STERILIZATION IN CHINA: EFFECTIVENESS AND COST

Chenying Zhang[1]
∗ *The Wharton School, University of Pennsylvania, Finance Department,*
E-mail: chezhang@wharton.upenn.edu

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China has experienced a large increase in its foreign exchange reserves since 2001, due to a continuous inflow of capital and the commitment to maintain a fixed rate against the dollar initially and then a crawling peg exchange rate regime. Among other things, the accumulation of foreign assets has an expansionary monetary effect and poses a challenge for domestic macroeconomic management. As a response, the People's Banks of China (PBC for short) sterilizes the increase in foreign assets by taking offsetting actions with domestic assets. This paper adapts a 2SLS method to estimate the extent of China's sterilization using quarterly data from 1995 to 2010. It also compares the sterilization cost with the central bank's income from investing foreign exchange reserves. I conclude that the sterilization has been highly effective to date. Moreover, so far the sterilization cost of the central bank can be fully covered by the income from foreign reserve investment. Projections into the future also show no sign of unsustainability, though the appreciation of the RMB may have a profound negative impact on the PBC's income from foreign reserves in domestic currency terms. (JEL:$E52, E58$)

Key Words: China, sterilization, foreign reserves investment

[1]Zhang: The Wharton School, University of Pennsylvania, address: Finance Department, the Wharton School, University of Pennsylvania,2300 Steinberg Hall - Dietrich Hall, 3620 Locust Walk, Philadelphia, PA 19104, email: chezhang@wharton.upenn.edu. I'm especially grateful to Franklin Allen, Karen Lewis, Qian QJ Jun, and Qi Liu for invaluable comments and suggestions.

1. INTRODUCTION

Due to growing exports and speculative capital inflows, China has experienced twin surpluses on both the capital and current accounts since 2001. The current account has been positive since the 1990s and grew substantially after 2005. In order to maintain the crawling peg exchange rate system it adopted in 2005, China has to keep purchasing the excess supply of foreign currencies to prevent its domestic currency the RMB from abrupt appreciations. As a result the country has been accumulating foreign reserves at a rapid pace. It surpassed Japan in 2006 to become the largest foreign reserves holder in the world, holding more than $2.85 trillion of reserves as in Dec., 2010 and more than $ 3 trillion in the first quarter of 2011. Figure 1 plots monthly foreign reserves as shown on the balance sheet of China's central bank, People's bank of China (PBC). The stock of foreign reserves has been increasing for every month since 2004 except for one month in 2008, one month in 2009 and May 2010. Some people attribute these drops to foreign capital outflows.

A large stock of foreign reserves has both pros and cons. On the plus side, abundant foreign reserves enable a country to maintain a stable exchange rate and to meet its foreign debt obligations. It can also be used to cushion the sudden shocks on a country's current and capital account. On the other hand, an increase in foreign exchange reserves leads to an accumulation of foreign assets, which is a component of the reserve money (i.e. the money base). Without intervention, this can translate into an expansion of the domestic monetary base. Table 1 shows a typical balance sheet of the central bank of China. The asset side consists of foreign assets and claims on domestic government and other intuitions. Foreign assets are mainly composed of foreign exchange and gold. On the liability side, reserve money (the money base) consists of currency issued and deposits as reserves. From the

balance sheet, one can calculate the net foreign assets (NFA) and net domestic assets (NDA) of the monetary authority. The bottom of the table shows how those two variables are defined. By definition, $Reserve\ Money = NFA + NDA$.An increase in NFA directly contributes to the increases in the reserve money, which then affects the broad money supply M2 through the identity $M2 = Reserve\ Money \times money\ multiplier$.

Thus an increase in foreign reserves, *ceteris paribus*, causes monetary expansion and puts inflationary pressures on the economy, resulting in an appreciation of the real exchange rate. For those reasons, the accumulation of foreign reserves poses a challenge for domestic macroeconomic management. Many East Asian countries have experienced similar problems induced by large private capital inflows that started in the late 1980s. This quickly drew attention from the literature on open economy macroeconomics. Montiel (1998) refers to it as the "capital inflow problem".

To offset the expansionary effect of the increasing foreign reserves, the central bank can sterilize the foreign assets by taking opposite actions with the domestic assets, or implement other contractionary monetary policies. As Takagi and Esaka (1999) documents, sterilization is a common practice for monetary authorities of East Asian countries such as Indonesia, Korea and Malaysia, during the capital inflow episode of 1987 – 1997. It is widely believed, as previous literature points out, that China has sterilized at least some of its rising foreign reserves. However, the exact effectiveness of sterilization is unclear. Since China has applied different methods at different times, "it is not straightforward to assess exactly how much sterilization has taken place" (Prasad and Goodfriend (2006)).

Despite China's effort to neutralize the expansionary effect of increasing for-

eign reserves, there are reasons why sterilization may not be as effective as the central bank wishes it to be. The famous "Trilemma" states that it is impossible for a country to achieve the following three goals simultaneously: monetary independence, exchange rate stability and financial integration. While choosing a combination of managed exchange rate and monetary independence, China has to impose effective capital controls. Nevertheless it has been documented that capital controls in China are somewhat porous. For example, Prasad and Wei (2005) documented large swings in the errors and omissions category under foreign reserves of China, which is "indicative of unrecorded capital flows into China". If this is the case, then a change in domestic assets will induce further capital inflows or outflows, which undermine domestic monetary policies such as sterilization.

The changes in domestic assets and foreign reserves thus have a contemporaneous relationship. Changes in one variable induce changes in another. A simple OLS would lead to a biased estimation due to endogeneity. Furthermore, since domestic monetary conditions are controlled by the central bank and are affected by many other factors besides foreign exchange reserves, it is necessary to estimate some monetary reaction functions of the central bank.

Prior work examining the effectiveness of monetary sterilization of China has employed different methods to circumvent the problems above. Wu, Ying (2006) performed a Johansen cointergration test on changes in NFA and NDA. He found that the coefficient of NDA in response to one unit change in NFA is -0.41. This is called the sterilization coefficient and a coefficient of -1 implies complete sterilization, since a unit increase in NFA is then fully offset by a contemporaneous decrease in NDA. A coefficient of 0, on the other hand, indicates zero sterilization. Wu's result thus implies incomplete sterilization. This method, while straightforward to

understand, ignores all the other monetary factors that may have affected NFA and NDA. He, Dong et al (2007) estimated a reduced VAR model with interest rate and domestic credit as controls, and gained a sterilization coefficient of -1. A VAR model uses lagged variable and has a clear advantage of circumventing the endogeneity problem. Nevertheless, VAR can only identify coefficients of lagged variables, making it impossible to detect the contemporaneous impact.

Among others, Ouyang, Alice Y., Rajan, Ramkishen S. and Willett, Thomas D. (2007a) applied two-stage least squares (2SLS) to estimate two simultaneous equations. The major challenge here is to find valid instruments that help to separately identify NDA and NFA. They used government expenditure as an instrument for NDA and the real effective exchange rate for NFA. The estimated sterilization coefficients ranged from -0.5 to -0.92 for the period of 1999 to 2005, which implies a close to full sterilization. However their argument of government expenditure having no direct effect on capital inflows is not very convincing. It is easy to imagine a scenario where fiscal expansions have an effect on the interest rates, which triggers outflows of capital. Kim, Woochan (2003) also documents empirical evidence that a high budget deficit has a negative effect on capital account liberalization using OECD data.

Following Ouyang, Rajan and Willett (2007a), in this paper I apply 2SLS to estimate the degree of recent sterilization in China, but with different instruments and updated data. This paper confirms their result that China has been able to carry out an almost complete sterilization up to the first half of 2010. The coefficients of capital mobility in this paper are comparable to those of Ouyang, Rajan and Willett (2007a). However unlike their paper, I find no obvious trend of increase in the degree sterilization, lending no support to the claim that sterilization

has become harder over the years.

The question that naturally comes next, which is also a question that has been drawing a lot of attention recently (e.g. Prasad and Wei 2005, Green, Stephen 2006, Ouyang, Rajan and Willett 2007, Zhang, Ming 2009), is whether the cost of sterilization can be fully covered by the PBC's income from foreign reserve investment. If not, the sterilization cost is likely to soon become too high for the central bank to sustain. Consequently the central bank may lose its control of the domestic monetary base. The answer here is not an obvious one. Some people have argued that China has been earning a premium from its foreign reserves accumulation due to a low domestic rate (Prasad and Wei 2005), while others are worried that the increasing issuance of PBC bills, which is the central bank's main sterilization tool, will soon impose too big a burden on the PBC (Zhang 2009).

In the second part of the paper, I compare the PBC's cost of sterilization and its income from foreign reserves investment. As Prasad and Wei (2005) conjecture, the PBC's income from foreign reserves investment has exceeded its sterilization cost consistently from 2003 to 2010. To my knowledge this is the first study to calculate and compare the actual sterilization cost of the PBC and its income from foreign reserves investment. I also make some simple linear projections of those costs and income. The projection shows that there is no sign of unsustainability in the near future. However, the continuous appreciation of the RMB may have a profound negative impact on the PBC's income from foreign reserves in domestic currency terms.

The next section briefly documents crucial background information on China's foreign reserves management and the evolution of the country's foreign exchange reserves, clarifying the concept and process of sterilization. It also discusses China's

major sterilization tools: open market operation and raising required reserves. Secton 3 explains the 2SLS method applied in this paper, describes the data and the empirical results. Section 4 shows the calculation and projection of the PBC's cost of sterilization and its income from foreign reserves investment. The final section concludes the paper.

2. OVERVIEW OF FOREIGN EXCHANGE RESERVES AND STERILIZATION TOOLS IN CHINA

2.1. China's foreign reserves management and evolution

Traditionally, the State Administration of Foreign Exchange (SAFE), which is a subsidiary of the PBC, is responsible for managing foreign reserves held by the central bank. The foreign reserves are recorded on the PBC's balance sheet and invested in low risk assets such as long term government bonds. In recent years however, the PBC has been making other uses of its foreign reserves.

Some foreign reserves were used to recapitalize the large state owned financial institutions. As a part of financial reforms, the Central Huijin Investment Company Limited was established in December 2003 as an investment subsidiary to improve the capital quality of the big state owned banks to prepare them for IPOs. The purpose of the Central Huijin is to improve corporate governance and initiate reforms of the banking sector, by creating an organizational structure where the PBC and the China government can operate as shareholders of the state owned banks. It had a registered capital of 50 million RMB which came from the Ministry of Finance, but its investment fund came from the PBC. From 2003 to 2008, the PBC made a few capital injections through Huijin to different state owned commercial banks and insurance companies, some of which came out of the foreign exchange

reserves. For example, it took a total of $45 billion from foreign reserves to invest in the Bank of China, the China Construction Bank and its subsidiary at the end of 2003. It made a capital injection of $15 billion to The Industrial and Commercial Bank of China in 2005.

Table 2 shows a list of capital injections of the Central Huijin Investment Company to state owned companies[2]. Some of the capital injection came from the foreign reserves directly (i.e. those amounts denominated in US dollars), some were said to come from repaid central bank loans (i.e. the 3 billion RMB injection to the Bank of Communication)[3]. If I assume that all the capital injections are completed within a month and use the exchange rate at the month end to convert the RMB amount to dollars, Huijin has injected an overall of $108.4 billion into state owned banks and the Galaxy Security company. As described above, some of the injections are taken from the foreign reserves. If one wants to consider the foreign exchange held by China as a country, this amount should be added back.

In September 2007, the China Investment Corporation (CIC) was established with the intent of utilizing the accumulating reserves for the benefit of the state. Special Treasury bonds of 1.5 trillion yuan ($207.91 billion) were issued by the Ministry of Finance to create the capital that the CIC needed. The Ministry of Finance then used the proceeds to purchase foreign exchanges from the PBC and put them under the management of the CIC. The CIC later acquired the Central Huijin Company from the PBC with $ 67 billions and made it a full subsidiary. As a result, many of CIC's investments and capital injections are still made under

[2] In September 2007, Huijin had effectively become a subsidiary of the CIC, which will be covered later. However it keeps operating and serving its purpose of recapitalizing stated owned banks.

[3] http://www.mecin.cn/Invest/Invest20080919000619.htm, the introduction of Huijing in Chinese.

the name of Huijin. The net effect of the establishment of the CIC on the PBC's balance sheet is a total reduction of $140.9 billion in foreign reserves.

The CIC makes occasional announcements about its investment, but the overall transparency of its investment strategy is low. Compared with the SAFE, the CIC makes more aggressive investments in equities. Table 3 shows an (incomplete) list of its investment projects.

Besides the PBC and its subsidiaries, financial firms and individuals of China are also allowed to make investments in foreign markets and thus hold some foreign exchange. Since 2001, domestic investors, including individual residents, have been allowed to invest their own foreign exchange in B-shares[4]. Starting from 2002, qualified foreign institutional investors (QFII) have been allowed to invest in the domestic capital market. Since 2004, insurance companies have been allowed to use their own foreign exchange to invest in the international capital market. When restrictions on qualified domestic institutional investors (QDII) were lifted in April 2006, domestic fund management companies (asset management companies) began to establish and sell products (mutual funds) to invest in the international capital market, first in a trial run by Hua An Fund Management in September 2006, and then in earnest from September 2007, after the China Securities Regulatory Commission (CSRC) established a new set of rules. In 2007, firms were allowed to hold foreign exchange in a current account at their discretion. In the same year, annual foreign exchange purchases and sales quotas for individuals were raised to US$ 50,000 to meet their needs for holding and using foreign exchange.

[4]China B shares are virtually the same as common shares (which are referred to as A shares), except that they were originally developed as stock shares for foreign investors. They are listed on Shanghai and Shenzhen stock exchanges and are denominated in RMB, but are payable in foreign currency. Before 2001, only foreign investors were allowed to purchase B shares.

As China is moving to a more liberal foreign exchange policy, the PBC and state banks are no longer the only institutions that can hold foreign exchange legally. However, since monetary sterilization is solely implemented and managed by the PBC, and I am interested in whether the PBC's foreign reserves investment return is enough to cover its sterilization cost, in this paper I only take into consideration the foreign reserves listed on the balance sheet of the PBC in this paper. All the other foreign exchange not currently held by the central bank are ignored in the estimation.

China has experienced a rapid increase in foreign reserves since 2003, due to the recorded twin surpluses in the current and capital accounts. Figure 2 shows the evolution of China's balance of payments. The current account surplus clearly contributes the most to the huge growth in foreign reserves. It was $12 billion in 1990. It grew rapidly and reached $249.9 billion in 2006, then $426.1 billion in 2008 and dropped back to 297.1 billion in 2009 due to a slow down in exports. A closer look reveals that the current account surplus has come mainly from the trade surplus, the share of which in the current account surplus was 84% in 2009[5]. At the same time, net exports grew from 2.5% of GDP in 2004 to 8% of GDP in 2008 and then 5% in 2009. The contribution of net exports to GDP growth also increased dramatically from an average of 3% from 2001 through 2004 (0.36 percentage points of GDP growth), to an average of 21% from 2005 through 2007 (2.4 percentage points of GDP growth). It dropped to 8% in 2008 due to a change in the economic conditions abroad. The capital account, mainly coming from FDI, was mostly positive during the period 1995 to 2009 as well, implying a net capital inflow. Since 2001, China has received annual FDI in excess of USD 40 billion.

[5] CEIC database

However the error and omission term was mostly negative before 2002, implying a net unrecorded capital outflow. The sign was reversed after 2002 and before 2009, when the global financial crisis took place.

The rapid accumulation of foreign reserves, combined with China's crawling peg exchange rate, calls for sterilization. Sterilization happens when the monetary authority tries to gain control of the reserve money in face of an exogenous increase in the NFA, by taking opposite actions with the net domestic assets. In other words, as the NFA increases, we may see the NDA decrease as a result of sterilization. Reserve money is kept unchanged in this way, preventing the broad money supply from soaring. However, an increase in the reserve money or the broad money supply per se does not necessarily mean that the PBC has lost control. The central bank may want the monetary base to increase anyway to keep up with economic growth, as in China's case. Figure 3 shows that both the reserve money and the broad money supply have been increasing in China as foreign reserves accumulate. Nevertheless the reserve money increases at a slower pace especially after 2005, indicating the operation of sterilization. The following session gives a overview of China's major sterilization tools.

2.2. Major sterilization tools

According to the monetary report published quarterly by the PBC, the main sterilization methods of China are open market operations (OMO) and raising required reserve ratios. Table 4 gives a summary of how the two methods work. OMO reduces the domestic assets by taking the excess liquidity out of the system, while raising required reserves reduces the money multiplier. From a central bank's point of view, however, increasing the level of required reserves as an attempt to

sterilize affects the liability side of its balance sheet in a similar way that open market operations do. If the interest paid on required reserves is equal to the interest on central bank bills, the two methods have the same impact on the central bank. Generally the cost of sterilization using required reserves is lower than open market operations, since the central bank pays minimum interest on required and excess reserves.

Open market operations in China mainly include bond issuance and short term repurchase operations (repos, usually within 91 days). There are also non-market tools such as transferring the deposits from the commercial banking system to the central bank and "window guidance"(moral suasion). In recent years, the PBC also started making foreign exchange swaps with big commercial banks as a tool of controlling liquidity. In November 2005 it was reported that the PBC made its first one-year swap of a total amount of $6 billion with 10 domestic commercial banks[6]. Unfortunately, the PBC usually doesn't make public announcements on swaps. Since 2005, the amount and timing of the PBC swaps remain secretive. Partial information can only be inferred from the annual reports of those commercial banks which are involved in the swaps with the PBC and are publicly listed. For example, China Construction Bank revealed a foreign exchange swap of $9 billion with the PBC in its 2006 annual report. Bank of China and the National Development Bank also revealed swaps of $41.5 billion and $22.9 billion respectively with the PBC in 2006[7].

Before 2002, open market operations are mainly done by issuing government

[6] From Xinhua News:
http://big5.xinhuanet.com/gate/big5/news.xinhuanet.com/fortune/2007-04/17/content_5987783.htm

[7] Banks are not required to reveal swap transactions in their annual reports. Even if they do, they may choose not to reveal the name of the counterparty. For example Bank of Communications revealed a swap of $5 billion in 2006 without giving the name of the other party. Thus it is very hard to get a good estimate of the PBC's swaps.

bonds. In September 2002 the PBC replaced the outstanding Treasury securities with central bank bills, when the stock of government bonds available shank to a low level. The first new PBC bill was issued in April 2003. Since then the PBC has been issuing bills on a weekly basis. There have been 265 total issuances by Aug 2010 and the volume of PBC bond outstanding is RMB 4.6 trillion up to April 2010[8], exceeding the volume of currency issue. PBC bills usually have a term of less than 1 year. The most frequently issued bills are the 3 month bills and the 1 year bills. Occasionally the PBC has also issued 3-year bills for urgent sterilization need (in late 2004 and early 2005, also at the beginning of 2007 and 2010) and 6 month bills (mostly before 2006). The PBC bills are issued as zero coupon bonds and are auctioned off to banks and other financial institutions at some discounted values in each issuance. They are traded in the interbank bond market, and are usually held by financial institutions such as commercial banks and money funds. Ever since their issuance, the central bank bills have replaced the Treasury and become the main tool in sterilization[9]. In May 2004, the PBC also announced the start of repo sales to depositary institutions (Green (2005)). Figure 4 shows the net central bank bill issuance since 2000, and figure 5 shows the total PBC bonds outstanding as a percentage of foreign reserves from 2000 to 2010. Both figures show an increasing trend in sterilization especially after 2006, using the amount of PBC bills as an indicator.

In general, altering reserve requirements as a tool of monetary control is always dealt with cautionality since it's considered to have too drastic an effect on the money supply through changing the money multiplier (Feinman (1993)). For

[8] http://fc.fund123.cn/Content.aspx?ArticleID=1671

[9] The government keeps issuing Treasury notes, of course. Those notes are no longer used as OMO tools.

example, the Federal Reserve has left reserve requirements essentially unchanged since the passage of the MCA in 1980[10]. One change happened in April 1992 to lower the requirement on transaction deposits from 12 percent to 10 percent. It is not uncommon for emerging economies in Asia to raise required reserve ratios as a method of sterilization though. Countries like Malaysia, Korea and Philippines have all used the method during the capital inflow episode (Takagi and Esaka (1999)).

China has been gradually raising the required reserve ratios since the third quarter of 2003, corresponding to an increase in foreign reserves inflows. The required reserve ratio was raised from 6% and reached its peak value of 17.5% in June 2008[11]. It then decreased a little to 15% by the end of 2008 but increased to 17% again in May 2010. However, in practice the effect of changing required reserve ratios may be limited in China's case, since depository institutions tend to maintain high excess reserve ratios (usually the same or even higher than the required ratio in the early years) due to a lack of alternative investment channels as the PBC has traditionally paid interest on both required and excess reserves. It was also believed that part of the excess reserves is used for interbank settlement and liquidity management purposes (Goodfriend and Prasad (2005)). An increase in the required reserve ratio may simply lead to a decline in the excess reserve ratio, leaving the money multiplier unchanged. To discourage the holding of excess reserves, China has decreased the interest on excess reserves from 1.62% (which was the same as the interest on required reserves) in 2003 to 0.72% in 2008.

[10] The Monetary Control Act, which mandated universal reserve requirements to be set by the Federal Reserve for all depository institutions. For more description on MCA, see J Feinman, "Reserve Requirements: History, Current Practice, and Potential Reform".

[11] China has introduced differentiated reserve requirements into the banking system in 2004. The second-tier banks, including the joint stock commercial banks which do not meet certain standard in terms of capital adequacy are subject to a higher reserve requirement than what is cited here.

Figure 6 plots the sum of required and excess reserve ratios. As described before, there is a trend of increase in required reserve ratio since 2003. However the total reserve ratio was actually dropping slowly until the end of 2006, when the increase in required reserve ratio started to accelerate. Before 2006 a large part of the effect of increases in required reserve ratios was offset by drops in excess reserves. This may be a reason for the PBC to increase its bond issuance through out the years to conduct a more effective sterilization.

To get an idea of the effectiveness of sterilization, figure 7 plots quarterly changes in NFA and NDA of China. Here foreign assets are calculated using the product of foreign reserves denominated in US dollars and exchange rates (RMB/US$). The changes in net foreign assets are adjusted for exchange rates to exclude the revaluation effect (see section 3.2 for the details on data and adjustment). Net domestic assets are defined as reserve money minus net foreign assets. The plot shows that China's net domestic assets have been declining since 2002, corresponding to a simultaneous increase in net foreign assets. Both figure 3 and figure 7 imply sterilization to some degree, but the implication is far from clear.

3. STERILIZATION COEFFICIENT ESTIMATION: DATA, METHODOLOGY AND EMPIRICAL RESULTS

3.1. 2SLS description

In this paper, I estimate the sterilization effect with 2SLS with innovative instrumental variables for NDA and NFA. Namely I propose to use the dummy variable for the 4th quarter as an instrument for NDA, and the past twelve month RMB/US$ exchange rate volatility as an instrument for NFA. As will be explained later, unlike government expenditure, the dummy variable for the 4th quarter is unambiguously

exogenous to the changes in NFA. The twelve month exchange rate volatility is also highly correlated with NFA.

One concern with this regression is the lack of theoretical foundation for the choices of control variables. Among a rich literature on monetary reaction functions, Brissmis-Gibson-Tsakalotos (BGT) (2002) explicitly derives two simultaneous equations used to estimate NFA and NDA from minimizing a simple loss function of the monetary authority, subject to some constraints. Ouyang et al. (2006) modified the BGT model and applied it to several Asian economies. Largely based on the BGT model and Ouyang et al(2007)'s modified model, I specify a set of two simultaneous equations as follows:

$$\begin{aligned}\Delta NFA_t &= \alpha_0 + \alpha_1 \Delta NDA_t + \alpha_2 \Delta mm_t + \alpha_3 \Delta CPI_{t-1} + \alpha_4 \Delta NX_{t-1} + \alpha_5 \Delta (r_t^* + E_t e_{t+1}) \\ &\quad + \alpha_6 y_{ct-1} + \alpha_7 ex\_vol_{t-12,t} + \alpha_8 \Delta G_t + \varepsilon_t \qquad (1) \\ \Delta NDA_t &= \beta_0 + \beta_1 \Delta NFA_t + \beta_2 \Delta mm_t + \beta_3 \Delta CPI_{t-1} + \beta_4 \Delta NX_{t-1} + \beta_5 \Delta (r_t^* + E_t e_{t+1}) \\ &\quad + \beta_6 y_{ct-1} + \beta_7 I_{Q^4,t} + \beta_8 \Delta G_t + \eta_t \qquad (2)\end{aligned}$$

NFA and NDA are adjusted[12] net foreign assets and net domestic assets respectively. Those are the main variables of concern. The control variables include mm (the money multiplier), CPI (price levels), NX (net exports), G (government expenditure), r^* (3-month US Treasury annual rate), e (nominal exchange rate RMB/US$), and finally y_{ct-1} (cyclical GDP). The first difference of the data is employed here to avoid a unit root problem.

α_1 is the offset coefficient. It measures how foreign capital inflow responds to a

[12] Meaning adjusted to exclude the revaluation effect. Method of adjustment will be described later.

change in domestic monetary environment. My main interest lies in the sterilization coefficient β_1, which measures how domestic assets respond to a change in net foreign assets. A β_1 of -1 would indicate complete simultaneous sterilization. An α_1 of -1 implies perfect capital mobility.

In BGT, both α_1 and β_1 are predicted to be negative. An increase in NDA implies an expansionary monetary policy, suppressing the domestic interest rate. This will result in a foreign capital outflow, which leads to a decrease in NFA. When capital controls are present, as in the case of China, capital mobility may be less than perfect, which translates into an α_1 greater than -1. The sterilization coefficient β_1 should be negative too, as long as the central bank is trying to mitigate the expansionary effect of an increase in NFA.

The set of equations can be estimated with two-stage least squares (2SLS). The two equations are separately identified by $ex\_vol_{t-12,t}$, which is the past twelve month RMB/US$ exchange rate volatility calculated by month-end exchange rate in the first equation and I_{Q4},which is a dummy variable that takes value 1 if it's the 4th quarter, and 0 otherwise in the second equation. The choice of $I_{Q4,t}$ is an innovation. It is due to the fact that Chinese commercial banks tend to hold significantly more reserves in each 4th quarter in preparation for large withdrawals before the Chinese New Year, according to the quarterly monetary report of the PBC. The New Year follows the lunar calendar and usually falls in February. It is a tradition for people to exchange gifts, buy new clothing and decorations, and repay their loans in the New Year. Children also receive cash from parents and relatives (the red packets). The NFA, however, should not be significantly impacted by the arrival of the Chinese New Year. In fact, the correlation between ΔNDA_t and $I_{Q4,t}$ is 0.53, while the correlation between ΔNFA_t and $I_{Q4,t}$ is -0.005.

The choice of $ex\_vol_{t-12,t}$ follows Brissimis, Gibson and Tsakalotos(2002), which claims that exchange rate deviation only affects the change in NFA but not NDA. Though China has maintained a fixed exchange rate until July 2005, we are still able to observe small fluctuations of the RMB/US$ rate during the whole sample period. In any month t (since I use quarterly data, t can only be March, June, September or December here), $ex\_vol_{t-12,t}$ is calculated as the standard deviation of monthly exchange rate from $t-12$ to t. The correlation between $ex\_vol_{t-12,t}$ and ΔNFA_t is 0.52, while it is -0.08 between $ex\_vol_{t-12,t}$ and ΔNDA_t. The other alternative instrument real effective exchange rate only has a correlation of less than 0.03 with ΔNFA_t.

The rest of control variables in the equations are chosen according to existing empirical literature in the area[13]. Those are the variables that motivate foreign capital flows in or out of the country, and variables that are important to monetary policy decisions. In particular, the use of the lagged terms in price change, cyclical income and net export further alleviates the endogeneity problem.

For some control variables in the above equations, it is obvious that their coefficients should take certain signs. Other coefficients require more detailed discussion.

The coefficients of the money multipliers in both equations, α_2 and β_2 are expected to be negative. A high mm_t indicates an overall expansionary policy and a low total reserve ratio. Expansionary policy leads to a drop in interest rate which induces capital outflow. A low total reserve ratio leads to a low level of reserve money and thus a smaller NDA component on the central bank's balance sheet.

Both coefficients of price change should be negative, since a higher inflation leads to reduced capital inflows as well as a contractionary monetary policy. However

[13] E.g. see Brissimis, Gibson and Tsakalotos(2002), He.D., C.Chu, C.Shu and A. Wong(2005), Ouyang, Rajan and Willett(2006).

there may exist a time lag between inflation and policy responses. In that case it is hard to predict which way the coefficients of price changes would go. The coefficients of net export is expected be positive for NFA, since an increase in NX contributes to NFA, *ceteris paribus.*

$\Delta(r_t^* + E_t e_{t+1})$ is a measurement of foreign interest rate adjusted by exchange rate. α_5 is negative since both an increase in foreign interest and an expected depreciation of domestic currency signal better investment opportunities abroad. β_5 is also expected to be negative since the uncovered interest parity implies that the central bank would want to raise the domestic interest rates as a response to a positive $\Delta(r_t^* + E_t e_{t+1})$.

The coefficient of cyclical income in equation 1, α_6, may be negative since an increase in real GDP worsens the balance of payments. However a high GDP may induce more capital inflows as it is a sign of overall economy strength. Similarly, the government usually decides to take a counter-cyclical monetary policy which leads to a negative β_6. On the other hand it is also possible that the government wants to stimulate the economy even more after economic growth, making β_6 positive. Similar arguments can be applied to α_8 and β_8, where government expenditure may have an ambiguous effect on NDA and NFA.

Finally, α_7 is expected to be negative since a more volatile exchange rate impedes capital inflows. However it is also possible that a more flexible exchange rate regime induces more speculative capital inflows. β_7 is expected to be positive since NDA increases with the arrival of Chinese New Year.

3.2. Data and Empirical results

3.2.1. Data summary

Most literature points out (both qualitatively and quantitatively) that sterilization did not become an issue in China until around 2000. This paper employs quarterly data from Q1 1995 to Q2 2010. Ideally data of high frequency should be used, however, monthly GDP of China are not available. I recognize the sample size is small, thus the estimated coefficients should be viewed with caution. All the data are from the CEIC database, IFS and the PBC's website, taken at the end of each period. Table 5 gives a description of the data sources and definitions.

ΔNFA_t, ΔNDA_t and ΔNX_{t-1} are scaled with the GDP of the corresponding period. Most other variables are expressed in logs. The Hodrick-Prescott (HP) method is applied to find the trend of the real GDP. Cyclical income is then calculated using real GDP and is scaled by the trend. Following Ouyang, Rajan and Willett (2007), the expected nominal exchange rate $E_t e_{t+1}$ is approximated in two ways: perfect foresight and static expectation. In perfect foresight, $E_t e_{t+1}$ equals $\ln e_{t+1}$. With static expectation, $E_t e_{t+1}$ equals $\ln e_{t+1}$.[14].

A standard ADF test is applied to test the stationarity of all the variables. The null hypothesis is that the variable has a unit root. Table 6 shows the summary statistics of the ADF test. All the variables are stationary at 5% significant levels.

The net foreign assets are calculated as the difference between foreign reserves minus gold and foreign liability. Foreign reserves data is from IFS and is dollar denominated. Foreign liability is taken from the PBC's balance sheet and is recorded mark-to-market in domestic currency (RMB). Thus net foreign assets are calculated as follows:

$$NFA_t = (foreign\ reserves_t \times e_t)\text{-}foreign\ liability_t$$

[14] See table 5 and the next section for a detailed explanation.

where e_t is the exchange rate of the RMB against the $US.

It is obvious that the value of NFA may change due to fluctuations in exchange rate. This type of change is not caused by an inflow of foreign assets and is irrelevant to the study. To exclude the revaluation effect, I follow Aizenman and Glick (2008) and calculate the adjusted NFA at time t-1 as $NFA_{t-1}(\frac{e_t}{e_{t-1}})$.

Therefore the change in net foreign assets excluding the revaluation effect is

$\Delta NFA_t = NFA_t - NFA_{t-1}(\frac{e_t}{e_{t-1}})$

Here I make a simplistic assumption that all the foreign reserves are in US dollars. Ideally, if the exact currency composition of China's foreign reserves is known, the revaluation effects should be adjusted for each currency. However no data is available on the exact composition of China's foreign reserves. In section 4 of the paper some approximations of the composition of China's foreign reserves are proposed, however as will be shown later in this section, a robust check with a different currency composition does not change the major findings. Previous literature[15] also suggests that estimation results on sterilization are usually robust to different currency compositions of reserves.

Finally the change in NDA is calculated as the residual under the identity: $\Delta NDA_t = \Delta RM_t - \Delta NFA_t$,

where RM stands for reserve money and is taken from the balance sheet of the PBC. Table 7 gives the summary statistics of all the variables.

3.2.2. 2SLS Empirical results

I use 2SLS to estimate the set of simultaneous equations. To avoid potential problems of autocorrelation and heteroskedasticity in residuals, Newey-West co-

[15] Ouyang, Rajan and Willett (2006), Prasad and Wei (2005)

variance is computed up to 3 lags. Small sample correction is performed for all the estimations. Table 8 presents summary statistics of the regression result. The numbers in the parentheses are standard errors.

The sterilization coefficient is between -0.934 and -0.793, indicating a high level of, but less than full sterilization by the PBC during my estimation period. This number is smaller than the estimated coefficients in Aizenman and Glick (2008). The reason for the divergence may lie in the fact that they used a simple OLS instead of 2SLS. The offset coefficient is between -.650 and -.649, implying some degree of capital mobility despite strict capital controls in China. This is related to the speculative "hot money" that flows into China under an expectation that the RMB will appreciate. As Goodfriend and Prasad pointed out, "the effectiveness of capital controls (in China) inevitably erodes over time" since domestic and international investors find channels such as exaggerating export invoices to evade them. This offset coefficient here is comparable to and slightly smaller than the estimation obtained in Ouyang, Rajan and Willett (2007).

The coefficients of Δmm_t are significant and of the right sign. The coefficients of ΔCPI_{t-1} are at least marginally significant, and has a significant positive impact on ΔNDA_t and ΔNFA_t. This can be due to the fact that both the monetary authorities and foreign investors need some time to react to a change in domestic price conditions, while the price change affects domestic assets more directly. Moreover, while NFA and NDA are relatively volatile, CPI are stable (with quarterly changes usually less than 2%) for most periods covered by the study, with the exception of the last three quarters of 2003, the last quarter of 2007 and first two quarters of 2008. This may cause statistical difficulties to detect the true relationship between the variables. ΔNX_{t-1} is of the right sign and $\Delta(r_t^* + E_t e_{t+1})$ has the wrong sign

in one specification, but both are insignificant.

Surprisingly, $I_{Q4,t}$ is of the wrong sign and both $I_{Q4,t}$ and $ex\_vol_{t-12,t}$ are insignificant. The first stage F-stat for $ex\_vol_{t-12,t}$ are 8.05 and 11.38 for the two cases. The first stage F-stat for $I_{Q4,t}$ is comparable. Those values are smaller than the conventional critical value of 10.3 for weak instrument test[16]. This suggests that the use of $I_{Q4,t}$ and $ex\_vol_{t-12,t}$ might be exposed to a weak instrument problem, which can lead to biased results in 2SLS. However Angrist and Pischke recently point out in their book "Mostly harmless econometrics" that a Monte-Carlo simulation shows that just identified IV is approximately unbiased unless the instrument is extremely weak. This provides me with some confidence in interpreting the results.

As a robust check, lagged control and dependent variables are added to the right hand side of the equation, as independent variables. The coefficients of CPI_{t-2} are of the right negative sign but insignificant, this lends some support to the previous explanations on positive coefficients of price changes. The offset coefficients are largely unchanged, while the sterilization coefficients remain negative but become significant only at a 10% level. The reason behind this is probably that NDA responds to contemporaneous changes as well as lagged changes in NFA. Sterilization may be completed over a couple of quarters. With a small sample size, it is harder to obtain significant coefficients for every lagged NFA. In fact as the next section shows, a simple VAR implies that the sterilization is mostly completed within the next two periods. The result is also robust to a different composition of the foreign reserves, namely 70% US dollars and 30% Euros[17].

Inspired by Aizenmand and Glick (2008), I estimate the sterilization coefficients

[16] See, for example, Stock and Yogo (2005)
[17] Results are not reported here to ensure conciseness of the paper.

with 2SLS using 40-quarter rolling samples. The sample period begins with 1995 Q1 to 2004 Q4, moves to 1995 Q2 to 2005 Q1 and ends with 2000 Q3 to 2010 Q2. There are 23 rolling periods in total. Figures 8 and 9 show a plot of the rolling coefficients with 95% confidence intervals. The x-axis corresponds to the end of the 40th quarter of each rolling sample. The coefficients are steady but with a slight downward trend, suggesting an increase in the degree of sterilization. However no definite conclusion can be reached given the large standard errors. This is not a direct contradiction to the findings in Aizenman and Glick (2008) or Ouyang, Rajan and Willett (2007) though, since the two studies cover different sample periods.

To further check the robustness of the result, I replace NDA by M2 and estimate the following equation:

$$\begin{aligned}\Delta M2 &= \lambda_0 + \lambda_1 \Delta NFA_{t-1} + \lambda_2 \Delta mm_t + \lambda_3 \Delta CPI_{t-1} + \lambda_4 \Delta NX_{t-1} + \lambda_5 \Delta (r_t^* + E_t e_{t+1}) \\ &\quad + \lambda_6 y_{ct-1} + \lambda_7 \Delta G_{t-1} + \nu_t\end{aligned}$$

Here ΔNFA_{t-1} is used instead of ΔNFA_t to break the mechanical relationship between NFA and contemporaneous money supply. The regression gives a λ_1 of .630 with a standard error of 0.616 for static expectation, and .669 with a standard error of 0.602 for perfect foresight. In both cases the λ_1 coefficient is not significantly different from 0. This implies that NFA from previous period has no significant impact on current M2.

3.2.3. Robust check: VAR to detect the effect of NFA on the price levels

If China has been successfully sterilizing the inflows of foreign capital, it should be able to insulate its domestic monetary conditions from the increase in NFA to a large degree. Figure 10 plots the percentage change in China's quarterly CPI and NFA from 1994 to 2010. Despite a continuous increase in NFA, CPI seems to be quite stable after 1997 except for the spikes in late 2003 and early 2008. To take a closer look at the problem, I study the direct impact of the changes in net foreign assets on domestic price levels by applying the following reduced form VAR:

$$\begin{aligned}
\Delta NFA_t &= \Phi_1 + \sum_{i=1}^{k} \Phi_{11,i}\Delta NFA_{t-i} + \sum_{i=1}^{k} \Phi_{12,i}\Delta NDA_{t-i} + \sum_{i=1}^{k} \Phi_{13,i}\Delta CPI_{t-i} + \varepsilon_{1t} \\
\Delta NDA_t &= \Phi_2 + \sum_{i=1}^{k} \Phi_{21,i}\Delta NFA_{t-i} + \sum_{i=1}^{k} \Phi_{22,i}\Delta NDA_{t-i} + \sum_{i=1}^{k} \Phi_{23,i}\Delta CPI_{t-i} + \varepsilon_{2t} \\
\Delta CPI_t &= \Phi_3 + \sum_{i=1}^{k} \Phi_{31,i}\Delta NFA_{t-i} + \sum_{i=1}^{k} \Phi_{32,i}\Delta NDA_{t-i} + \sum_{i=1}^{k} \Phi_{33,i}\Delta CPI_{t-i} + \varepsilon_{3t}
\end{aligned}$$

where NFA, NDA and CPI are defined as before. The VAR measures the transmission of an impulse from net foreign assets to net domestic assets, as well as to the price levels. If the result from the section above is true, the change in NFA should have limited effects on CPI.

This is a very simple VAR with only 3 variables. It is appropriate in this setting because I want to focus on the effect of net foreign assets on the price levels. Moreover, it is well known that the Cholesky decomposition used to orthogonalize the variance-covariance matrix of the VAR residuals imposes a recursive causal structure from the top variables to the bottom variables. Including too many control variables makes it harder to decide on a sensible order of all those variables. Here it is assumed that NFA affects other two variables contemporaneously but not vice versa. This ordering is based on the previous 2SLS result, which shows that an

increase in NFA triggers the change in NDA in the opposite direction. On the other hand, the inflow of foreign capital is not so much induced by a change in domestic assets. Both of the foreign assets and domestic assets are assumed to affect price levels contemporaneously.

Based on Akaike Information Criterion, 4 is selected as the optimum lag number. Figure 11 shows the orthogonalized impulse response function. From the graph, NDA responds significantly to a change in NFA. Namely NDA drops when NFA increases and most of the changes are completed within the first two following quarters. Shocks to net foreign assets have little influence on price levels. The responses of NDA and CPI can be interpreted as the impact of changes in net foreign assets has been effectively neutralized, which restates the previous result that the PBC's sterilization operations have been successful.

A Granger causality test indicates that $\triangle NFA_t$ Granger causes $\triangle NDA_t$, not the other way around. $\triangle NFA_t$ does not Granger cause $\triangle CPI_t$. This suggests that the sterilization is effective in the sense that change in NFA does not have a positive effect on the price levels. The magnitude of $\triangle CPI_t$'s response to changes in lagged $\triangle NFA_t$ is also at the minimum as figure 11 shows. Over all, the VAR results support my conclusion from the previous section that the PBC is carrying out a high degree of sterilization.

4. THE STERILIZATION COST BORN BY THE PBC

The aforementioned section concludes that China has been capable of carrying out an almost complete sterilization. In spite of a rapid increase in foreign reserves, China is able to maintain a relatively independent monetary policy.

However, the sterilization comes at a cost. As the foreign reserves keep accumu-

lating, the PBC has to issue more debt for sterilization purpose, which may drive up the interest rates on the PBC bills. Eventually the cost may become too high for the central bank. The appreciation of the RMB against the US dollar can also contribute to a net capital loss in domestic currency terms, since the PBC bills are denominated in RMB and the foreign reserves are denominated in US dollars. On the other hand, the foreign reserves have been increasing consistently. The growing investment return from the foreign reserves helps to offset the cost and sustain the sterilization operation.

In the following section I estimate the PBC's cost of sterilization and compare it with its income from the foreign reserves investment from the period 2003 to 2010, taking exchange rate fluctuation into consideration. A back-of-the-envelope calculation indicates that at the current interest and exchange rate, China's foreign exchange reserves have to drop around 36% (or to put it in another way, the RMB has to appreciate by more than 50% against the US dollar) before it fails to cover the sterilization cost of the PBC. A projection of the sterilization cost and the income from foreign reserves investment also indicates no sign of unsustainability in the near future.

4.1. Comparison of the sterilization cost and the PBC's investment income

The cost of sterilization is generated from two categories on the liability side on the PBC's balance sheet: the interest payments on the outstanding PBC bonds and on the total (required and excess) reserves. Since repos usually have terms of less than 91 days and are of a much smaller scale compared to PBC bonds, the interest payments on them are small and thus are ignored here.

The volume, term and final price of each bond issuance are published by the PBC every week. From this data, the interest expenses associated with each issuance can be calculated. The expense is then distributed evenly into each month until the bond reaches maturity (the same concept as amortization in accounting). The total cost of PBC bills in a certain month can be calculated by summing up the interest expenses associated with all of the currently outstanding bonds. Figure 12 plots the weighted monthly interest rate of the PBC bills with different terms. Contrary to popular belief, though the interest rate peaked in 2008 there is no obvious trend of a continuous increase in the interest rates over the years.

Unlike many other countries, China pays interest on both required reserves and excess reserves. The current annual interest rate is 1.62% for required reserves and 0.72% for excess reserves. Historically the interest rates have been higher. Table 9 shows the historical adjustments of reserve interest rates.

Month-end data of total reserve amount can be found on the PBC's balance sheet, starting from 2000. Since the bond interest payment is calculated as an average amount over the month, I also replaced the month-end reserve data by the month-average reserve amount (calculated by taking the average of previous and this month-end data). However the PBC's balance sheet does not distinguish between required reserves and excess reserves, which makes the precise calculation of interest payment on reserves impossible. To deal with the problem, I calculate the upper (and lower) bound of the monthly interest payments, corresponding to the extreme cases where all reserves are required reserves (or excess reserves). The actual interest payments on reserves must lie somewhere in between. The total cost of sterilization is calculated by adding up the interest payments on both the PBC bonds and the total reserves.

There is one caveat in the method mentioned above. Not all the interest paid on reserves by the PBC can be categorized as sterilization cost, since the commercial banks are always required to hold some reserves. Strictly speaking, the lower bound calculated here should be higher than the "true" lower bound if we assume the repo costs are negligible. This wouldn't hurt my result though, since this overestimated lower bound is exceeded by the income from foreign reserves investment as a result.

The estimation of the PBC's income from foreign reserves investment is less straightforward. China has been very cautious in revealing information on the compositions of its international reserves and no public information is available. It is widely believed, however, that China's foreign reserves mainly consist of US dollars, Japanese Yen and Euros. To get a rough approximation of the composition of China's foreign reserves, I use quarterly international reserves composition of emerging markets from IMF Currency Composition of Official Foreign Exchange Reserves (COFER) database, only taking into account assets denominated in US dollars, Euros and Japanese Yen. This approximation is consistent with the conventional belief that around 70% of China's foreign reserves are in US dollars (Morrison and Labonte (2008)). The composition is expressed in percentage, thus even though foreign reserves are denominated in dollars, there is no need to worry about the exchange rate change between Yen/Euro and dollar when calculating the average yields.

Yields on these assets are approximated by five-year government bonds issued by the corresponding national governments (for Euro assets, it's an average of the bonds of several national governments in the Euro area). Those data are published by the respective central banks and are the average values over the month. Long-term bonds are used in the approximation because according to the data published

by the Federal Reserve, only 6.7% of China's holding of US Treasury securities (official and unofficial combined) are short term Treasury bills during the period from 2003 to 2009. The rest are all some forms of long term securities. The Fed's data does not distinguish between private or institutional investors and the monetary authorities. However, foreign reserves account for a majority of China's US Treasury holdings. It is safe to conclude that the PBC holds mostly long term bonds as its investment. The treasury securities alone, long term and short term combined, account for 36% of China's foreign reserves[18]. The monthly yield on foreign reserves is then calculated as the average of yields on assets denominated in those three currencies, weighted by the percentage composition implied by COFER. In addition, the gain/loss caused by monthly exchange rate changes is taken into account when converting dollar income to RMB.

The approximation results in an average annual return of 3.39% for the period from April 2003 to June 2010, which is used to further calculate PBC's total income from foreign reserves. Liu (2008) estimated the annual yield on China's foreign reserves to be between 3.6% and 4.3%, for the period from 2000 and 2007. My estimation is lower than that in Liu (2008), most likely due to a drop in the US treasury rate after 2007. Using yields on two-year and ten-year government bonds as a benchmark would result in an average annual yield of 2.74% and 4.03% respectively.

The total income from the foreign reserves investment is calculated as $\text{Income}_t = (\text{Average Foreign Reserve}_t \times \text{Average}[e_t] - \text{Income}_{t-1}) \times \text{yield}_t$, where the subscript t stands for the values at time t. Since the foreign reserves and exchange rates

[18] According to the statistics on foreign net purchase of US securities published by Fed, China's total purchase includes U.S government bonds, some cooperate bonds and very little U.S. cooperate stocks. However the term structure of the bonds and the exact break down of China's holding of US assets are not available. Here I use the long term government bond as a proxy.

data from IFS are at the end of month, average monthly values are calculated using data from this and previous month. Income from the previous month is deducted from this month's average foreign reserves stocks to get the principle amount for this month. I here make the simple assumption that the income earned from foreign reserves each month is not re-invested and can indeed be used to cover the sterilization cost. In this way, there is no double counting the interest earned.

Figure 13 plots the PBC's estimated monthly income from foreign reserves investment using ten-year and five-year bonds respectively and its cost of sterilization, starting from April 2003, when the first new PBC bill was issued. From the graph one can see that the positive gap between income and cost has been growing since 2005, but has recently taken a downturn at the end of 2008 and widened again afterwards, mainly due to a drop in long term foreign interest rates. Due to a combination of rapid increases in foreign reserves and high yields on reserves investment, the PBC's income from foreign reserves investment calculated from both types of bonds have been exceeding the upper bound of sterilization cost consistently, with the only exception in December 2008, where the income from five-year yields falls below the upper bound on cost but still stays above the lower bound. At the current exchange rate and keeping the PBC's cost constant, China's foreign reserves will have to drop 36% before the income from five-year bonds hits the lower bound. Another way to look at it is that the RMB would have to appreciate by more than 50% against the US dollar before the income from five-year bonds fails to cover the lower bound, assuming the exchange rates of the RMB against the Euro and the Yen stay constant.

If foreign interest rates keep dropping, China will suffer a more drastic decrease in its income from foreign reserves, especially if its investment is of a shorter term

than that was estimated. Figure 14 plots the same graph as before but with five-year and two-year bond yields as proxies instead. Since the short/medium term foreign interest rate has dropped sharply, investment yields from two-year government bond cannot cover PBC's interest expenses after late 2008. Moreover, China holds some of the US ABS (Asset-Backed Securities). Though the exact amount is unknown, the ABS may be another source for the losses in foreign reserves.

Using different compositions leaves the conclusion largely unchanged. Especially, in one experiment all the Euros are replaced with Japanese Yen, leaving the proportion of US dollars unchanged. Since Japanese government bonds have much lower yields than their US and European counterparts, this experiment leads to a lower value of the investment income from foreign reserves. In this case, the income from the 10-year bond still exceed both the upper and lower bounds on sterilization cost in every month except for December 2008. The yields from 5-year bond exceeds the cost lower bound except for December 2008.

4.2. Linear Projections

As a thought experiment, I also performed simple linear projections of the sterilization cost and the income from foreign reserves investment. Figure 15 shows the projected values from July 2010 through June 2015 using COFER compositions. The projected values and standard errors of the upper/lower bound on sterilization costs are calculated using OLS based on the data from July 2005 to June 2010. Foreign reserves denominated in dollars are projected under a linear regression based on the values from the same period and the investment yield is assumed to stay constant at the June 2010 level. Future exchange rates of RMB against US$ are also projected linearly, based on the values between July 2005 and June 2010. The

projected income from foreign reserves investment is calculated as $\text{Income}_{pro,t+j} = (\text{Average Foreign Reserve}_{pro,j} \times \text{Average}[\text{e}_{pro,j}] - \text{Income}_{pro,j-1}) \times \text{yield}_{June2010}$, where the subscript stands the projected value at time j after June 2010. Standard errors of the income from foreign reserves investment are calculated using delta methods assuming the covariance matrix of foreign reserves and exchange rates is diagonal. As before, I convert the month-end data of foreign reserves and exchange rates to month-average. Those data are then used in the projection.

We can see that even with RMB appreciating, according to figure 15 the ten-year bond income still stays well above the upper cost bound. The upper cost bound only start to catch up with the 5 year bond income in the end of 2012. I also did a similar experiment with the exchange rate fixed at the June 2010 level. Without the appreciation, even the five-year bond income stays above the upper cost bound. Using two-year bond income produces a drastically different picture in the projection, of course. As the previous section indicates, the foreign exchange investment income estimated from two-year government bond always stays below the lower cost bound (graph is not shown here). However it is quit unlikely that China will switch massively to a shorter term investment in the near future.

Admittedly this projection is very parsimonious. Nevertheless it sends an important message that among all the things, the appreciation of the RMB and the terms of the invested Treasuries have profound impacts on the PBC's income from foreign reserves. This does not mean that the PBC's sterilization is not sustainable, though. Firstly there is no reason why China would want to switch to a short investment horizon in terms of foreign reserves. Secondly as the RMB appreciates, the speculative capital inflow into the country will be reduced. In that case, the PBC will no longer need to engage in such massive sterilizations. I thus conclude

that as long as China is able to keep a stable interest rate paid on the PBC bills and experiences no sudden drop in foreign reserves, there is no obvious reason why the PBC will lose its capacity of extensive sterilizations in the near future.

Having said that, I recognize that sterilization might have other unobserved costs besides interest payments. For example, it was argued that domestic interest rates on the PBC bills were artificially kept low by the central bank, in order to sustain low interest payments on bonds. This so-called financial repression environment hinders the financial market from working efficiently. Furthermore, raising the required reserve ratio posts a cost on domestic commercial banks by lowering their profit margin. The cost of those is, however, hard to quantify. Moreover, there is little definite evidence showing that the PBC bond is indeed overpriced. It is obvious that the PBC bills should have a lower rate than other corperate bonds since the bills are implicitly backed by the Chinese government and thus are considered to be default free. The only comparable security here is probably the Treasury bond of similar terms issued by the Ministry of Finance, which is also auctioned off and is traded in the interbank markets and at the exchanges. The average annual yields of China's one year government bond traded at the exchanges are 2.84% and 3.13% in 2007 and 2008 respectively[19], which are actually lower than the PBC bill rates in the same period. Since the Treasury bonds are traded at the exchanges and thus are accessible by the general public, their yields should better reflect the market expectations. The fact that the PBC bills have a higher rate sheds some doubts on the claim that the PBC bills rates are intentionally suppressed. Of course one can always argue that the PBC suppresses the domestic rates on RMB denominated assets in general. The validation of this claim is beyond the scope of this paper.

[19] Data from Bloomberg, index GCNY1YR

5. CONCLUSION

This paper studies the degree of sterilization and capital mobility in China in the recent episode of a crawling peg exchange rate and rapid foreign reserve accumulation. The results suggest a sterilization coefficient between -0.8 and -0.9, and an offset coefficient of around -0.6. This implies that the PBC has been carrying out a almost full sterilization, and the capital controls in China are somewhat porous but still effective. In spite of a continuous inflow of foreign exchange, China seems to be able to maintain a steadily increasing monetary base and a stable price level. A reduced form VAR confirms the result that the impact of changes in net foreign assets has been effectively neutralized. The sterilization coefficients in this paper lie within the wide range offered by Aizenman and Glick (2008). They are smaller than those obtained by He et al. (2005) and greater than those of Wu (2006) and Ouyang, Rajan and Willett (2007). The offset coefficients in the paper are comparable to those of Ouyang, Rajan and Willett (2007). Unlike in Aizenman and Glick (2008), rolling regressions show that there is no obvious increasing trend in sterilization coefficients from 2004 to 2008. A small sample size in this paper and a different time frame and method may have contributed to the differences.

Secondly, I estimate the lower and upper bounds on PBC's cost of sterilization and compare them with the income the PBC earns from investing foreign exchange reserves in long term foreign government bonds. Calculation shows that so far the PBC's sterilization cost can be fully covered by its income from foreign reserves, which provides support to Prasad and Wei (2005)'s claim that there are in fact net marginal benefits to a combination of large reserves holding and continuous sterilization in China's case. Projections of future sterilization cost and foreign reserves investment income also show no sign that sterilization will become unsustainable

in the near future. However further appreciation of RMB and a switch to short term bond may have a profound negative impact on the PBC's income from foreign reserves investment in domestic currency terms. As China is moving towards a more liberal exchange rate policy, it will probably suffer a capital loss on its foreign exchange reserves in RMB terms. Nevertheless, in this case the resulting decrease in the speculative capital inflows will mitigate the need for sterilization.

TABLE 1: Balance sheet of the PBC

Total Asset	**Total Liability**
Foreign assets	Reserve money
Claims on government	Deposits of financial corporations excluded from Reserve Money
Claims on depository corporations	Bond outstanding
Claims on other financial and non -financial corporations	Foreign liabilities
Other assets	Other liabilities
	Deposits of government
Net Foreign Assets = Foreign assets- foreign liabilities	
Net Domestic Assets = Claim on depository corporations + Claims on other financial and non-financial corporations+Claim on government + Other assets - Deposits of financial corporations excluded from Reserve Money - Bond outstanding - Deposits of government - Other liabilities = Reserve Money – Net Foreign Assets	

TABLE 2: Capital injections from the Central Huijing Company

Institutions	Date	Amount (billions)	Miscellaneous
Bank of China	Dec 2003	22.5 $US	
China Construction Bank	Dec 2003	20 $US	
Jianyin Investment Company	Dec 2003	2.5 $US	
Bank of communication	June 2004	3 RMB	
Industrial and Commercial Bank of China	April 2005	15 $US	
Galaxy Security Company	June 2005	10 RMB	
Shenyin & Wanguo Security Company	Aug 2005	2.5 RMB	Plus 1.5 Billion RMB in loan
Guotai Junan Securities Co	Aug 2005	1 RMB	Plus 1.5 Billion RMB in loan
China Galaxy Financial Holding Co.	Aug 2005	5.5 RMB	
China reinsurance (group) Co.	April 2007	2 $US	
China Everbright Banks	Nov 2007	20 RMB	
National Development Bank	Dec 2007	20 $US	
Agricultural Bank of China	Oct 2008	19 $US	

Source: Huijin's office website

TABLE 3: Investment Projects of the CIC

Institutions	Date	Amount ($billions)	Type of investment
The Blackstone Group	May 2007	3.0	Pre-IPO, 9.4% equity
China Railway Group	Nov 2007	0.1	Pre-IPO, equity
Morgan Stanley	Dec 2007	5.0	mandatory convertible securities, 9.9% equity
Visa	Mar. 2008	0.1	Pre-IPO, equity
JCFlowers	April 2008	3.2	Private Equity Fund

Source: Perspective of China foreign exchange investment, Zhang Min

TABLE 4: Sterilization Tools

Method	Steps
OMO bond issuance or repo	1. NFA increases by ΔNFA. 2. $RM = NFA + NDA$ increases by ΔNFA. 3. NDA decreases by ΔNDA, and RM is back to previous level. 4. $M2 = RM \times mm$ in unchanged.
Raise required reserve ratio	1. NFA increases by ΔNFA. 2. RM increases. 3. mm decrease. 4. $M2 = RM \times mm$ in unchanged as a net effect.

where RM is reserve money, and mm is the money multiplier.

TABLE 5: Variable Description and Definition

Variable	Description	Calculated as	Data Source
NFA_t	Foreign reserves minus gold denominated in US dollars minus foreign liabilities	$Foreignreserves_t \cdot e_t(RMB/\$)$-$ForeignLiabilities_t$	IFS
ΔNFA_t	The change in NFA excluding revaluation effects, scaled by GDP	$\frac{NFA_t - NFA_{t-1}(\frac{e_t}{e_{t-1}})}{GDP_t}$	IFS
ΔNDA_t	The change in NDA scaled by GDP	$\frac{(\Delta reservemoney_t - \Delta NFA_t)}{GDP_t}$	PBC
mm_t	Money multipliers	$M2_t$/reserve money$_t$	PBC
Δmm_t	Change in $\ln mm$	$\ln(mm_t) - \ln(mm_{t-1})$	PBC
ΔCPI_{t-1}	Lagged change in consumer price index, as a measure of change in price level	$\ln(CPI_{t-1}) - \ln(CPI_{t-2})$	IFS
ΔNX_{t-1}	Lagged change in net export scaled by GDP	$\frac{(NX_{t-1} - NX_{t-2})}{GDP_{t-1}}$	CEIC and author's calculation
$\Delta(r_t^* + E_t e_{t+1})$	Change in foreign interest rate plus the expected nominal exchange rate. The foreign interest rate is the rate of US 3-month Treasury rate.	$\Delta(r_t^* + \ln e_{t+1})$if perfect foresight	IFS
		$\Delta(r_t^* + \ln e_t)$if static expectation	
y_{ct-1}	Lagged cyclical GDP. The real output deviated from its trend. The trend is measured by a H-P filter	$\frac{\ln(\text{Real GDP}) - \text{HP trend}}{\text{HP trend}}$	CEIC
$\triangle G_t$	change in government expenditure scaled by GDP	$\frac{G_t - G_{t-1}}{GDP_t}$	CEIC
$\Delta ex\_vol_{t-12,t}$	past twelve month RMB/USD exchange rate volatility	$\frac{\sum_{i=0}^{12}(e_{t-i} - \overline{e_{t-12,t}})^2}{12}$	CEIC
$I_{Q4,t}$	Dummy for the 4^{th} quarter	1 if it's the 4^{th} quarter, 0 otherwise	

TABLE 6: ADF test results (with constant)

Variable	Test Stat (t)	Type of Test
ΔNFA_t	–5.496 ** (0.000)	with trend
ΔNDA_t	-8.367 ** (0.000)	without trend
Δmm_t	-9.206** (0.000)	
ΔCPI_{t-1}	-6.285** (0.000)	
ΔNX_{t-1}	-11.756** (0.000)	
$\Delta(r_t^*+E_te_{t+1})$	-3.217** (0.002) for perfect foresight -3.391**(0.001) for static expectation	
y_{ct-1}	-10.143** (0.000)	
$\triangle G_t$	-15.151** (0.000)	
$\Delta ex\_vol_{t-12,t}$	-1.748** (0.04)	

Note: (**)denotes significance at 5% level.

TABLE 7: Summary statistics of variables, Q1 1995 to Q4 2008

Variable	Obs.	Mean	Std. Dev.	Min	Max
ΔNFA_t	62	.0619	.048	-.001	.201
ΔNDA_t	62	-.026	.081	-.205	.158
Δmm_t	62	.0076	.060	-.123	.149
ΔCPI_{t-1}	62	.031	.052	-.021	.238
ΔNX_{t-1}	62	.006	.010	-.021	.025
$\Delta(r_t^*+E_te_{t+1})$	62				
Perfect insight		-.005	.010	-.05	.001
Static expectation		-.004	.010	-.05	.001
y_{ct-1}	62	.000	.019	-.033	.048
ΔG_t	62	-.0045	.095	-.204	.129
$ex\_vol_{t-12,t}$	62	.038	.061	.000	.257

TABLE 8: 2SLS estimation of simultaneous equations, Q1 1995-Q4 2008

	Perfect Foresight		Static Expectation	
Explanatory Var	ΔNFA_t	ΔNDA_t	ΔNFA_t	ΔNDA_t
Constant	.024 (.023)	.027* (.015)	.023 (.024)	.034*** (.012)
ΔNFA_t	−−	**-.793** **(.340)**	−−	**-.934*** **(.232)**
ΔNDA_t	**-.650** **(.312)**	−−	**-.649** **(.313)**	−−
Δmm_t	-.689** (.303)	-1.01*** (.179)	-.683** (.303)	-1.00*** (.181)
ΔCPI_{t-1}	.175* (.103)	.219*** (.054)	.187* (.107)	.208*** (.051)
ΔNX_{t-1}	.292 (.313)	.514 (.557)	.283 (.316)	.553 (.567)
$\Delta(r_t^*+E_te_{t+1})$	-.137 (.298)	.198 (.464)	-.276 (.359)	-.402 (.402)
y_{ct-1}	-.075 (.432)	.553 (1.64)	-.063 (.435)	.589 (1.57)
ΔG_t	-.030 (.103)	.122 (.345)	-.027 (.104)	.127 (.331)
$I_{Q4,t}$	−−	-.012 (.039)	−−	-.012 (.036)
$ex\_vol_{t-12,t}$	.064 (.105)	−−	.039 (.119)	−−
Excluded Instruments	$I_{Q4,t}$	$ex\_vol_{t-12,t}$	$I_{Q4,t}$	$ex\_vol_{t-12,t}$
R-square	0.93	0.86	0.93	0.88
Centered R-square	0.81	0.84	0.81	0.86

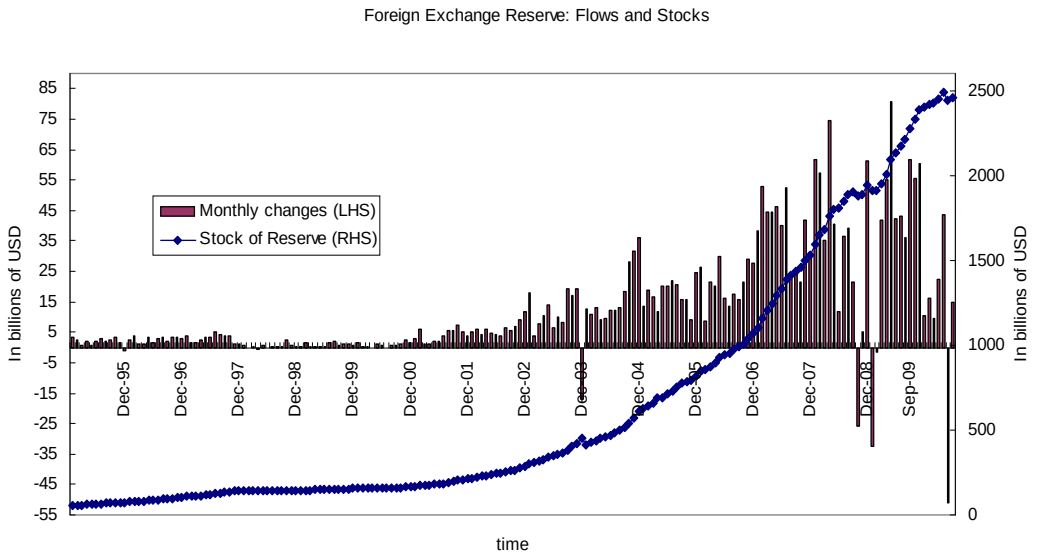
(*), (**), (***) denotes significance at 10%,5% and 1% level

TABLE 9: Historical adjustment of reserve interest rates, 1996 to May 2010

time of adjustment	required reserve	excess reserve
1996.05.01	8.82	8.82
1996.08.23	8.28	7.92
1997.10.23	7.56	7.02
1998.03.21	5.22	
1998.07.01	3.51	
1998.12.07	3.24	
1999.06.10	2.07	
2001.09.11		
2002.02.21	1.89	
2003.12.21		1.62
2004.03.25		
2005.03.17		0.99
2008.01.01		
2008.11.27	1.62	0.72
2008.12.23		

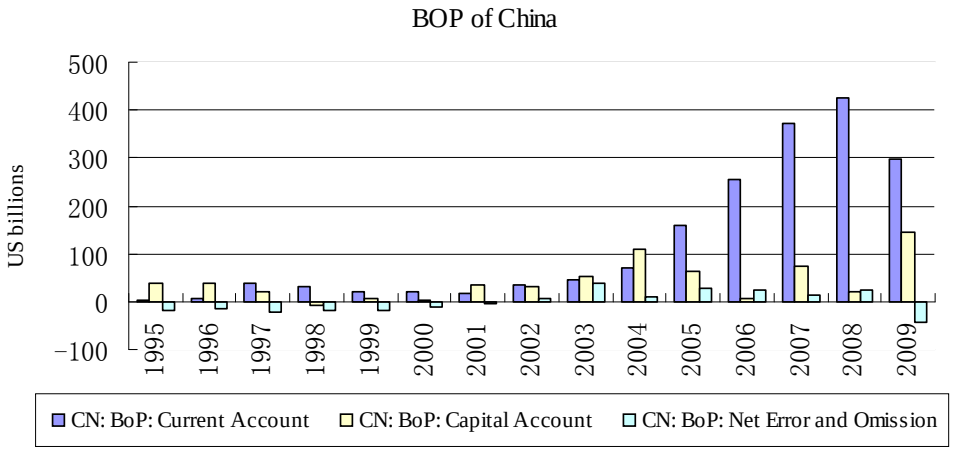
Source: PBC website

FIG. 1



Source: CEIC

FIG. 2



Source: CEIC

FIG. 3

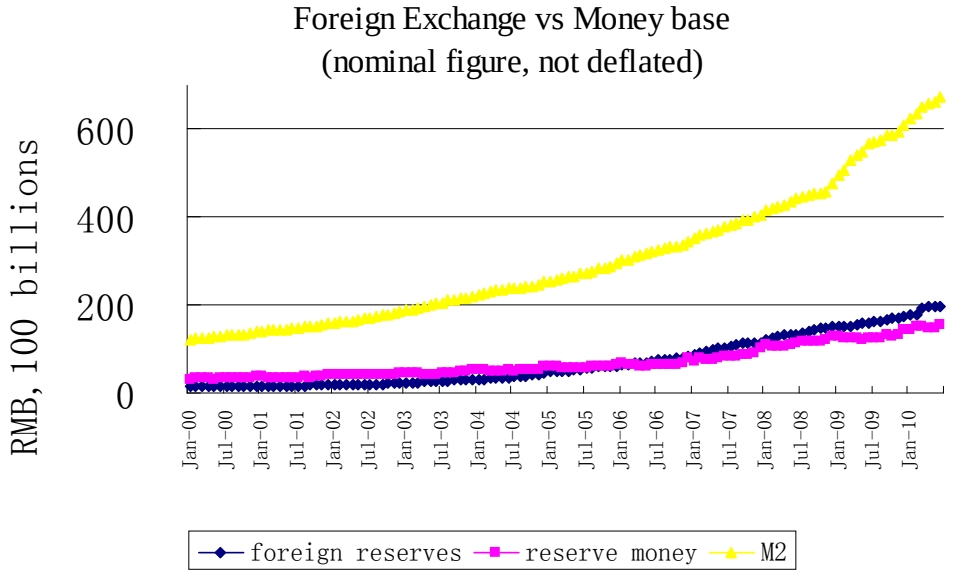
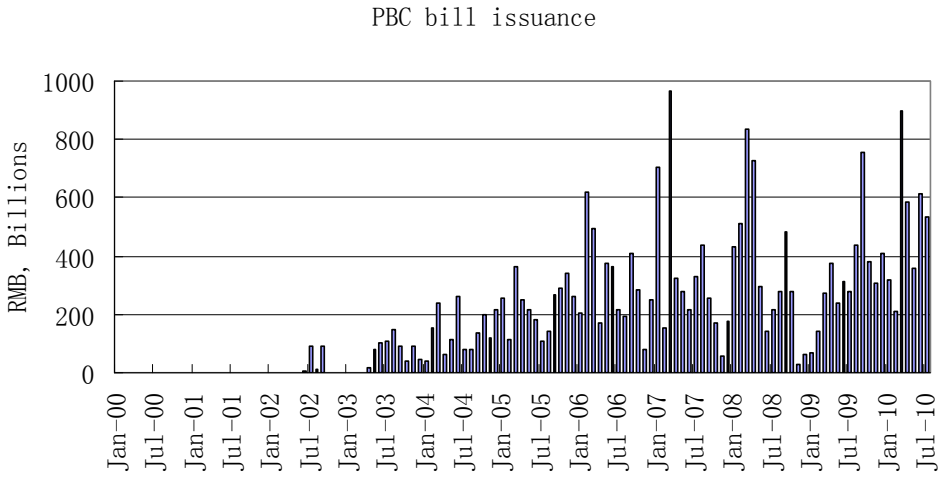
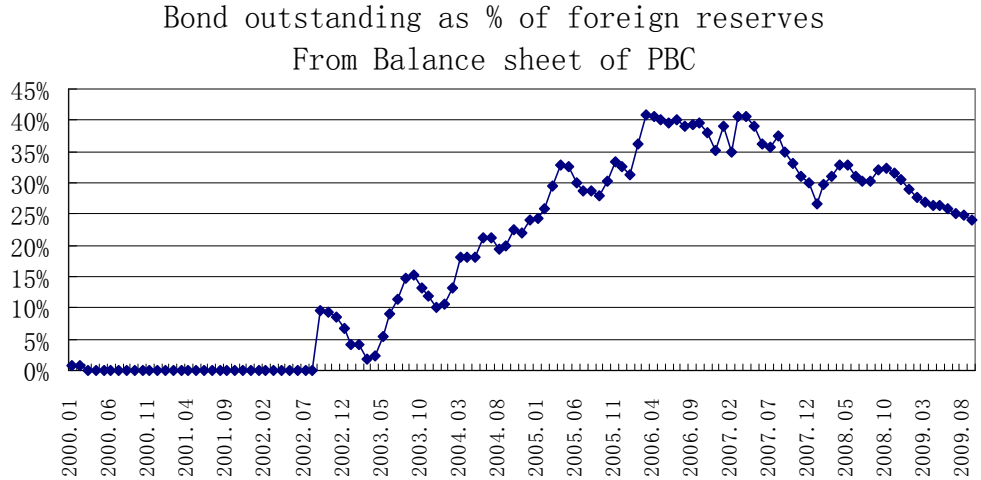


FIG. 4



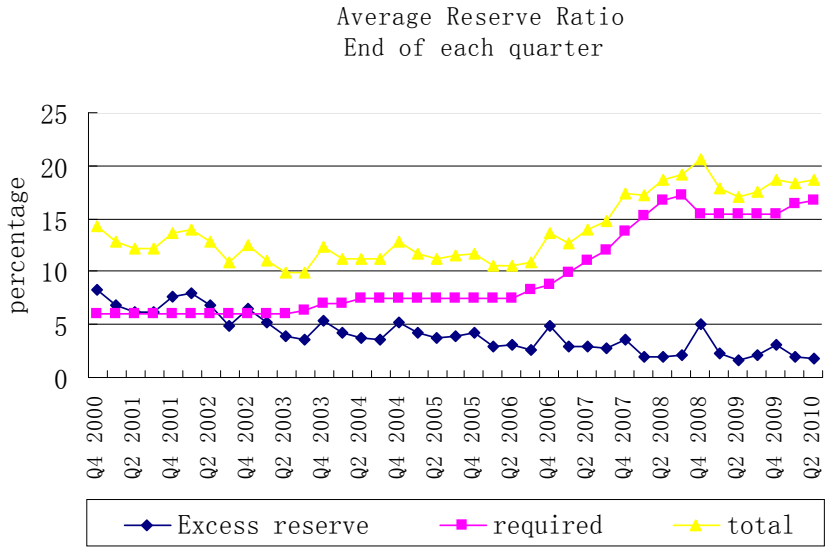
Source: CEIC

FIG. 5



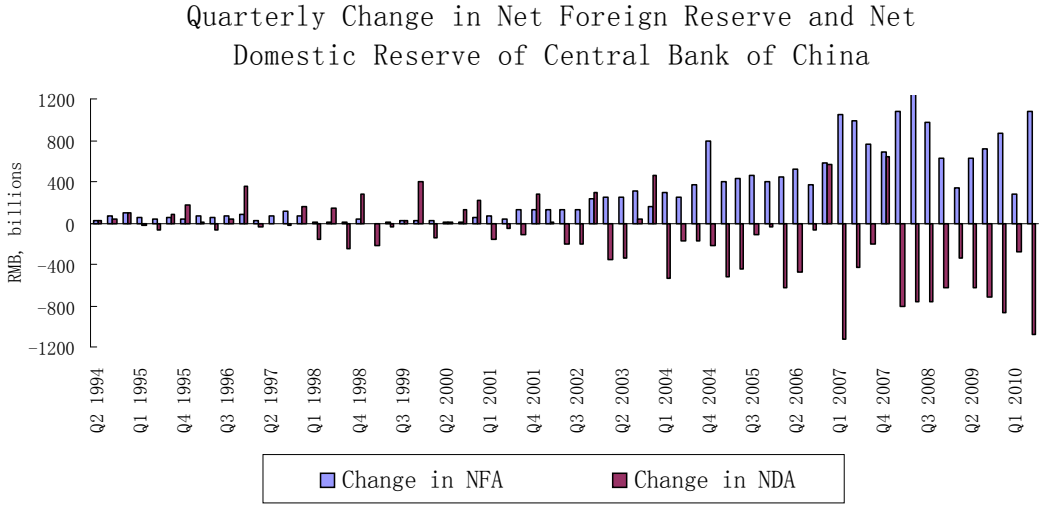
Source: CEIC, PBC, author's calculation

FIG. 6



Source: PBC, author's calculation

FIG. 7



Source: IFS, author's calculation

FIG. 8

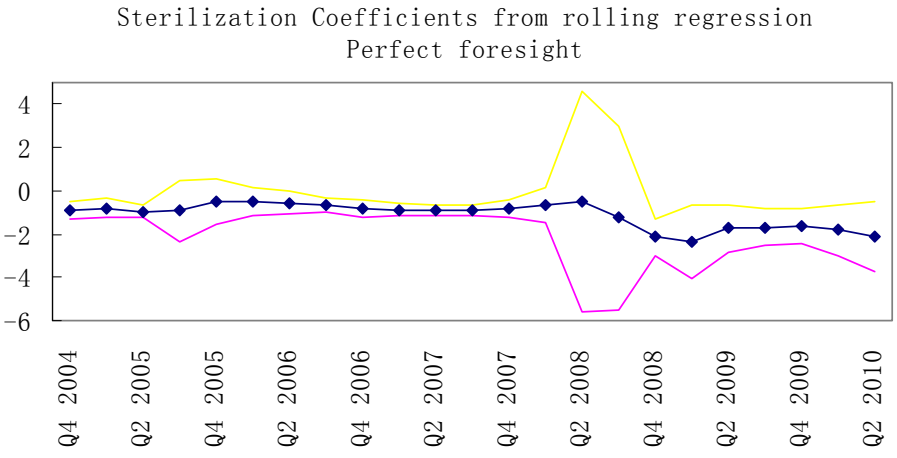

Sterilization Coefficients from rolling regression
Perfect foresight
4
2
0
−2
−4
−6
Q4 2004
Q2 2005
Q4 2005
Q2 2006
Q4 2006
Q2 2007
Q4 2007
Q2 2008
Q4 2008
Q2 2009
Q4 2009
Q2 2010

FIG. 9

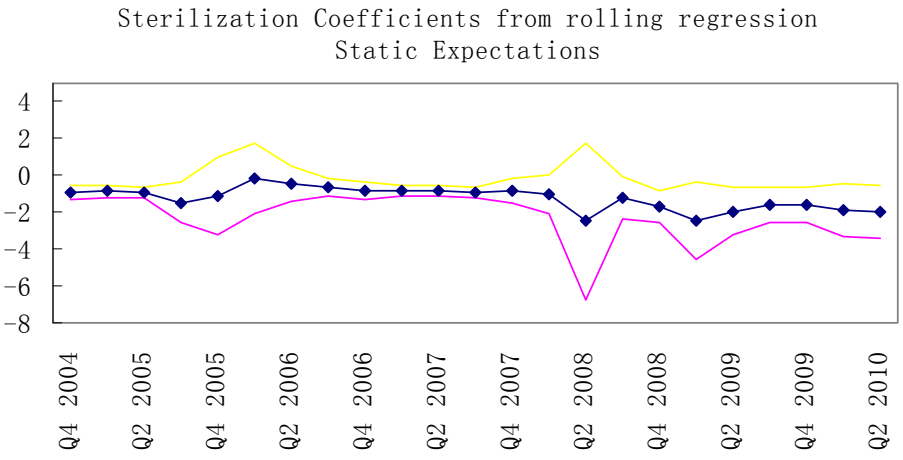
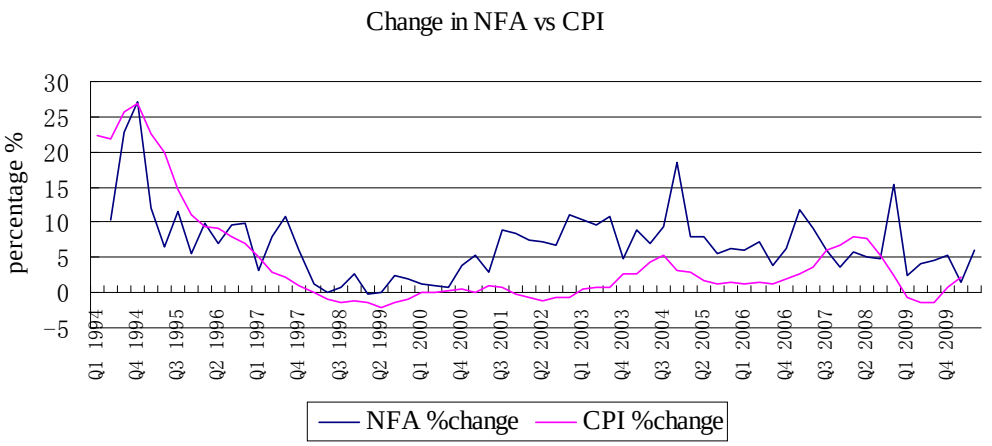

Sterilization Coefficients from rolling regression
Static Expectations
4
2
0
−2
−4
−6
−8
Q4 2004
Q2 2005
Q4 2005
Q2 2006
Q4 2006
Q2 2007
Q4 2007
Q2 2008
Q4 2008
Q2 2009
Q4 2009
Q2 2010

FIG. 10



Source: IFS, author's calculation

FIG. 11

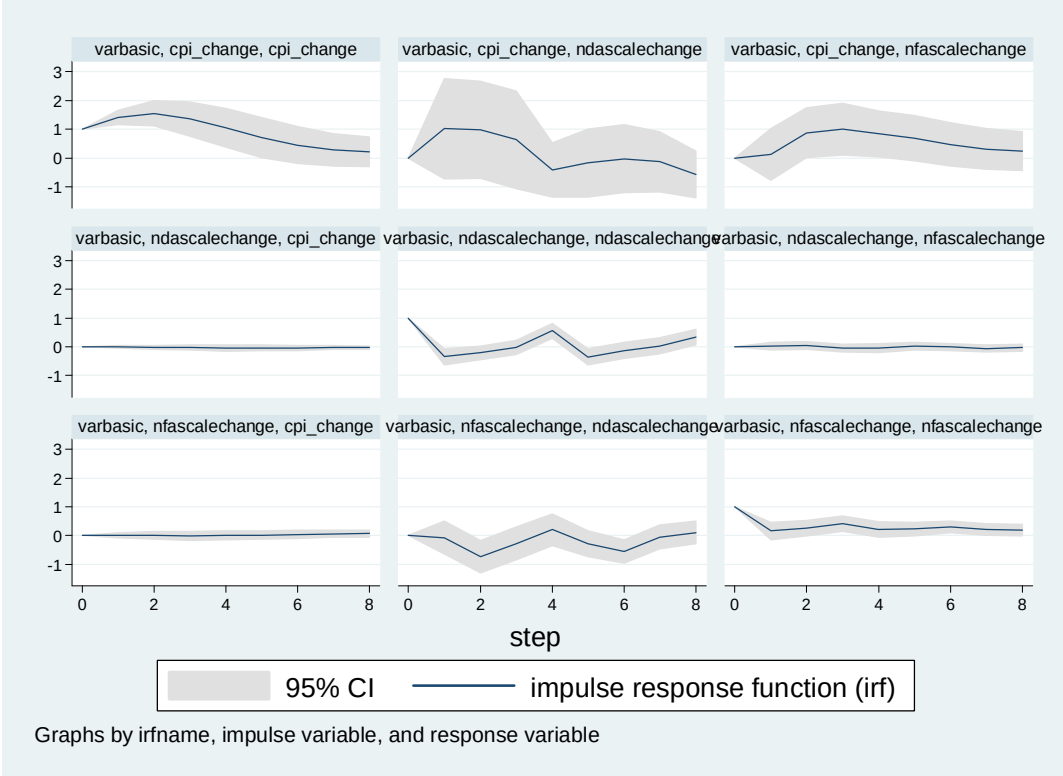
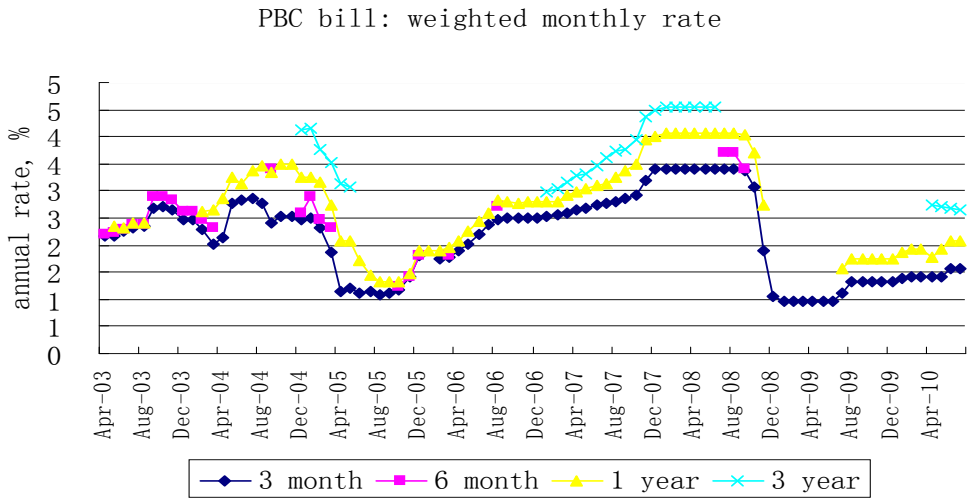
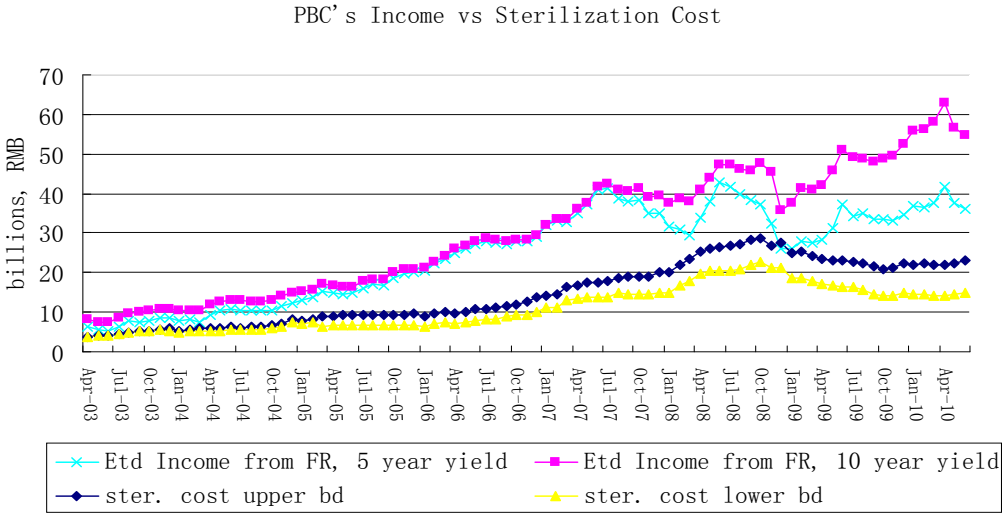

varbasic, cpi_change, cpi_change
varbasic, cpi_change, ndascalechange
varbasic, cpi_change, nfascalechange
varbasic, ndascalechange, cpi_change
varbasic, ndascalechange, ndascalechange
varbasic, ndascalechange, nfascalechange
varbasic, nfascalechange, cpi_change
varbasic, nfascalechange, ndascalechange
varbasic, nfascalechange, nfascalechange
3
2
1
0
-1
0
2
4
6
8
step
95% CI
impulse response function (irf)
Graphs by irfname, impulse variable, and response variable

FIG. 12



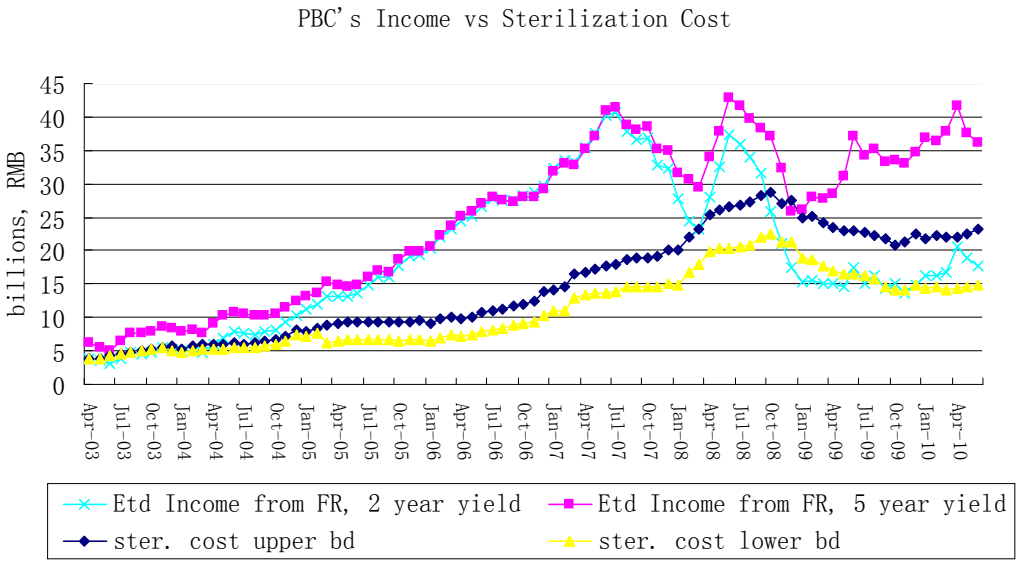
Source: PBC, author's calculation

FIG. 13



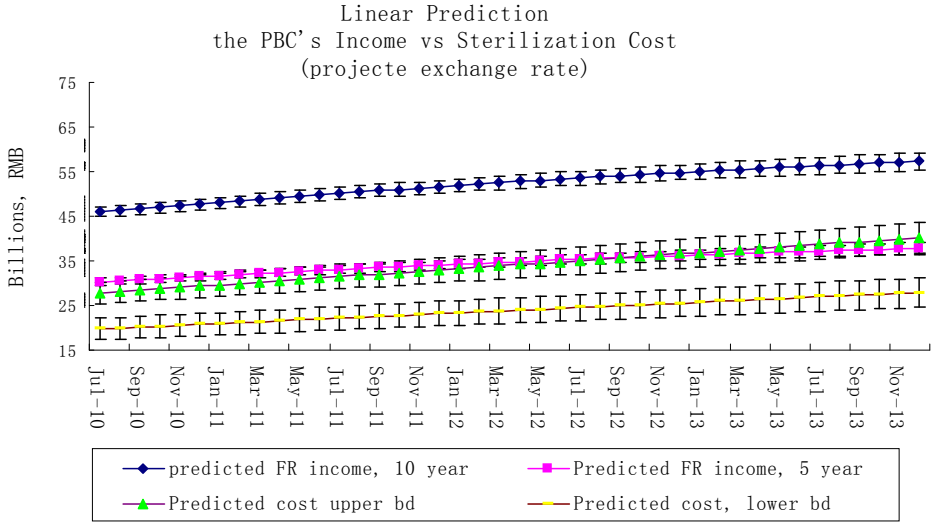
Source: cofer, European Central Bank, Fed, Japan Ministry of Finance, PBC, author"s calculation

FIG. 14



Source: cofer, European Central Bank, Fed, Japan Ministry of Finance, PBC, author"s calculation

FIG. 15



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