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Research Article

The Effectiveness and Sustainability of the Sterilization Policy in China

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The aim of this paper is to examine the sterilization policy in China. First, several indices are used to measure the status of China's markets and to determine effectiveness and sustainability of the sterilization policy and the possible impacts it may have induced. Second, within a microeconomic framework, we incorporate the housing price variable into the target loss function of the monetary authority to explore its financial capabilities and evaluate the effectiveness and sustainability of China's sterilization policy. The empirical results show that Chinese monetary authorities sterilize almost all of the effects of international capital inflows and increase foreign exchange reserves on the monetary base. That is, increased capital mobility does not sabotage the independence of the Chinese monetary policy. Nevertheless, analyses of the sustainability of sterilization policy indicate that the sustainability of the monetary sterilization policy has been seriously challenged since March 2008, which suggests that Chinese monetary authority has endured tremendous pressure for unsustainable sterilization.

1. Introduction

Ever since the start of economic reforms in 1978, China's economic system has gradually shifted towards capitalism and globalization, with steady growth in the volume of foreign trade and a large number of foreign investments in the country. In the beginning of the 1990s, China continued to adjust the exchange rate of the RMB and adopted a dual exchange rate system in 1994, thereby effectively steering the economic system to become export oriented. After China accepted current account convertibility in 1996 in accordance with an agreement with IMF, it joined the World Trade Organization in 2001. The country has witnessed rapid increase in its foreign trade and inflows of foreign direct investments.

However, during the process of actual management of its economy, the monetary authority is usually forced to adopt conflicting currency policies in order to maintain the stability of its currency's internal and external value. In Krugman's theory of impossible trinity, it is impossible simultaneously to have full capital mobility, fixed exchange rate, and an independent monetary policy.[1] In recent years, with RMB appreciation expectation and anticipation of increase in value of RMB denoted assets, inflows of short-term international capital into China have risen steadily as the issue of the impossible trinity looms over the nation.[2]

By the end of June 2012, China's foreign exchange reserves had reached USD 3,240.01 billion, equivalent to 70.84% of People's Bank of China's total assets at that point of time. During substantial growth in foreign exchange reserves, China's funds outstanding for foreign exchange have also grown steadily due to the government's efforts to alleviate the pressure on the RMB's appreciation. During the period from 2003 to 2012, China's funds outstanding for foreign exchange have grown by as much as 10.61 times; the growth margin constitutes 99.11% of the increase in narrow money M1 in the same period.[3] In order to stabilize money supply and to alleviate the risks of excess liquidity, inflation, and asset price bubble, People's Bank of China (PBC) has implemented various policies such as issuing central bank bills, raising reserve requirement ratio, and implementing loan allocations.

But as the Chinese government endeavored to alleviate the impact of the steep growth in foreign exchange reserves

on domestic currency demand and liquidity through various sterilized intervention policies, the growing costs of sterilization have also impacted the effectiveness and sustainability of the foreign exchange surplus sterilization policy. Starting from 2002, the scale of bill issuance by People's Bank of China has expanded drastically and the proportion of the monthly balance of central bank bills against the Bank's total debt skyrocketed from 2.91% in 2002 to 22.11% in 2008.[4] Although the scale of bill issuance slowed in 2011, the proportion was still at 8.31%.[5] The cost of interest paid by People's Bank of China for sterilization (using bank bills) reached its peak at RMB 8,639 billion in 2008. Despite having gradually decreased over time, the cost of such operations still reached RMB 2,761 billion in 2011. With the interest that People's Bank of China has to cover for the reserve requirement, the costs of issuing central bank bills and raising the reserve requirement ratio as tools for sterilization were RMB 3,005 billion in 2011 (equivalent to 14.95% of China's foreign exchange reserve for the same year). These serve as apparent signs that the sustainability of China's sterilization policies faces tough challenges.[6]

The issues of effectiveness and sustainability of sterilization policy have been the subjects of debates in different circles. Despite the fact that China has successfully sterilized most of the impact of its growing foreign exchange reserves on the domestic money supply, the effectiveness of capital controls has been steadily declining and foreign exchange reserves have been constantly growing, resulting in rising costs of sterilization which have made sustainability of sterilization policies increasingly difficult. Inadequate sterilization is resulting in excessive money supply and liquidity, causing influxes of funds into the asset market, thereby causing asset prices to rise steadily. As such, acquiring sufficient understanding of China's sterilization policies has become an issue that requires immediate attention. Therefore, this paper aims to adopt microeconomic foundations for the construction of a model of sterilization and offset coefficients that fit China's monetary stance to evaluate the effectiveness and sustainability of China's sterilization policies. In addition to acquiring sufficient understanding of China's currently monetary policies, we can deal with the issue of improper model configuration.

After introduction, the second section of this paper offers a brief overview of relevant research conducted on sterilization policies, while the third section aims to shed light on the current status of foreign exchange reserves accumulation and sterilization instruments used in recent years. The fourth section focuses on empirical models, and the fifth section covers the data and empirical results, followed by conclusions of this paper.

2. Literature Review

Whether a nation adopts a fixed foreign exchange rate or a managed floating exchange rate system, its monetary authorities must inevitably rely on foreign exchange market intervention as a means of maintaining exchange rate stability. When faced with a surplus in balance of payments, monetary authorities strive to maintain existing exchange rates by purchasing foreign exchange in the market while releasing high power domestic currency of equivalent value. But in order to achieve the target exchange rate and maintain domestic credit stability, monetary authorities also implement sterilized intervention policies to offset the additional money supply that comes from the increase in funds outstanding for foreign exchange. Starting from 1994, China's foreign exchange reserve has grown rapidly due to a surplus in balance of payment and as a result People's Bank of China has been searching and deploying new sterilization tools to maintain stability of RMB exchange rate and domestic credit. Among the currency sterilization tools, including relending (1994–2001) and national debt sterilization (1998–2002) adopted by the Bank, the two most important tools frequently deployed by People's Bank of China are central bank bill sterilization (2002–present) and reserve requirement ratio adjustment (2006–present).

The key that determines the success of sterilized intervention made by a nation's monetary authority for effective foreign exchange market adjustment and maintenance of exchange rate stability lies in sustainability of the intervention. For nations that implement sterilized intervention, as the volume of funds outstanding against foreign exchange grows, the central bank faces increasing difficulty in implementation of sterilized intervention due to the huge costs and the declining effectiveness of monetary policy decision making process.[7] In the discussion on the effectiveness of sterilization manipulation, Frankel [1] analyzed four factors that can trigger capital inflows in developing counties and maintained that sterilized intervention widens the interest spread between domestic and foreign markets, thereby accelerating the growth of funds outstanding for foreign exchange and money supply, making it even more difficult to achieve the given sterilization goal.[8] Also, it affects the independence of the nation's monetary policies. Reinhart et al. [2] believe that sterilization manipulations drive domestic interest rates further up and attract more foreign investments, thereby making sterilization even more difficult and rendering the operation extremely costly. And as such, governments should either give up or reduce the scale of sterilization operations or even opt to control capital mobility as an alternative solution.

Spiegel [3] developed an open-economy version of the Bernanke-Blinder model which indicates that sterilization efforts through increases in reserve requirements have limited impact if viable financial alternatives to the commercial banking sector exist. After having studied cases of sterilization in seven emerging economies in Asia (Indonesia, Korea, Malaysia, Philippines, Singapore, Taiwan, and Thailand), he found Korea to be in possession of the largest nonbank financial sector and that, in times of high international capital inflows, the monetary authority in Korea had limited success with its approach of sterilizing inflowing capital by open market manipulation and increased reserve requirement ratio.

Caballero and Krishnamurthy [4] constructed a theoretical model to validate the ineffectiveness of currency sterilization and went one step further to discuss the opposite effect of short-term capital inflows as the consequence of sterilization policies. Their research pointed out that when a country lacks the connection with the international financial market, sterilization policies may elevate the risks of liquidity

and result in continued inflow of short-term capital, which leads to increase in money supply and overappreciation of domestic currency.

Glick and Hutchison [5] analyzed the impact of sterilization of central bank bills on the base currency in China and the empirical results revealed that the sterilization coefficient is within the interval from −0.6 to −1.5.[9] However, starting from the fourth-quarter of 2006, due to China's constantly growing foreign exchange reserve, the effectiveness of sterilization policies started to decline and this led to the rapid growth of reserve money. Zhang [6] surveyed the various estimations about China's sterilization coefficient from 1994 to 2009. The estimate of sterilization coefficient after 2003 is within the interval from −0.996 to −0.852 (significant at more than 5%), which indicates that PBC's sterilization has been quite successful in maintaining the independence of domestic money and credit growth after the introduction of central bank bills and reserve requirement ratio.

With sterilized intervention policies growing in strength, sustainability of sterilization operations has become an important issue. Calvo [7] pointed out that currency sterilization causes a central bank's domestic debt to grow rapidly. If the central bank's domestic debt is not fully indexed to the price level, sterilization policies trigger a vicious cycle of inflation through massive accumulation of domestic debt. In other words, sterilized intervention should not be sustained. Therefore, the government should issue domestic bonds at corresponding price levels to alleviate inflationary pressures. Christensen [8] used a vector autoregression (VAR) model that incorporated domestic credit, foreign exchange reserve, domestic interest rate, foreign interest rate, and so forth for analysis of correlation between massive capital inflows and sterilized intervention in the Czech Republic from 1993 to 1996. Results of this paper revealed that sterilized intervention for neutralizing effects of capital inflows proved to be successful initially. But with the progression of time, elevated domestic interest rates eventually attract more capital inflows, thereby raising the cost of sterilized intervention and ultimately rendering the policy unsustainable.

Sterilization was virtually a game between Czech Republic's commercial banks and its central bank. The commercial banks would borrow loans from international market at low interest rates and invest in domestic sterilization bonds that offered a higher rate of return. And thus, given the conditions of significant interest rate spread between domestic and foreign market and limited controls on capital, the Czech monetary authority was essentially encouraging more inflows of short-term capital with its sterilization operations.

Using simultaneous equations, Ouyang and Ramkishen [9] empirically validated the correlation between domestic net assets and foreign net assets, in addition to an analysis of China's foreign exchange reserves, structure of its sources, and the consequences of the nation's currency policies in the 1990s. Findings from the research showed that China's sterilized intervention policies were unsustainable due to the substantial burden on the nation's treasury and actually produced the opposite results due to escalation of capital inflows and fragility of the financial system as time passed. Mohanty and Turner [10] indicated that, between 2000 and 2004, the central banks of Korea, the Czech Republic, and Israel issued currency-stabilizing bonds of values equivalent to 300%, 200% and, 150% of their respective reserve money for the purpose of sterilization operations. Issuance of central bank bonds on such massive scale not only increases the difficulty of currency management for the central bank but also raises the expenditure on interest payment when domestic interest rates go up, which renders sterilization operations too costly to last.

Based on the relevant international experience, most monetary authorities around the world that engage in sterilization manipulation in the open market tend to drive up the level of domestic interest rates [2]. If a nation's economy is not synchronous with (or even goes against) foreign economies in terms of trends of change, it can possibly attract more international capital arbitrage, which can further widen the gap between domestic and international economic indicators. More space for arbitrage encourages more capital inflows and ultimately creates a vicious cycle that renders sterilization manipulation measures unsustainable.

The existing literature mostly focuses on analysis of sterilization coefficient estimation or sustainability of the sterilization policy. With the exception of the sterilization model, little research is based on microeconomic frameworks in the circumstances of today. With sterilization policies that are unsustainable and cannot be used to sterilize all of the effects of international capital inflows and increasing foreign exchange reserves on the monetary base, the expectation of the RMB's appreciation would trigger and attract more foreign capital to China, thereby further impacting the currency policies, economy, and capital markets. In order to examine the effectiveness of sterilization tools adopted by People's Bank of China, this paper has taken the approach proposed by Brissimis et al. [11] to adopt microeconomic foundations for the construction of a model of sterilization and offset coefficients that fit China's monetary stance to evaluate the effectiveness of China's sterilization policies. Secondly, with analysis of China's sterilization policies completed, this paper has modified Frenkel's [12] basis of argument by using simple theoretical models to discuss the sustainability of China's sterilization policy.

3. Accumulation of Foreign Exchange Reserve and Sterilization Instruments in China

The PBC foreign exchange reserves have been increased continuously since 1993, an increase of 188.69 billion USD by 1997, at an average annual growth rate of 52.96%. Due to incessant current account surpluses and capital inflows from 2003 until 2007, with an average annual increase of about 194.67 billion USD in foreign exchange reserves, China overtook Japan to become the world's largest holder of foreign exchange reserves in 2006. At the end of 2012, China's foreign exchange reserves amounted to 3,311.59 billion USD, accounting for approximately 30.28% of the world's total foreign reserves.[10]

The continuing accumulation of foreign exchange reserves has substantially exacerbated pressure on RMB to appreciate. Driven by the expected appreciation of RMB,

Table 1: Funds outstanding for foreign exchange, reserve money, and the monthly balance of central bank bills.

	Funds outstanding for foreign exchange (1)	Reserve money (2)	Proportion (3) = (1)/(2) (%)	Balance of central bank bills
2000	1,429.11	3,649.15	39.16	—
2001	1,785.64	3,985.17	44.81	—
2002	2,322.33	4,513.82	51.45	148.75
2003	3,484.69	5,284.14	65.95	303.16
2004	5,259.26	5,885.61	89.36	1,107.90
2005	7,121.11	6,434.31	110.67	2,029.60
2006	9,898.03	7,775.78	127.29	2,974.06
2007	12,837.73	10,154.54	126.42	3,446.91
2008	16,843.11	12,922.23	130.34	4,577.98
2009	19,311.25	14,398.50	134.12	4,206.42
2010	22,579.51	18,531.11	121.85	4,049.72
2011	25,358.70	22,464.18	112.89	2,333.67
2012	25,853.35	25,234.52	102.45	1,388.00

Source: People's Bank of China, http://www.imf.org/external/index.htm.
Unit: billion RMB.

large amounts of foreign direct investment (FDI) and short-term international capital have flowed into China, leading to increases in foreign exchange settlement in the capital account. In order for People's Bank of China to stabilize its foreign exchange rates, it continues to purchase excess supply of foreign exchange in the foreign exchange market, resulting in excess liquidity in the domestic money market and rising inflationary pressure.

According to the trend of the effective exchange rate index of RMB shown in Table 2, RMB showed depreciation compared to other countries' currencies before the reform of RMB exchange rate regime in June 2005. However, after reforming the RMB exchange rate regime showed appreciation over other currencies. In January 2002, the nominal and real effective exchange rate indexes of RMB were 101.37 and 100.14. In June 2005, the nominal and real effective exchange rate indexes of RMB dropped to 86.49 and 83.53; the rate of depreciation for each index during this period was 14.68% and 16.59%. Compared to June 2005, the nominal and real effective exchange rate indexes of RMB in July 2005 were 88.06 and 84.99. Each of the indexes rose to 114.21 and 118.79 in December 2013; the rate of appreciation during the period for the nominal effective exchange rate index was 29.70% and 39.77% for the real effective exchange rate index. Notably the disparity between nominal and real effective exchange rate indexes began to increase in October 2010; the fluctuation of the real effective exchange rate index was significantly higher than the nominal effective exchange index, showing increasing pressure of inflation in China.

Table 1 shows that funds outstanding for foreign exchange were only 1,429.11 billion RMB in 2000, accounting for 39.16% of the base money. However, the figure surged to 25,853.35 billion RMB in 2012, accounting for up to 102.45% of the reserve money. This indicates that the independence of monetary policy of Chinese monetary authorities has been severely challenged.

In the context of the constant buildup of China's foreign exchange reserves, the PBC has undertaken a series of sterilization operations to alleviate excessive liquidity and inflationary pressure resulting from huge funds outstanding for foreign exchange. Owing to the small size of the market for treasury bonds, the PBC has started issuing central bank bills for sterilization, in addition to open market operations such as outright sales of government bonds and repurchase agreements. The official launch of issuance of central bank bills by the PBC was on April 22, 2003. The central bank bills' balance has progressively increased, from 303.16 billion RMB in 2003 to 4,577.98 billion RMB in 2008. While this has gradually decreased in recent years, the balance was still RMB 1,388 billion by the end of 2012 (Table 1).

Faced with unceasing pressures of excessive liquidity due to balance of payments surplus, the PBC has strengthened liquidity management of the banking system as the main objective of its monetary policy in 2006, coupled with the use of other sterilization instruments such as open market operations and reserve requirement ratio, in order to suck the excess liquidity out of the banking system. In addition to issuance of central bank bills along with the repo operations for increasing the intensity of open-market sterilization operations, the PBC, facing rapid growth in domestic credit, adjusted the reserve requirement ratios 41 times between March 1998 and March 2012 (Figure 3). The PBC lowered the reserve requirement ratios only seven times during this period, when facing the Asian financial crisis, the US subprime mortgage crisis, and the problem of sluggish economy in 1998, 2008, and 2011, respectively. The PBC raised the reserve requirement ratios for rest of the period to deal with the issue of excess liquidity. By the end of 2012, the reserve requirement ratios for large- and small- and medium-sized financial institutions were 20% and 16.5%, respectively.

Relatively a huge proportion of the monetary base is released during the process of intervening in the foreign

Table 2: Variables and data sources.

Variable	Data source
$\Delta \mathrm{NFA}_t^*$: $\dfrac{\Delta[\mathrm{NFA}_t - \mathrm{NFA}_{t-1}((e_t - e_{t-1})/e_{t-1}) - (i_{\mathrm{TB}_t}/12)((\mathrm{NFA}_{t-1} + \mathrm{NFA}_t)/2)]}{\mathrm{GDP}_t}$	CEIC database
$\Delta \mathrm{NDA}_t^*$: $\dfrac{\Delta \mathrm{MB}_t}{\mathrm{GDP}_t} - \Delta \mathrm{NFA}_t^*$	CEIC database
$\Delta \mathrm{mm}_t$: $\ln\left(\dfrac{M_{2,t}}{\mathrm{MB}_t}\right) - \ln\left(\dfrac{M_{2,t-1}}{\mathrm{MB}_{t-1}}\right)$	CEIC database
Δp_{t-1}: $\ln(\mathrm{CPI}_t) - \ln(\mathrm{CPI}_{t-1})$	CEIC database
$H_{c,t-1}$: $\dfrac{(\text{Housing price})_{t-1} - (\text{Housing price trend})_{t-1}}{(\text{Housing price trend})_{t-1}}$	CEIC database
$Y_{c,t-1}$: $\dfrac{(\mathrm{GDP})_{t-1} - (\text{GDP trend})_{t-1}}{(\text{GDP trend})_{t-1}}$	CEIC database
$\Delta G_{c,t}$: $\left(\dfrac{\text{fiscal deficit}}{\mathrm{GDP}}\right)_t - \left(\dfrac{\text{fiscal deficit}}{\mathrm{GDP}}\right)_{t-1}$	CEIC database
$\Delta \mathrm{REER}_{t-1}$: $(\mathrm{REER})_t - (\mathrm{REER})_{t-1}$	TEJ database
Ee_{t+1}: the 3-month RMB/USD nondeliverable forward rate in logarithmic terms	Bloomberg
$r_t - r_t^*$: the interest rate differential between People's Bank of China and the US Federal Funds	TEJ database
$r_{s,t} - r_{s,t}^*$: the stock return differential between China and the USA	CEIC database and TEJ database
i: interest rate on 3-month central bank bills	PBC
$\tilde{r}$: the interest on required reserves	PBC
L: the value of the current issuance of central bank bills minus the value of maturing central bank bills	PBC
$\tilde{R}$: the deposits with central bank from the balance sheet of other depository corporations	PBC
RE: the value of foreign exchange reserve expressed in RMB	CEIC database
e: the rates of change in exchange rate	CEIC database
r: the yield on 3-month US Treasury bills	TEJ database

exchange market by the PBC. In order to achieve the goals of its monetary policy and alleviate inflationary pressure, the PBC intervenes in the foreign exchange market and at the same time actively adopts sterilization measures, for neutralizing the impacts of excess liquidity due to increasing foreign exchange reserves through opposite changes in the net domestic assets, thereby maintaining steady growth of money supply.

Figure 4 shows that the monetary base experienced rapid growth and fluctuations from 1998 to 2012, soaring to its highest of 30.59% in 2007 from 2.29% in 1998. The broad money supply M2 relatively maintained a steady growth from 1998 to 2008, at an average growth rate of 16.23%, and started to experience significant fluctuations since 2008.

The steady growth of M2 proves that Chinese monetary authorities effectively sterilize the impacts of capital inflows and increase foreign reserves on the domestic money supply. That is, large-scale foreign exchange market intervention and sterilization operations have significant influence on the money supply in China. However, volatile fluctuations of M2 after 2008 also pose challenges to the sustainability of China's sterilization policy.

While sufficient foreign exchange reserves help stabilize the economy, excessive foreign reserves may create tremendous pressure on the monetary authorities. In the case of lacking elasticity in exchange rates, the central bank opts to convert the external pressure on RMB to the internal momentum for monetary expansion. Nonetheless, with expanding balance of payments surplus, excessive foreign reserves held by the PBC incur interest costs of sterilized intervention, opportunity costs of inefficient allocation of capital, and exchange rate risk. Furthermore, as the problem of excess money can be temporarily avoided by sterilization measures, operations for sterilization in the medium-to-long term may still result in risks such as overheating of the economy, inflation, and asset price bubbles.

4. Empirical Model

The empirical model is divided into two parts. First, a model of offset and sterilization coefficients that fits China's monetary stance was constructed based on microeconomic foundations to evaluate the effect of China's sterilization policy. Second, a simple theoretical model was used to explore the sustainability of sterilization policy of People's Bank of China and to determine whether the PBC can control domestic money supply without sacrificing the policy's credibility. The following section describes each empirical model.

4.1. Effectiveness of the Sterilization Policy. Most of the studies in extant literature have failed to provide solid microeconomic foundations when specifying models for offset and sterilization coefficient estimation, leading to less stringent choices of control variables. The present paper aims to construct, with reference to the model of Brissimis et al. [11], a theoretical framework to better reflect the working of China's economy to evaluate the effectiveness of the sterilization policy in China.

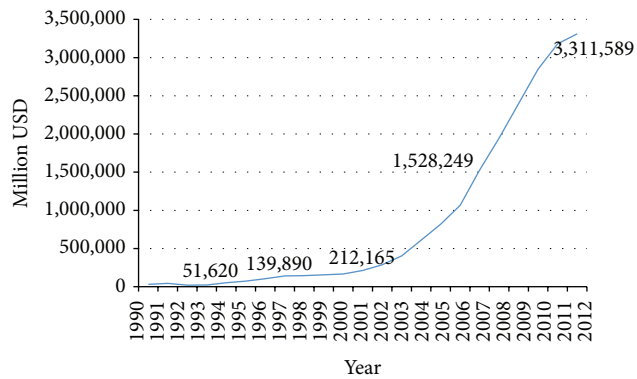

Figure 1: Accumulation of foreign exchange reserve in China—2000 to 2012. Source: TEJ database.

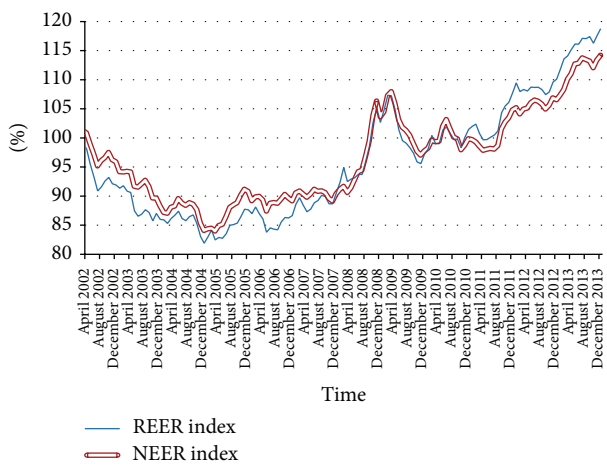

Figure 2: Renminbi effective exchange rate index—January 2002 to December 2013. Note: REER index represents the real effective exchange rate, and NEER index stands for the nominal effective exchange rate index. The base period for both indexes is 2010. Source: CEIC database.

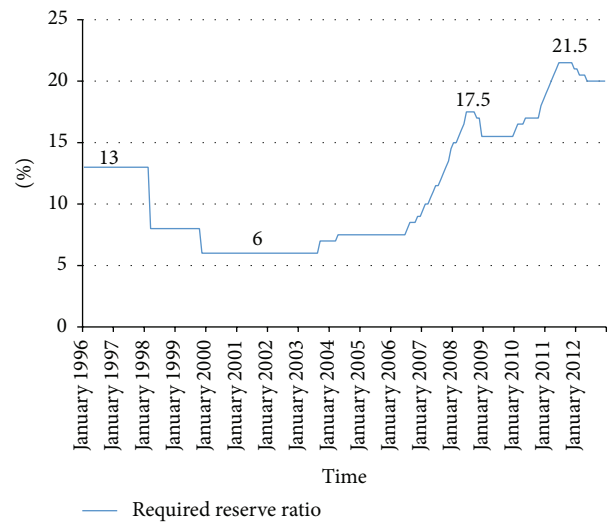

Figure 3: Change of required reserve ratio in China. Source: the same as in Figure 1.

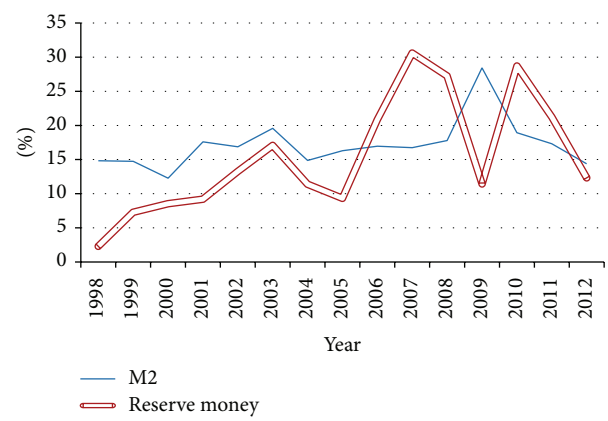

Figure 4: Growth rate of reserve money and M2—1998 to 2012. Source: the same as in Figure 2.

Brissimis et al. [11] assumed that the central bank has an objective function (a loss function), including the squared deviation of the current exchange rate from its target, the squared deviation of the logarithm of the price level from its target, the squared deviation of real income from its trend, a measure of the volatility of interest rates, and a measure of the volatility of exchange rates.

Maintaining the stability of price level and economic growth is the priority for China's monetary authorities. Considering China's currently managed floating exchange rate system and interest rate policy, we assume that the target loss function of China's monetary authorities includes the squared deviation of the price level from its target and the squared deviation of real income from its trend. In addition, as real estate in China has been an important investment target, China has recently taken a considerable number of policy measures to maintain stable housing prices and to avoid economic impacts resulting from volatility of housing prices. Therefore, the target loss function of China's monetary authorities is defined as follows:[11]

$$L_t = \alpha\left(p_t - p_t^T\right)^2 + \beta\left(Y_t - Y_t^T\right)^2 + \gamma\left(H_t - H_t^T\right)^2, \quad (1)$$

where p_t, Y_t, and H_t denote inflation rate, gross domestic product, and housing prices at period t, respectively; p_t^T, Y_t^T, and H_t^T are the target and trend values of each variable.

In order to simplify the loss function in (1), we substitute $Y_{c,t}$ and $H_{c,t}$ for $Y_t - Y_t^T$ and $H_t - H_t^T$, respectively, and subtract p_{t-1} from both $p_t p_t^T$. Δp_t^T is assumed to be zero.[12] We can rewrite (1) in a slightly different form, as follows:

$$L_t = \alpha\left(\Delta p_t\right)^2 + \beta\left(Y_{c,t}\right)^2 + \gamma\left(H_{c,t}\right)^2, \quad (2)$$

where L_t is the loss function of the monetary authority at the end of time t; Δp_t is the change in the inflation rate at time t; $Y_{c,t}$ is the cyclical income at period t and $H_{c,t}$ is the cyclical housing price at period t. The central bank has an objective

to minimize the loss function in (2) in order to obtain the optimal foreign exchange market intervention rule $\Delta\mathrm{NFA}_t$ and domestic money market intervention rule $\Delta\mathrm{NDA}_t$. The constraints that reflect the working of the economy in China for the monetary authorities' loss function are analyzed in turn.[13]

Cyclical Income. For the specification of cyclical income, we follow the theoretical formulation outlined in Brissimis et al. [11] and hypothesize that the cyclical income depends on the change in money supply and the stance of the government's fiscal policy. The equation takes the following form:[14]

$$\begin{aligned} Y_{c,t} = {} & \varpi_1 \left[\left(\Delta\mathrm{NFA}_t + \Delta\mathrm{NDA}_t \right) \mathrm{mm}_t + \mathrm{MB}_t \Delta\mathrm{mm}_t \right] \\ & + \varpi_2 Y_{c,t-1} + \varpi_3 \Delta G_{c,t}, \end{aligned} \tag{3}$$

where $\varpi_1 > 0$, $0 < \varpi_2 < 1$, and $\varpi_3 > 0$. $\Delta\mathrm{mm}_t$ is the change in money multiplier; and MB_t is the monetary base. Besides, $G_{c,t}$ represents the stance of government fiscal policy, which is measured by the budget deficit as percent of GDP.

Inflation. Since China trades with other countries frequently, inflation in China is hypothesized to depend not only on the change in money supply and inflation of previous period but also on the impacts of exchange rate volatility. China often uses deposit reserves and interest rate policy, influencing the money multiplier through the liquidity of commercial banks, to affect money supply. As a result, the constraint for inflation is defined as follows:[15]

$$\begin{aligned} \Delta p_t = {} & \tau_1 \left[\left(\Delta\mathrm{NFA}_t + \Delta\mathrm{NDA}_t \right) \mathrm{mm}_t + \mathrm{MB}_t \Delta\mathrm{mm}_t \right] \\ & + \tau_2 \Delta p_{t-1} + \tau_3 \Delta e_t, \end{aligned} \tag{4}$$

where $\gamma_1 > 0$, $0 < \gamma_2 < 1$, and $\gamma_3 > 0$. Δp_{t-1} and Δe_t are inflation rate in the previous period and change in the exchange rate at the current period. In addition to the above specification, we set the following constraint specifically for Δe_t:[16]

$$\begin{aligned} \Delta e_t = {} & -c\lambda_0 + \left(c + c\lambda_1 \omega_1 \mathrm{mm}_t \right) \Delta\mathrm{NFA}_t \\ & + \left(c\lambda_1 \omega_1 \mathrm{mm}_t \right) \Delta\mathrm{NDA}_t + \left(c\lambda_1 \omega_1 \mathrm{MB}_t \right) \Delta\mathrm{mm}_t \\ & + \left(c\lambda_1 \varpi_2 \right) Y_{c,t-1} + \left(c\lambda_1 \varpi_3 \right) \Delta G_{c,t} \\ & + \left(c\lambda_2 \right) \Delta\mathrm{REER}_{t-1} \\ & + \Delta \left[Ee_{t+1} - \left(r_t - r_t^* \right) - \left(r_{s,t} - r_{s,t}^* \right) \right], \end{aligned} \tag{5}$$

where REER_{t-1} is the real effective exchange rate in time $t-1$; e_t is the exchange rate at time t; Ee_{t+1} is the expected exchange rate at time $t+1$; r_t is the domestic interest rate; r_t^* is the foreign interest rate; $r_{s,t}$ and $r_{s,t}^*$ are yields of domestic and foreign investment, respectively.

This equation includes a number of well-known propositions. First, an increase in foreign exchange reserves as a result of intervention to sell the domestic currency causes Δe_t to increase. Second, an increase in the domestic component of the monetary base causes Δe_t to increase. Third, an increase in the money multiplier causes the interest rate to decline and hence the domestic currency to depreciate. Next, an increase in cyclical income is likely to cause imports to increase and hence cause Δe_t to increase. In addition, the higher fiscal deficit indirectly decreases export and increases import and thus the domestic currency to depreciate.

Furthermore, the real effective exchange rate is calculated as a weighted average of real exchange rates of the national currency to the currencies of its main trading partners. Generally speaking, the United States is the biggest trade partner of China; thus, the change in the real effective exchange rate will lead Δe_t to increase. Finally, an increase in the expected rate of depreciation, a decrease in the interest rate spread, and a fall in the investment yield of stocks spread will cause Δe_t to increase as capital flows out of domestic assets.

Substituting (5) into (4) obtains

$$\begin{aligned} \Delta p_t = {} & \left(\tau_1 \mathrm{mm}_t + \tau_3 c + \tau_3 c\lambda_1 \omega_1 \mathrm{mm}_t \right) \Delta\mathrm{NFA}_t \\ & + \left(\tau_1 \mathrm{mm}_t + \tau_3 c\lambda_1 \omega_1 \mathrm{mm}_t \right) \Delta\mathrm{NDA}_t \\ & + \left(\tau_1 \mathrm{MB}_t + \tau_3 c\lambda_1 \omega_1 \mathrm{MB}_t \right) \Delta\mathrm{mm}_t + \tau_2 \Delta p_{t-1} \\ & + \left(\tau_3 c\lambda_1 \varpi_2 \right) Y_{c,t-1} + \left(\tau_3 c\lambda_1 \varpi_3 \right) \Delta G_{c,t} \\ & + \left(\tau_3 c\lambda_2 \right) \Delta\mathrm{REER}_{t-1} \\ & + \tau_3 \Delta \left[Ee_{t+1} - \left(r_t - r_t^* \right) - \left(r_{s,t} - r_{s,t}^* \right) \right]. \end{aligned} \tag{6}$$

Cyclical Housing Price. For the specification of cyclical housing price, it is hypothesized that the cyclical housing price depends on the change in money supply and the cyclical housing price in the previous period. Therefore, the constraint for cyclical housing price takes the following form based on the assumptions in footnote 12:

$$\begin{aligned} H_t = {} & \phi_1 \left[\left(\Delta\mathrm{NFA}_t + \Delta\mathrm{NDA}_t \right) \mathrm{mm}_t + \mathrm{MB}_t \Delta\mathrm{mm}_t \right] \\ & + \phi_2 H_{t-1}. \end{aligned} \tag{7}$$

Under a typical managed floating exchange rate system, we hypothesize that monetary authorities minimize their loss function by altering domestic credit and undertaking exchange rate intervention. Consequently, the following two equations can be derived by solving the partial derivatives $\partial L_t / \partial \Delta\mathrm{NFA}_t = 0$ and $\partial L_t / \partial \Delta\mathrm{NDA}_t = 0$, subject to the constraints in (3), (6), and (7):

$$\begin{aligned} \Delta\mathrm{NFA}_t^* = {} & \pi_1 + \pi_2 \Delta\mathrm{NDA}_t^* + \pi_3 \Delta\mathrm{mm}_t + \pi_4 \Delta p_{t-1} \\ & + \pi_5 H_{c,t-1} + \pi_6 Y_{c,t-1} + \pi_7 \Delta G_{c,t} \\ & + \pi_8 \Delta\mathrm{REER}_{t-1} \\ & + \pi_9 \Delta \left[Ee_{t+1} - \left(r_t - r_t^* \right) - \left(r_{s,t} - r_{s,t}^* \right) \right], \end{aligned} \tag{8}$$

$$\begin{aligned}\Delta \mathrm{NDA}_t^* = {} & \theta_1 + \theta_2 \Delta \mathrm{NFA}_t^* + \theta_3 \Delta \mathrm{mm}_t + \theta_4 \Delta p_{t-1} \\ & + \theta_5 H_{c,t-1} + \theta_6 Y_{c,t-1} + \theta_7 \Delta G_{c,t} \\ & + \theta_8 \Delta \mathrm{REER}_{t-1} \\ & + \theta_9 \Delta \left[Ee_{t+1} - \left(r_t - r_t^*\right) - \left(r_{s,t} - r_{s,t}^*\right)\right].\end{aligned} \tag{9}$$

These two equations are used in the current regression model to examine the effectiveness of the monetary authority's sterilization policy. In order to be in line with the assumption of model stability and exclusion of irrelevant factors from the original variables' specifications, definitions of the variables are modified.

In (8) and (9), $\Delta \mathrm{NFA}_t^*$ is the change in the adjusted net foreign assets scaled by GDP;[17] $\Delta \mathrm{NDA}_t^*$ is the change in the adjusted net domestic asset scaled by GDP;[18] $\Delta \mathrm{mm}_t$ is the change of money multiplier for M2 in logarithmic terms; Δp_{t-1} is the change of consumer price index in logarithmic terms in time $(t-1)$; $H_{c,t-1}$ is the cyclical housing price index in time $(t-1)$; $Y_{c,t-1}$ is the cyclical income in time $(t-1)$;[19] $\Delta G_{c,t}$ is the change in government expenditure scaled by GDP; $\Delta \mathrm{REER}_{t-1}$ is the change of the REER in logarithmic terms; Ee_{t+1} is the expected nominal exchange rate (foreign currency per US dollar) in logarithmic terms.[20] $(r_t - r_t^*)$ is the interest rate differential between People's Bank of China and the US Federal Funds and $(r_{s,t} - r_{s,t}^*)$ is the stock return differential between China and the USA.

π_2 in (8) is the offset coefficient of regressing capital flows on the monetary policy.[21] When $\pi_2 = 0$, capital is immobile, which means that the impact of a change in net domestic assets on the domestic money supply is substantial. When $\pi_2 = -1$, capital is perfectly mobile, indicating that the effect of a change in net domestic assets on the domestic money supply can be completely offset by capital mobility and thus independence of the monetary policy of the central bank is undermined. In general, capital is less than perfectly mobile and thus we expect that $-1 < \pi_2 < 0$.

In addition to the offset coefficient, there are seven control variables in (8). Increases in inflation and cyclical housing prices lead to an expected currency depreciation; an increase in the money multiplier causes domestic money supply to increase and hence the interest rate too declines; an increase in government deficit leads to a decrease in trade surplus; all of these four factors result in decrease in foreign capital inflows. We thus expect π_3, π_4, π_5, and π_7 to be smaller than 0.

Furthermore, an increase in cyclical income is likely to not only cause imports to increase and thus the trade surplus and foreign exchange reserves to decrease but also boost the confidence of foreign investors. This thereby encourages capital inflows. The real effective exchange rate increases, causing the trade surplus and the foreign exchange reserves to decrease while at the same time the domestic currency appreciates. This leads to inflows of foreign speculative capital. Expectations of RMB's appreciation increase the upward pressure on RMB, which then attracts inflows of foreign capital. A decrease in the interest rate spread, a fall in the investment yield of domestic stocks, and a rise in the investment yield of foreign stocks increase relative USD yields, negatively affecting capital inflows. As a result, we expect these three coefficients, π_6, π_8, and π_9, to be either positive or negative.

θ_2 in (9) is the sterilization coefficient of the monetary policy. When $\theta_2 = -1$, it represents the fact that the PBC can sterilize all effects of international capital inflows and increase in foreign exchange reserves on the monetary base, meaning that a change in net foreign assets of central bank leads to a change of the same magnitude but in the opposite direction in net domestic assets. The effect of capital mobility on the monetary base is completely sterilized, resulting in no change in the monetary base. $\theta_2 = 0$ means the absence of sterilization, indicating that the central bank does not change the volume of domestic assets as a means of sterilization in response to a change in foreign assets. As China's current monetary situation is usually somewhere in the continuum of these two extremes, we expect that $-1 < \theta_2 < 0$.

In addition to the sterilization coefficient, there are seven control variables in (9). The central bank usually implements a tight monetary policy in response to a rise in the money multiplier and increase in inflation, the cyclical housing price, the cyclical income, and the government fiscal deficit. We hence expect coefficients θ_3, θ_4, θ_5, θ_6, and θ_7 to be smaller than zero.

Moreover, a stronger upward pressure on RMB will force the monetary authorities to implement an expansionary monetary policy to alleviate the pressure on RMB. A decrease in the interest spread between domestic and foreign markets, a decrease in the investment yield of domestic stocks, and a rise in the investment yield of foreign stocks reduce foreign capital inflows. The central bank then implements a tight monetary policy in order to maintain a stable exchange rate. We therefore expect that θ_9 could be positive or negative.

4.2. Sustainability of Sterilization Policy. Generally speaking, sustainability refers to the capacity to maintain a process or a state. High costs of sterilization undermine the central bank's solvency, further affecting investors' confidence in credibility of the central bank, rendering the sterilization operations unsustainable. Three methods have been often employed in the literature to examine the effect of sterilization costs on sustainability of sterilization. The first method defines net sterilization cost as the interest on the central bank's bills minus the US Treasury bill rate. This ignores the impact of the exchange rate on sterilization costs and uses only the direct costs as an indicator of sustainability of sterilization. The second method is relatively stringent. It considers the relationship between the interest rate of the central bank's bills and the growth rate of GDP. However, there is no direct relationship between the credibility of the central bank and GDP growth. Hence the current study takes the third approach to analyze sustainability of sterilization policy. We discuss the relationship between central bank's sterilization costs and its holdings of foreign exchange reserves.

As nowadays China mostly depends on raising the reserve requirement ratios and issuing central bank bills as sterilization instruments, only the third method is used [12] to explore sustainability of sterilization bills. The present study uses a simple theoretical model to analyze the sustainability of

PBC's sterilization by drawing on the methodology outlined in Frenkel [12] and modifying its theoretical arguments.[22]

The credibility of monetary policy is based on the assets held by the central bank. When sterilization is a way of central bank's bills and reserve requirement ratios, the central bank's principal assets include foreign exchange reserves, and its principal liabilities include monetary base, interest payments on its bills, and interest payments on deposit reserves. We assume that the change of total central bank assets is as follows:

$$dA = dRE = RdE + EC + ErR, \tag{10}$$

where dA is the change in total central bank assets and R, E, r, and C are the foreign exchange reserves, the exchange rate, the yield of foreign exchange reserves, and the foreign currency bought by the central bank as part of intervention for maintaining stability of the exchange rate, respectively. RE is the foreign exchange reserves denominated in domestic currency. Besides, the change in the foreign exchange reserve denominated in domestic currency includes RdE, EC, and ErR, which represent gains and losses due to exchange rate volatility, new additions to foreign exchange reserves, and the return earned on the original foreign exchange reserves, respectively.

Besides, we assume that the change of total central bank liabilities in response to the sterilization policy takes the following form:

$$dP = dB + dL + d\widetilde{R}, \tag{11}$$

where dP is the change in the total liabilities of the central bank, dB is the monetary base released due to exchange rate intervention, and L and $\widetilde{R}$ are the debts incurred by issuance of central bank bills and reserve requirements as two instruments of sterilization policy, respectively. iL and $\widetilde{r}\widetilde{R}$ represent the interest on central bank bills and reserve requirements, respectively. When denominating these terms in domestic currency, (11) can be rewritten as follows:

$$dP = EC + iL + \widetilde{r}\widetilde{R}. \tag{12}$$

In order to avoid high sterilization costs that may threaten the sustainability of sterilization operations and policy credibility, we assume that sustainable sterilization is required when the increase of liabilities is smaller than or equal to the increase of foreign exchange reserve:

$$EC + iL + \widetilde{r}\widetilde{R} \leq RdE + EC + ErR. \tag{13}$$

Crossing out EC and then dividing by RE for both sides of the above equation yield

$$i\left(\frac{L}{RE}\right) + \widetilde{r}\left(\frac{\widetilde{R}}{RE}\right) \leq \left(\frac{RdE}{RE}\right) + \left(\frac{ErR}{RE}\right). \tag{14}$$

Multiplying (RE/L) gives

$$i + \widetilde{r}\left(\frac{\widetilde{R}}{L}\right) \leq (e + r)\left(\frac{RE}{L}\right), \tag{15}$$

where $e = dE/E$. Equation (15) represents the rule for sustainability of the sterilization policy; the left-side of the equation can be viewed as the ratios of sterilization cost of the central bank; the right-hand side represents adjusted yields of foreign exchange reserves. Specifically, E is the nominal exchange rate (foreign currency per US dollar); i and L are interest rate on 3-month central bank bills and the monthly balance of central bank bills; r and RE are yield on 3-month US Treasury bills and the value of foreign exchange reserve expressed in RMB, respectively, and $\widetilde{r}$ and $\widetilde{R}$ are the interest on required reserves and reserve requirements, respectively.

5. Data and Empirical Results

In this section, empirical analysis has been conducted with an offset and sterilization coefficient model to examine the process of international capital flows and the effectiveness of monetary policies. A framework that can be used to analyze sustainability of sterilization policies adopted by the PBC based on the correlation between its sterilization costs and China's foreign exchange reserve is proposed.

5.1. Data Description and Unit Root Tests. There are two parts in the empirical analysis. The empirical data in the first part contains a total of 134 observations from February 2002 to March 2013. That in the second part has a total of 103 observations from June 2003 to December 2011. As the smallest accounting frequency is quarterly for China's published GDP, the monthly GDP data employed in the present study is derived by decomposing the quarterly GDP, weighted by the ratio of monthly gross industrial output to the quarterly gross industrial output.

Since there is no differentiation between the reserve requirements and excess reserves in the balance sheet of the PBC, it is difficult for us to calculate the exact amount of interest payments by the PBC on the reserve requirements and excessive reserves. As a result, we use the deposits with central bank from the balance sheet of other depository corporations as an alternative variable representing the reserve requirements. We then use the corresponding ratios of reserve requirement to obtain the approximate amount of monthly interest payments by the PBC. Table 2 summarizes the measurement and sources of the various data used in the estimating equations.

This paper has adopted the augmented Dickey-Fuller (ADF) method of Dickey and Fuller [13] to test whether the time series is stationary. The results are listed in Table 3. The results of ADF unit root tests reveal that all variables are stationary at the 5% level of significance.

5.2. Empirical Results

5.2.1. Effectiveness of the Sterilization Policy. Equations (8) and (9) are simultaneous equations. Simultaneous equation system is considered to be more theoretically stringent. Nevertheless, considering that China's economy is in transition, sound market operations and transmission mechanism have not existed among various economic variables. Simultaneous

Table 3: Unit root test for effectiveness of the sterilization policy.

Variable	τ statistic
ΔNFA_t^*	-10.21^{***}
ΔNDA_t^*	-11.15^{***}
Δmm_t	-10.27^{***}
Δp_{t-1}	-5.22^{***}
$H_{c,t-1}$	-3.66^{***}
$Y_{c,t-1}$	-2.27^{**}
$\Delta G_{c,t}$	-4.07^{***}
$\Delta REER_{t-1}$	-8.897^{***}
$\Delta[Ee_{t+1} - (r_t - r_t^*) - (r_{s,t} - r_{s,t}^*)]$	-12.05^{***}

Note: $**$ and $***$ denote that the τ statistic is significant at 5% and 1% levels, respectively.

Table 4: Granger causality test result.

Null hypothesis	Chi-square	Problem
ΔNFA_t^* does not Granger-cause ΔNDA_t^*	0.24453	0.9507
ΔNDA_t^* does not Granger-cause ΔNFA_t^*	0.31366	0.9189

Table 5: Parameter estimates.

	ΔNFA_t^*	ΔNDA_t^*
Intercept	0.063^{***}	0.045^{***}
ΔNFA_t^*	—	-0.831^{***}
ΔNDA_t^*	-0.717^{***}	—
Δmm_t	-3.479^{***}	-4.691^{***}
Δp_{t-1}	2.506^{**}	3.003^{**}
$H_{c,t-1}$	-0.055	0.070
$Y_{c,t-1}$	-0.147^{**}	-0.124^{*}
$\Delta G_{c,t}$	-0.051	-0.082^{*}
$\Delta REER_{t-1}$	-0.550	-0.335
$\Delta[Ee_{t+1} - (r_t - r_t^*) - (r_{s,t} - r_{s,t}^*)]$	0.002	-0.021
$\overline{R}^2$	0.586	0.884
DW	1.979	2.072

Note: $*$, $**$, and $***$ denote that the z statistic is significant at the 10%, 5% and 1% levels, respectively.

equations cannot be used to analyze the functional relationships among various economic variables representing structural characteristics of the economic system. In addition, if the endogeneity problems of ΔNFA_t^* and ΔNDA_t^* are not serious, results obtained from simultaneous equation estimation may not be necessarily better than those obtained by using the generalized least squares method.[23]

In order to further confirm the correlation between ΔNFA_t^* and ΔNDA_t^*, a causality test has been conducted (Table 4). Based on the results in Table 3, there is no causal relationship between ΔNFA_t^* and ΔNDA_t^*. Accordingly, we use the generalized least squares method to estimate (7) and (8).[24]

Table 5 shows results of estimations of the empirical model obtained through the use of the generalized least squares method. From Table 4, the offset and sterilization coefficients of international capital flows on monetary policy are -0.717 and -0.831, respectively.[25] These indicate that 70% of the change in net domestic assets of the central bank was offset by a negative change in the net foreign assets and 80% of the change in net foreign assets of the central bank was offset by a negative change in net domestic assets. This suggests that implementation of the large-scale sterilization by the PBC was effective.

In addition, coefficients of money multiplier are statistically significant and negative in all regressions. It is shown that a rise in the money multiplier increases the money supply and pushes interest rate down, leading to outflows of foreign capital. China's monetary authority is inclined to adopt a tight monetary policy to offset the increase in money supply caused by a higher money multiplier. The coefficients of the cyclical income in both equations are significantly negative, indicating that the higher the real output exceeding the potential output is, the larger the resulting negative impact on the current account surplus than on the attraction of foreign capital is. The monetary authority also tends to implement a tight monetary policy to suppress excessive growth of the economy. Moreover, the effect of government budget deficit on the net domestic credit is significantly different from zero. This indicates that, in order to maintain the stability of the social system, the central bank adopts a tighter monetary policy stance in response to increases in the government budget deficit.

Furthermore, the effects of previous inflation volatility on net foreign assets and net domestic credit are not negative, as expected. The possible reason is that China in recent years has experienced rapid economic growth, accompanied by rising inflation. Foreign investors who are optimistic about China's economic outlook go to seek investment opportunities in China, leading to increases in net foreign assets. In order to maintain a stable foreign exchange market, the central bank cannot help inject money in the domestic market, even if coupled with sterilization operations.

Therefore, coefficients of the change of consumer price index in logarithmic terms in time $(t-1)$ are statistically significant and positive in all regressions. The other variables are generally insignificant in the regressions and have inconsistent signs. These findings, statistically insignificant or with incorrect signs of the variable coefficients, may be due to the fact that while the dependent variables are fairly volatile, the independent variables are quite stable.[26]

We also apply LM test and ARCH test to each equation to ensure the accuracy of the empirical model. The results are presented in Table 6. LM and ARCH tests show that the null hypotheses of no serial correlation and heteroscedasticity cannot be rejected at the 5% level of significance. Besides, CUSUM values fall within the two critical lines at the 5% significance level. Therefore, these equations are statistically stable.

5.2.2. Sustainability of Sterilization Policy. From the perspective of the central bank's financial resources, sustainability of sterilization operations depends on whether the central bank can make a profit. If the central bank is in surplus, the profit from its role as issuer of the currency exceeds the cost of sterilization operations, which are thus sustainable. On the

Table 6: Residual diagnostics.

	ΔNFA_t^*		ΔNDA_t^*	
	Statistic	Problem	Statistic	Problem
LM test	0.947	0.504	0.836	0.613
ARCH test	0.444	0.942	0.118	0.999

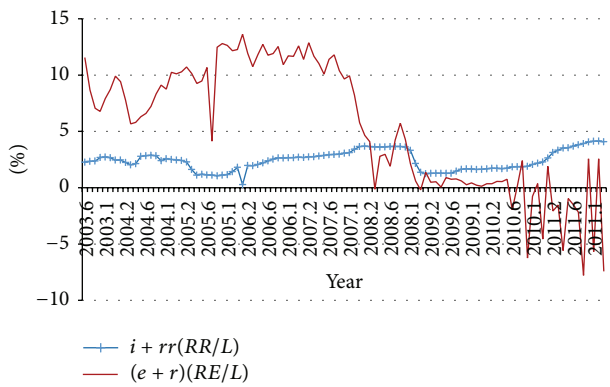

Figure 5: Determination of sustainability of monetary sterilization.

contrary, if the cost of sterilization is too high and profitability of the central bank is compromised, sustainability of the sterilization policy is questionable.

As changes in the value of foreign assets due to exchange rate fluctuations do not correspond to the cash flow in the current period, this does not bring substantial pressure on the central bank in the short term. If we specify the short-term model without including gains and losses from exchange rate volatility, operations of sterilization policies might be sustainable. However, exchange rate volatility in the long run reduces the value of foreign exchange reserves relative to the domestic assets. When considering changes in the value of foreign exchange reserves because of exchange rate volatility, it is likely that sterilization is unsustainable.

For an overview of the ratios of sterilization cost and adjusted yields of foreign exchange reserves, we examine the sustainability of China's monetary sterilization policy based on the estimation of (15) and the result is depicted in Figure 5. Figure 4 shows that the ratios of sterilization cost were lower than the adjusted yields of foreign exchange reserves until March 2008. Afterwards, there are changes. The ratios of sterilization cost were higher than the adjusted yields of foreign exchange reserves between March and June, while the former was lower than the latter from July to September. Except for January 2009 and August 2010, the ratio of sterilization cost and the adjusted yields of foreign exchange reserves in the rest of the periods do not meet the requirements of (15).[27]

There have been major changes in the balance sheet of the PBC in recent years. The growth of foreign exchange reserves is larger than the development of the economic system. Currency in circulation accounts for only a small portion of the central bank's liabilities; the major parts are the domestic liabilities that require payment of interest. This adds to the financial burden of the PBC and also results in increasing uncertainty of PBC's surplus.

In addition, issuance of central bank bills only helps ease the problem of short-term excess liquidity. If the PBC continues to issue central bank bills as a sterilization measure in the long run, it will further increase its financial burden. Furthermore, while the adjustment of reserve requirement ratios strengthens the autonomy of PBC and effectiveness of sterilization policy, long-term sterilization activities push up the interest rate in the financial market. This further encourages inflows of foreign capital which in turn neutralize the effectiveness of the sterilization policy. The resultant costs increase the difficulties in implementing the monetary policy.

Based on the foregoing analysis, sterilization operations undertaken by the monetary authorities in China have been increasing in recent years. This not only pushes up the market interest rate but also brings about imbalance in the asset structure of the monetary authorities, resulting in a vicious cycle of monetary policies. The sterilization costs are positively related to the yield of central bank's bills and the required deposit reserve ratio and negatively related to the yields of foreign investments. As a result, in the current environment of economic downturn in western countries and lower yields of foreign investment, adoption of sterilization policy further adds to burdens of the monetary authorities. Under the current international economic environment, sterilization will become unsustainable over a long period of time, in the future. As a consequence, the imbalance in the international balance of payment will inevitably have to be adjusted.

6. Conclusion

To stabilize the exchange rate of the RMB and further realize sustainable development of China's economy in the context of persistent balance of payments surplus and the intensified upward pressure on the RMB, the PBC uses a variety of sterilization measures and foreign exchange market interventions to reduce excess liquidity and maintain the stability of RMB exchange rate and the monetary policy independence.

Based on microeconomic foundations and with the perspective of minimizing the target loss function of monetary authorities, this paper aims to construct a refined model for offset and sterilization coefficient estimation to evaluate the effectiveness of China's sterilization policy. Besides, empirical data are used to further explore financial capabilities of the central bank in order to understand the sustainability of the sterilization policy. The empirical results show that Chinese monetary authorities sterilize almost all effects of international capital inflows and increase in foreign exchange reserves on the monetary base. That is, increase in capital liquidity does not sabotage the independence of the Chinese monetary policy. Nevertheless, analyses of sustainability of the sterilization policy indicate that the sustainability of the monetary sterilization policy has been seriously challenged since March 2008.

In the context of rising costs of sterilization, massive and persistent international capital inflows have made it difficult for the PBC to achieve its twin goals of currency stability and monetary policy independence. In light of these

circumstances, the monetary authority should not only adjust the maturity structure of the central bank bills to ease the pressure for making interest payments but also actively develop diversified sterilization tools to compensate for the inadequate effects of sterilization measures. Moreover, the monetary authority should relax restrictions on capital outflows and adjust the imbalance in the balance of payments. Furthermore, this should help improve the exchange rate system and mechanism for adjusting the exchange rate to adjust the external imbalance of the economy and expand the ratio of foreign reserves held by enterprises and for gradually abolishing the provision on "allowable foreign exchange working position" for designated banks. These measures can alleviate pressure on the PBC for its passive role in the foreign exchange market interventions.

The persistent balance of payments surplus has eroded the autonomy of the central bank. As a result the Chinese government should focus on policy coordination. In addition to increasing the issuance of government bonds and raising the proportion of government bonds within the monetary authority's assets, coupled with effective exchange rate management to control for speculative foreign investment, the government has to adjust the corresponding macroeconomic policy in order to effectively address the economic and asset bubbles due to excess liquidity.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

Endnotes

1. Refer to Krugman [14].
2. In order to keep the value of the RMB stable, People's Bank of China has to constantly interfere with the foreign exchange market by making purchases, which has resulted in expansion of the monetary base. On the other hand, in order to suppress potential inflation that might accompany the overheated investment flows since 2003, People's Bank of China had to keep the speed of expansion of the monetary base and credit, thereby resulting in conflicting goals of maintaining RMB stability and preventing overheating of the economy.
3. See the Chinese State Administration of Foreign Exchange, http://www.safe.gov.cn/.
4. The monthly balance of central bank bills is defined as the value of the current issuance of central bank bills minus the value of maturing central bank bills.
5. See People's Bank of China, http://www.pbc.gov.cn/.
6. Figures are calculated based on the statistics published by People's Bank of China.
7. The huge costs of foreign exchange sterilization are mainly due to the massive replacement of foreign currency assets by domestic bonds caused by the central bank's sterilization operations in the open market. This raises the interest rates of domestic bonds while lowering the rate of return on foreign currency assets. The domestic and foreign interest rate spread results in substantial deficit for the central bank and may even partially offset the bank's sterilization efforts.
8. The four factors include (1) foreign interest rate reduction; foreign capital would flow to developing nations to ensure higher rates of return; (2) in order to alleviate inflationary pressure, nations with capital inflows raise domestic interest rates that appeal to foreign capital; (3) increased domestic money demand due to various reasons, thereby driving up interest rates, which appeals more to foreign capital; and (4) changes in external conditions that lead to improved trade balance, thereby increasing domestic exports. As a result, total domestic demand increases and thereby creates pressure to increase domestic interest rate.
9. The sterilization coefficients (i.e., how much domestic money creation responds to a change in international reserves) of international capital flow on monetary policy are the percentage of the change in net foreign assets of the central bank which is used to offset by a negative change in net domestic assets. For example, when the sterilization coefficient is −0.6 it means that at least 40 percent of the growth in foreign reserves is translating into reserve money growth.
10. See International Monetary Fund (IMF), http://www.imf.org/external/index.htm.
11. With a shortage of other viable channels of investment in China, real estate market and stock market are main asset markets in China. As China recently only took a considerable number of policy measures to maintain stable housing prices but did not take any policy for stock market, therefore, the target loss function of China's monetary authorities only contains the variable of cyclical housing price and puts the variable of yields of foreign investment in (5).
12. In order to simplify the analysis, after subtracting p_{t-1} from both p_t and p_t^T, we can get that $p_t - p_t^T$ equals $\Delta p_t - \Delta p_t^T$.
13. $\Delta\mathrm{NFA}_t$ and $\Delta\mathrm{NDA}_t$ are the changes in the net foreign assets and net domestic assets, respectively.
14. Since the volume of central bank's net other assets and equity capital are smaller, we assume that $\mathrm{MB}_t = \mathrm{NFA}_t + \mathrm{NDA}_t$ to simplify the analysis.
15. We first assume that $\Delta p_t = \gamma_1 \Delta M_{2t} + \gamma_2 \Delta p_{t-1} + \gamma_3 \Delta e_t$, where $M_{2t} = \mathrm{MB}_t \cdot \mathrm{mm}_t$ is the money supply M_2 at time t. $\Delta p_t = \gamma_1 \left[\left(\Delta\mathrm{NFA}_t + \Delta\mathrm{NDA}_t\right)\mathrm{mm}_t + \mathrm{MB}_t \Delta\mathrm{mm}_t\right] + \gamma_2 \Delta p_{t-1} + \gamma_3 \Delta e_t$, can be derived by using the specification in footnote 14.
16. The exchange rate used in this paper is based on direct terms (renminbis of per foreign currency unit).
17. There is no correlation between changes in net foreign assets and changes in the monetary base and capital mobility due to nonpolicy factors such as interest rate volatility and interest income. Therefore, the resulting

changes in asset values due to interest rate volatility and interest income are excluded from the change in the net foreign assets. The change in the net foreign assets due to RMB exchange rate appreciation is $RE_t = \mathrm{NFA}_{t-1}[(e_t - e_{t-1})/e_{t-1}]$, where e_t is the monthly exchange rate (RMB to USD) at time t. The interest income of the foreign exchange reserves is $\gamma_t = (i_{TB_t}/12)\cdot[(\mathrm{NFA}_{t-1}+\mathrm{NFA}_t)/2]$, where i_{TB_t} is the US 10-year Treasury yield. Therefore, we specify the adjusted net foreign assets scaled by the monthly GDP as $\mathrm{NFA}_t^* = (\mathrm{NFA}_t - RE_t - \gamma_t)/\mathrm{GDP}_t$.

18. Using the specification in footnote 12, $\mathrm{NDA}_t^* = (\mathrm{MB}_t/\mathrm{GDP}_t) - \mathrm{NFA}_t^*$ is the adjusted net domestic asset scaled by the monthly GDP.

19. $H_{c,t-1}$ is calculated as the proportion of housing price minus housing price trend against house price trend, and $Y_{c,t-1}$ is calculated as the proportion of GDP minus GDP trend against GDP trend. Hodrick-Prescott (HP) filter method is used to measure the trend of each variable in this paper.

20. The 3-month RMB/USD nondeliverable forward rate (NDF) in logarithmic terms is used to substitute Ee_{t+1}.

21. The offset coefficient is the effect of a change in central bank net domestic assets on domestic money supply that was offset by the capital inflows.

22. In the context of China's financial system, monetary policy is often different from the operations in the western countries. Qunatitative instruments (reserves) are preferred over price instruments (intereste rate). China has raised the reserve requirement ratios several times in recent years in an attempt to recover the funds outstanding for foreign exchange; therefore, the model specification has to take into account the increases in central bank liabilites due to the adoption of deposit reserve policy.

23. The P values of endogeneity test of $\Delta\mathrm{NFA}_t^*$ and $\Delta\mathrm{NDA}_t^*$ are 0.0853 and 0.4656, respectively. The test results show that the null hypotheses of no endogeneity problems of $\Delta\mathrm{NFA}_t^*$ and $\Delta\mathrm{NDA}_t^*$ cannot be rejected at the 5% level of significance.

24. Granger [15] defined causality among variables based on a "prediction" perspective. In addition to considering past values of x variable when predicting x_t, if past values of y variable help predict x_t, then y variable Granger-causes variable x_t. When the Granger causality test shows that y variable does not Granger-cause x variable, it cannot be viewed as variable y does not help explain x_t variable. It can only be used to determine lead-lag relationship between variables.

25. The empirical result is similar to Glick and Hutchison [5] and Zhang [6] survey of the various estimates about China's sterilization coefficient from 2003 to 2009. High levels of sterilization indicate that PBC's sterilization has been quite successful in maintaining the independence of domestic money and credit growth after the introduction of central bank bills and reserve requirement ratio.

26. Since (8) and (9) are derived by the theoretical model, the control variables cannot be chosen completely arbitrarily. Accordingly, we cannot use robust test to test the robustness of the model.

27. The financial crisis that began in 2007 spread and gathered intensity in 2008; the global response to the financial crisis began to take shape in late 2008s. On October 8, 2008, the world's major central banks, including the Federal Reserve, the European Central Bank, the Bank of England, and the PBC, lowered interest rates in unison. Since the short/medium term foreign interest rate has dropped sharply, investment yields earned on foreign assets cannot cover PBC's interest payments on the outstanding PBC bonds and on the total (required and excess) reserves after late 2008s. Thus, a projection of the sterilization cost and the income from foreign reserves investment also indicate that the sterilization policy of PBC will become unsustainable in the future.

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