the policy rate and the amount of central bank bills increase less. Since less central bank bills are issued, the amount of liquid asset available for banks increases less. Thus, bank credit increases less after the shock hits.
Figure 7: Impulse responses to an increase in exports demand (Fixed nominal monetary base)

Blue line (solid): OMO only - optimal R rule
Red line (dashed): OMO+RRR - joint optimal rules
Figure 8: Impulse responses to a decrease in foreign interest rate (Fixed nominal monetary base)

Blue line (solid): OMO only - optimal R rule
Red line (dashed): OMO+RRR - joint optimal rules
6 Conclusion

Since the early 2000s, the PBOC (China’s central bank) had been actively intervening China’s foreign exchange market to prevent sharp appreciation of Chineses RMB. To absorb the increase in monetary base caused by its currency intervention, the PBOC started to issue central bank bills as sterilization instruments since the early 2000s. During 2000-2007, though China’s foreign reserves had significantly increased, its monetary base had been kept almost unaffected by its intervention, which implies that the PBOC had conducted complete sterilization during that period. If monetary multiplier were invariant, the expansionary effects of intervention should have been largely removed by complete sterilization. However, both M2 and bank credit in China had sharply increased during the complete sterilization period which implies a rise in M2 multiplier and a decoupling of bank credit and monetary base.

During the complete sterilization period, central bank bills, issued as sterilization instruments, had been the most actively transacted asset with the highest turnover rate in the inter-bank bond market. The transaction of central bank bills accounted for around a quarter of the total transaction in inter-bank bond market.

These facts imply that sterilized intervention, which increased the supply of central bank bills, a type of liquidity management instruments for banks, may have contributed to banks’ balance sheet expansion. In fact, central bank bills can be substitutes for bank reserves for liquidity management purpose. As banks’ holdings of central bank bills increase, they may reduce their holdings of excess reserves, leading to increase in money multiplier and expansions of banks’ balance sheet. Thus, even if the currency intervention is completely sterilized in the sense that monetary base is kept unaffected, it still can be expansionary.

Comparing to open market operation, raising required reserve ratio, which directly freezes the increase of monetary base caused by intervention, can be more effective in countering the expansionary effects of intervention. Since 2007, the PBOC started to actively adjust its required reserve ratio and gradually stopped to issue new central bank bills. The switch from monetary sterilization to reserve requirement reflects the PBOC’s awareness of the benefits of reserve requirement policy.

We reproduced these facts in a calibrated DSGE model with Chinese characteristics, i.e. fixed exchange rate, large export sector and capital account control. The key component of the model is the liquidity management of banks. In the model, banks hold both central bank bills and excess reserves as part of their liquidity management. As sterilized intervention increases banks’s holdings of central bank bills, they reduce their holdings of excess reserves, which leads to a higher money
We explicitly model the balance sheet of the central bank. The central bank holds foreign assets and issue reserve money and central bank bills. A positive external shock puts appreciation pressure on domestic currency. Under fixed exchange rate regime, the excess supply of foreign assets are absorbed by the central bank, which expands the central bank’s balance sheet. As results, the total amount of liquid assets available for banks (bank reserves and central bank bills) increases, which can potentially have expansionary effects on the economy. In our model, external shock can affect the domestic economy via changing the size of the central bank’s balance sheet.

We use the calibrated DSGE model to examine the optimal choice of monetary instruments. We assume that the central bank potentially has accesses to two policy instruments, i.e. open market operation (OMO) and required reserver ratio (RRR). The central bank is assumed to choose the reaction coefficients in the policy rules to minimize a simple quadratic loss function. We consider two external shocks, export demand shock and foreign interest rate shock, which are two common external shocks China faces.

We compare the central bank’s stabilization performances under two policy regimes. In the first case, the central bank only has access to OMO, while in the second case, the central bank can do both OMO and RRR. By allowing the central bank to use RRR as an additional policy tool, its stabilization performance is significantly enhanced. When the central bank can conduct both OMO and RRR policy, in responding to a positive external shock, it raises RRR to freeze the increase of monetary base and thus issues less central bank bills as it does in the first case. As results, money multiplier and bank credit increase less than they do in the first case.
References


