Sterilized Intervention and Optimal Chinese Monetary Policy

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Abstract

Since the early 2000s, China's central bank has been intervening actively in foreign exchange markets to prevent sharp appreciation of Chinese Yuan. At the same time, it issued central bank bills, a type of short-term central bank debt, to absorb the increase in monetary base caused by its intervention. This should have effectively neutralized the effects of intervention if the money multiplier were invariant. However, M2 and bank credit increased significantly during the period of sterilized intervention even if the monetary base remained almost unaffected, which implies an increase in the money multiplier. We reproduce these facts in a calibrated DSGE model wherein banks hold central bank bills issued as sterilization tools as liquidity management instruments. Banks reduce holdings of excess reserves as they hold more central bank bills, which raises money multiplier and leads to expansion of banks' balance sheets. Our DSGE framework allows us to study the optimal choice of monetary policy instruments. Compared to open market operations, raising required reserve ratio can directly freeze the excess liquidity and more effectively counter the effects of intervention. Allowing the central bank to use reserve requirement as an additional policy instrument can significantly reduce fluctuations in macro-economic variables.

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1 Introduction

Since the early 2000s, China's growing balance of payments surplus has exerted great upward pressure on Chinese Yuan. To prevent sharp appreciation of the Yuan,[1] the People's Bank of China (PBOC, China's central bank) has been intervening actively in foreign exchange markets by purchasing foreign assets; thereby accumulating massive international reserves (Figure 1). When the PBOC purchases foreign assets, an equivalent amount of base money is released, putting expansionary pressure on China's economy. To neutralize the expansionary effects of currency intervention,[2] the PBOC issues central bank bills,[3] 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 the monetary base remained nearly unaffected.[4]

Complete sterilization, which kept China's monetary base unaffected by its currency intervention, should have largely neutralized the effects of intervention if money multiplier were invariant. However, M2 and bank credit rose significantly during the period of sterilized intervention even if the monetary base remained nearly unaffected, which implies an increase in the money multiplier (Figure 3).[5] This paper examines the extent to which open market operations[6] can neutralize the effects of intervention. In addition, it studies the optimal choice of monetary policy instruments and the optimal policy rules given China's current external policy regimes.

Central bank bills, issued as sterilization instruments, are highly liquid on China's interbank bond market.[7] During the period of sterilized intervention, central bank bill transactions on the interbank bond market increased to 40% of total transactions in 2008 (Figure 2). Moreover, central bank bills also have the highest turnover rate of all assets transacted on the interbank bond market.

[1]Immediate appreciation of the Yuan might not top China's policy response list, due to either 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]The PBOC uses central bank bills as open market operation instruments due to its limited holdings of government debts.

[4]According to Burdekin and Siklos (2008), China even over-sterilized reserve accumulation.

[5]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.

[6]The most typical method of sterilization (in a narrow sense) is open market operations. In a broad sense, any activity of the central bank that is aimed to neutralize the effects of intervention can be considered as sterilization.

[7]Assets transacted in China's interbank bond market are mostly highly liquid safe assets, such as, central bank bills, government bonds, and financial bonds (i.e. bonds issued by policy banks). China's interbank bond market is much more developed than its interbank unsecured lending market. 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.

These facts imply that central bank bills can be substitutes for excess reserves in banks' liquidity management. When banks hold more central bank bills, they may reduce holdings of excess reserves. This can raise the money multiplier and lead to expansion of banks' balance sheets. Thus, complete sterilization may not be able to sterilize completely since the issuance of central bank bills can have expansionary effects on the economy. Compared to open market operations, raising required reserve ratio can directly freeze the excess liquidity and more effectively counter the expansionary effects of intervention. Since 2008, the PBOC gradually stopped issuing central bank bills and begun to use required reserve ratio as a stabilization instrument, which may well reflect the PBOC's awareness of the benefits of reserve requirement policy (Figure 4).

Our model highlights the roles of liquid assets—excess reserves and central bank bills—in banks' liquidity management and the central bank's role in supplying liquid assets. In the model, all funds are channeled through banks.[8] Banks raise deposits from households and lend to firms. After loans are extended, a random fraction of the bank's deposits are transferred out of the bank. The deposit transfers can only be settled with liquid assets (excess reserves and central bank bills). If the bank has insufficient liquid assets, its reserves fall below the required level and it incurs a penalty. Thus, more lending relative to the bank's holdings of liquid assets increases it liquidity risk. In our model, currency intervention can have effects on bank lending by affecting the supply of liquid assets.

We explicitly model the balance sheet of the central bank. The central bank holds foreign assets and issues bank reserves and central bank bills. Under a fixed exchange rate regime, the excess supply of (demand for) foreign assets is absorbed by the central bank, and external imbalances directly translate into changes in the central bank's balance sheet. Open market operations only replace one liquid asset (bank reserves) with another (central bank bills) without changing the total quantity of liquid assets. Thus, its effectiveness depends on the extent to which central bank bills are substitutable for bank reserves. In the extreme case wherein they are perfect substitutes, the Modigliani-Miller theorem for open market operations (Wallace, 1981) holds, and monetary sterilization has no effect at all. To capture the difference between bank reserves and central bank bills, we follow Andolfatto and Williamson (2015) and assume bank reserves can be used to settle a wider array of transactions than can central bank bills.[9] As results, open market operations have effects on the economy, but the effects can be limited.

Our model departs from the standard bank lending channel view by introducing banks' liquidity management. The standard view follows the textbook money multiplier, which suggests that reserve

[8] China's financial markets are less developed compared with its banking system and a large portion of funds are channeled through banks.

[9] 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).

requirements constrain money creation and lending, and thus changes in monetary base directly affect the amount of lending banks can undertake. Per the doctrinaire view, complete sterilization, which ensures that currency intervention exerts no effect on the monetary base, should be able to neutralize the effects of intervention. In our model, however, excess reserves and central bank bills are substitutable for use in liquidity management and the excess reserve ratio declines as bank hold more central bank bills. Thus, sterilized intervention, which raises banks' holdings of central bank bills, endogenously raises the money multiplier and leads to expansion of banks' balance sheets.

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

We calibrate the model using macroeconomic and interbank bond market data from China. We use the calibrated model to examine the central bank's stabilization performance under different monetary policy regimes.

To help understand why the PBOC's complete sterilization during 2000-2006 failed to neutralize the expansionary effects of its intervention, we examine the responses of the economy following two positive external shocks—an increase in exports demand and a decrease in foreign interest rate. We assume that the central bank conducts open market operations to fix the nominal monetary base, which reflects the PBOC's monetary policy stance during 2000-2006. We find that the money multiplier and bank credit increase significantly as expected following a positive external shock. Positive external shocks put upward pressure on the exchange rate of the domestic currency. Since the nominal exchange rate is fixed, the central bank absorbs the balance of payments surpluses by raising 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, which raises money multiplier and leads to expansion of banks' balance sheets.

We use the same DSGE framework to study the optimal choice of monetary policy instruments and optimal policy rules. We consider two external shocks—an exports demand shock and a foreign interest rate shock. We assume that the central bank potentially can employ two different monetary policy instruments—open market operation (OMO) and reserve requirement ratio (RRR). When it exercises either instrument, it has to follow a Taylor-style rule. We consider two monetary policy regimes. Under the first regime, the central bank can conduct only OMO. Under the second regime, the central bank can employ both policy instruments. For each case, the 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 the RRR according to economic conditions, volatilities in macro-economic variables decreased significantly. To help understand how RRR policy helps to stabilize the economy, we examine the responses of the economy under the two monetary policy regimes. When the central bank has access to both policy instruments, it sells fewer central bank bills and raises required reserve ratio when responding to the shocks. In this case, the money multiplier and bank credit raise less after the shock.

Related Literature

Traditional monetary policy literatures focus on the interest channel of monetary transmission, but we focus on the role of banks. The role of banking system in the transmission of monetary policy was less studied in macroeconomics,[10] and only recently have economists begun to explicitly model the banking sector in DSGE models, e.g. Curdia and Woodford (2009), Gerali et al. (2010) and Ennis (2014). We explicitly model the banking sector and focus on banks' liquidity management.[11] However, we study an economy with Chinese characteristics. In particular, we study how sterilized intervention shifts the supply of bank credit by changing the supply of outside liquidities and the optimal choice of monetary policy instruments given China's current external policy regime.

Our paper also relates to the literatures that studies the central bank's role in supplying liquid assets. After the recent global crisis erupted, central banks in developed economies expanded their balance sheets to unprecedented levels via large scale asset purchases. Motivated by these dramatic changes in central banks' balance sheets, 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 medium of exchange, and Ennis (2014) and Bianchi and Bigio (2014) focus on their role in liquidity management of banks. Our paper also emphasizes the role of public liabilities, but in different context. Since the early 2000s, the PBOC has been expanding its balance sheet significantly as a result of its currency intervention. This also dramatically increased the amount of central bank liabilities (bank reserves and central bank bills). In this context, we study the optimal choice of monetary policy instruments and the optimal policy rules for the PBOC to counter the expansionary effects of its currency intervention.

[10] Exception is Bernanke and Blinder (1988)

[11] 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.

Our work also relates closely to the analyses of the association between credit booms and capital inflows. Ample evidence shows that capital inflows increase before credit booms peak (Mendoza and Terrones, 2012). In addition, Magud, Reinhart and Vesperoni (2012) has shown that capital inflows lead to more credit growth in economies with less flexible exchange rate regimes, and attribute the credit expansion to increasing monetary bases from partial sterilization.

The paper proceeds as follows. Section 2 reviews the PBOC's currency intervention and monetary policy. We construct the model in Section 3, calibrate it in Section 4 and present empirical applications in Section 5. Section 6 concludes.

2 Currency Intervention and Monetary Policy in China

2.1 Currency Intervention and Monetary Sterilization

Since the early 2000s, China's foreign exchange market intervention greatly changed the PBOC's balance sheet. As shown in Figure 1, the PBOC's holdings of foreign assets (foreign reserves and gold) have been increasing aggressively since 2000. In addition, the composition of the PBOC's assets was changed significantly. Foreign assets accounted only for 40% of the PBOC's assets in 2000, but 84% in 2013. Obviously, the expansion of the PBOC's balance sheet was mainly caused by its currency intervention.

When purchasing foreign assets, the PBOC releases equivalent amount of base money, which can put expansionary pressure on the economy. To neutralize the effects of currency intervention, the PBOC depends mainly on two monetary tools—open market operation (OMO) in the early 2000s and required reserve ratio (RRR) in the late 2000s.

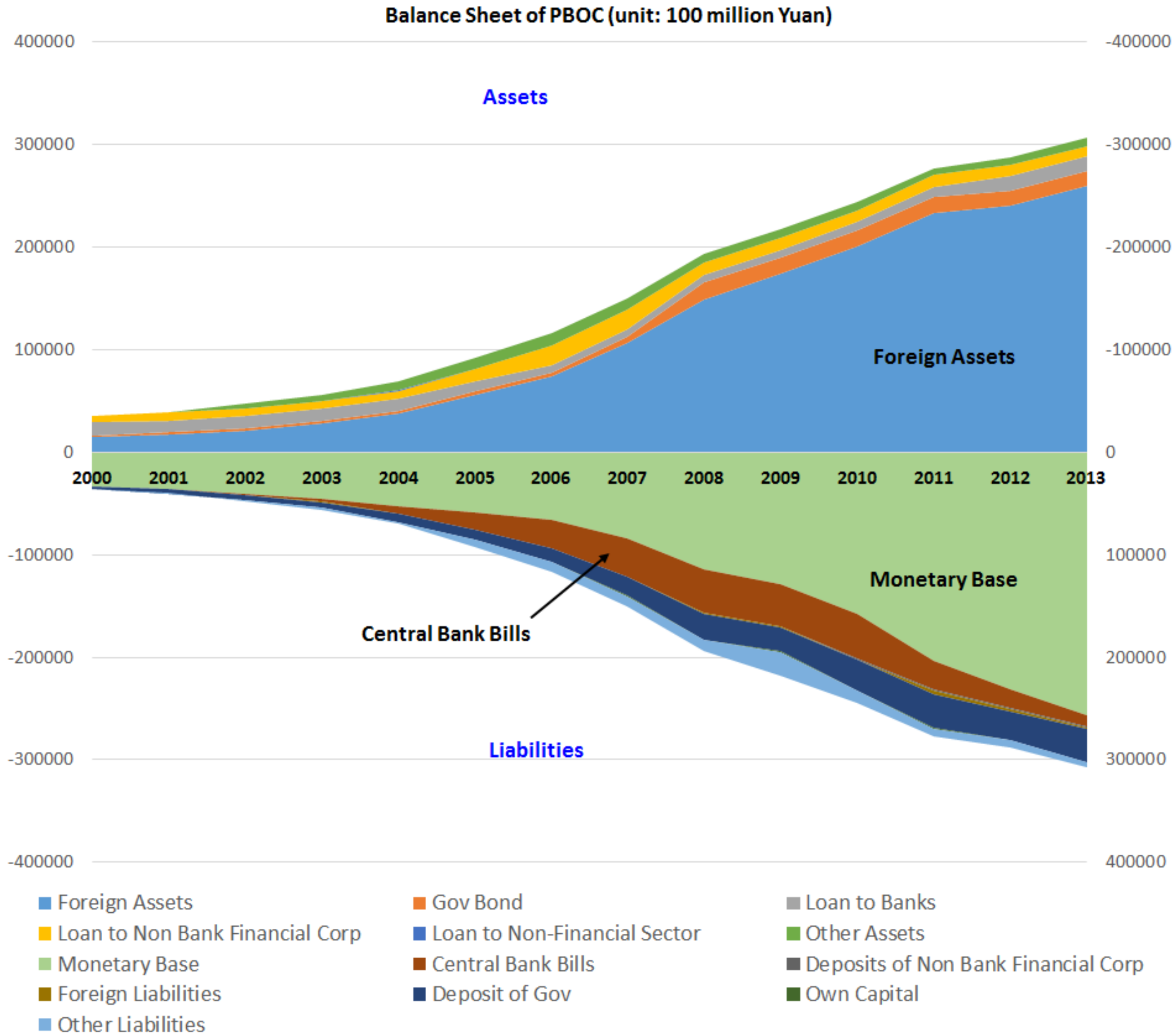

Figure 1: The Balance Sheet of PBOC

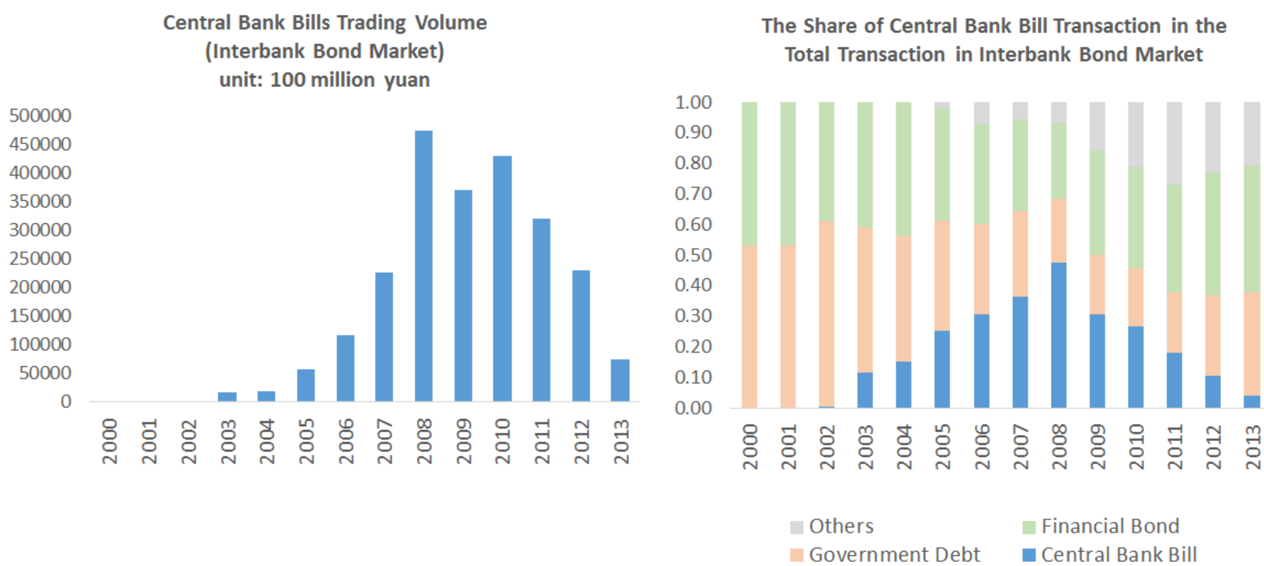

Figure 2: Transaction of Central Bank Bills in the InterBank Market

During the early 2000s, the PBOC depended mainly on OMO to sterilize its currency intervention. Since 2002, the PBOC begun 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 increased only moderately and its share in the PBOC's total liabilities decreased from 92% to 56%. (Figure 1)

2.2 Central Bank Bill Transactions on the Interbank Bond Market

The central bank bills, issued as sterilization instruments, are highly liquid on China's interbank bond market. The left panel of Figure 2 shows the volume of central bank bill transactions (both 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.

As shown in Figure 2, central bank bill transactions increased significantly during the period of sterilized intervention (2000-2006), and begun to decrease after 2008 as the PBOC gradually stopped issuing central bank bills (Figure 1). Central bank bills are an important type of liquid asset transacted on the interbank bond market. The share of central bank bill transactions in the total transactions reached 38% in 2008, which was even larger than the share of government bond

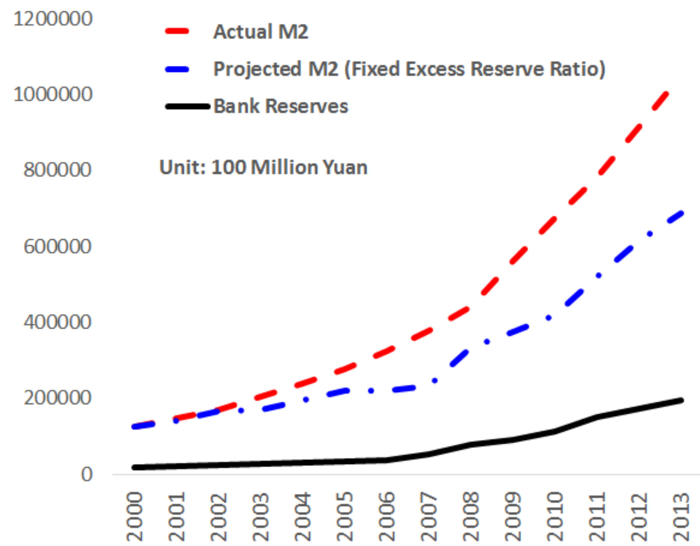

Figure 3: Monetary Aggregates and Bank Reserves in China

Black line (solid): bank reserves; Red line (dashed): actual M2; Blue line (dash-dot): projected M2.
Projected M2 is 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.

transactions by 30% .

In addition, central bank bills have the highest turnover rate of all assets transacted on the interbank bond market. During 2000-2013, the average annual turnover rate of central bank bills is around 8, while those of government bonds and financial bonds[12] are around 4 and 6 respectively.

2.3 Decoupling of Monetary Base and M2

Central bank bills are highly liquid on the interbank bond 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 decrease holdings of excess reserves, which raises monetary multiplier and leads to expansion of banks' balance sheets. The PBOC's sterilized intervention (2000-2006) might have contributed to the decoupling of M2 and monetary base during the same period.

As shown in Figure 3, during the period of sterilized intervention, M2 had increased significantly (by around 160%), while base money has increased only by around 90%. The divergence between

[12] They are mainly bonds issued by Chinese policy banks.

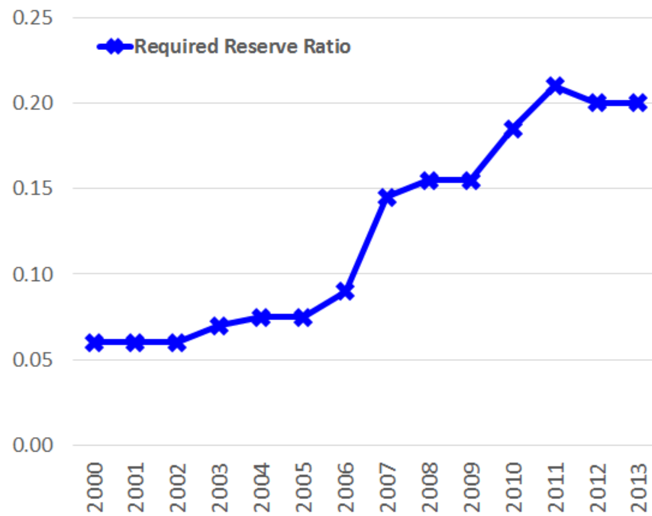

Figure 4: Required Reserve Ratio of China

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.

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. The blue line (dash-dot) shows the projected M2 for the fixed excess reserve ratio, i.e. the amount of M2 banks would have if the excess reserve ratio were kept at its 2000 level, given the actual levels of bank reserves and required reserve ratio. The significant positive gap between the actual and the projected M2 indicates a drop in the excess reserve ratio.

2.4 Reserve Requirement Policy

Since 2007, the PBOC begun 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 PBOC.

After 2006, the PBOC gradually stopped issuing central bank bills, and, as a result, reserve money increased by around 300% during 2007-2013 (Figure 1). After 2008, the PBOC counters the expansionary pressure from currency intervention mainly 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 OMO 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. Since 2008, the Federal Reserve Bank of the US has been keeping the short term interest rates near zero. The three-month interest rate on the US Treasury Bills drops below the three-month interest rate on the PBOC's central bank bills, which increased the "quasi-fiscal loss" of currency sterilization (Chang, Liu and Spiegel, 2015). Besides the ineffectiveness of sterilization, the increases in sterilization costs could be another reason that made the PBOC switch from monetary sterilization to RRR management.

3 The Model

We consider a global economy with two countries—home country 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 of agents—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 funds are channeled through banks. Banks raises deposits from households and lend to entrepreneurs. In addition, banks hold two types of liquid assets, excess bank reserves and central bank bills, as liquidity management instruments. The spread between lending rate and deposit rate depends on banks' liquidity management cost, which in turn is determined by banks' holdings of liquid assets relative to the size of their deposits.

Retailers buy whole sale intermediate goods from entrepreneurs, differentiate them into retail intermediate goods, and sell them to domestic goods producers, who assemble retail intermediate goods using a CES technology. The markets for retail intermediate goods are monopolistically competitive. Retailers set prices for their own products to maximize their profits subject to a price adjustment cost. Final goods are produced by combing domestic goods and foreign goods. In the labor market, labor intermediaries buy whole sale labor services from households at a competitive price and sell them in monopolistically competitive markets.

We assume households can hold both domestic and foreign assets, while foreign investors can not hold domestic assets. Households encounter a portfolio adjustment cost when changing their portfolio shares of domestic and foreign assets. Due to the imperfect substitutions between domestic and foreign assets, the model allows for deviations from the standard uncovered interest rate parity.

The central bank holds foreign assets and issues bank reserves and central bank bills. It adopts fixed exchange rate regime and conducts currency intervention to keep the nominal exchange rate at its target. The excess supply of (demand for) foreign assets are absorbed by the central bank. In the benchmark model, the central bank is only allowed to conduct open market operation. In an extension of the model, we allow the central bank to adjust required reserve ratio in responding to changes in economic conditions.

3.1 Households

Households live for infinite periods. They consume final goods and supply labor. The preference of household i is given by

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

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, ψ is the relative weight of leisure in the utility function, and ι is the inverse Frisch elasticity of labor supply.

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

$$C_t(i) + \frac{D_t(i)}{P_t} + (1+\mathit{\Gamma}_t) \frac{e_t F_{ht}(i)}{P_t} = w_t^H N_t(i) + \frac{D_{t-1}(i) R_{t-1}^D}{P_t} + \frac{e_t F_{h,t-1}(i) R_{t-1}^*}{P_t} + \mathit{\Pi}_t + T_t \tag{2}$$

where

$$\mathit{\Gamma}_t = \mathit{\Gamma} \left(\frac{D_t}{D_t + e_t F_{ht}} - \bar{\varphi} \right) \tag{3}$$

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 $F_{ht}(i)$, Π_t and T_t are the lump-sum transfers from household owned firms and the public sector, $\mathit{\Gamma}_t$ 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 households. We assume the portfolio adjustment cost function $\mathit{\Gamma}(.)$ has $\mathit{\Gamma}'(0) > 0$.

Let λ_t denote the Lagrangian multiplier for the budget constraint (2). The optimal choice of labor supply implies

$$w_t^H = \frac{\psi N_t(j)^\iota}{\lambda_t} \tag{4}$$

Let $\pi_t = P_t/P_{t-1}$ denote the inflation rate. The optimal choice of $D_t(i)$ and $F_{ht}(i)$ implies

$$1 = \beta E_t \left(\frac{\lambda_{t+1}}{\lambda_t} \frac{R_t^D}{\pi_{t+1}} \right) \tag{5}$$

$$1 + \mathit{\Gamma}_t = \beta E_t \left(\frac{\lambda_{t+1}}{\lambda_t} \frac{R_t^*}{\pi_{t+1}} \frac{e_{t+1}}{e_t} \right) \tag{6}$$

By linearizing both sides and combing the above two equations, we can obtain the generalized UIP (uncovered interest parity) condition:[13]

$$\hat{R}_t^D - \hat{R}_t^* = E_t \Delta \hat{e}_{t+1} + \mathit{\Gamma}'(0) \bar{\varphi} \hat{\varphi}_t \tag{7}$$

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 labor intermediaries buy wholesale labor services from households at a competitive price w_t^H and sell them on monopolistically competitive markets. Labors sold by different intermediaries are considered to have different types. Competitive labor packers assemble the differentiated labor in a CES aggregator and sell the homogeneous labor to the entrepreneurs.

The individual labor intermediary takes as given the wage level W_t^s and labor packers' demand function and chooses a price $W_t^s(i)$ to maximizes its expected discounted dividend flows subject to quadratic price adjustment costs. The labor intermediary i solves the following problem

$$\max_{W_t^s(i)} E_t \sum_{k=0}^{+\infty} \beta^k \left(\frac{\lambda_{t+k}}{\lambda_t} \right) \left\{ \left(\frac{W_{t+k}^s(i)}{P_{t+k}} - w_{t+k}^H \right) N_{t+k}(i) - \frac{\Omega_w}{2} \left(\frac{W_{t+k}^s(i)}{\pi^w W_{t+k-1}^s(i)} - 1 \right)^2 \left(\frac{W_{t+k}^s}{P_{t+k}} \right) N_{t+k} \right\}$$

where $N_t(i)$ is the demand for labor sold by intermediary i. It is given by

$$N_t(i) = \left(\frac{W_t^s(i)}{W_t^s} \right)^{-\theta_w} N_t \tag{8}$$

The wage level W_t^s is related to $W_t^s(i)$ by $W_t^s = \left[\int_0^1 W_t^s(i)^{1-\theta_w} di \right]^{\frac{1}{1-\theta_w}}$. Here, θ_w is the elasticity of substitution between different labors and Ω_w governs the size of price adjustment costs.

[13] In the absence of portfolio adjustment costs $\mathit{\Gamma}_t$, the above equation corresponds to the standard UIP condition.

In a symmetric equilibrium where $W_t^s = W_t^s(i)$ for all i, the optimal pricing rule implies

$$w_t^H = \left\{ \frac{\theta_w - 1}{\theta_w} + \frac{\Omega_w}{\theta_w} \left[\left(\frac{\pi_t^w}{\pi^w} - 1 \right) \frac{\pi_t^w}{\pi^w} - \beta E_t \left(\frac{\lambda_{t+1}}{\lambda_t} \right) \left(\frac{N_{t+1}}{N_t} \right) \left(\frac{w_{t+1}^H}{w_t^H} \right) \left(\frac{\pi_{t+1}^w}{\pi^w} - 1 \right) \frac{\pi_{t+1}^w}{\pi^w} \right] \right\} w_t^E \tag{9}$$

where $w_t^E \equiv \frac{W_t^s}{P_t}$ is the real cost of labor faced by entrepreneurs. In the absence of price adjustment costs, the real cost of labor w_t^E would be equal to the markup times the real wage rate w_t^H.

3.3 Entrepreneurs

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

$$E \sum_{+\infty}^{t=0} \beta_e^t \ \log\left(C_t^e\right) \tag{10}$$

where C_t^e denotes the entrepreneur's consumption in period t. Entrepreneurs' discount factor, β_e, is assumed to be lower than that of households β.

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

$$Y_t^w = e^{z_t^a} K_t^{\eta} N_t^{1-\eta} \tag{11}$$

where z_t^a 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

$$C_t^e + w_t^E N_t + \frac{R_{t-1}^L L_{t-1}}{P_t} + q_t K_{t+1} \leq mc_t Y_t^w + \frac{L_t}{P_t} + q_t(1-\delta)K_t \tag{12}$$

where $mc_t \equiv P_t^w / P_t$ denotes the relative price of whole sale intermediate goods in terms of final goods, w_t^E is the real price of labor faced by entrepreneurs, R_t^L is the nominal interest rate on loans, q_t is the real price of physical capital, and δ is the depreciation rate of capital.

We assume that the amount the entrepreneur can borrow from banks is constrained by her holdings of physical capital:

$$\frac{R_t^l L_t}{P_t} \leq \nu E_t \left[q_{t+1} \pi_{t+1} (1-\delta) \right] K_{t+1} \tag{13}$$

where ν 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 banks L_t, to maximize her life time utility (10), subject to her production technology (11), the budget constraint (12) and the borrowing constraint (13).

Let λ_t^e and μ_t denote the Lagrangian multipliers associated with the budget constraint (12) and the borrowing constraint (13) respectively. The optimal labor demand is given by

$$w_t^E = (1-\eta) mc_t \frac{Y_t^w}{N_t} \tag{14}$$

The optimal choices of L_t and K_t imply

$$1 = \beta_e E_t \left(\frac{\lambda_{t+1}^e}{\lambda_t^e} \frac{R_t^L}{\pi_{t+1}} \right) + \mu_t \frac{R_t^L}{P_t} \tag{15}$$

$$q_t = \beta_e E_t \left[\frac{\lambda_{t+1}^e}{\lambda_t^e} \left(mc_{t+1} \eta \frac{Y_{t+1}^w}{K_{t+1}} + (1-\delta) q_{t+1} \right) \right] + \mu_t \nu E_t [q_{t+1} \pi_{t+1} (1-\delta)] \tag{16}$$

3.4 Retailers

Retailers buy whole sale intermediate goods from entrepreneurs at a competitive price mc_t, 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 by combing $Y_t^d(i)$ using a CES aggregation technology. An 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 the retailer i is thus given by

$$\max_{P^d(i)} E_t \sum_{k=0}^{+\infty} \beta^k \left(\frac{\lambda_{t+k}}{\lambda_t} \right) \left\{ \left(\frac{P_{t+k}^d(i)}{P_{t+k}} - mc_t \right) Y_{t+k}^d(i) - \frac{\Omega_p}{2} \left(\frac{P_{t+k}^d(i)}{\pi_d P_{t+k-1}^d(i)} - 1 \right)^2 \left(\frac{P_{t+k}^d}{P_{t+k}} \right) Y_{t+k}^d \right\}$$

where $Y_t^d(i)$ is the demand for the intermediate good i. It is given by

$$Y_t^d(i) = \left(\frac{P_t^d(i)}{P_t^d} \right)^{-\theta_p} Y_t^d \tag{17}$$

Here, the price level of domestic goods P_t^d is related to the prices of retail intermediate goods $P_t^d(i)$ by $P_t^d = \left[\int_0^1 P_t^d(i)^{1-\theta_p} di\right]^{\frac{1}{1-\theta_p}}$, $\theta_p > 1$ governs the elasticity of substitution between differentiated retail intermediate goods, and Ω_p represents the size of price adjustment cost.

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

$$mc_t = \left\{ \frac{\theta - 1}{\theta} + \frac{\Omega_p}{\theta} \left[\left(\frac{\pi_t^d}{\pi^d} - 1 \right) \frac{\pi_t^d}{\pi^d} - \beta E_t \left(\frac{\lambda_{t+1}}{\lambda_t} \right) \left(\frac{Y_{t+1}^d}{Y_t^d} \right) \left(\frac{q_{t+1}^d}{q_t^d} \right) \left(\frac{\pi_{t+1}^d}{\pi^d} - 1 \right) \frac{\pi_{t+1}^d}{\pi^d} \right] \right\} q_t^d \quad (18)$$

where $q_t^d \equiv P_t^d / P_t$ 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_t^d 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_t^d, and foreign goods, denoted by Y_t^f. The production technology is given by

$$Y_t = \tilde{\alpha} \left(Y_t^d \right)^{\alpha} \left(Y_t^f \right)^{1-\alpha} \quad (19)$$

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

Let P_t^d be the price of domestic good, and P_t^f 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

$$Y_t^d = \alpha \left(\frac{P_t^d}{P_t} \right)^{-1} Y_t \quad (20)$$

$$Y_t^f = (1-\alpha) \left(\frac{e_t P_t^f}{P_t} \right)^{-1} Y_t \quad (21)$$

3.6 Capital Goods Producers

Capital good 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 $1 - \frac{\Omega_i}{2} \left(I_t / I_{t-1} - 1 \right)^2$. Capital goods producers choose inputs I_t to maximize the expected life time profits while taking the price of capital q_t as given. Their objective function is given by:

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

The first order condition is given by:

$$q_t \left[1 - \frac{\Omega_i}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 - \Omega_i \left(\frac{I_t}{I_{t-1}} - 1 \right) \left(\frac{I_t}{I_{t-1}} \right) - \beta E_t \Omega_i \left(\frac{\lambda_{t+1}}{\lambda_t} \right) \left(\frac{I_{t+1}}{I_t} - 1 \right) \left(\frac{I_{t+1}}{I_t} \right)^2 q_{t+1} \right] = 1 \tag{22}$$

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

3.7 Banking Sector

All funds are channeled via banks. Banks can invest on three assets, which are loans, denoted by L_t, central bank bills, denote by B_t, and excess bank reserves, denoted by E_t. The source of funds is household deposits, denoted by D_t. Let rr_t be the required reserve ratio. A bank's balance sheet is 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 on 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

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

Here, ϕ_t is the liquidity management cost which is endogenously determined.

Liquidity Management. Each period is divided into three stages—the lending stage, the liquidity management stage, and the balancing stage. In the lending stage, a bank raises deposits and builds its investment portfolios. In the liquidity management stage, an idiosyncratic shock hits the bank, and a fraction ω of its deposits are transfered to other banks. Here, ω is i.i.d. across banks and over time, which has mean μ_ω and variance σ_ω^2. When $\mu_\omega = 0$, the liquidity shock only redistributes deposits across banks, but does 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 ωD_t units of deposits back in the third stage. As results, the initial cross-sectional distribution

Liquidity Management of Banks in Period t		
Stage One: Lending Stage	Stage Two: Liquidity Management Stage	Stage Three: Balancing Stage
Raises deposits D_t and Lend L_t. Chooses E_t and B_t	A fraction ω of D_t is transferred to other banks. Liquid assets are used to settle the transaction.	Bank receives ωD_t deposit inflows. The initial distribution of deposits is recovered.

Table 1: Liquidity Management of Banks

of deposits is recovered in the third stage.

We assume loans are illiquid and banks cannot do unsecured borrowing from each other.[14] The deposit transfers can only be settled with liquid assets (bank reserves and central bank bills). To settle a transfer, a bank can use bank reserves 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. With probability γ, 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.[15] 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 τ of the amount of transfer that could not be settled with its liquid assets.

Let $\bar{\omega}_{1t}$ ($\bar{\omega}_{2t}$) denote the maximum levels of deposit outflows that can be settled with excess reserves E_t (excess reserves and central bank bills E_t+B_t). They are given by

$$\bar{\omega}_{1t} = \frac{E_t}{D_t} \quad and \quad \bar{\omega}_{2t} = \frac{E_t+B_t}{D_t} \tag{25}$$

Thus, the expected liquidity manage cost for the bank is given by

$$\phi_t = \tau \left[\gamma \int_{\bar{\omega}_{1t}}^{1} (\omega - \bar{\omega}_{1t})\, dF(\omega) + (1-\gamma) \int_{\bar{\omega}_{2t}}^{1} (\omega - \bar{\omega}_{2t})\, dF(\omega) \right] \tag{26}$$

[14]The unsecured interbank borrowing is undeveloped in China.

[15]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).

Profits Maximization. The optimal choice of L_t, E_t, B_t and D_t implies

$$R_t^L - R_t = \tau(1-\gamma)H(\bar{\omega}_{2t}) \tag{27}$$
$$R_t^L - R_t^E = \tau\left[\gamma H(\bar{\omega}_{1t}) + (1-\gamma)H(\bar{\omega}_{2t})\right] \tag{28}$$
$$(1-rr_t)R_t^L + rr_t R_t^E - R_t^D = \tau\left[\gamma G(\bar{\omega}_{1t}) + (1-\gamma)G(\bar{\omega}_{2t})\right] \tag{29}$$

where

$$H(\bar{\omega}_{it}) = 1 - F(\bar{\omega}_{it}) \quad and \quad G(\bar{\omega}_{it}) = \int_{\bar{\omega}_{it}}^{1} \omega dF(\omega) \quad for \quad i = 1,2 \tag{30}$$

Open Market Operations. Given the amount of deposits D_t, open market operations, which replace one liquid asset with another, only affect $\bar{\omega}_{1t}$; however, they have no effect on $\bar{\omega}_{2t}$. As shown in (27)-(29), the extent to which open market operations can affect the spread between the lending rate and the deposit rate depends on the value of γ. In the extreme case where $\gamma = 0$, open market operations have no effect and the Modigliani-Miller Theorem for open market operation 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:

$$X_t = \left(\frac{P_t}{e_t P_t^f}\right)^{-\xi} X_t \tag{31}$$

where P_t^f is assumed to be constant and normalized to one, and X_t follows the following stochastic process

$$\log X_t = (1-\rho_x)\log \bar{X} + \rho_x \log X_{t-1} + \sigma_x \varepsilon_t^x \tag{32}$$

Here, ρ_x is the persistence parameter, σ_x is the standard deviation of foreign demand shock, and ε_t^x 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

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

where ρ_r is the persistence parameter, σ_r is the standard deviation of foreign interest rate shock, and ε_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 of the home country. The current account surplus expressed in real term is thus given by

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

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

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

3.9 Central Bank

The central bank holds foreign assets and issues 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

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

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 in foreign exchange market to fix the nominal exchange. The excess supply of (demand for) foreign assets is then absorbed the central bank. Thus, we have

$$\frac{e_t \left(F_{ct} - R_{t-1}^* F_{c,t-1}\right)}{P_t} = CA_t + KA_t \tag{37}$$

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 one 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

$$\hat{R}_t = \phi_{rp}\hat{\pi}_t + \phi_{ry}\hat{Y}_t \tag{38}$$

where ϕ_{rp} and ϕ_{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 M_t to respond to inflation and output.

$$\hat{M}_t = \phi_{mp}\hat{\pi}_t + \phi_{my}\hat{Y}_t \tag{39}$$

where ϕ_{mp} and ϕ_{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:

$$\hat{rr}_t = \phi_{ep}\hat{\pi}_t + \phi_{ey}\hat{Y}_t \tag{40}$$

where ϕ_{ep} and ϕ_{ey} 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

$$Y_t = C_t + C_t^e + I_t + X_t + Adj_t \tag{41}$$

$$Y_t^d = \int_0^1 Y_t^d(i)di \tag{42}$$

$$N_t = \int_0^1 N_t(i)di \tag{43}$$

$$F_t = F_{ct} + F_{ht} \tag{44}$$

$$M_t = E_t + rr_t D_t \tag{45}$$

where Adj_t 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 $\{P_t, P_t^d, P_t^w, w_t^H, w_t^E, q_t, R_t^D, R_t^B, R_t^L\}$ and aggregate quantities $\{C_t, C_t^e, Y_t, Y_t^d, Y_t^f, X_t, K_t, I_t, N_t, D_t, B_t, M_t, F_{ht}, F_{ct}, F_t\}$, and also individual prices $\{W_t^s(i), P_t^d(i)\}$ and quantities $\{Y_t^d(i), N_t(i)\}$ 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 problems 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 parameters are divided into five groups, which include the parameters in the utility function, those in the production function, those that characterize rigidities, those that characterize financial frictions, and those that are related to international trade. The values of calibrated parameters are presented in Table 2.

For the parameters in the utility function, the subject discount rate of households β is set to 0.99. The subjective discount rate of entrepreneurs β^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 χ is set to 0.5.

For the parameters in the production sector, the depreciation rate of capital δ is set to 0.03. To ensure a high investment rate in steady state, which is a typical characteristic of China, the capital share in the production function η is set to 0.5. Thus, the steady state saving rate is around 45%.

For the rigidity parameters, the elasticity of substitution between different retail goods θ_p is set to 10 which yields a mark-up around 0.11. The price adjustment cost Ω_p is set to 60 so that the model is in line with a Calvo pricing model that has a duration of price contracts of four quarters. The elasticity of substitution between different labor θ_w and the wage adjustment cost Ω_w are set to 5 and 100 respectively, which is consistent with the estimate by Gerali et al. (2010). The investment adjustment cost Ω_i is set to 2 so that the inverse elasticity of investment to capital price is around 2, which is consistent with Iacoviello (2005). The steady state share of domestic assets $\bar{\varphi}$ and the steady state 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 in the final goods α is set to 0.8 so that the import-to-GDP ratio is 80% in the steady state, which is consistent with Chinese data during 1990-2009. Following Chang, Liu and Spiegel (2015), we set the elasticity of foreign demand for domestic goods ξ to 1.5.

For the parameters in the banking sector, the liquidity shock ω is assumed to follow a Logistic distribution, which is consistent with the estimate by Bianchi and Bigio (2014). The mean of the liquidity shock μ_w is set to 0. Thus, the liquidity shock only redistributes deposits across banks and does not affect the total deposits in the whole banking system. The penalty rate for bank overdraft τ, the share of transfers that can only be settled with bank reserves γ, and the standard deviation of liquidity shock σ_ω 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 transactions to deposits of 0.05 (quarterly). These targets are consistent with Chinese interbank bond market data during the period of sterilized intervention.

For the exogenous processes, we set the persistences of both shocks, ρ_x and ρ_r, to 0.9, and set their standard deviations, σ_x and σ_r, to 0.01.

Parameters	Description	Value
	Preferences	
β	subjective discount rate (households)	0.99
β^e	subjective discount rate (entrepreneurs)	0.98
ψ	weight of leisure in utility function	12
ι	inverse Frisch elasticity	2
χ	habit formation coefficient	0.5
	Technologies	
η	capital share in production function	0.5
δ	quarterly capital depreciation rate	0.03
	Rigidities	
θ_p	elasticity of substitution between differentiated goods	11
θ_w	elasticity of substitution between differentiated labor	5
Ω_p	price adjustment cost	60
Ω_w	wage adjustment cost	100
Ω_i	investment adjustment cost	2
	Portfolio Adjustment	
$\Gamma'(0)$	steady state portfolio adjustment cost	0.6
$\bar{\varphi}$	steady state share of domestic assets	0.9
	Financial Sector	
ν	loan-to-value ratio	0.55
γ	share of transfer can only be settled with reserves	0.2
μ_ω	mean of liquidity shock ω	0
σ_ω	std. of liquidity shock ω	0.215
τ	penalty rate if reserve fall below the required level	0.0325
	External Sector	
ξ	elasticity of foreign demand for domestic goods	1.5
α	share of domestic goods	0.8
R^*	steady state foreign interest rate	1
P^f	steady state foreign price level	1
	Monetary Policy (Benchmark)	
ϕ_{rp}	response coefficient to inflation in interest rate	1.5
ϕ_{ry}	response coefficient to output growth	0.5
$\bar{rr}$	steady state required reserve ratio	0.08
$\bar{R}^E$	steady state interest rates on bank reserves	1.005
	Exogenous Processes	
ρ_x	persistence of export demand shock	0.9
ρ_r	persistence of foreign interest rate shock	0.9
σ_x	std of export demand shock	0.01
σ_r	std of foreign interest rate shock	0.01

Table 2: Parameter Calibration

5 Optimal Monetary Policy

In this section, we examine the central bank's stabilization performance under different monetary policy regimes. We consider two external shocks—an export demand shock and a foreign interest rate shock. These two shocks can be the most important external shocks China faces.

5.1 Why Can't Complete Sterilization Sterilize Completely?

In this subsection, we assume that the central bank conducts monetary policy by fixing nominal monetary base, i.e. $M_t = \bar{M}$, which reflects the PBOC's monetary policy stance during the period of sterilized intervention 2000-2006. Even if the PBOC's intervention was completely sterilized, broad money (M2) and bank credit still increased significantly during this period, which implies a rise in money multiplier and a decoupling of monetary base and broad money. To help understand these facts, we examine the dynamic responses of the economy to the two external shocks.

First, consider the effects of a positive export demand shock. Fig.5 shows the dynamics of the model in response to the shock. A higher export demand increases exports and puts 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 fixed, the central bank issues central bank bills to sterilize its intervention, which leads to persistent increases in the quantity of central bank bills. Since central bank bills are substitutes for excess bank reserves for use in liquidity management, as banks hold more central bank bills, they reduce holdings of excess reserves. This raises the 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 can not sterilize completely since the issuance of central bank bills has expansionary effects as well. The expansion of bank credit 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 offsets the expansionary effects of the 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, which put upward pressure on the domestic currency. To fix the nominal exchange rate, the central bank intervenes in the foreign exchange market. Sterilized intervention increases banks' holdings of central bank bills, which facilitates banks' liquidity management. This leads to an expansion of bank credit, which raises the aggregate demand and inflation. Under a fixed exchange rate regime, inflation implies an appreciation in domestic currency, which worsens the current account and alleviates the expansionary effects of the shock.

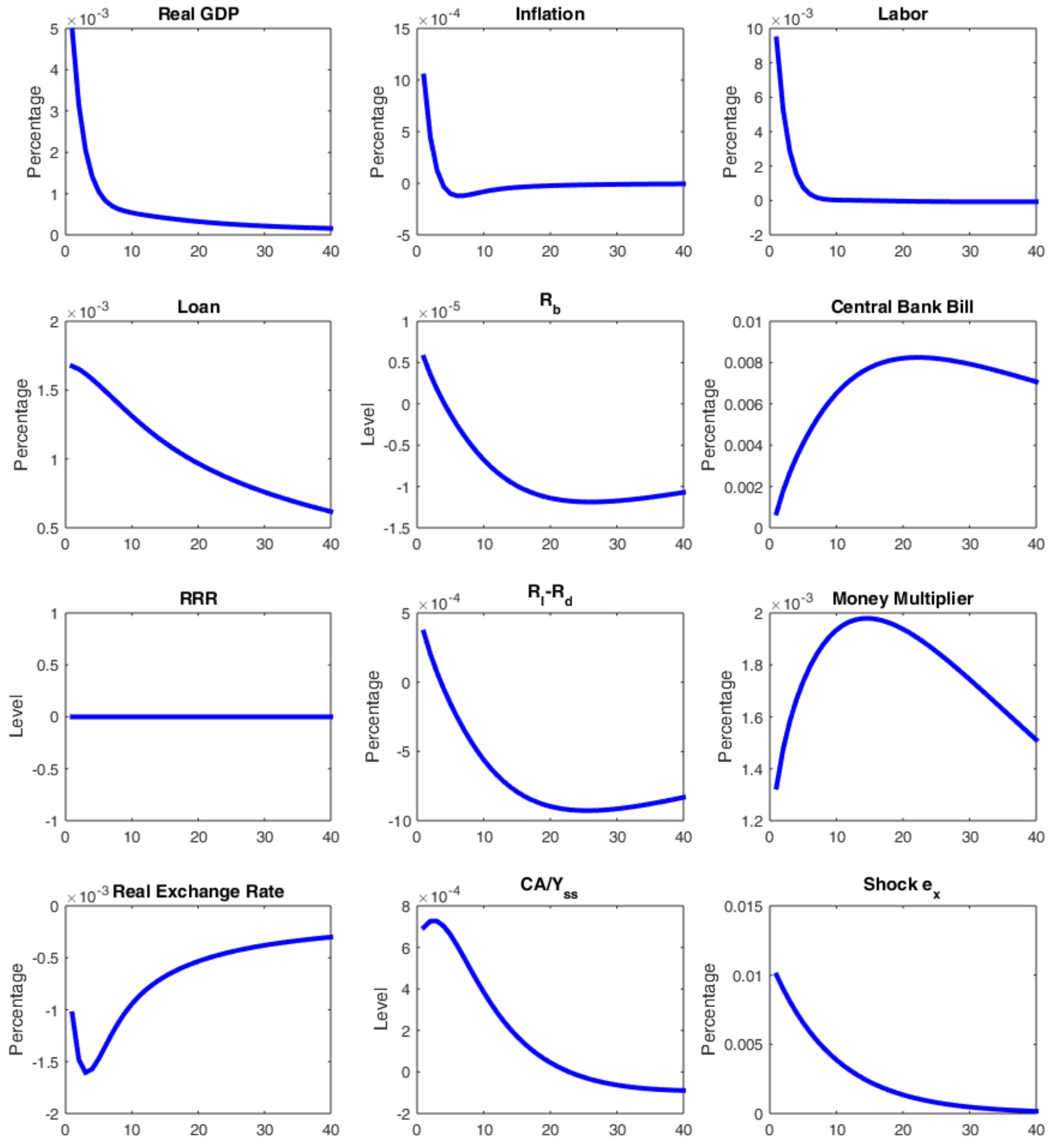

Figure 5: Impulse responses to an increase in export demand (Fixed nominal monetary base)

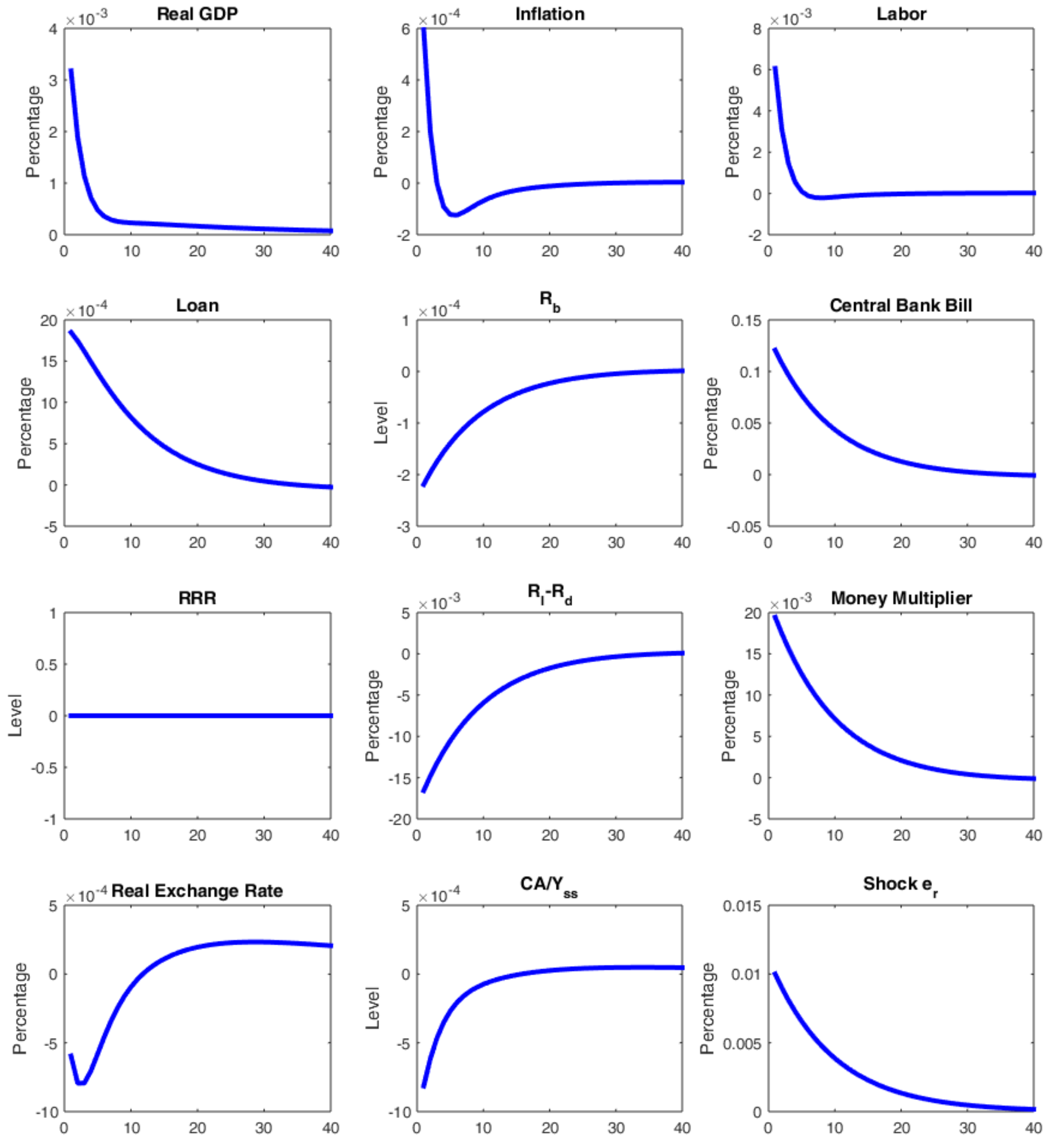

Figure 6: Impulse responses to a decrease in foreign interest rate (Fixed nominal monetary base)

5.2 Optimal Monetary Policy

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

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

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

$$L = E(\hat{\pi}_t^2) + \lambda_y E(\hat{Y}_t^2) + \lambda_{ca} E(CA_t/\bar{Y})^2 \tag{46}$$

where $CA_t/\bar{Y}$ denotes the current account surplus normalized by the steady state output. An alternative way to specify the central bank's objective is to use the households' welfare function implied by their utility function. However, most central banks receive mandate 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 λ_y and λ_{ca} to one.

Table 3 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) the standard Tylor rule and (ii) the 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 the standard Tylor rule and the optimized RRR policy rule and (ii) the jointly optimized interest rate rule and RRR policy rule.

Policy Rules				
	I. Open Market Operation Only		II. OMO + Reserve Requirement	
Parameters	Taylor Rule	Optimal Interest Rate Rule	Taylor+Optimal RRR	Joint Optimal Rules
ϕ_{rp}	1.50	1.75	1.50	0.30
ϕ_{ry}	0.50	0.59	0.50	0.89
ϕ_{ep}	-	-	-2.18×10^3	-0.14×10^3
ϕ_{ey}	-	-	1.74×10^3	0.58×10^3
Stand Deviation $\left(\times 10^{-3}\right)$				
$\hat{Y}$	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
$\hat{q}_f$	10.9	13.5	7.0	6.5
$CA/\bar{Y}$	3.0	3.8	3.9	3.6
Loss Function $\left(\times 10^{-5}\right)$				
	4.7	4.4	1.6	1.5

Table 3: Standard Deviations under Different Policy Combinations

By allowing the central bank to adjust the required reserve ratio according to economic conditions, its stabilization performance is greatly enhanced. In particular, the standard deviations of loan dropped significantly, which indicates that the required reserve ratio policy does help stabilize bank credit. Under a fixed exchange rate regime, the size of the central bank's balance sheet is affected by the external shocks. A positive external shock puts upward pressure on the domestic currency. To fix the nominal exchange rate, the central bank expands its balance sheet to absorb the excess supply of foreign assets. As results, the total amount of liquid assets (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 the excess liquidity. Thus, RRR policy helps stabilize credit by stabilizing the amount of liquid assets available to banks.

Under the optimal RRR rules, the required reserve ratio increases with the output growth and decreases with the inflation rate. An increase in the output growth calls for a policy tightening by raising required reserve ratio. However, the 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 quantities 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 overall stabilization performance is enhanced by switching from (i) the combination of the standard Tylor rule and the optimized RRR rule to (ii) the jointly optimal rules. However, not all the standard deviations are decreased. Actually, the standard deviation of current account surplus decreases, while that of inflation increases. When the economy faces export demand shocks, there could be a trade-off between inflation and exports stabilization. After a positive export demand shock, the demand for domestic goods increases and the domestic price level rises. Under a fixed exchange rate regime, domestic inflation implies an appreciation of real exchange rate, which tends to reduce the exports, mitigating the expansionary effects of the shock. In this case, the central bank may not be able to stabilize inflation and current account surplus simultaneously. The jointly 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 to stabilize the economy, we compare the impulse responses of the key macro-economic variables to two external shocks under different monetary policy regimes.

We consider two expansionary external shocks—an increase in the export demand and a decrease in the foreign interest rate. Fig.7 and Fig.8 display the impulse responses of the key macro variables following the two 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 the optimal interest rate rule. The red (dashed) line shows the responses when the central bank has access to both OMO and RRR, and follows the jointly optimal policy rules. We compare the central bank's stabilization performances under the two monetary policy regimes, and investigate how the RRR policy helps stabilize the economy.

The central bank's stabilization performance is significantly enhanced when it is allowed to use RRR as an additional policy instrument. 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 puts upward pressure on the domestic currency. To fix the nominal exchange rate, the central bank absorbs the excess supply of foreign assets by raising the monetary base. Under different monetary policy regimes, the policy instruments respond differently after the shock.

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. However, central bank bills are substitutes for excess bank reserves for use in the liquidity management. As banks hold more central bank bills, they reduce holdings of excess reserves. This raises the money multiplier and partially offsets the effects of contractionary monetary policy.

Under the jointly 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 the RRR policy freezes the excess liquidity generated by intervention, the monetary multiplier and bank credit increase less after the shock.

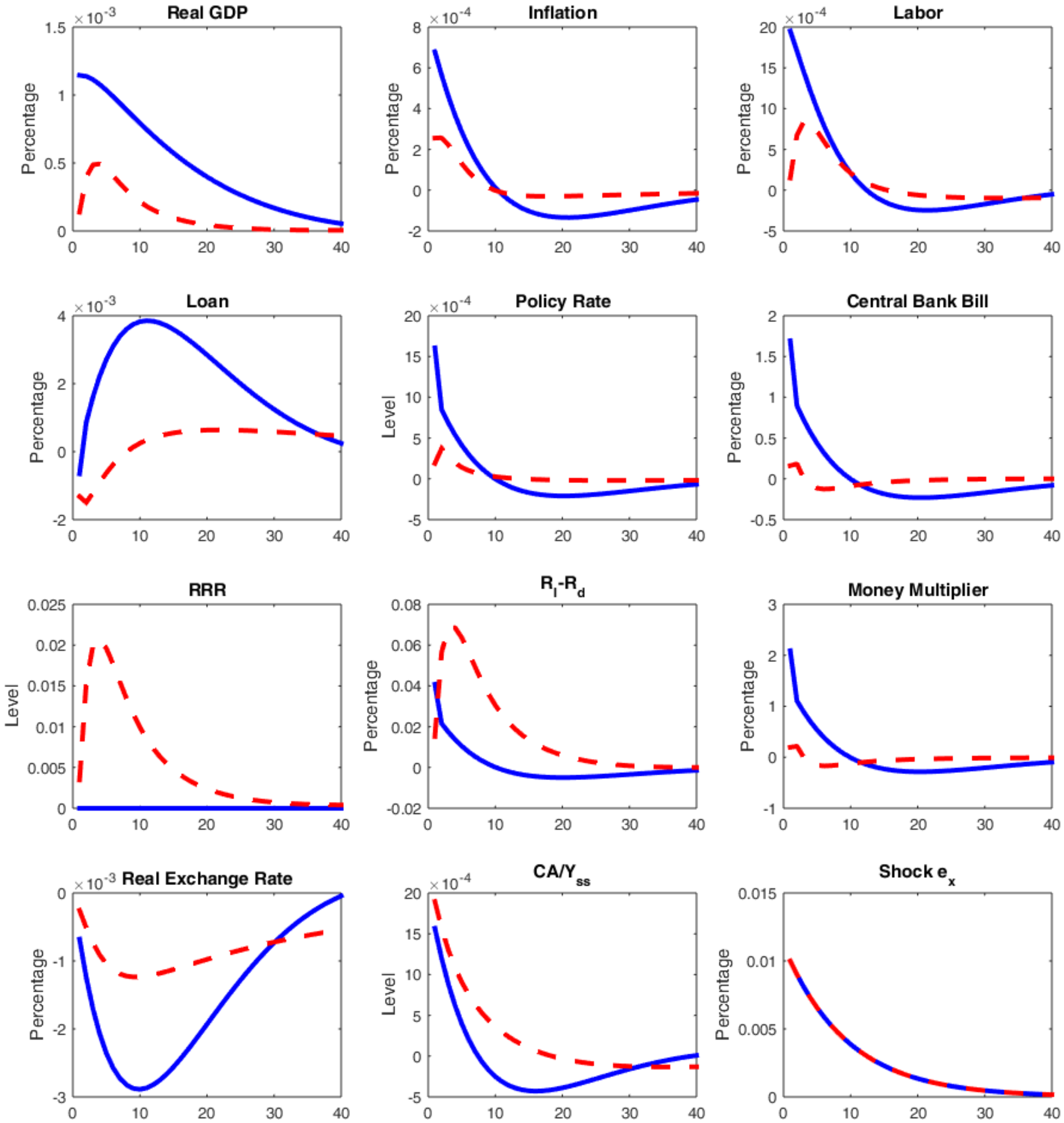

Figure 7: Impulse responses to an increase in exports demand
blue line (solid): OMO only - optimal interest rate rule
red line (dashed): OMO+RRR - joint optimal rules

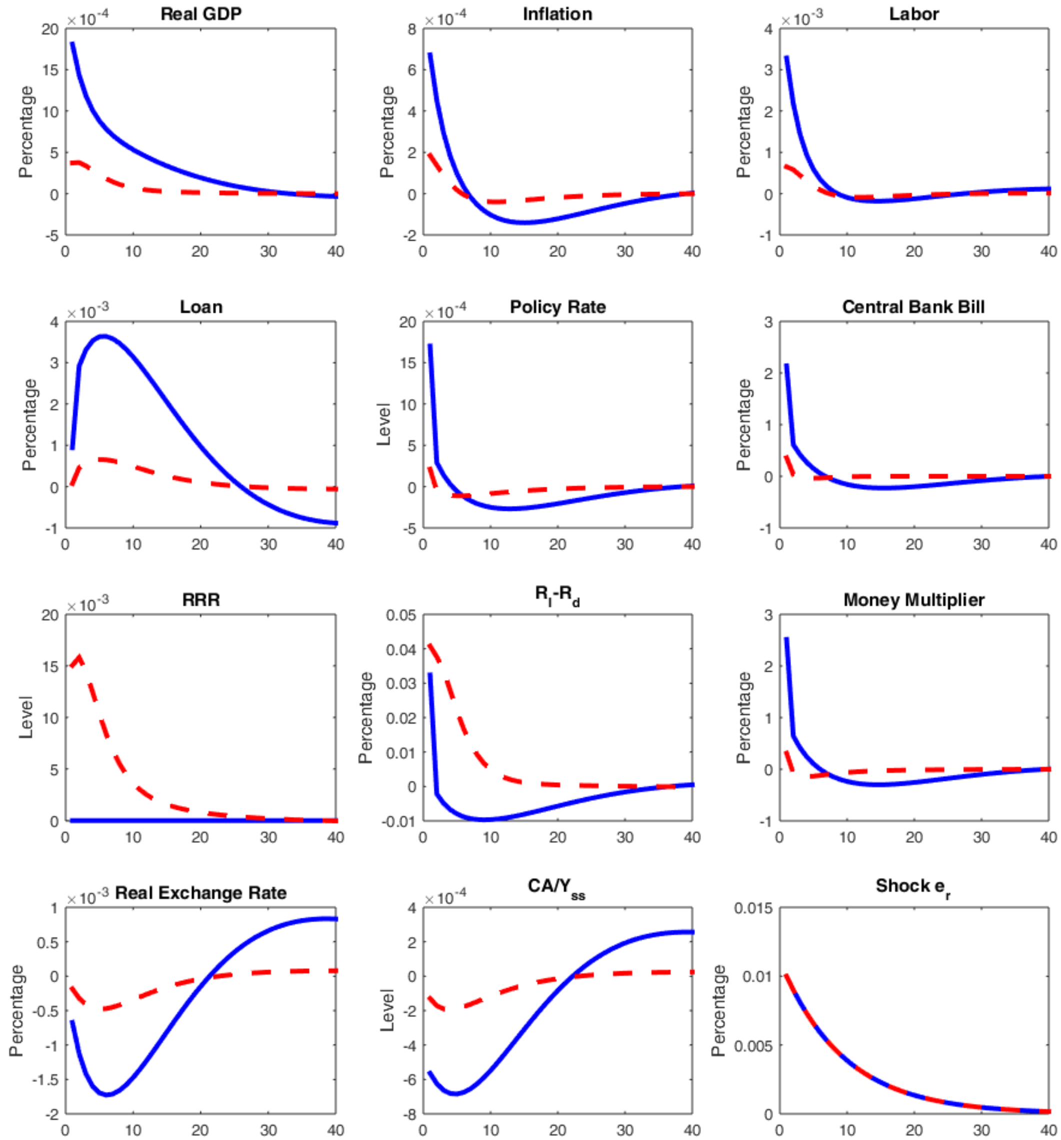

Figure 8: Impulse responses to a decrease in foreign interest rate
blue line (solid): OMO only - optimal interest rate rule
red line (dashed): OMO+RRR - joint optimal rules

6 Conclusion

Since the early 2000s, the PBOC had been intervening actively in foreign exchange markets to prevent sharp appreciation of the Yuan. To absorb the increase in monetary base caused by currency intervention, the PBOC issued central bank bills as sterilization instruments. During 2000-2006, China's foreign reserves had increased significantly; however, its monetary base remained nearly unaffected. This implies that the PBOC had conducted complete sterilization during that period. If the monetary multiplier were invariant, the expansionary effects of intervention should have been largely removed by complete sterilization. However, M2 and bank credit in China increased sharply during the period of sterilized intervention, which implies a rise in M2 multiplier and a decoupling of bank credit and monetary base. Motivated by these facts, we have examined the extent to which open market operations can neutralize the effects of intervention, and studied the optimal choice of monetary policy instruments and the optimal policy rules given China's current foreign exchange rate regimes.

The key component of our model is the liquidity management of banks. In the model, banks hold liquid assets —central bank bills and excess reserves —as part of their liquidity management. Sterilized intervention increases banks's holdings of central bank bills. As a result, banks hold less excess reserves. This raises the money multiplier and leads to expansion of banks' balance sheets. Thus, complete sterilization cannot fully remove the expansionary effects of intervention. Our model departs from the standard bank lending channel view which follows the textbook money multiplier by introducing banks' liquidity management. In our mode, open market operations endogenously change the money multiplier in such a way that the effects of the monetary policy is partially offset.

We use the calibrated DSGE model to study the optimal choice of monetary instruments and the optimal policy rules given China's current foreign exchange rate policy. We compare the central bank's stabilization performances under two policy regimes. Under the first regime, the central bank can only employ OMO. Under the second regime, the central bank can use both OMO and RRR. By allowing the central bank to use RRR as an additional policy tool, its stabilization performance is enhanced significantly. In addition, monetary policy instruments respond to the shocks differently under the two regimes. When the central bank is allowed to employ both OMO and RRR, it raises RRR and issues less central bank bills when responding to positive external shocks.

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