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China’s Foreign Exchange Reserve Accumulation and Its Currency Composition Management

中国の外貨準備の蓄積と通貨構成管理

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Chapter 1. Introduction

In the past two decades, the foreign exchange reserve holdings of East Asia and Petroleum Exporting Countries have increased dramatically. After a temporary suspension following the global financial crisis, the uptrend resumed at an accelerated pace. In the meantime, China's foreign exchange reserves have experienced a rapid growth since 1990, reaching 3.84 trillion dollars by the end of 2014[1], with an average annual growth rate exceeding 13% since 1988. Meanwhile, the ratio of foreign exchange reserves to GDP also increased from 8% to 38% (Figure 1-1). Since then, impacts of foreign exchange reserve accumulation on global economy become more and more conspicuous.

In addition to satisfying the temporary external financing need and defending the state from external shocks, holding large-scale foreign exchange reserves also brings financial and policy challenges to the monetary authorities. As for China, along with the foreign exchange reserve accumulation, funds outstanding for foreign exchange[2] have grown rapidly. The proportion of funds outstanding for foreign exchange to base money continues to grow from 45.7% in 1999Q1 to 102.3% in 2014Q4 exceeding 100% since 2005 (Figure 1-2). Thus, the underlying inflation pressure is likely to be aroused by the excessive monetary base. In the meanwhile, as a significant symptom of external imbalance, the rapid accumulation of foreign exchange reserves may influence a country's macro-economy in various ways. The monetary authorities holding huge foreign exchange reserves may be also faced with the dilemma of monetary policy failure[3], exchange rate volatility loss and interest rate risk. Consequently, excessive foreign exchange reserve accumulation might destabilize the international financial system rather than prevent the financial crisis and contribute to the build-up of global imbalance, thereby eliminate the positive impact on the macroeconomic.

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[1] Source: State Administration of Foreign Exchange, China.

[2] Funds outstanding for foreign exchange are the money the People's Bank of China pays financial institutions, including commercial banks, each month in exchange for the foreign currency they receive from trade surpluses, foreign investments and other sources. Because the RMB remains inconvertible under the capital account, foreign capital that enters China in most cases will be sold to the central bank. Therefore, the change of funds outstanding for foreign exchange also reflects the change trend of foreign exchange reserves.

[3] The huge trade surplus leads to the renewed international pressure for currency appreciation, and then attracts more capital inflow into China. Because of the continuous double surpluses, China's foreign exchange reserves have been extraordinarily growing in recent years. In lack of the resilience of exchange rate regime changes, the monetary policy will be constrained if the People's Bank of China offsets the effects of reserve accumulation on the monetary base by adopting sterilization intervention policy in the long term. Nowadays, in most countries, the intermediate target of monetary policy moved from the monetary supply into the interest rate. Due to the restriction of sterilization intervention policy, it is neither able to control the monetary aggregate effectively, nor utilize the interest rate policy flexibly. The essence of which is the special performance of 'dilemma' in China.

Thus, the first purpose of this thesis is to analyze the macroeconomic impacts of China's foreign exchange reserve accumulation. A newly proposed Pure-sign-restriction Approach within a Vector Autoregression framework is utilized in order to achieve this goal. The key issue in applying VAR methodology is to identify the foreign exchange reserve accumulation shock. This is usually done by appealing to some certain informational orderings about the transmission mechanism of foreign exchange reserve accumulation to the real economy. Without being explicit about the a priori theorizing, it is difficult to distinguish between assumptions and conclusions. However, in terms of impacts of foreign exchange reserve accumulation, there is no broadly accepted a prior theorizing in the literature. What is therefore desirable in this case is to find a way to make the a priori theorizing explicit and to use as little of it as possible, while at the same time leaving the question of interest open. Inspired by the research of Uhlig (2005) on monetary policy shocks, this thesis proposes to push this idea all the way, and to identify the effects of foreign exchange reserve accumulation by directly imposing sign restrictions on the impulse responses. We assume that a foreign exchange reserve accumulation shock leads to increases in foreign exchange reserves held by the State Administration of Foreign Exchange and in funds outstanding for foreign exchange, but exert no restrictions on the responses of other variables.

The empirical results present a mixed picture of the diversification debate. An important finding is that the effects of foreign exchange reserve accumulation on all variables are ambiguous initially, but then the impact on the base money becomes significant and increases approximately in the same proportion as foreign exchange reserve accumulation under the sign restriction methodology even after isolating the business cycle shock, monetary policy shock and external shock. However, foreign exchange reserve accumulation has no significant influence on the inflation and the real effective exchange rate. In the meanwhile, with the addition of analysis on the sterilization intervention, we find that the People's Bank of China efficiently offsets the effects of foreign exchange reserve accumulation on the monetary base using central bank bill issuance and reserve deposit ratio adjustment, though these policies become less efficient over time. Consequently, the base money caused by foreign exchange reserve accumulation is moderate rather than excessive. On the contrary, we find that foreign exchange reserve accumulation has significant impacts on all variables from the beginning under the traditional impulse response analysis with the confirmed order of variables. It is therefore suggested that the assumption for variable order in the VAR system can potentially influence the empirical results. As the sign restriction approach does not suffer from the order problem, thus our findings much better reflect the real world conditions of China's sterilization policy.

The second purpose of this thesis is to estimate the currency composition of China's foreign

exchange reserves and assess its effectiveness of management. Compared to the continuously inflated scale, the currency composition of foreign exchange reserves and its change not only reveal differentiated asset management strategies but also can be employed to infer possible influences of dynamic asset adjustment behaviors on the future asset prices. It is the strictly confidential currency composition of official foreign exchange reserves for individual country that constitutes a critical obstacle for further investigations on the management of foreign exchange reserves. As far as China, although no convincing public information on the currency composition of foreign exchange reserves could be found, it is widely believed that the share of dollar denominated assets is extremely high. Since 2002, the weakening of the U.S. dollar against a basket of currencies (Figure 1-3) has brought great attention to the loss of China's foreign exchange reserves caused by the devaluation of primary currencies. Although the State of Administration of Foreign Exchange has more than once expressed the views that the appreciation of renminbi will not directly cause the loss of foreign exchange reserves and the book profit of foreign exchange reserves is far more than its book loss, the loss related to exchange rate fluctuation and interest rate variation does exist. Adjusting the currency composition of foreign exchange reserves is supposed to be a powerful risk management tool for China. Moreover, the introduction of the euro in 1999 offers the management entities an alternative to the U.S. dollar. The rising current account deficits and growing external debts of the United States in recent years also motivate the management entities to avoid dollar assets. Many researchers have reported a dramatic reserve currency shift from the U.S. dollar to the euro between 2001 and 2003 (Papaioannou *et al.*, 2006; Zhang *et al.*, 2010; Sheng, 2013). However, the European sovereign debt crisis seems to severely hinder the internationalization of the euro. Does China diversify its foreign exchange reserves out of the U.S. dollar? What is the currency composition of China's foreign exchange reserves and how does China adjust it? Does China effectively manage its foreign exchange reserves? All these answers not only help us further understand the management behaviors of the world's biggest reserve management entity but also provide references for other countries, and thus contribute to the existing literature.

The biggest obstacle in previous studies is the lack of convincing data that could be used to estimate the currency composition. Based on basic portfolio accounting identities, the change of foreign exchange reserves is decomposed into two parts: the net purchase change and the non-purchase change, by virtue of the Balance of Payments and the International Investment Position. Based on the newly constructed data, we estimate the latent currency composition of China's foreign exchange reserves within the framework of Constrained Least Squares only imposing some generally accepted bound constrains. Among a large number of literatures, Sheng (2013) is supposed to be the first attempt to precisely estimate the currency composition of

China's foreign exchange reserves. In order to build the State-space Gaussian Mixture Model, Sheng (2013) assumes that the value shares of foreign assets follow random walk processes. However, many previous literatures report that the shares of major currencies in global reserve holdings are quite stable (Eichengreen and Mathieson, 2000; Chinn and Frankel, 2007). Considering the bearing capacity of financial markets, it is impossible for the monetary authorities to randomly adjust the currency composition. Thus, the assumption seems unreasonable. Instead, we only assume that the value shares of different currencies fluctuate slightly in a commonly accepted range. As Sheng (2013) points, the estimated currency composition is the *ex post* realized currency portfolio, rather than the *ex ante* one estimated through the traditional mean-variance optimality analysis.

Furthermore, we also discuss the impacts of currency composition adjustment on the portfolio risk of foreign exchange reserves. Foreign exchange reserve management involves dynamically adjusting the currency composition, asset classes, and term structure, *etc*. The currency composition adjustment is one of the most attractive macro-management strategies. The effective management behaviors should be any actions that would reduce the portfolio risk of foreign exchange reserves. The Variance Sensitive Analysis proposed by Manganelli (2004) provides an easy to use way about asset allocation management, which not only reveals the risk sources but also points out the direction of optimization. As highly risk-averse investors, most central banks are more inclined to diversify their foreign exchange reserves so as to decrease their reserve portfolio risk. In other words, reserve asset portfolios tend to be risk-averse, with priority for liquidity and security before profit or carrying cost considerations. Thus, we mainly focus on the nexus between portfolio risk and currency composition management here. The variance sensitive analysis is appropriate to assess the management behavior of China's foreign exchange reserves and to determine its future directions.

The most important finding is that, although the primary currency composition was stable, China had paid more and more attention to the emerging international currencies, such as the Canadian dollar and the Australian dollar. The U.S. dollar, the euro, the pound sterling and the Japanese yen were still four dominant currencies in China's foreign exchange reserves. However, the total share of these four currencies significantly decreased from 2008 to 2012. Especially, China may have tried to introduce the Canadian dollar and the Australian dollar as alternatives to the pound sterling and the Japanese yen, respectively, since 2012Q4. In the whole sample period, China did not significantly diversify its foreign exchange reserves out of the U.S. dollar to other international currencies. However, a downtrend of the U.S. dollar share during the subprime crisis and an uptrend of it since 2011 were found. This means that China tries to alternatively take the portfolio diversification strategy and portfolio rebalance strategy rather than stick to

either one of them. In addition, the European sovereign debt crisis did have prominent influence on China's foreign reserve management and caused China to decrease the shares of the euro and the pound sterling since 2010. Nevertheless, by the end of 2015Q1, China held about 63.6% of its reserves in the U.S. dollar, 19.6% in the euro, 3.09% in the Japanese yen, 4.89% in the pound sterling, 2.22% in the Canadian dollar, 2.03% in the Australian dollar and 0.09% in the Swiss franc.

Another important finding is that the currency composition management of China's foreign exchange reserves was relatively effective. Before 2014Q3, the first derivative of the U.S. dollar was always positive while those of other currencies were always negative and vice versa after 2014Q4. With respect to the absolute values of derivatives, all of them rapidly declined in 2012. Although diversifying out of the U.S. dollar was not always decreasing the portfolio risk of foreign exchange reserves, the portfolio diversification strategy during the subprime crisis was indeed a smart move. On the contrary, the reduction of the euro during European sovereign debt crisis may not be a good choice. Nevertheless, the portfolio rebalance since the end of 2014 did contribute to the management of China's foreign exchange reserves. In the meantime, the introduction of the Canadian dollar and the Australian dollar may effectively improve the management of China's foreign exchange reserves due to the fact that they had larger derivatives in absolute values.

According to previous studies, some traditional factors, such as the *country size*, *inertia*, *confidence in the value of reserve currency*, have significant influences on the decision of currency composition. Yet most of these researches, especially for those on determinants of the currency composition of individual country's foreign exchange reserves, are controversial, because they all build on analyses about the aggregate data of global level or country groups due to the reluctance of the monetary authorities to release data on foreign exchange reserve composition. In other words, whether the currency composition of individual country's foreign exchange reserves will change with the alterations of its own trade structure, foreign debt composition or the domestic economic development and foreign economic situations has not been investigated. Thus, the third purpose of this thesis is to figure out what drives the currency composition decision of China's foreign exchange reserves. Based on the estimated currency composition, we analyze possible determinants of the relative change of currency composition including China's differentiated import and export trade structures and the composition of foreign debts in addition to many traditional factors found in previous literatures. In order to address these concerns, two-currency group (the U.S. dollar and the euro) and four-currency group (the U.S. dollar, the euro, the pound sterling and the Japanese yen) panel regressions with cross-section weighted standard errors are established, respectively.

Like previous studies, we find that the inertia and confidence in the value of currency strongly affect the currency composition decision of China's foreign exchange reserves. In addition, as expected, the increase of export trade is conducive to enhancing the value share of that currency in total foreign exchange reserves. However, the influence of import trade is only statistically significant in the four-currency group regressions. These findings suggest that, when making the currency composition decision, the State Administration of Foreign Exchange will emphasize the influence of export trade structure in the two-currency group while will also pay attention to the change of import trade structure in the four-currency group. Another interesting finding is that the composition of foreign debts is negatively related to the currency composition change of China's foreign exchange reserves, which is inconsistent with most previous studies. This probably means the State Administration of Foreign Exchange may try to seek for foreign debt composition arbitrage rather than asset-liability collaborative management due to the fact that China's foreign assets are significantly more than its foreign debts. Furthermore, we find that additional variables, such as long term bond yields, inflation and exchange rate volatility, have little impact on the currency composition decision of China's foreign exchange reserves.

The thesis is organized as follows:

Chapter 1 provides an outline of the thesis.

Chapter 2 reviews previous studies on foreign exchange reserves.

Chapter 3 empirically analyzes the impacts of China's foreign exchange reserve accumulation. First, a traditional impulse response analysis is executed by giving foreign exchange reserves one standard error positive shock. Then, a pure-sign restriction approach only identifying a single reserve accumulation shock is utilized. Finally, a reserve accumulation shock is identified after isolating the business cycle shock, monetary policy shock and external shock. Moreover, we also look through the foreign exchange sterilization behavior of the People's Bank of China and make a simple analysis to see the sterilization efficiency in order to further confirm previous empirical results.

Chapter 4 begins with constructing the new data of the non-purchase change of foreign exchange reserves and then estimates the latent currency composition of China's foreign exchange reserves within the framework of constrained least squares only imposing some generally accepted bound constrains. Finally, based on the estimated currency composition, the variance sensitive analysis is employed to assess the impacts of currency composition adjustment on the portfolio risk of foreign exchange reserves.

Chapter 5 starts with discussing possible determinants of the relative change of currency composition considering both China's differentiated import and export trade structures and the composition of foreign debts in addition to many traditional factors found in previous literatures.

Then, two-currency group (the U.S. dollar and the euro) and four-currency group (the U.S. dollar, the euro, the pound sterling and the Japanese yen) panel regressions with cross-section weighted standard errors are established, respectively.

Chapter 6 summarizes some contributions of this thesis and also points out the direction for future research.

Chapter 2. Literature Reviews

2.1 Macroeconomic Impacts of Foreign Exchange Reserve Accumulation

It is well-known that foreign exchange reserves can be used to meet the demand of imports and external liabilities. In addition to these basic functions, foreign exchange reserve is also an important macroeconomic management tool to accomplish various policy objectives, such as conducting foreign exchange intervention in order to maintain the exchange rate stability in a fixed exchange rate regime (Bahmani-Oskooee, 1985), or to avoid exchange rate overshooting during market dysfunction or turmoil periods in a floating rate regime. Since 1997, global financial crises have frequently broken out, which have made many developing countries realize the importance of holding adequate foreign exchange reserves as a risk buffer and defense against external shocks (Aizenman and Lee, 2008; Moore and Glean, 2016). Some Keynesians argue that an increase in foreign exchange reserves improves the current account, and consequently enhances the aggregate output. That is, the central bank could maintain the competitiveness of the tradable sector by the undervalued nominal exchange rate through reserve accumulation in the short run. Yet the current account needs to be balanced and the real exchange rate ought to be adjusted to the equilibrium value in the long run.

However, holding large scale foreign exchange reserves also brings financial and policy challenges to the monetary authorities. What are the effects of large scale foreign exchange reserve accumulation on the domestic economy? This issue concerns not only China but also other East-Asian countries that have a similar export-led economic development mode. In previous studies, Rodrik (2006) finds that the social costs of excess reserves have increased steeply since 'excess' reserves have risen sharply, and stand at close to 1% of GDP in developing countries. However, there is no direct information source on the costs of short term borrowing to estimate robustly. In contrast, some researchers point out that the cost of holding foreign exchange reserves may have been considerably overstated (Levy Yeyati, 2006). Vallence (2012) explores some of the key subjects concerning Australia's foreign exchange reserves holding and management, such as the reason of holding foreign exchange reserves and its cost, risk mitigation strategies, and the appropriate reserve level. He finds that compared to the social cost, the potential payoffs of holding foreign exchange reserves are the improvements of macroeconomic output and financial stability.

Furthermore, Polterovich and Popov (2003) conduct a cross-country study and report that the reserve accumulation through real exchange rate undervaluation accompanied by FDI inflow has

a positive effect on the long-term economic growth of developing countries. Based on the new data made available through the IMF Special Data Dissemination Standard (SDDS) Reserve Template, Dominguez *et al.* (2012) find that the higher reserve accumulations prior to the crisis are associated with higher post-crisis GDP growth. However, one key flaw of their analysis is not considering the two major reserve accumulating countries, namely China and Saudi Arabia. Kruskovic and Maricic (2015) examine the relationship between foreign exchange reserve change and economic growth using a balanced panel with fixed individual effects and Granger causality test for Brazil, China and Russia and find that the increase of foreign exchange reserves leads to economic growth but not vice versa. Otherwise, some researchers also investigate the impacts of foreign exchange reserve accumulation on macroeconomic variables, such as inflation (Steiner, 2010; Usman and Waheed, 2010), and foreign exchange rate (Ahmed and Pentecost, 2006; Mohanty and Tuner, 2006).

However, compared with empirical studies, the research based on theoretical model is relatively weak. Korinek and Serven (2010) derive a simple analytical formula for welfare and find that real exchange rate depreciation through the foreign reserve accumulation would increase domestic production and lead to dynamic welfare gains due to these externalities. Benigno and Fornaro (2012) study a two-sector, tradable and non-tradable, small open economy, and show that the government can use reserves to exploit knowledge spillovers in the tradable sector, thereby amplifying the positive impact of reserve accumulation on growth. Moreover, considering the trade-off between costs and benefits from reserve accumulation, Fukuda and Kon (2010) construct a simple small open economy model, which consists of tradable and non-tradable sectors with different capital intensities, and explore the potential long-run impacts of reserve accumulation on the maturity structure of external debt, capital accumulation and economic growth. They find that an unexpected rise in foreign exchange reserves has no impact on the real exchange rate, but an increase in foreign exchange reserves leads to a decline in consumption, although investment and economic growth may improve when the tradable sector is capital intensive.

2.2 International Reserve Currency: History and Evolution

During the gold standard era, the pound sterling dominated the financial world. However, due to the misguided policymaking and the world war, the pound sterling was replaced by the U.S. dollar as the leading international currency[4]. Eichengreen (2011) argues that the 'size, stability, liquidity' of financial markets are the most important determinants of international

[4] Eichengreen and Flandreau (2012) indicate that the dollar began to replace the pound sterling after the establishment of the Federal Reserve of United States in 1913. However, Chinn and Frankel (2007) believe that the dollar only overtook the pound sterling after the World War Ⅱ.

reserve currency status. Thus, the establishment of the Federal Reserve in 1913 and the development of American financial markets also had significant impacts on the rise of the U.S. dollar. Hartmann (1998) and Eichengreen (2005) point out that the argument that there is only one international currency according to network externalities in the use of money for transactions, does not apply to the arrangement of the currency composition of foreign exchange reserves. As highly risk-averse investors, most central banks are more inclined to diversify their foreign exchange reserves so as to decrease their reserve portfolio risk.

Recently, with the growing international role for the euro, some argue that the euro in fact has got the prerequisites for a major international currency (Portes and Rey, 1998; Bergsten, 1997). Some even point out that the euro may have already become the 'alternative' international currency (Papaioannou *et. al,*, 2006; Galati and Wooldridge, 2006). However, the dominant argue that the international impact of euro as an important foreign reserve currency would be small (Frankel, 1995; Eichengreen, 1998). In addition, compared with the U.S. dollar, the euro may have some disadvantages due to its relatively illiquid bond market, weak central bank system and deteriorating debt problems. Thus, it is inconceivable that a large-scale shift in reserve composition from the U.S. dollar to the euro similar to that from the pound sterling to the U.S. dollar in the 1920s and 1930s could happen (Eichengreen and Flandreau, 2008).

Furthermore, with the positive and rapid development of China's financial markets, some argue that the renminbi is challenging the reserve currency status of the U.S. dollar in some extent (Kawai and Pontines,2014). However, due to the incomplete convertibility of the renminbi, the instability of capital markets and the financial regulation disturbances from the authorities, the challenge is relatively limited in the short term. Overall, a crash of the dollar and the loss of its reserve currency status as the pound sterling will be a low probability event (Eichengreen, 2011). But, Eichengreen (2011) points out that three things including China dumping the dollar, investors' confidence for the United States lost, as well as continuous runaway government spending are identified as the most influential events that incur the dollar crash.

2.3 The Currency Composition of Foreign Exchange Reserves

Literatures on the currency composition of foreign exchange reserves develop along two directions: the individual country's optimal currency composition, and determinants of the currency composition of foreign exchange reserves on a global level.

Most studies about individual country appear to be normative researches discussing what the optimal currency composition should be rather than empirical analyses based on actual data discussing what the currency composition really is. In numerous studies, Mean-Variance analysis (M.V. method) concerning central bank's risk-return objective has become the dominant

approach. Papaioannou *et al.* (2006) conduct one of the most comprehensive analyses about the optimal composition using a dynamic mean-variance optimization framework with portfolio rebalancing costs, and find that the euro's share has increased substantially indeed becoming the 'alternative' international currency. Based on Papaioannou *et al.* (2006), Zhang *et al.* (2010) use copula functions to estimate the variance-covariance matrix of currency returns in order to eliminate the shortcoming of the traditional assumption of a multivariate normal distribution and obtain 18 different possible reserve portfolios. Beck and Rahbari (2011) estimate optimal dollar and euro shares for 23 emerging market countries using M.V. method and find that optimal reserve portfolios are dominated by anchor currencies, and the dollar acts as a safe haven currency during the period of sudden stops.

However, because asset returns are usually fat-tailed and non-normal distribution (Bouye *et al.*, 2000), the M.V. method is probably not sufficient as a tool for analyzing wealth diversification. Furthermore, recent researches indicate that the inadequacy of this method lies in not considering the asymmetries and dependence complexities in the returns distribution (Hong *et al*., 2007; Ammann and Suss, 2009). Thus, in order to model these features including fat-tail, asymmetric and complex dependence of currency returns, Zhang *et al*. (2015) further build a flexible framework based on pair-copula construction to analyze the optimal currency composition of China's foreign exchange reserves. They find that even though the U.S. dollar takes the largest share, the incorporation of fat-tail, asymmetric and complex dependence features would lead to other currencies to be more chosen for China's foreign exchange reserve diversification.

Moreover, Dooley (1986) emphasizes that the M.V. method of balancing between return and risk is inapplicable to the foreign reserve management with the motives of precautionary and liability demands. Especially, when using the M.V. method, three problems should be solved in advance: the choice of reference currency, the estimation of asset returns and the determination of variance-covariance matrix between asset returns. In addition, most studies are fundamentally achieved within the framework of a single-period, static M.V. model. Theoretically, the currency composition management aims mainly at eliminating exchange rate volatility risk and therefore is supposed to be a dynamic adjusting process to which little existing literature relates. However, with the recent development of other new frontier econometric methods, such as continuous-time models (Zhou and Li, 2000), dynamic optimum models under imperfect markets (Basak and Chabakauri, 2010), for a large picture, the multi-period or dynamic analysis might be used in the M.V. framework.

Unlike the traditional M.V. method, Sheng (2013) turns the decomposition equation into a time-varying parameter state-space model with Gaussian mixture distribution and detects the

latent currency portfolio of China's foreign exchange reserves from 2000 to 2007. He finds that the value shares of the euro, the Australian dollar and the pound sterling increased from 5% to 20%, from 2.3% to 4.7% and from 2.6% to 3.5%, respectively, but the value share of the yen remained stable. This implies that China diversified its currency composition of foreign exchange reserves and did this by mostly increasing its holdings in the euro. However, due to the idealistic assumption and the inaccurate data, the results in Sheng (2013) are probably too subjective and disputable.

Lastly, a large number of studies on this issue have been performed by Chinese researchers in recent years. Xu and Zhang (2010) conduct a detailed literature review on foreign exchange reserve currency composition management. While others including Sheng and Zhao (2007) and Zhang *et. al*. (2010) explore the currency composition of China's foreign exchange reserves. Kong (2010), Wang (2011) and Shi and Nie (2012) discuss the issue of currency composition adjustments. However, most of these studies pay sufficient attention to the optimal currency composition rather than the actual composition.

On the other hand, some researchers explore determinants that the pound sterling and the U.S. dollar could keep their status as continuously dominant international currencies (Frenkel and Sondergaard, 1997; Eichengreen, 2005, 2011; Eichengreen and Flandreau, 2008, 2012). Since the introduction of the euro, attention has been turned into the research that if the euro could rival the U.S. dollar and when the holdings of euro asset in foreign exchange reserves are comparable with or even exceed the holdings of dollar asset in amount (Bergsten, 1997; Feldstein, 1997; Portes and Rey, 1998; Eichengreen, 1998; Cohen, 2003; Chinn and Frankel, 2007; Galati and Wooldridge, 2009). Recently, research on whether the renminbi will emerge as an new international reserve currency has been paid attention to (Subramanian and Kessier, 2012; Eichengreen, 2013; Prasad, 2014; Lee, 2014).

Analyses about determinants of the currency composition of foreign exchange reserves stems from the discussions about international currency theory. Based on some early literatures such as Kindleberger (1981) and McKinnon (1979), *etc*., Krugman (1984) analyzes the basic roles of the dollar as the international currency and emphasizes that the country size is an important determinant of international currency choice. Matsuyama *et al*. (1993) suggest that the relative size and the possibility of multiple equilibria in use of an international currency play important role in explaining the emergence and evolution of international currencies. They also find that the internationalization of a currency can improve its national welfare. Rey (2001) suggests that the network externalities and the pattern of international trade determine the possibility of multiple equilibriums in the internationalization of currencies. Recently, Eichengreen *et al.* (2016) find that the country size, persistence effects and policy-credibility effects strongly affect the

foreign reserve currency status. Although the first factor appears to be weakened in the post-Bretton Woods system, the last two become stronger.

In methodology, there are two conventional approaches to analyze determinants of currency composition: one is the Mean-Variance Approach and the other is the Transaction Approach. The mean-variance approach provides a meaningful method in modeling the needs of central banks' portfolio diversification in order to achieve return maximization for a given level of risk or risk minimization for a given return. Accordingly, the risk and return of reserve currencies are important factors influencing the currency composition decision of foreign exchange reserves. However, Dooley (1986) argues that the mean-variance approach is more suitable for the analysis about the wealth allocation of net holdings rather than the gross holdings, like the foreign exchange reserves, which only includes assets but not liabilities. On the other hand, the transaction approach provides a more practicable basis and argues that market transaction activities, such as the financing of foreign trade, the settlement of foreign debt obligations and the needs of foreign exchange market intervention, *etc.*, are major factors in determining the currency composition of foreign exchange reserves.

Dooley *et al.* (1986, 1989) explore determinants of the currency composition of foreign exchange reserves by combining the mean-variance approach and the transaction approach (so called 'DLM method'), finding that the foreign exchange rate regime and foreign exchange trading needs are two key factors when developed or developing countries determine the currency composition of foreign exchange reserves. Furthermore, for developing countries, the currency composition of foreign debts is also an important determinant. Furthermore, Dooley *et. al.* (2003) report that the trade links and currency pegs have important impacts on central banks' diversification strategies in East Asia and Latin America.

Recently, many researches based on the transaction approach have emerged. Chinn and Frankel (2007) argue that the pattern of output, the size and depth of financial markets, the confidence in the currency value and the network externalities, all influence the currency composition of foreign exchange reserves. Following the steps of Chinn and Frankel (2007), Chen and Peng (2007) regress the currency shares of foreign exchange reserves on different determinants using a cross-section fixed effect model in the panel regression, and find that the GDP share, the lagged currency share and the market capitalization are statistically significant. However, although both studies allow for possible nonlinear problems, the influence of the introduction of the euro as well as the latent time-varying coefficients problem are not analyzed. Similarly, Lee (2014) finds that the size of output and the development of financial market has significant influence on reserve currency status and predicts that the renminbi has great potential to become a new reserve currency given the rapid growth of Chinese economy and its rising

international influence.

Hatase and Ohnuki (2009) find that the trade structure, the foreign debt structure and the stability of potential reserve currencies can strongly affect the shifts of currencies in Japan's foreign exchange reserves. Eichengreen and Mathieson (2000) employ the DLM method and Tobit estimation based on IMF data analyzing the currency composition of emerging and transition economies, and find that the relationships between the currency composition of foreign exchange reserves and other factors, *i.e.*, debt payments, trading needs and the exchange rate regime, kept relatively stable. Based on the panel analysis about central and Eastern European countries, Ito *et. al.* (2015) reveal that both trade invoicing and currency movements drive the change of official reserve composition.

Since the introduction of the euro in 1999, studies on whether the euro would bring a significant change in the currency composition of foreign exchange reserves have got much attention. Galati and Wooldridge (2009) investigate the relationship between financial markets and the international status as the reserve currency, and find that the U.S. dollar as the dominant reserve currency is supported by the big size, high quality and sufficient liquidity of American financial markets. Similar results are also found in previous studies, *e.g.* Eichengreen (1998), Cooper(2000) and Chinn and Frankel (2007).

Moreover, It is important to note that most studies find that the shares of major currencies in global reserve holdings are very persistent, that is the inertia in the use of reserve currency would affect the currency composition of foreign exchange reserves (Eichengreen and Mathieson, 2000; Chinn and Frankel, 2007; Galati and Wooldridge, 2009; Eichengreen *et al*., 2016).

Nevertheless, due to the reluctance of central banks to release data on reserve composition**,** literatures on determinants of the currency composition of foreign exchange reserves are mainly conducted by the IMF through regressing actual currency shares on macroeconomic, financial and trade factors. Meanwhile, the cross-country regression analysis is generally performed to study determinants of the currency composition of foreign exchange reserves, no matter on the global overall level or for country groups. However, researchers outside the IMF cannot proceed in similar studies. Especially, limited studies have explored determinants of the currency composition of individual country's foreign exchange reserves. Thus, it is hard to further check empirical results, which are controversial.

Chapter 3. Macroeconomic Impacts of China's Foreign Exchange Reserve Accumulation: A Vector Autoregression Analysis Using Pure-sign-restriction Approach*

In contrast to the existing literatures, this chapter regards foreign exchange reserve accumulation as a kind of external shock and tries to explore its impact using the newly proposed Pure-sign-restriction Approach within a Vector Autoregression framework. More specifically, we assume that a reserve accumulation shock leads to increases in foreign exchange reserves held by the People's Bank of China and in funds outstanding for foreign exchange, all of which are generally accepted in the literature. Crucially, we impose no restrictions on the responses of other variables including the real output and CPI because they are the focus of this investigation.

In order to figure out the impacts of reserve accumulation more precisely, firstly, Pure-sign-restriction Approach is utilized only identifying a single reserve accumulation shock. Then, a reserve accumulation shock is identified after isolating three relevant shocks: a business cycle shock, a monetary policy shock and an external shock based on the analytical framework of Mountford and Uhlig (2009). Notably, the effect of reserve accumulation on base money and inflation will also depend on the degree of sterilization policy applied by the monetary authorities (Steiner, 2010). Consequently, we also look at the sterilization intervention behavior of the People's Bank of China in order to further confirm the empirical results.

3.1 How does Foreign Exchange Reserve Accumulation Influence the Macro-economy?

As a significant symptom of external unbalance, there are various ways through which reserve accumulation influences the real economy based on different theories. The most significant way in China relating reserve increases to economic growth would probably be that reserve accumulation causes money growth in circulation which further leads to investment growth and economic boom. Between 1994 and 2011, China carried out a kind of obligatory foreign exchange selling system which requires export companies to sell their exchange revenues to the People's Bank of China, and companies are not allowed to retain exchange revenues. In fact, the obligatory foreign exchange selling system strengthens the link

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between foreign exchange reserves and domestic money as well as expands the scale of reserves.

Thus, in the following section, we first inspect the link between foreign exchange reserve accumulation and the money supply according to the money multiplier theory and the balance sheet of central bank.

At the center of the financial system is the central bank, whose balance sheet identity has the form

$$B = D + R \tag{3.1}$$

where B denotes the base money, D denotes domestic assets of central bank and R represents foreign exchange reserves.

Then, the link between the money supply and the monetary base can be described by the following equation on the basis of the money multiplier

$$M = \frac{1+c}{c+r} \times B = m(c,r) \times B, \qquad (m > 1) \tag{3.2}$$

where M, $m(c,r) = (1+c)/(c+r)$, c and r respectively represent the money supply, the money multiplier, the currency-deposit ratio and the deposit reserve ratio.

People, who hold less currency and more deposits, will cause bank reserves to increase and thus expand the money supply. Generally, when the interest rate rise, people begin depositing money into banks to earn greater interest rate return, and thus higher interest rates lower the currency-deposit ratio (Szulczyk, 2014)[5]. Moreover, the deposit reserve ratio is determined by the central bank and sometimes is used as a tool in monetary policy, influencing the country's borrowing and interest rates by changing the amount of funds available for banks to make loans with. A high deposit reserve ratio implies a low money supply and high interest rate. Thus, the currency-deposit ratio and deposit reserve ratio are the functions of interest rate.

$$c = c(i) \qquad r = r(i) \tag{3.3}$$

The money multiplier in equation (3.2) tells us the quantity of money supply that can be created. Combining equation (3.1) with (3.3) can lead us to the following equation,

$$M = m(c,r) \times (D + R) = m(i) \times (D + R) \tag{3.4}$$

It is clear that equation (3.4) indicates that change in foreign exchange reserves, given the currency-deposit ratio and deposit reserve ratio, will influence the high powered money if the monetary authority does not undertake corresponding sterilization policy. Domestic money supply will then increase on account of the multiplier effect.

[5] Szulczyk (2014) indicates that wealth, financial risk and underground activities can influence the currency-deposit ratio beyond interest rate. However, these factors are difficult to do exactly quantitative analysis. In this chapter, we only focus on the relationship between the currency-deposit ratio and interest rate. Furthermore, Dornbusch and Frencel (1984) also show that the currency-deposit ratio is determined by deposit reserve rate as well. That is, the rise in deposit reserve rate raises the confidence and thereby reduces the currency-deposit ratio, which in turn increases the money multiplier.

On the balance sheet of the People's Bank of China, reserve accumulation on the one hand means on-going growth of foreign assets; on the other hand, the direct consequence of reserve accumulation is the passive issuance of monetary base as well as the continuous increase of other reserves in domestic finance system. Furthermore, this part of base money issuance related to reserve accumulation will transform to money supply in circulation through the money creation process of banking system. In order to maintain foreign exchange rate stability, the monetary authority must purchase foreign currency and meanwhile sell out national currency, which will cause passive money issuing. The export-oriented growth mode and relatively undervalued RMB exchange rate have led to long-term trade surplus accompanied by foreign reserve accumulation. When perceiving that trade surplus and foreign reserves are growing too quickly, the People's Bank of China will recycle the passive money issuance through open market operations. On the asset side, foreign exchange reserves constitute the main part of the foreign assets of the People's Bank of China. Reserve accumulation leads to the growth of foreign assets and the increase of the ratio of foreign assets to total assets. Meanwhile, along with foreign reserve accumulation, money supply in the domestic financial system expands as a result of the passive increase of base money.

Next, we will build an *IS-LM* model to discuss the impacts of foreign exchange reserve accumulation on the macro-economy.

The equilibrium condition in the goods market for an open economy can be written as,

$$Y = C(Y - T) + I(i) + G + NX(Y - T, E) \tag{3.5}$$

where *Y, T, C, I, G*, *NX, E* respectively represent the aggregate output, tax, consumption, investment, government expenditure, net exports and exchange rate. It is well-known that the *LM* curve is derived from the equilibrium condition of the money market as the following equation,

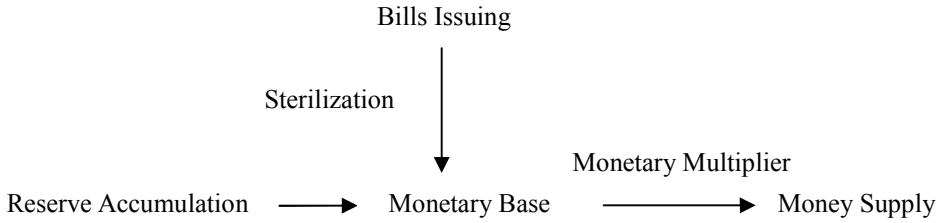
$$\frac{M}{P} = L(Y, i) \tag{3.6}$$

where *M*/*P* denotes the money supply in real terms, and *L*(*Y*, *i*) denotes the demand for money in real terms, which depends on the aggregate output *Y* and interest rate *i*.

Combining equations (3.4) and (3.5) with (3.6) leads to

$$Y = f(R, D, E, P) \tag{3.7}$$

According to the above-mentioned framework, reserve accumulation may cause a growth of money in circulation which will lead to investment growth and economic boom. However, it is worth noting that there are various ways through which reserve accumulation may influence the real economy based on different theories. The transmission mechanism of a foreign exchange reserve accumulation shock may be far more complicated than any theoretical expectation. Apparently theoretical analysis in the existing literature is far from enough.



This chapter makes an attempt to steer away from this shortcoming and investigate the impacts of foreign reserve accumulation under a more realistic condition. It is well-known that the variation in international reserves is nothing but a shift in the overall balance of payments. According to the Monetary Approach to the Balance of Payments (*MABP*), balance of payments is essentially a monetary phenomenon and must be analyzed in terms of money stock adjustment. In fact, the idea that changes in the money stock are important in explaining balance-of-payments adjustment was already present in *Mundell*'s model, but it was further developed by the *MABP* to give these changes an exclusive importance in the context of a different model based on a pure stock-adjustment behavior. Thus it is reasonable to use the similar approach identifying the monetary supply shock to explore the influence of reserve accumulation. Based on all these, we chose seven important macroeconomic variables and adopted the analytical framework of Uhlig (2005) about the effects of monetary policy to employ the Pure-sign-restriction Approach investigating the impact of reserve accumulation.

3.2 The Vector Autoregression Model

3.2.1 Data

China has changed its exchange rate regime from a peg to the U.S. dollar to the managed floating exchange rate regime since July 21st, 2005. In order to avoid the influence from the exchange rate regime change, seven variables at a monthly frequency from August 2005 to September 2015 including the foreign exchange reserves[6], funds outstanding for foreign exchange, base money, real added value of industrial output, real effective exchange rate indices, domestic credit[7] and consumer price index (CPI) are used to build the VAR model. Due to the fact that China reports quarterly GDP since 2005 thus not long enough to match other 6 variables,

[6] The dollar-denominated foreign exchange reserves are adjusted by the spot USD/CNY exchange rate from the Board of Governors of the Federal Reserve System to obtain the foreign reserves denominated in RMB.

[7] The data of domestic credit cannot be directly obtained from the balance sheet of the People's Bank of China, so we calculate it through summarizing the claims on government, claims on other depository corporations, claims on other financial corporations and claims on non-financial sector. All data come from the People's Bank of China.

added value of industrial output as the alternative of output is used to build the VAR system[8]. CPI was converted to the fixed base index beginning from January 2001. Funds outstanding for foreign exchange and base money come from the People's Bank of China. Real effective exchange rate indices come from the Bank for International Settlements (BIS).

Before building a VAR model, unit-root tests should be carried out. However, unit-root test and deterministic trend test entangle with each other. Technically, testing stationarity relies on predetermining if there is an implied deterministic trend or not. Meanwhile, judging whether there is a deterministic trend or not needs the information of data stationarity. Trend-stationarity and difference-stationarity are two competing models to depict economic time series. Perron and Yabu (2009) develop a deterministic trend test with no need of priori knowledge of data stationarity. In order to build a more convincing VAR model, we employ the procedure based on a Feasible Quasi Generalized Least Squares method proposed by Perron and Yabu (2009) to estimate deterministic trends in data and choose the most convincing unit-root model among different competing hypotheses with or without trend and constant.

Thus the procedure proposed by Perron and Yabu (2009) was used to test for the logarithm of all variables. All deterministic trend test results are reported in Table 3-1.

Empirical results in Table 3-1 show that the slope coefficients for the logarithm of all seven variables are significant at least at 95% level. Based on these results, we chose to test stationarity for all seven variables with a deterministic trend and constant. All unit-root test results, which show that all seven variables are trend-stationarity process at least at 95% significant level, are reported in Table 3-2. Thus the logarithm of all seven variables could be used to build a VAR model.

The second step was to set up the VAR model. According to the aforementioned transmission channel of reserve accumulation influencing the real economy, we built a VAR model using the logarithm of all seven variables in the sequential order of foreign exchange reserves, funds outstanding for foreign exchange, base money, domestic credit, real added value of industrial output, CPI and real effective exchange rate with a constant and used Akaike Information Criterion (AIC) to choose the optimal lag length.

3.2.2 Identifying Reserve Accumulation Shock

Consider a VAR framework given by

[8] Before 2007, the National Bureau of Statistics (NBS) released monthly added value of industrial output. However, since 2007, the NBS altered to only report growth rates. Besides, in order to eliminate the impact of unfixed traditional Spring Festival holiday and enhance data comparability, the NBS had not published the growth rate in January since then. For this reason, I first obtain the first two months accumulated added value of industrial output according to the accumulated growth rate compared with the same period of last year, and then subtract the added value in February calculated from the growth rate compared with the same month last year. Lastly, transform them to real values with January 2001 as the base month according to the month-on-month growth rate released since 2011.

$$Y_t = B_1 Y_{t-1} + B_2 Y_{t-2} + \cdots + B_l Y_{t-l} + u_t, \qquad t = 1, \cdots, T \tag{3.8}$$

where Y_t is an $m\times 1$ vector of data at time t=1-l, …, T, B_i are coefficient matrices of size $m\times m$ and u_t is the one-step ahead prediction error with variance-covariance matrix Σ. There is not much disagreement about how to estimate the VARs. The disagreement starts when discussing how to decompose the prediction error u_t into economically meaningful or fundamental innovations which is necessary for examining the impulse responses.

Suppose there are a total of m mutually independent and normalized fundamental innovations written as a vector v of size $m\times 1$ with $E[vv']=I_m$. What is needed is to find a matrix A such that $u_t=Av_t$. The jth column of A represents the immediate impact on all variables of the jth fundamental innovation, one standard error in size. The only restriction on A emerges from the covariance structure

$$\Sigma = E[u_t u_t'] = AE[v_t v_t']A' = AA' \tag{3.9}$$

In order to achieve identification, three procedures are used to obtain the restrictions: the first is to choose A to be a Cholesky factor of Σ and imply a recursive ordering of the variables as in Sims (1986); the second is to rely on some structural relationships between the fundamental innovations $v_{t,i}$, i=1, …, m and the one-step ahead prediction errors $u_{t,i}$, i=1, …, m as in Bernanke (1986), and Blanchard and Watson (1986); the third is to separate transitory from permanent components as in Blanchard and Quah (1989). The way that an agnostic sign-restriction approach deals with is quite different. First, it identifies the impulse vector corresponding to specific shocks. Note that we are solely interested in the response to foreign reserve accumulation shock: there is therefore a priori no reason to also identify the other m-1 fundamental innovations. Here we focus on its application, but more information about the impulse vector can be found in Uhlig (2005). We suppose that a reserve accumulation shock leads to the increase in funds outstanding for foreign exchange after choosing some restriction horizon $K \geq 0$ (Table 3-3).

Assumption 1. A reserve accumulation impulse vector is an impulse vector a, so that the impulse responses[9] to a of foreign exchange reserves and funds outstanding for foreign exchange are not negative, all at horizons k = 0, …, K.

Given some VAR coefficient matrices B=[B'_1, B'_2, …, B'_l], some error variance-covariance

[9] We build a VAR model using the logarithm of all 7 variables, rather than the first differences. Therefore, the restrictions are indeed imposed on the impulse responses while not on the cumulative impulse responses. Besides, we focus on the application of sign restriction methodology thus omit some technical statements. More information about the definition of impulse vector and assumption A.2 can be found in Uhlig (2005).

matrix Σ, and some horizon K, let $A(B, \Sigma, K)$ be the set of all reserve accumulation impulse vectors. Because this is obtained from inequality constraints, one cannot obtain exact identification. In order to deal with this issue, Uhlig (2005) proposes two different but related approaches based on a Bayesian method: the Pure-sign-restriction Approach and the Penalty-function Approach.

Assumption 2 (for the Pure-sign-restriction Approach). The parameters (B, Σ, α) are drawn jointly from a prior on $\bullet^{l\times m\times m}\times\psi_m\times\varphi_m$. The prior is proportional to a Normal-Wishart in (B, Σ), whenever $a=\tilde{A}(\Sigma)\alpha$ satisfies $a\in(B, \Sigma, K)$ and zero elsewhere, *i.e.* is proportional to a Normal-Wishart density multiplied with an indicator variable on $\tilde{A}(\Sigma)\alpha \in (B, \Sigma, K)$.

Under the assumption A.2 in Uhlig (2005), the Pure-sign-restriction Approach is implemented in the following way. Given the assumed Normal-Wishart posterior for (B, Σ), the posterior is obtained by the usual Normal-Wishart posterior for (B, Σ) times the indicator function on $\tilde{A}(\Sigma)\alpha \in (B, \Sigma, K)$. To draw from this posterior, a joint draw is taken from both the posterior for the unrestricted Normal-Wishart posterior for the VAR parameters (B, Σ) as well as a uniform distribution over the unit sphere $\alpha_{in}\varphi_m$. The impulse vector a is constructed and the impulse responses $r_{k,j}$ at horizon $k=0, \ldots, K$ for the variables j, representing foreign exchange reserves and funds outstanding for foreign exchange are calculated. If all these impulse responses satisfy the sign restrictions, the draw is kept. Otherwise, it will be discarded. This is repeated sufficiently and statistics are calculated based on the draw kept.

3.3 Empirical Results

In order to assess the impacts of reserve accumulation more precisely, we make three comparative analyses. First, a traditional impulse response analysis was executed by giving foreign exchange reserves one standard positive shock. Next, a pure-sign-restriction approach only identifying a single reserve accumulation shock was utilized. Finally, a reserve accumulation shock was identified after isolating a business cycle shock, monetary policy shock and external shock based on the analytical framework of Mountford and Uhlig (2009). AIC was used to determine the optimal lag length. In order to further confirm our empirical results, we also looked through the foreign exchange sterilization behavior of the People's Bank of China and made a simple analysis to see the sterilization efficiency.

The VAR system consists of the logarithmic form of these seven variables at a monthly frequency from August 2005 to September 2015, having two lags and a constant.

3.3.1 Traditional Impulse Responses

According to the aforementioned transmission channel of reserve accumulation influencing the real economy, we built a VAR model in the sequential order of foreign exchange reserves, funds outstanding for foreign exchange, base money, domestic credit, real added value of industrial output, CPI and the real effective exchange rate. All results of traditional impulse response analysis are illustrated in Figure 3-1.

In response to the reserve accumulation shock, funds outstanding for foreign exchange did not react strongly immediately but increased approximately in the same proportion as reserve accumulation after six periods. This makes sense, because funds outstanding for foreign exchange are the results of reserve accumulation under foreign exchange settlement and sale.

Base money reacted sluggishly initially and increased slowly from two periods to five periods but not as much in percentage terms as reserve accumulation. However, as time passed by, base money increased more rapidly, for base money issuance related to reserve accumulation would become money supply in circulation through the money creation of banking system. Meanwhile, mild inflation pressure and renminbi (RMB) appreciation showed up immediately following the shock.

Domestic credit gradually decreased swiftly, typically dropping by 1.5% within one period. That is, the People's Bank of China actively reduced various bond asset purchases in order to alleviate the pressure of the passive release of base money caused by foreign reserve accumulation. Meanwhile, real added value of industrial output increased gradually and the most significant influence of reserve accumulation on industrial output reached approximately two fifth as much in percentage terms as reserve accumulation.

These results appear to show that reserve accumulation directly or indirectly impacts all seven variables. However, it is doubtful whether the result of traditional impulse response is related to the assumption of the variable order made on the basis of theoretical analysis. Besides, what needs to be remembered is that there are various ways through which reserve accumulation may influence the real economy based on different theories. The actual transmission process of foreign exchange reserve accumulation influencing the money supply is more complicated than any theoretical expectation.

In addition, from the prospective of sterilization intervention, these results mean that the People's Bank of China may not offset the effects of reserve accumulation on the monetary base through related monetary policy or, alternatively, that sterilization intervention in the foreign exchange market does not have a sufficient large effect. The passive base money launch is still a consequence of reserve accumulation.

3.3.2 Impulse Responses to Reserve Accumulation Shock Identified by Sign Restrictions

After the traditional VAR analysis, a Pure-sign-restriction Approach only identifying the reserve accumulation shock was employed to obtain further understanding.

A reserve accumulation shock is defined as a shock that moves foreign exchange reserves and funds outstanding for foreign exchange up for the next following eight months.[10] An overview of identifying sign restrictions on the impulse responses is provided in Table 3-3. The impulse responses to a single reserve accumulation shock identified by Pure-sign-restriction Approach are illustrated in Figure 3-2.

It is worth noting that the responses of all variables to reserve accumulation shock except for foreign exchange reserves and funds outstanding for foreign exchange are not restricted at all by the identification method, and their responses are quite interesting compared to traditional impulse response analysis. Funds outstanding for foreign exchange and foreign exchange reserves still increase in basically the same velocity.

However, the effects of reserve accumulation shock on all variables in the first five periods were ambiguous. From this point, reserve accumulation had a positive influence on base money and made it increase approximately in the same proportion as reserve accumulation. However, it is important to note that reserve accumulation had no significant influence on inflation and real effective exchange rate. That is, the base money caused by reserve accumulation is moderate rather than excessive.

Impulse responses identified by the Pure-sign-restriction Approach showed that the People's Bank of China may offset the effects of reserve accumulation on the monetary base in a number of ways, and the sterilization intervention seemed to be effective. However, as time passed by, the effect of sterilization intervention degraded gradually as with other economic policies. We believe this result is more suitable to explain the actual economic policy stance of the People's Bank of China. For instance, during the first half of 2005, the People's Bank of China injected 1 trillion RMB base money through foreign exchange purchases and then withdrew 761 billion RMB using flexible open market operations to make a certain degree sterilization. Furthermore, it has strengthened its sterilization intervention policy since the second half of that year in the face of growing overheating pressures. However, to fully sterilize the influence of reserve accumulation can be challenging (Mohanty and Turner, 2006), considering the fiscal cost of intervention, future monetary imbalance, and financial sector imbalance. As a consequence, the government usually attempts partial sterilization rather than full sterilization.

With regard to the concrete policy tools of sterilization and the sterilization efficiency, we

[10] Besides K=8, we also try a wide range of different Ks and find no significant changes. Thus the empirical results are relatively robust and depend little on the selection of K.

will make a detailed discussion in the following analysis.

3.3.3 Impulse Responses to Multiple Shocks Identified by Orthogonal Sign Restrictions

The Pure-sign-restriction Approach shows us a quite different picture than traditional impulse response analysis. However，it is difficult to distinguish the movements in macroeconomic variables caused by foreign reserve accumulation shock from those in response to other possible shocks such as an expansive monetary policy or a booming business cycle. In order to more precisely understand the impacts of reserve accumulation, we make a further trial isolating reserve accumulation shock from three other relevant shocks which may potentially mislead the empirical results.

A booming business cycle shock is defined as a shock that moves output up for eight months following the shock. An expansive monetary policy shock moves base money, domestic credit, and price up for eight months after the shock, and a positive external shock is defined as a shock which promotes reserve accumulation and output growth. Moreover, in order to include the characteristic of RMB appreciation facing China, one extra restriction on exchange rate change was added when identifying an external shock. Thus, an external shock tailored for China is defined as a shock which moves foreign exchange reserves and real added value of industrial output up and the exchange rate down for eight months after the shock[11].

We require the business cycle, monetary policy and external shocks to be orthogonal to each other. The main purpose of characterizing these three shocks is to filter out the automatic responses of foreign exchange reserves and funds outstanding for foreign exchange to them.

Lastly, a reserve accumulation shock is identified as a shock that moves foreign exchange reserves and funds outstanding for foreign exchange up for eight months following the shock and meanwhile meets the requirement that they are orthogonal to the business cycle, monetary policy and external shocks.

The impulse responses to the reserve accumulation shock (Figure 3-3) showed very similar empirical results to these identifying a single foreign reserve accumulation shock. The effect of a reserve accumulation shock on base money remained to be significant but diminished slightly. Sterilization intervention basically eliminates the link between reserve accumulation and base money, thus decreasing the passive money launch. Meanwhile, both figures 3-2 and 3-3 show that the effect of reserve accumulation shocks on domestic credit is ambiguous. It suggests that People's Bank of China could have possibly neutralized the negative influence of excess base money growth caused by reserve accumulation using other more efficient operations rather than

[11] For simplicity, we are imposing sign restrictions on the similar variables as Mountford and Uhlig (2009) do to identify the business cycle and monetary policy shocks.

reducing bond asset purchases from government or corporations.

The impulse responses to the business cycle shock, monetary policy shock and external shock are separately shown in Figures 3-4 to Figure 3-6. The results show that monetary policy shock and external shock have a very remarkable positive impact on base money and output, and business cycle shock has a significant positive impact on output. Therefore, without orthogonalization to the business cycle, monetary policy and external shocks, sign restriction methods maybe overestimate the impact for real added value of industrial output in response to reserve accumulation shock.

In addition, in response to the monetary policy shock, the effect on the real added value of industrial output was significant initially but became ambiguous after six periods. Relatively, from this point, RMB depreciation began to show up. In other words, an expansive monetary policy had no effect on output in the long term. Similar to Frankel and Wei (2007), our findings suggest that China's de facto exchange rate regime remains pegged to the U.S. dollar, even after shifting to the managed floating exchange rate regime.

3.4 Sterilization Intervention Policy and Sterilization Efficiency

During the period from 2007 to 2009 of rapidly increasing of foreign exchange reserves, the proportion of funds outstanding for foreign exchange to base money is even close to the highest 140% (Figure 1-2), which suggests that funds outstanding for foreign exchange have probably become the primary channel to release base money. This indicates that the People's Bank of China needs to take measures to eliminate the underlying inflation pressure caused by the excess monetary base.

Impulse response results to the reserve accumulation shock identified by Pure-sign-restriction Approach show that in the early stage, impacts of foreign reserve accumulation on base money are not significant. Moreover, inflation does not appear to be influenced by reserve accumulation. These occur probably because the People's Bank of China sterilized the influence of base money passive release caused by the increase of funds outstanding for foreign exchange. In order to further confirm these empirical results, we looked through the foreign exchange sterilization behavior of the People's Bank of China and made a simple analysis to see the sterilization efficiency by adapting the regression equation similar to Aizenman and Glick (2008).

First, we will discuss the specific sterilization operation behavior of the People's Bank of China. Figure 3-7 illustrates that the People's Bank of China has two prominent ways to sterilize the passive base money release: one is to issue central bank bills through open market operations and the other is to adjust the reserve requirement ratio[12] for domestic financial institutions. From

[12] In contrast to most other countries, the People's Bank of China seeks to sterilize the effects of reserve inflows, not just on the reserve money base by, for example, government bonds or central bank bills or by using swaps,

2003 to 2011, the bill issuance of the People's Bank of China continued to grow from 58.89 billion to 4717.96 billion, and the deposit reserve ratio increased from 6% to 20.5% by 33 reserve requirement ratio adjustments, thus recycling 17.02 trillion base money during this time. Meanwhile, the sharp increase of public deposits to some extent implies that the authority probably tried to reduce the deposits in commercial banks to indirectly weaken the negative influence of passive money supply growth led by the increase of funds outstanding for foreign exchange.

As far as the relative importance of different sterilization operations (Figure 3-8), during 2003 and 2008, the People's Bank of China paid more attentions to the sterilization effect through bond issuance. In 2006, in particular, the proportion of sterilization through bond issuance reached up to 36%, obviously outpacing other sterilization modes, and started to decrease afterwards, ending with less than 3% as of the end of 2013.

Meanwhile, compared with the high-cost bond issue sterilization operation[13], the adjustment of the reserve requirement ratio gained more and more attention. During the period from September 2003 to June 2011, the proportion of base money shrink due to reserve requirement ratio adjustments to the funds outstanding for foreign exchange increased from 26.7% to 71.6%. However, the influence of adjusting the reserve requirement ratio is not easy to control, and overshooting adjustment will lead to the shrinkage of total social financing and negatively influence economic development. Thus, the adjustment of reserve requirement ratio has no longer been frequently used in recent years. As of September, 2015, it was even decreased to 17.5%. In contrast, the proportion of public deposits is basically maintained between 10% and 20%. Although having been declining in recent years, it still plays an important role. However, from the point of the proportion of total sterilization, the People's Bank of China is more inclined to take partial sterilization policy other than fully sterilizing reserve accumulation.

We now turn to quantitatively analyze the degree of sterilization by estimating a simple regression with the domestic asset change of the People's Bank of China on the change of foreign exchange reserves, where the change is measured over four quarters, and scaled by the level of reserve money stock four quarters ago. We also include the rate of nominal GDP growth on the right-hand side to control for other explanatory variables that might influence the demand for money.

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but also on the broader money supply by increasing the deposit reserve ratio. However, because of uncontrollability of its policy effect, more frequent adjustments of deposit reserve ratio would have a negative impact on the domestic economy and financial system. Therefore, this tool is not used much anymore in many countries except in China.

[13] Sterilization operations such as selling central bank bills and government bonds also have costs. First, there is the cost of sterilization associated with the difference between the returns paid on central bank liabilities issued to sterilize domestic liquidity and the returns earned on foreign reserve assets. Second, greater use of open market instruments, especially selling central bank bills, can hinder the development of money market and boost money market interest rates up.

$$\frac{\Delta DC_t}{BM_{t-4}} = \alpha + \beta \times \frac{\Delta FR_t}{BM_{t-4}} + Z_t + \varepsilon_t \qquad (3.10)$$

where ΔFR is the change in net foreign reserve assets of central bank, ΔDC is the change in net domestic credit assets, BM denotes the reserve money stock (base money), Z is defined as the rate of nominal GDP growth and ε is stochastic disturbance.

We estimated the sterilization coefficient, β, with OLS using 40-quarter rolling samples. β = -1 represents full monetary sterilization of reserve changes, while β = 0 implies no sterilization. A value of the sterilization coefficient between -1 and 0, $-1 < \beta < 0$, indicates partial sterilization.

The results are plotted in Figure 3-9, and show that the extent of sterilization was relatively limited until early 2005, but the sterilization coefficient began rising from roughly 0.1 in 2006, accelerating in the following years into 2013 when it reached 0.5. The results are also consistent with the findings in the above analysis. That is, the inflows of foreign exchange reserves were being sterilized frequently by the People's Bank of China, since 2006, primarily through sales of the central bank bills and reserve requirement ratio adjustments. However, the plot peaked at almost 1.0 in the latter half of 2013, and illustrates a reversal of China's sterilization behavior in 2014. This obvious decline in China's sterilization efficiency can be attributed to several possibilities such as transfer of foreign exchange reserves to China's new sovereign wealth fund, the China Investment Corporation, established in the latter half of 2007, slowdown in the growth of China's foreign exchange reserves, or limitation to the extent of the ability of the People's Bank of China to sterilize its massive reserve inflows. However, with one important note, the time lag of monetary policy may have existed and influenced the People's Bank of China to achieve the desired target of monetary policy.

3.5 Summary

We have presented a new approach for identifying the effects of reserve accumulation shock utilizing the methodology of pure-sign restrictions. This method uses only the information in the macroeconomic variables and minimal assumptions to identify the shock based on the VAR model.

Sign restriction analysis showed that a reserve accumulation shock had a significant positive impact only on base money. In other words, the excessive accumulation of foreign exchange reserves cannot promote economic growth. However, it is important to notice that sign restriction method overvalued the impact on base money in response to a reserve accumulation shock when not filtering out the business cycle, monetary policy and external shocks. On the other hand, we found that reserve accumulation had a significant impact on all of the variables from the beginning under the traditional impulse response analysis with the confirmed order of variables.

However, our analysis on the sterilization intervention found that the People's Bank of China frequently offset the effects of reserve accumulation, though the effect of this policy became less efficient over time. These findings suggest that the assumption for variable order in the VAR system can potentially influence the empirical results.

Chapter 4. Does China Effectively Manage Its Foreign Exchange Reserves? Revisiting the Currency Composition Adjustment

The currency composition adjustment is an important tool for large scale foreign exchange reserve management. As China's foreign exchange reserves unceasingly accumulates, the currency composition management appears to be more and more important. In this chapter, we estimate the currency composition of China's foreign exchange reserves and assess its effectiveness of management.

4.1 Foreign Exchange Reserves in the Balance of Payments and the International Investment Position

Until now, little light has been shed on relevant themes about China's foreign exchange reserve portfolio. In this field, the U.S. Treasury International Capital System (TIC) and the International Monetary Fund (IMF) Currency Composition of Official Foreign Exchange Reserves (COFER) are two widely used data sources. However, as Prasad and Wei (2007) point out, based on such following two reasons, the TIC report is probably not an appropriate representative of the U.S. dollar asset portfolio: first, the TIC report records the direct transactions between U.S. residents and the counterparties located in China, which excludes the indirect purchase of the People's Bank of China through oversea branches, and may underestimate the reserve portfolio; second, the investment mentioned in the TIC report refers to the security investment of all Chinese residents in the United States including not only foreign exchange reserve investment but also other domestic institutions' investments[14], and thus is not the same concept as the investment of foreign exchange reserve portfolio. In addition, the TIC report is helpless to explore the composition about euro and yen assets. As to the IMF COFER, it builds on a voluntary reporting basis. China only reports a representative portfolio on a partial basis and thus the data is incomplete[15]. In short, there is no convincing public data that could be used to infer the currency composition of China's foreign exchange reserves.

Thanks to the revision about relevant accounting principles, the data of non-purchase change could be constructed combining the Balance of Payments and the International Investment Position. On February 5th, 2010, the State Administration of Foreign Exchange declared to revise

[14] For example, since 2007, domestic commercial banks have been allowed to submit part of reserves against deposit in the form of foreign exchange. It is not supposed to be counted as national foreign exchange reserves, while it is included in the TIC report.

[15] According to the IMF, China will gradually increase the reported portfolio to full coverage of foreign exchange reserve assets within a period of around two to three years.

the accounting principle of foreign exchange reserves, which was that the foreign exchange reserves in the Balance of Payments would only record the net transaction data (net purchases) henceforth, while the inventory change of foreign exchange reserves caused by other non-trading factors, such as exchange rate fluctuation and interest rate variation, would reflect in the International Investment Position. In the meantime, data from 2003 to 2008 were also adjusted in accordance with the new accounting principle. This revision does not only get closer to the international practice, but also helps us recognize the sources of reserve variation. According to the new accounting principle, the change of the net position of foreign exchange reserves in the International Investment Position can be decomposed into two separate parts: the first is the flow part, namely the net trading part recorded in the Balance of Payments; the second is the inventory change caused by other non-trading factors. For a long time, the net purchase is the

$$\Delta IIP_t = \underbrace{Flow_t}_{Net\ purchase\ (BOP)} + \underbrace{\Delta Stock_{t-1}}_{Exchange\ rate\ fluctuation+Interest\ rate\ variation+Impacts\ of\ other\ non-trading\ factors}$$

primary cause of foreign exchange reserve accumulation (Figure 4-1). However, since the 2008 global financial crisis, the change of foreign exchange reserves caused by exchange rate volatility and interest rate variation has become more and more significant. Meanwhile, it is worth noting that China's monetary authority has begun to shrink its huge foreign exchange reserves through some active or passive management operations since 2014.

We decomposed the change of foreign exchange reserves into the net purchase change and non-purchase change, which is consistent with the behavior-model-free method of Sheng (2013). However, we expanded the decomposition equation to include 7 primary international currencies. The decomposition only relies on portfolio accounting identities and budget constraints for central bank's holding of foreign exchange reserves. Based on the decomposition, we constructed more convincing data rather than took the computed reserve change denominated in the U.S. dollar as the proxy of the net purchases as Sheng (2013) did[16].

4.2 Estimating the Currency Composition of China's Foreign Exchange Reserves

4.2.1 Decomposing the Change of Foreign Exchange Reserves

This section decomposed the change of foreign exchange reserves into the net purchase change as well as the non-purchase change, and related the change rate of non-purchase part to the currency composition, investment returns and exchange rate volatility.

At first, in order to calculate investment returns, we simply supposed that China's foreign

[16] Sheng (2013) computes the net purchases of reserves in the U.S. dollar value using the data of foreign exchange assets in renminbi on the balance sheet of the People's Bank of China and foreign exchange rate. His way to calculate the net purchases indirectly includes the influence of exchange rate and thereby lacks of accuracy.

exchange reserves totally invested on highly rated sovereign debts. In order to further improve the quality and transparency of information disclosure, the State Administration of Foreign Exchange has started to release monthly reserve data according to the IMF Special Data Dissemination Standard (SDDS) in the Reserve Template since June 2015. According to the disclosure of the State Administration of Foreign Exchange, China's foreign exchange reserves are comprised of securities, and currency and deposits. The share of currency and deposits in total foreign reserves is so small compared with that of securities (Table 4-1). Due to that the return on currency and deposits is relatively low and stable, the change of foreign exchange reserves is more likely associated with its security investment. To simplify the calculation of investment returns, we temporarily put aside the term structure of securities and supposed that the securities the State Administration of Foreign Exchange held concentrated on 10-year sovereign credit debts.

Accordingly, China's foreign exchange reserves denominated in the U.S. dollar at time t (FR_t) consisted of 7 assets, namely the U.S. dollar (USD_t), the euro (EUR_t), the pound sterling (GBP_t), the Japanese yen (JPY_t), the Swiss franc (CHF_t), the Canadian dollar (CAD_t) and the Australian dollar (AUD_t). Let $e_t^{USD/GBP}$, $e_t^{USD/JPY}$, $e_t^{USD/EUR}$, $e_t^{USD/CHF}$, $e_t^{USD/CAD}$, and $e_t^{USD/AUD}$ denote the nominal exchange rates of corresponding currencies against the U.S. dollar, respectively. According to the portfolio accounting identity[17], foreign exchange reserves at time t could be expressed as,

$$\begin{aligned} FR_t = {} & USD_t + GBP_t e_t^{USD/GBP} + JPY_t e_t^{USD/JPY} + EUR_t e_t^{USD/EUR} \\ & + CHF_t e_t^{USD/CHF} + CAD_t e_t^{USD/CAD} + AUD_t e_t^{USD/AUD} \end{aligned} \tag{4.1}$$

At time t+1, the State Administration of Foreign Exchange purchased new foreign assets, received investment returns from the previous holdings of foreign exchange reserves, and adjusted its reserve portfolio in foreign exchange market. The budget constraint for holding foreign reserve assets was given by

$$\begin{aligned} FR_{t+1} = {} & \Delta^{ps} Sec_{t+1} + \left(1 + r_t^{USD}\right) USD_t + \left(1 + r_t^{GBP}\right) GBP_t e_{t+1}^{USD/GBP} \\ & + \left(1 + r_t^{JPY}\right) JPY_t e_{t+1}^{USD/JPY} + \left(1 + r_t^{EUR}\right) EUR_t e_{t+1}^{USD/EUR} \\ & + \left(1 + r_t^{CHF}\right) CHF_t e_{t+1}^{USD/CHF} + \left(1 + r_t^{CAD}\right) CAD_t e_{t+1}^{USD/CAD} \\ & + \left(1 + r_t^{AUD}\right) AUD_t e_{t+1}^{USD/AUD} + \pi_{t+1} \end{aligned} \tag{4.2}$$

where $\Delta^{ps} Sec_{t+1}$ denoted the net purchase change of foreign exchange reserves denominated in the U.S. dollar (the process diversifying the newly increased foreign exchange reserves on different assets)[18]. r_t^j, j=*USD*, *GBP*, *JPY*, *EUR*, *CHF*, *CAD*, *AUD*, represented the investment

[17] More information could be found in Dominguez (2012), Dominguez *et. al.* (2012) and Sheng (2013).
[18] In our simplified analysis, foreign exchange reserves were all invested in the highly rated sovereign debts.

return rate of asset i from time t to time t+1. π_{t+1} represented the net profit or loss caused by portfolio adjustment in foreign exchange market[19].

It is noteworthy that the behavior of portfolio adjustment is essentially a trading process which requires the transaction subject to sell some assets and buy other assets with these corresponding funds in the meantime. Generally, the amount of assets remains unchanged. Thus, $\Delta^{ps}Sec_{t+1}$ does not relate to the gross portfolio adjustment trading but refers to the net purchase of foreign assets.

Besides, we supposed that the State Administration of Foreign Exchange was able to swiftly accomplish this kind of asset transformation without trading loss. The only profit or loss of portfolio adjustment came from the difference between the buying price and the selling price of the same asset.

Therefore, the change of foreign exchange reserves could be obtained by subtracting equation (4.1) from equation (4.2).

$$\begin{aligned} FR_{t+1} - FR_t = {} & \Delta^{ps}Sec_{t+1} + GBP_t\left(e_{t+1}^{USD/GBP} - e_t^{USD/GBP}\right) \\ & + JPY_t\left(e_{t+1}^{USD/JPY} - e_t^{USD/JPY}\right) + EUR_t\left(e_{t+1}^{USD/EUR} - e_t^{USD/EUR}\right) \\ & + CHF_t\left(e_{t+1}^{USD/CHF} - e_t^{USD/CHF}\right) + CAD_t\left(e_{t+1}^{USD/CAD} - e_t^{USD/CAD}\right) \\ & + AUD_t\left(e_{t+1}^{USD/AUD} - e_t^{USD/AUD}\right) + r_t^{USD}USD_t + r_t^{GBP}GBP_t e_{t+1}^{USD/GBP} \\ & + r_t^{JPY}JPY_t e_{t+1}^{USD/JPY} + r_t^{EUR}EUR_t e_{t+1}^{USD/EUR} + r_t^{CHF}CHF_t e_{t+1}^{USD/CHF} \\ & + r_t^{CAD}CAD_t e_{t+1}^{USD/CAD} + r_t^{AUD}AUD_t e_{t+1}^{USD/AUD} + \pi_{t+1} \end{aligned} \tag{4.3}$$

The change rate of foreign exchange reserves could be formulized by,

Thus, the net purchase of reserves equals to the purchase of securities $\Delta^{ps}Sec_{t+1}$.

[19] Like Sheng (2013) , we assume that the State Administration of Foreign Exchange adjust its reserve portfolio at the beginning of each period, and keeps it the same for the remaining time in this period.

$$
\begin{aligned}
\dot{FR}_{t+1} &= \frac{FR_{t+1} - FR_t}{FR_t} \\
&= \frac{\Delta FR}{FR_t} \\
&= R_{t+1}^{ps} + \frac{\pi_{t+1}}{FR_t} + r_t^{USD}\frac{USD_t}{FR_t} + \frac{GBP_t}{FR_t}\left(e_{t+1}^{USD/GBP} - e_t^{USD/GBP} + r_t^{GBP} e_{t+1}^{USD/GBP}\right) \\
&+ \frac{JPY_t}{FR_t}\left(e_{t+1}^{USD/JPY} - e_t^{USD/JPY} + r_t^{JPY} e_{t+1}^{USD/JPY}\right) \\
&+ \frac{EUR_t}{FR_t}\left(e_{t+1}^{USD/EUR} - e_t^{USD/EUR} + r_t^{EUR} e_{t+1}^{USD/EUR}\right) \\
&+ \frac{CHF_t}{FR_t}\left(e_{t+1}^{USD/CHF} - e_t^{USD/CHF} + r_t^{CHF} e_{t+1}^{USD/CHF}\right) \\
&+ \frac{CAD_t}{FR_t}\left(e_{t+1}^{USD/CAD} - e_t^{USD/CAD} + r_t^{CAD} e_{t+1}^{USD/CAD}\right) \\
&+ \frac{AUD_t}{FR_t}\left(e_{t+1}^{USD/AUD} - e_t^{USD/AUD} + r_t^{AUD} e_{t+1}^{USD/AUD}\right)
\end{aligned} \tag{4.4}
$$

where $R_{t+1}^{ps} = \Delta^{ps} Sec_{t+1} / FR_t$ represented the net purchase rate of foreign exchange reserves.

Let $R_{t+1}^{nps} = \dot{FR}_{t+1} - R_{t+1}^{ps} = \Delta^{nps} Sec_{t+1} / FR_t$ represent the non-purchase change rate of foreign exchange reserves, where $\triangle^{nps} Sec$ denotes the non-purchase change in the existing assets caused by exchange rate volatility, interest rate variation and other non-trading factors. A key assumption on this point is that the volatility of exchange rate and the swing of interest rate are two most important non-purchase influential factors on the change of foreign exchange reserves. The change of foreign exchange reserves at time *t* thus could be decomposed into two relevant parts: the net purchase change and the non-purchase change.

Let

$$
share_t^i = \begin{cases} \dfrac{USD_t}{FR_t}, i = USD \\ \dfrac{i_t e_t^{USD/i}}{FR_t}, i = GBP, JPY, EUR, CHF, CAD, AUD \end{cases}
$$

represent the value share of asset *i* in foreign exchange reserves at time *t*. The non-purchase change rate of foreign exchange reserves could be restructured as,

$$
\begin{aligned}
R_{t+1}^{nps} &= \Delta^{nps} Sec_{t+1} / FR_t \\
&= c_{t+1} + r_t^{USD} \times share_t^{USD} + share_t^{GBP} \times \frac{e_{t+1}^{USD/GBP} - e_t^{USD/GBP} + r_t^{GBP} e_{t+1}^{USD/GBP}}{e_t^{USD/GBP}} \\
&+ share_t^{JPY} \times \frac{e_{t+1}^{USD/JPY} - e_t^{USD/JPY} + r_t^{JPY} e_{t+1}^{USD/JPY}}{e_t^{USD/JPY}} \\
&+ share_t^{EUR} \times \frac{e_{t+1}^{USD/EUR} - e_t^{USD/EUR} + r_t^{EUR} e_{t+1}^{USD/EUR}}{e_t^{USD/EUR}} \\
&+ share_t^{CHF} \times \frac{e_{t+1}^{USD/CHF} - e_t^{USD/CHF} + r_t^{CHF} e_{t+1}^{USD/CHF}}{e_t^{USD/CHF}} \\
&+ share_t^{CAD} \times \frac{e_{t+1}^{USD/CAD} - e_t^{USD/CAD} + r_t^{CAD} e_{t+1}^{USD/CAD}}{e_t^{USD/CAD}} \\
&+ share_t^{AUD} \times \frac{e_{t+1}^{USD/AUD} - e_t^{USD/AUD} + r_t^{AUD} e_{t+1}^{USD/AUD}}{e_t^{USD/AUD}}
\end{aligned}
\tag{4.5}
$$

where $c_{t+1}=\pi_{t+1}/FR_t$ denoted the net profit or loss rate from portfolio adjustment in foreign exchange markets.

In order to more intuitively understand the non-purchase change rate of foreign exchange reserves, equation (4.5) could be rearranged as,

$$
\begin{aligned}
R_{t+1}^{nps} &= c_{t+1} + r_t^{USD} \times share_t^{USD} + r_t^{GBP} \times share_t^{GBP} + r_t^{JPY} \times share_t^{JPY} + r_t^{EUR} \times share_t^{EUR} \\
&+ r_t^{CHF} \times share_t^{CHF} + r_t^{CAD} \times share_t^{CAD} + r_t^{AUD} \times share_t^{AUD} \\
&+ share_t^{GBP} \times \left(1 + r_t^{GBP}\right) \times \frac{e_{t+1}^{USD/GBP} - e_t^{USD/GBP}}{e_t^{USD/GBP}} \\
&+ share_t^{JPY} \times \left(1 + r_t^{JPY}\right) \times \frac{e_{t+1}^{USD/JPY} - e_t^{USD/JPY}}{e_t^{USD/JPY}} \\
&+ share_t^{EUR} \times \left(1 + r_t^{EUR}\right) \times \frac{e_{t+1}^{USD/EUR} - e_t^{USD/EUR}}{e_t^{USD/EUR}} \\
&+ share_t^{CHF} \times \left(1 + r_t^{CHF}\right) \times \frac{e_{t+1}^{USD/CHF} - e_t^{USD/CHF}}{e_t^{USD/CHF}} \\
&+ share_t^{CAD} \times \left(1 + r_t^{CAD}\right) \times \frac{e_{t+1}^{USD/CAD} - e_t^{USD/CAD}}{e_t^{USD/CAD}} \\
&+ share_t^{AUD} \times \left(1 + r_t^{AUD}\right) \times \frac{e_{t+1}^{USD/AUD} - e_t^{USD/AUD}}{e_t^{USD/AUD}}
\end{aligned}
\tag{4.6}
$$

It is easily to find that the non-purchase change rate is equal to the summation of the net profit or loss rate from portfolio adjustment, the investment return rate of the existing assets and the valuation change caused by exchange rate fluctuation.

4.2.2 Estimating the Currency Composition Based on Constrained Least Squares

In terms of empirical research, estimating the currency composition of China's foreign exchange reserve is a rather thorny problem. Convincing researches and empirical results are

quite rare. The recent work of Sheng (2013) is quite inspiring. For the first time, he estimates the currency composition of China's foreign exchange reserves through State-Space Gaussian Mixture Model, which deals with the unobserved currency composition as time-varying parameters to be estimated. However, one of the key defects of Sheng (2013) is that the currency composition strictly relies on the setting about state equation. In fact, there is neither prior information about state values nor information about state transitions to guide the setting about empirical model. Thus, the assumption implied in state space model is probably too subjective and disputable. Unlike Sheng (2013), we revised these inappropriate settings and estimated the currency composition of China's foreign exchange reserves using constrained least squares, which only exerted widely acceptable boundary assumptions on the parameters to be estimated.

To estimate the value shares of different currencies in foreign exchange reserves, we assumed that there was a random disturbance, *e.g.* personal errors and omission in accounting, to equation (4.5) and turned it into such following simple regression model.

$$R_{t+1}^{nps} = c_{t+1} + \mathbf{rr}_t \times \mathbf{Share}_t + \varepsilon_t \tag{4.7}$$

where

$$R_{t+1}^{nps} = \frac{\Delta^{nps} Sec_{t+1}}{FR_t}, \qquad t = 1, 2, ..., T$$

$$\mathbf{Share}_t = \left[share_t^{USD}, share_t^{GBP}, share_t^{JPY}, share_t^{EUR}, share_t^{CHF}, share_t^{CAD}, share_t^{AUD} \right]^T$$

$$\mathbf{rr}_t = \left[rr_t^{USD}, rr_t^{GBP}, rr_t^{JPY}, rr_t^{EUR}, rr_t^{CHF}, rr_t^{CAD}, rr_t^{AUD} \right]$$

$$rr_t^i = \begin{cases} r_t^{USD} & i = USD \\ \dfrac{e_{t+1}^{USD/i} - e_t^{USD/i} + r_t^i e_{t+1}^{USD/i}}{e_t^{USD/i}} & i = GBP, JPY, EUR, CHF, CAD, AUD \end{cases}$$

where R_{t+1}^{nps} represented the non-purchase change rate of foreign exchange reserves at time t+1, $\mathbf{Share}_t$ was a 7×1 vector denoting the value share of major reserve currencies at time t, and $\mathbf{rr}_t$ was a 1×7 vector, which consisted of the investment returns of major currencies covering exchange rate volatility and interest rate variation at time t.

The significant difference between our research and previous work, *i.e.* Sheng (2003), is that we did not make any assumptions about the change of currency composition but assumed it randomly fluctuated in a specific range. This kind of specification considers both the relative stability of latent currency composition and its possible dramatic change. Some findings show that the shares of major currencies in global reserve holdings are very persistent (Eichengreen and Mathieson, 2000; Chinn and Frankel, 2007). Due to the limited bearing capacity of financial markets, it is impossible for reserve management entities to dramatically adjust the currency composition without affecting the market price. Thus it seems more reasonable and prudent to

assume the value shares of foreign assets in foreign exchange reserves fluctuate slightly in a certain range. Certainly, our setting not only covers the characteristic of gradually changed parameters but also allows for possible jumps of the currency composition and breaks, which were handled as mixture innovations in the Gaussian state equation in Sheng (2003). Notably, we did not assume any processes or forms to follow for the possible adjustment of currency composition but let data speak for themselves. Remember that in addition to these widely acceptable boundary constraints we did not impose any other possible restrictions.

Rearranging equation (4.7) with bound constraints and another equality constraint about the sum of value shares, *e.g.* the sum of value shares of selected reserve currencies equals to 1, could lead us to the equivalent optimal problem of estimating the currency composition of China's foreign exchange reserves at time *t*,

$$\min_{\mathbf{Share}_t} \quad \frac{1}{2}\left\| \begin{pmatrix} 1 & \mathbf{rr}_t \end{pmatrix} \cdot \begin{pmatrix} c_{t+1} \\ \mathbf{Share}_t \end{pmatrix} - R_{t+1}^{nps} \right\|_2^2 \tag{4.8}$$

subject to

$$\begin{aligned} &\sum_i share_t^i = sum_t \\ &L_t^i \le share_t^i \le U_t^i \end{aligned}, \qquad i = USD, GBP, JPY, EUR, CHF, CAD, AUD$$

where sum_t was the sum of the shares of primary currencies at time *t*. L^i_t and U^i_t denoted the lower and upper bounds of the share of currency *i* at time *t*, respectively. Therefore, estimating the currency composition of foreign exchange reserves is equivalent to solving the constrained linear least square problem at any time *t* during the whole sample range.

With respect to empirical estimation, our research might rely on two crucial parameter settings: one is the sum of the shares of primary currencies, and the other is the setting about lower and upper boundaries. As far as the sum of all shares, given the existence of other reserve currencies besides these 7 selected currencies, the sum of value shares in our research should be a little smaller than 1. Therefore, we used data from the IMF-COFER to calculate a approximation. Due to such following two reasons, this approximation is appropriate: one is that China is one of the reporters of the IMF-COFER. As world's largest reserve holding country, the composition of China's representative foreign reserve portfolio will significantly influence the IMF-COFER, especially the composition of the foreign exchange reserves of emerging and developing countries. The other reason to make this approximation is that recent work, *e.g.* Sheng (2013), also verifies the rationality of using the COFER as an alternative when studying the currency composition of China's foreign exchange reserves. As for the determination of lower and upper bound constraints, we made a trade-off between the IMF-COFER and the trade relations of China with selected countries and set the target shares of the U.S. dollar, the euro, the pound sterling, the Japanese yen, the Swiss franc, the Canadian dollar and the Australian dollar

to the range of 55%~70%, 15%~30%, 3%~7%, 1%~5%, 0~1%, 2%~4% and 1%~3%, respectively. Afterwards, we employed the *lsqlin* active-set algorithm in MATLAB Optimization Toolbox solvers to solve a series of constrained linear least square problems.

4.3 Portfolio Adjustment and Risk Change: A Perspective from Variance Sensitivity

How should China manage the currency composition of its huge foreign exchange reserves? Specific operation rules rely on the influence of currency composition adjustment on portfolio variance. The Variance Sensitive Analysis proposed by Manganelli (2004) could evaluate the impact that each individual currency has on the foreign reserve portfolio variance and thus would help the State Administration of Foreign Exchange to improve the management of China's foreign exchange reserves.

The variance sensitive analysis could be performed in the context of univariate GARCH models. Noticeably, the portfolio return and the estimated parameters of the GARCH model are functions of the weights. Consequently, the estimated portfolio variance is a function of the portfolio weights, both through the vector of portfolio returns and through the estimated parameters.

Let y_t^{fr} be the return of foreign reserve portfolio composed by n+1 major international currencies. y_t^i represented the return of currency i at time t, for t=1, ..., T, and i=1, …, n+1. a_i denoted the weight of currency i. Then, the portfolio return of foreign exchange reserves at time t was $y_t^{fr} = \sum_{i=1}^{n+1} a_i y_t^i$.

Assume that y_t^{fr} followed a zero-mean process with a GARCH(p, q) conditional variance h_t,

$$\begin{aligned} y_t^{fr} &= \sqrt{h_t}\varepsilon_t \qquad \varepsilon_t \left| \Omega_t \bullet (0,1) \right. \\ h_t &= z_t'\theta \end{aligned} \tag{4.9}$$

where

$$\underset{m\times 1}{z_t} = \left(1, y_{t-1}^2, ..., y_{t-q}^2, h_{t-1}, ..., h_{t-p}\right)'$$

$$\underset{m\times 1}{\theta} = \left(\alpha_0, \alpha_1, ..., \alpha_q, \beta_1, ..., \beta_p\right)'$$

$$m = p + q + 1$$

$$\Omega_t = \left\{a, [y_j^1]_{j=1}^{t-1}, ..., [y_j^{n+1}]_{j=1}^{t-1}\right\}$$

where $\boldsymbol{a}$ denoted the n-vector of currency composition[20].

The potential influence of any currency composition adjustment on the portfolio variance of

[20] Since the sum of weights a_i should be 1, the n+1 weight can be written as a function of the others and given by 1 minus the sum of the other weights, $a_{n+1} = 1 - \sum_{i=1}^{n} a_i$.

foreign exchange reserves could be evaluated by computing the first derivative of reserve portfolio variance with respect to currency weights.

Let $\hat{h}_t = \hat{z}_t'\hat{\theta}$ be the estimated variance. It is noticeable that not only the vector $\hat{z}_t'$, but also the vector of estimated coefficients $\hat{\theta}$, depends on ***a***. The first derivative of $\hat{h}_t$ with respect to ***a*** is given by,

$$\underset{n\times 1}{\frac{\partial \hat{h}_t}{\partial a}} = \underset{n\times m}{\frac{\partial \hat{z}_t'}{\partial a}} \underset{m\times 1}{\hat{\theta}} + \underset{n\times m}{\frac{\partial \hat{\theta}'}{\partial a}} \underset{m\times 1}{\hat{z}_t} \tag{4.10}$$

In order to determine the concavity, it may be necessary to compute its second derivative,

$$\begin{aligned}\underset{n\times n}{\frac{\partial^2 \hat{h}_t}{\partial a \partial a'}} = \underset{n\times m}{\frac{\partial \hat{z}_t'}{\partial a}} \underset{m\times n}{\frac{\partial \hat{\theta}}{\partial a'}} + \underset{n\times m}{\frac{\partial \hat{\theta}'}{\partial a}} \underset{m\times n}{\frac{\partial \hat{z}_t}{\partial a'}} + \underset{n\times mn}{\left(\underset{1\times m}{\hat{\theta}'} \otimes \underset{n\times n}{I_n}\right)} \underset{mn\times n}{\frac{\partial}{\partial a'}} vec\left(\frac{\partial \hat{z}_t'}{\partial a}\right) \\ + \underset{n\times mn}{\left(\underset{1\times m}{\hat{z}_t'} \otimes \underset{n\times n}{I_n}\right)} \underset{mn\times n}{\frac{\partial}{\partial a'}} vec\left(\frac{\partial \hat{\theta}'}{\partial a}\right)\end{aligned} \tag{4.11}$$

where $\otimes$ denoted the Kronecker product and I_n was an ($n\times n$) identity matrix.

To evaluate the behavior of derivatives, the implicit function theorem must be applied to the first-order conditions of the log-likelihood maximization problem. The first-order conditions for equation (4.9) were

$$T^{-1}\sum_{t=1}^{T} \left.\frac{\partial l_t(\theta)}{\partial \theta}\right|_{\theta=\hat{\theta}} = 0 \tag{4.12}$$

where $l_t(.)$ was the time t component of the log-likelihood function.

The **Theorem 1** in Manganelli (2004) derives the analytical expressions for $\frac{\partial \hat{\theta}'}{\partial a}$ and $\frac{\partial}{\partial a'} vec\left(\frac{\partial \hat{\theta}'}{\partial a}\right)$ and the other terms are easily obtained. Noticeably, in order to compute the sensitivity of GARCH variances from the simple series of portfolio returns, equations (4.10) and (4.11) and **Theorem 1** make use of not only the portfolio returns of foreign exchange reserves, but also the returns of primary currencies. A positive derivative would indicate that the currency composition adjustment will influence the portfolio variance of foreign exchange reserves in the same direction and vice versa for a negative derivative.

4.4 Data and Results

4.4.1 Data

The data used to construct empirical estimations are the non-purchase change rate of foreign exchange reserves, investment returns of major currencies, and exchange rates of selected

currencies against the U.S. dollar.

The non-purchase change rate of foreign exchange reserves was obtained by subtracting the net purchase rate of foreign exchange reserves from the change rate of foreign exchange reserves. This work can be done because the State Administration of Foreign Exchange has revised the accounting principle since 2010 and revised the data from 2003 to 2008 accordingly. The Balance of Payments was used to calculate the net purchase rate of foreign exchange reserves and the International Investment Position was employed to obtain the change rate of foreign exchange reserves. Our sample of the non-purchase change rate of foreign exchange reserves covers the period from 2003Q1 to 2015Q2. Apparently, the variation tendency of the change rate of foreign exchange reserves relatively kept pace with that of the net purchase rate before 2008 global financial crisis (Figure 4-2). However, since the outbreak of the global financial crisis, the discrepancy between the change rate of foreign exchange reserves and the net purchase rate became more and more conspicuous. This implies that the non-trading factors have began to play an important role in foreign reserve accumulation. Therefore, the loss caused by the volatility of exchange rate and the swing of interest rate may do exist.

As for investment returns of major currencies, we used 10-year benchmarked government bond yields as proxies. For liquidity and security reasons, most foreign reserve management entities are highly risk-averse. All countries surveyed invest the bulk of their assets in securities of highly rated sovereigns (IMF, 2005). As for China, data from the composition of holdings of U.S. securities show that the proportion of long-term debts to total securities amounted to over 90% during the period from 2002 to 2011 (Figure 4-3). Therefore, following Dominguez *et al.* (2012), we used 10-year benchmarked government bond yields to proxy for returns on 'securities' and subtracted the inflation rates of host countries to convert nominal yields into real yields[21]. In spite of this, it is noticeable that this dispose is relatively conservative and is likely to underestimate the investment returns because China could hold more risky assets. Apparently, the nominal 10-year benchmarked government bond yields were relatively stable over the period from 2002 to 2008, but then dropped dramatically during the global financial crisis (Figure 4-4). In addition, the downtrends of nominal bond yields were rather obvious since the 2008 global financial crisis. This directly relates to the repeatedly implemented Quantitative Ease operations, or alike Large-scale Asset Purchase Program, both of which boost the price and lower the yields. Interestingly, the real bond yields are much more fluctuated than the nominal yields. On average, the yields of the euro and the Australian dollar are significantly larger than other selected currencies without regard to the effect of exchange rate (Table 4-2). Meanwhile, the yield of the

[21] Data of bond yields come from the Organization for Economic Co-operation and Development (OECD). Data of inflations come from the Federal Reserve System. In order to preferably reflect the real yields during the investment period, we calculated the quarterly holding period return rate through the equation, $r_{quarter}=(1+r_{year})^{1/4}-1$.

Australian Dollar is the least fluctuated. In terms of exchange rate, most selected currencies appeared to appreciate against the U.S. dollar while only the Japanese yen depreciated against the U.S. dollar before the financial crisis (Figure 4-5)[22]. During the crisis, the U.S. dollar abruptly depreciated against most currencies except for the Japanese yen. The Japanese yen kept stable to the U.S. dollar during the crisis maybe due to the fact that the Japanese monetary authority conducted active foreign exchange market intervention. During the period from 2010 to 2012, the exchange rates of primary currencies remained relatively stable. Since 2013, the U.S. dollar showed the tendency of depreciation once again.

Moreover, referring to the IMF-COFER, we chose five primary currencies, namely the U.S. dollar, the pound sterling, the euro, the Japanese yen and the Swiss franc to construct our empirical estimation during the period from 2003Q1 to 2012Q3, while put in the Canadian dollar and the Australian dollar since 2012Q4.

4.4.2 Empirical Results about the Currency Composition of China's Foreign Exchange Reserves

We not only studied the common characteristic of currency composition evolution in the whole sample period but also explored its heterogeneity at different stages. Four subsamples: the pre-subprime crisis stage (before 2007Q2), the global financial crisis stage (from 2007Q3 to 2009Q4), the European sovereign debt crisis stage (from 2010Q1 to 2013Q4) and the Quantitative Ease (QE) stage (after 2010Q4)[23], were used to reflect those relatively important historical stages that might cause the State Administration of Foreign Exchange to adjust the currency composition. In order to obtain more convincing results, the deterministic trend test proposed by Perron and Yabu (2009) was employed to make sure if there were any trends in different subsamples[24].

Our results present a mixed picture of the diversification debate. First, the U.S. dollar, the euro, the pound sterling and the Japanese yen were still four dominant reserve currencies for China and the currency composition were very persistent. Second, overall, the State Administration of Foreign Exchange did not significantly diversify its foreign exchange reserves out of the U.S. dollar to other international currencies. However, the State Administration of Foreign Exchange did decrease the euro and the pound sterling since 2010, which may illustrate

[22] Data of foreign exchange rates come from the International Monetary Fund.

[23] Since the late 2008, the U.S. Federal Reserve System has launched more than one round of quantitative easing. However, the first round of quantitative easing from November, 2008 to June, 2010 is mainly about buying mortgage-backed securities, which may not directly influence the treasury bond market. On the contrary, since the second round of quantitative easing, the Federal Reserve System directly purchases the medium- and long-term treasury bonds. Thus, we defined our QE stage as the period after 2010Q4.

[24] Perron and Yabu (2009) develop a deterministic trend test with no need of priori determination about data stationary. In other words, it can test for a possible deterministic trend no matter the variables are stationary or not.

the concerns about European sovereign debt crisis. Third, the total share of four dominant currencies significantly decreased from 2008 to 2012, which means that the State Administration of Foreign Exchange has paid more attention to the emerging currencies. Especially, the State Administration of Foreign Exchange may have introduced the Canadian dollar and the Australian dollar into the currency composition of China's foreign exchange reserves as alternatives to the pound sterling and the Japanese yen, respectively, since 2012Q4.

4.4.2.1 The estimated currency composition of China's foreign exchange reserves

Figure 4-6 presents the estimated currency composition of China's foreign exchange reserves and Figure 4-7 shows the change of the total share of four dominant currencies. Table 4-3 reports the relevant descriptive statistics.

In terms of quantity, the U.S. dollar, the euro, the pound sterling and the Japanese yen were still four most important international currencies for the management of China's foreign exchange reserves. Although, the shares of the Australian dollar and the Canadian dollar were higher than that of the Swiss Franc, they were unable to compete with the pound sterling or even the Japanese yen. The total share of four most important currencies experienced a significant decline from 2008Q1 to 2012Q2, but yet exceeded 90%. Before the breakout of 2008 global financial crisis, the total share of the U.S. dollar, the euro, the pound sterling and the Japanese yen stabilized at the level of 98%. During the period of financial crisis, the State Administration of Foreign Exchange diversified its foreign exchange reserves out of the four dominant currencies and cut down the total share at the rate of 0.35% per quarter on average. Since 2012Q3, the total share stabilized at the level of 92%. In sum, although the U.S. dollar, the euro, the pound sterling and the Japanese yen still dominates the currency composition of China's foreign exchange reserves, the diversification during crisis may illustrate that the State Administration of Foreign Exchange begins to pay more attention to other international currencies and tries to actively improve the management of huge foreign exchange reserves.

With respect to the stability of primary currencies, the shares of the Swiss franc and the Japanese yen fluctuated more violently than those of the pound sterling, the euro and the U.S. dollar, which confirms that the State Administration of Foreign Exchange takes the active adjusting strategy to manage China's foreign exchange reserves. Given the limited market bearing capacity, massive diversification out of dominant currencies in the short term may not be a good choice for the State Administration of Foreign Exchange. Keeping the stability of dominant currencies is still an important strategy for the management of China's foreign exchange reserves. On the whole, the State Administration of Foreign Exchange has maintained a relatively stable currency composition during our sample period. This is consistent with most

studies, *e.g.* Chinn and Frankel (2007), who claim that the shares of major currencies in reserve holdings are very persistent.

4.4.2.2 The segmented evolution trends about primary currencies

Table 4-4 reports the empirical results of deterministic trend tests about the value shares of primary currencies at different stages.

No significant trends could be found in any of the five traditional international currencies during the whole sample period. In the long term, the State Administration of Foreign Exchange appears to try to keep the currency composition stable. Yet local trends were still detected in segmented subsamples.

Before the subprime crisis, the share of the pound sterling significantly ascended while the share of the Japanese yen descended. In absolute values, the increasing rate of pound sterling share was 3.9449 (0.2004%÷0.0508%≈3.9449) times of the decreasing rate of Japanese yen share. This means the State Administration of Foreign Exchange not only tries to convert Japanese yen assets into pound sterling assets but also invests more newly increased foreign exchange reserves on the pound sterling.

During the period of global financial crisis, the share of the U.S. dollar fell off along with the decline of the pound sterling. The decrease of U.S. dollar share reflects the intention that the State Administration of Foreign Exchange tries to avoid the crisis. This finding confirms that the State Administration of Foreign Exchange does diversify China's foreign exchange reserves probably through buying emerging international currencies. In addition, compared with the massive increase of pound sterling share before, the State Administration of Foreign Exchange seems to rebalance its currency composition and moderately decreases the share of rapidly increased pound sterling assets.

Since the breakout of European sovereign debt crisis, both shares of the euro and the pound sterling dropped while the value share of the Swiss franc ascended slightly for security reasons. The large-scale decrease of euro assets reveals the concern of the State Administration of Foreign Exchange for European sovereign debt crisis.

Notably, the sum of the quarterly average change of five traditional international currencies was negative since the 2007Q3. This finding displays that the State Administration of Foreign Exchange has probably tried to enhance the purchase of other international currencies, such as the Canadian dollar and the Australian dollar, since the 2008 global financial crisis.

4.4.2.3 The correlations between the shares of primary currencies

Figure 4-8 exhibits the scatter plots in combination with Pearson correlation tests and Figure

4-9 displays the image plots of Pearson correlations.

With regard to the correlations of currency composition, no high correlation ($|\rho|>0.8$) between the shares of primary currencies could be found in the whole sample period while the correlations in different subsamples showed some heterogeneity.

As for the correlations between U.S. dollar share and euro share, only weak-negative correlation ($|\rho|<0.3$) could be found significantly at 10% level in the whole sample. This finding seems not to support the traditional view of decreasing the U.S. dollar and increasing the euro in practice. However, if we focus on different subsamples, quite distinct pictures will show up. Before the subprime crisis, the value share of the U.S. dollar moderately correlated ($0.5<|\rho|<0.8$) with the share of the euro significantly at 10% level. During the 2008 global financial crisis, high-negative correlation between the value shares of the two most dominant currencies was found significantly at 5% level. Although the European sovereign debt crisis weakened this negative correlation, it became extremely high again significantly at 1% level in the QE stage. All these findings indicate that before crisis the State Administration of Foreign Exchange considers diversifying huge foreign exchange reserves out of the U.S. dollar as the primary task (to avoid the 'dollar trap') and thus the U.S. dollar and the euro share are relatively separate; however, reversely adjusting the shares of the two most important currencies is still an important managing tool during the crisis. The analogue also existed in the relation between the share of the U.S. dollar and the share of the pound sterling. One exception is that during the global crisis the share of the U.S. dollar was moderately negatively correlated with the share of the pound sterling. This finding confirms the results of deterministic trend test in Table 4-4.

As for the correlations among the shares of the euro, the pound sterling, and the Swiss franc, the share of the euro was moderately positively correlated with the share of the pound sterling and was weakly negatively correlated with the share of the Swiss franc in the whole sample. Moreover, these correlations among them had increased since European sovereign debt crisis. The correlation between the share of the euro and the share of the Japanese yen was very similar to that between the euro and the Swiss franc. The only distinction was the higher correlation coefficient. These findings indicate that the State Administration of Foreign Exchange takes the pound sterling as the equivalent of the euro while takes the Japanese yen and the Swiss franc as the substitutions of the euro.

As for the correlations among the shares of the pound sterling, the Japanese yen and the Swiss franc, moderate negative correlation between the share of the pound sterling and the share of the Japanese yen was found in the whole sample period significantly at the 1% level. In the meantime, the share of the pound sterling was moderately negatively correlated with the share of the Japanese yen significantly at 10% level both before the subprime crisis and during the

European sovereign debt crisis. No significant correlation between them could be found either in the stage of global financial crisis or in the QE stage. The analogue positive correlations between the share of the Japanese yen and the share of the Swiss franc could also be found only with higher correlation coefficients in absolute values. In addition, the share of the pound sterling had been keeping the moderate negative correlations with the share of the Swiss franc except during the period of global crisis. These findings also confirm the analysis that to the State Administration of Foreign Exchange the Japanese yen are equivalent to the Swiss franc and can be used to substitute the pound sterling to improve the management of foreign exchange reserves.

In addition, when inspecting the correlations among all 7 primary currencies, new findings that the share of the Canadian dollar were highly positively correlated with the share of the Australian dollar and both of them were positively correlated with the share of the pound sterling and the share of the Japanese yen could be found. It is worth noting that the share of the Canadian dollar was highly positively correlated with the share of the pound sterling significantly at 5% level while the share of the Australian dollar was highly positively correlated with the share of the Japanese yen. This may mean that the State Administration of Foreign Exchange introduces the Canadian dollar and the Australian dollar into the currency composition of China's foreign exchange reserves as alternatives to the pound sterling and the Japanese yen, respectively.

4.4.2.4 Comparisons with IMF COFER and Sheng (2013)

Figure 4-10 presents the estimated value shares of the U.S. dollar and the euro, their local trends and the corresponding shares of emerging and developing economies and advanced economies reported in the IMF COFER.

The most important finding is that the value shares of the U.S. dollar and the euro in China's foreign exchange reserves were very close to the shares of emerging and developing economies. This is not weird because China holds such huge foreign exchange reserves that the composition of China's foreign exchange reserves would be sufficient to influence the reported results of emerging and developing economies. Although China has only reported a representative portfolio on a partial basis, he will gradually increase the reported portfolio to full coverage of foreign exchange reserve assets within a period of around two to three years. Before 2012Q1, the U.S. dollar share of China's foreign exchange reserves was inferior to that of advanced economies, while the euro share of China's foreign exchange reserves was superior to that of advanced economies. In 2007, the U.S. dollar share and the euro share of China's foreign exchange reserves once tried to converge to those of advanced economies respectively. However,

the true convergence happened in 2012. This finding may suggest that the State Administration of Foreign Exchange has recently taken a portfolio rebalancing strategy, buying more dollars at cheaper prices (Lim 2007; Truman and Wong, 2006), and thus pushes up the share of U.S. dollar rapidly.

Another notable finding is that the State Administration of Foreign Exchange did try to lower the share of the U.S. dollar during the 2008 global financial crisis while raised it once again since QE2. Before the 2008 global financial crisis, the value shares of the U.S. dollar and the euro remained stable. During the global financial crisis, the share of the U.S. dollar decreased in the velocity of 0.30% per quarter. When the QE2 began, the share of the U.S. dollar rose again at 0.42% per quarter.

In addition, the State Administration of Foreign Exchange did take active measures to avoid the negative influence of European sovereign debt crisis and attempted to reduce the share of the euro. Since the breakout of European sovereign debt crisis, the share of the euro declined at 0.52% per quarter.

Figure 4-11 illustrates the estimated value shares of the pound sterling, the Japanese yen, the Swiss franc, their local trends and the corresponding shares of emerging and developing economies and advanced economies reported in the IMF COFER.

The significant discovery is that the value shares of the pound sterling, the Japanese yen and the Swiss franc of China's foreign exchange reserves were also close to those of emerging and developing economies while persistent discrepancies between those shares of China's foreign exchange reserves and the shares of advanced economies were found. The pound sterling share of China's foreign exchange reserves was higher than that of advanced economies while the shares of the Japanese yen and the Swiss franc were lower than those of advanced economies respectively. These findings show that the State Administration of Foreign Exchange might pay too much attention to the pound sterling. At this point, the Brexit may become a big blow to the management of China's foreign exchange reserves.

Moreover, the shares of primary currencies were not immutable and frozen. Before the Subprime Crisis, the pound sterling share of China's foreign exchange reserves increased at 0.2% per quarter. Since the global financial crisis, the pound sterling share of China's foreign exchange reserves decreased at -0.05% per quarter. However, this change was by no means unique. In the same period, the pound sterling share of advanced economies also showed a similar tendency. Before 2007Q2, the Japanese yen share of China's foreign exchange reserves descended at -0.05% per quarter. Meantime, the Japanese yen share of advanced economies experienced a similar decline process. During the European sovereign debt crisis, both the Swiss franc share of China's foreign exchange reserves and the share of advanced economies ascended at 0.0045% per quarter.

These findings confirm that the State Administration of Foreign Exchange takes the active management strategy other than the buy-and-hold passive strategy to flexibly adjust its reserve composition.

Sheng (2013) is believed to be the first attempt to estimate the currency composition of China's foreign exchange reserves. In general, our results are consistent with Sheng (2013). Both Sheng (2013) and our work find a relatively stable currency composition. Yet our empirical results have two significant disparities.

First, the importance of primary currencies in our work is different from that in Sheng (2003). Sheng (2013) reports a currency composition of the U.S. dollar 67.3%, the euro 22%, the Australian dollar 4.7%, the pound sterling 3.5% and the Japanese yen 2.5% sorted by the size of their shares by the end of 2007. Our finding is that China held about 61.9% of its reserves in the U.S. dollar, 27.6% in the euro, 6.3% in the pound sterling, and 2.6% in the Japanese yen in the same time. Sheng (2013) lists the Australian dollar as the third important currency in the composition of China's foreign exchange reserves following the U.S. dollar and the euro but dominating the pound sterling and the Japanese yen. This appears to be inconsistent with the international status of primary currencies and our findings. The share of the U.S. dollar in Sheng (2013) is higher than that in our work while the share of the euro in Sheng (2013) is lower than that in our work. The difference between the former two is very close to that between the latter two. The value share of the Japanese yen in our work is in close proximity to that in Sheng (2013). Yet our estimation about the share of the pound sterling is significantly higher than that in Sheng (2013). The estimation results about the shares of the U.S. dollar, the euro and the pound sterling in Sheng (2013) are similar to those of advanced economies reported in IMF COFER while the estimated Japanese yen share in Sheng (2013) shows no significant difference to that of emerging and developing economies. However, all of our findings are consistent with those of emerging and developing economies. Thus, the coherency of inner logic in our results is better than that in Sheng (2013).

Second, other than relatively stable currency composition, our results also report possible deterministic trends in the evolution of primary currencies. Other than confirming the segmented trends of U.S. dollar share and euro share, our work also pays attention to possible trends implied in the shares of other international currencies. Sheng (2013) claims that the value share of the Japanese yen remains stable during the sample period. However, our deterministic trend tests find a faint but statistically significant downward trend in the share of the Japanese yen as well as a rapidly increased upward trend in the value share of the pound sterling before the end of 2007. Considering the rapidly accumulated foreign exchange reserves in this period, our findings reveal not only the need of foreign reserve diversification but also its pursuit to higher

investment returns.

4.4.2.5 The portfolio adjustment profit/loss rate and robustness check

Figure 4-12 illustrates the proportion of the difference between holding period returns based on estimated currency composition and portfolio adjustment profit/loss to the absolute value of holding period returns. It is easy to find that the net loss of portfolio adjustment mainly happened in the period of global financial crisis. Furthermore, the proportion of the net profit of portfolio adjustment increased in recent time, which implies that the management capacity of the State Administration of Foreign Exchange is significantly enhanced.

Figure 4-13 displays the estimated net profit/loss rate from portfolio adjustment. Since 2012, the profit rate of portfolio adjustment jumped high significantly. Combined with declined non-purchase change rate, this finding show that not only the investment return of foreign exchange reserves is descending but also the negative influence of exchange rate volatility is gradually increasing.

In order to check the empirical results, we made a simple comparison between the non-purchase change rate of foreign exchange reserves and its fitted values computed through the regression equation.

The non-purchase change rate of foreign exchange reserves and its fitted value are illustrated in Figure 4-14. The fitted results were quite fascinating. No large disparities between the real value and the fitted value were found except for during the period from the second half of 2005 to the first half of 2009. The obvious discrepancies may be caused by several possibilities, such as the unpredictable fluctuations in exchange rate due to the global financial crisis, RMB exchange rate regime change happened on July 21st, 2005, as well as the frequent foreign market interventions led by the People's Bank of China during the period from 2006 to 2008. These possibilities might increase the influence of other non-trading factors other than exchange rate and interest rate on the non-purchase change rate of foreign exchange reserves.

Moreover, the coefficient of determination for our constrained least squares estimation was 0.9536. All these findings indicate that our empirical results are robust.

Although we are unable to further check our results because China does not publicly report its currency composition, our results are consistent with Sheng (2013) and the news report in the *Wall Street Journal*, both of which believe that the currency composition of China's official foreign reserves is very similar to the world's reserve portfolio. Our results illustrate that by the end of 2015Q1, China held about 63.6% of its reserves in the U.S. dollar, 19.6% in the euro, 3.09% in the Japanese yen, 4.89% in the pound sterling, 2.22% in the Canadian dollar, 2.03% in the Australian dollar and 0.09% in the Swiss franc, which is very close to the IMF COFER.

4.4.3 Empirical Results about Variance Sensitive Analysis

Based on the estimated currency composition and calculated real 10-year benchmarked government bond yields, we constructed the investment returns of foreign reserve portfolio consisting of 7 primary currencies to estimate the univariate GARCH model and derived the sensitivity of the univariate portfolio GARCH variance to the shares of reserve currencies.

The empirical results also present a mixed picture of the diversification debate. First and foremost, diversifying out of the U.S. dollar was not always decreasing the portfolio risk of foreign exchange reserves. The State Administration of Foreign Exchange should alternatively take the portfolio diversification and portfolio rebalance strategies. Second, the reduction of the euro during European sovereign debt crisis may not contribute much to the management of foreign exchange reserves. Nevertheless, the management of China's foreign exchange reserves was relatively effective.

Figure 4-15 illustrates the hierarchical clustering of the real returns of primary currencies and their segment plots of basic return statistics. Cluster dendrogram reveals the similarity of the returns of primary currencies. In order to obtain robust clustering results, initially, each object was assigned to its own cluster and then the algorithm proceeded iteratively, at each stage joining the two most similar clusters, continuing until there was just a single cluster. At each stage distances between clusters were recomputed by the Lance-Williams dissimilarity update formula according to the *complete linkage method with an Euclidean distance measure* being used.

The result showed that (1) the Swiss franc was the most similar currency to the euro and they were relatively similar to the U.S. dollar; (2) the Canadian dollar was the most similar currency to the pound sterling and they were relatively similar to the Australian dollar but dissimilar to the U.S. dollar and the euro; (3) the Japanese yen was relatively similar to the U.S. dollar but dissimilar to the pound sterling. Combined with the descriptive statistics about returns, these findings confirm the latent possibility of adding in the Canadian dollar as an alternative to the pound sterling as well as adjusting the share of the Swiss franc as an supplement to the management of the euro. In the meantime, diversifying out of the U.S. dollar and the euro to other reserve currencies, *e.g.* the Canadian dollar and the Australian dollar, may improve the overall risk adjusted returns of the portfolio. In addition, the adjustment against each other between the U.S. dollar and the euro may frequently happen, given the limited market capacity of other currencies and the similarity of the U.S. dollar and the euro.

Figure 4-16 shows the first derivatives of foreign reserve portfolio variance with respect to different currencies. We used the estimated currency composition to build up the investment portfolio of China's foreign exchange reserves and conducted the variance sensitivity analysis.

Remember that a positive derivative would imply that the change of the share will influence the variance risk of foreign reserve portfolio in the same direction, and vice versa for a negative derivative.

The most significant finding is that in most times of our sample period the first derivative of the U.S. dollar was positive while those of other currencies were negative. Intuitively, this finding supports the view that reducing the share of the U.S. dollar would lower the risk of China's foreign exchange reserves.

With respect to the sign of derivatives, the sign of the first derivative of the U.S. dollar was always opposite to those of other currencies. Before 2014Q3, the first derivative of the U.S. dollar was positive while those first derivatives of other currencies were negative, which indicates that decreasing the U.S. dollar would lower the risk of foreign reserve portfolio. Since 2014Q4, the first derivative of the U.S. dollar became negative while those of others turned into positive, which implies that increasing the U.S. dollar would lower the risk of foreign reserve portfolio. As a rational manager, the State Administration of Foreign Exchange should take portfolio diversification strategy before 2014Q3 while pursue portfolio rebalance after that.

As for the absolute values of derivatives, all of them rapidly declined in 2012, and thus the absolute values of the first derivatives of primary currencies between 2003 and 2011 were significantly larger than those between 2013 and 2014. In general, the absolute value of the first derivative of the Japanese yen was the smallest. The absolute value of the first derivative of the U.S. dollar was close to those of the pound sterling and the Swiss franc. Relatively, the absolute values of the first derivatives of the Australian dollar and the Canadian dollar were larger than those of traditional reserve currencies, *e.g.* the U.S. dollar and the pound sterling. Notably, the absolute value of the first derivative of the euro was the largest among 5 traditional reserve currencies. In fact, an active manager could accomplish the reduction of portfolio variance risk by replacing the currency that has a small first derivative in absolute value with the currency that has a larger one. Thus, it seems reasonable for the State Administration of Foreign Exchange to diversify out of traditional reserve currencies to other emerging international currencies.

Combined with the estimated latent currency composition, the variance sensitive analysis is capable to help us review the foreign reserve management practice of the State Administration of Foreign Exchange. Generally, the reserve management entity should seek to preserve the value of foreign exchange reserves, within the prudent risk limits that form the framework for reserve management. As a consequence, reserve asset portfolios tend to be risk-averse, with priority for liquidity and security before profit or carrying cost considerations. Thus, we mainly focus on the nexus between portfolio risk and currency composition management here.

In general, the currency composition management of China's foreign exchange reserves was

relatively effective. Before the subprime crisis, the State Administration of Foreign Exchange kept the shares of the U.S. dollar and the euro stable while increased the purchase of pound sterling assets and decreased the purchase of Japanese yen assets. Due to that the absolute value of the first derivative of the pound sterling was larger than that of the Japanese yen, the State Administration of Foreign Exchange successfully lowered the portfolio risk of foreign exchange reserves through this relative adjustment. During the global financial crisis, the State Administration of Foreign Exchange more severely cut down the share of the U.S. dollar than reduced the share of the pound sterling. This operation still achieves the risk reduction and improves the management of China's foreign exchange reserves. Notably, the negative first derivative of the euro during European sovereign debt crisis showed that there was no need to diversify out of the euro. However, the State Administration of Foreign Exchange still reduced the share of the euro for the sake of asset security. In addition, the absolute values of primary currencies in 2012 declined sharply. This decline creates a beneficial condition for portfolio rebalance. In particular, the State Administration of Foreign Exchange could improve the management of foreign exchange reserves through buying more U.S. dollar assets as well as decreasing the purchase of euro and pound sterling assets, or converting part of euro and pound sterling assets into U.S. dollar assets, due to a negative first derivative of the U.S. dollar and positive first derivatives of other currencies since 2014Q4.

Figure 4-17 displays the first derivative of the U.S. dollar and its estimated value share. The share of the U.S. dollar was negatively correlated with the first derivative of the U.S. dollar. Apparently, the State Administration of Foreign Exchange lowered down the value share of the U.S. dollar when its first derivative was relatively high and vice versa. This finding confirms the effectiveness of U.S. dollar share management.

4.5 Summary

The constrained least square results showed that China maintained a stable currency composition. The U.S. dollar, the euro, the pound sterling and the Japanese yen were still four dominant reserve currencies for China. Overall, China did not significantly diversify its foreign exchange reserves out of the U.S. dollar to other international currencies. However, a downtrend of U.S. dollar share during the subprime crisis and a uptrend of it since 2011 were found. This means China tries to alternatively take the portfolio diversification strategy and portfolio rebalance strategy rather than stick to either one of them. In addition, the European sovereign debt crisis did concern China and thus the State Administration of Foreign Exchange began to decrease the shares of the euro and the pound sterling since 2010. The total share of four dominant currencies significantly decreased from 2008 to 2012. This reveals that China has

started to pay more attention to the emerging international currencies. Especially, China may have introduced the Canadian dollar and the Australian dollar as alternatives to the pound sterling and the Japanese yen, respectively. By the end of 2015Q1, China held about 63.6% of its reserves in the U.S. dollar, 19.6% in the euro, 3.09% in the Japanese yen, 4.89% in the pound sterling, 2.22% in the Canadian dollar, 2.03% in the Australian dollar and 0.09% in the Swiss franc.

The variance sensitive analysis illustrated that before 2014Q3 the first derivative of the U.S. dollar was always positive while those of other currencies were always negative and vice versa after 2014Q4. Apparently, diversifying out of the U.S. dollar was not always decreasing the portfolio risk of foreign exchange reserves. The decrease of euro share during European sovereign debt crisis may not contribute much to the management of foreign exchange reserves. With respect to the absolute values of derivatives, all of them declined rapidly in 2012 and the absolute values of emerging international currencies were larger than those of traditional reserve currencies. Thus, the introduction of the Canadian dollar and the Australian dollar as alternatives of the pound sterling and the Japanese yen, respectively, may improve the management of China's foreign exchange reserves. Nevertheless, the currency composition management of China's foreign exchange reserves were still relatively effective.

Chapter 5. What Drives the Currency Composition Adjustment of China's Foreign Exchange Reserves?

The currency composition of foreign exchange reserves serves for China's foreign economic communications. The decision of currency composition should allow for various structures of external payments, such as foreign trades, foreign debts, direct investments, and so on. Moreover, when formulating the strategies of currency composition management, the State Administration of Foreign Exchange may also make a reference to the currency composition of global foreign exchange reserves. Of course, the currency composition is not monotonous but dynamically adjusted. The decision of currency composition should take the market capacity, liquidity, characteristics of risk and return, and long-term development trend, *etc.*, into account and should be continuously dynamically adjusted according to the variation tendency of economy and market as well as investment needs.

For the time being, it is not clear what drives the currency composition adjustment of China's foreign exchange reserves. Thus it is meaningful to explore determinants of the currency composition of China's foreign exchange reserves and ask many interesting questions, such as whether the rapid growth of export trade affected the currency composition? Moreover, there is a big difference between the structure of China's import trades and the structure of export trades. As the two most important reserve currency issuing countries (regions), the United states and the Euro area are both China's important export trade partners. However, in terms of imports, the import trades of China from Japan overpass those from the United States (Figure 5-1). Thus, it is reasonable to expect that the difference between the structure of exports and the structure of imports might lead to differentiated influences on the decision of the currency composition of China's foreign exchange reserves.

5.1 Modeling the Currency Composition of China's Foreign Exchange Reserves

The decision of currency composition should allow for various structures of external payments, such as foreign trades, foreign debts, direct investments, and so on. In order to figure out what determines the currency composition of China's foreign exchange reserves, regression models were built up based on the previous constrained least square results. In other words, the estimated currency composition of China's foreign exchange reserves was used as the dependant variable.

5.1.1 Key Factors

Based on the previous literature review, a series of factors could influence the decision on the currency composition of foreign exchange reserves. In general, such following three determinants are believed to have dominant influence.

a. Country Size

The relative weight of reserve currency country's output, finance and international trade in the global level not only reveals its dominant international status but also endows it with a big natural advantage to develop and maintain its foreign currency status. In general, the larger a reserve currency country's share in output, finance and international trade, the more likely the other countries will use its currency as trade or foreign debt invoicing currency, and as the vehicle currency for financial transactions or interventions in foreign exchange market. Two commonly used indicators to reflect country size in the global overall level or country groups are the GDP or international trade. However, these two variables are hard to reflect the linkage between the reserve currency country and the reserve management country when being used in the case of individual country. In this paper, bilateral trades of China relatively to different reserve currency countries were used as the measurement of country size.

b. Confidence in the Value of Reserve Currency

Technically, the stability in value is a necessary condition for an international currency even if it were only used as a unit of account. Hartmann and Issuing (2002) stress that the price stability is an important determinant for the maintenance and development of an international currency. More importantly, the depression of foreign exchange rate would weaken the attractiveness of holding this kind of currency and thereby discourages its international use as an reserve currency. For example, along with the depreciation of the U.S. dollar during the period from 1977 to 1979, the U.S. dollar share in global overall reserves also declined in the late 1970s. Like Eichengreen *et al.* (2016), we used the three-year average change rate of currency value against the special drawing right (SDR) basket as a confidence measure of reserve currency.

c. Network Externalities

The international money has the characteristic of natural monopoly. If a country's currency has taken up the international status, it will possess some advantages of scope economy, network effect as well as long-term formative currency using habit. There exists the prominent 'conversion cost': if some individual country or country group wants to give up using the existing international currency and tries to search for some alternatives, he must persuade other

dealers to make the same alteration. The inertia of currency using is one of the primary causes that the U.S. dollar could maintain its international status. And also it is why the pound sterling could still hold its position for a relatively long time although the comprehensive national strength of U.K. was not that strong as before after the World War Ⅱ (Tavlas, 1998). Because there is a strong inertia bias in favor of the international currencies using from the past, the currency composition of foreign exchange reserves may not change immediately corresponding to the variation of determinants, at least not in the short run. For example, the pound sterling remained to be the dominant international currency even long after the United States surpassed the United Kingdom as the largest economy either in terms of GDP or trade (Eichengreen and Flandreau, 2008). For simplicity, we use the lagged currency composition to reflect the inertia effect in capturing network externalities.

5.1.2 The Basic Model

Like most existing empirical literatures (Chinn and Frankel, 2007; Hatase and Ohnuki, 2009; Eichengreen *et al.*, 2016), we also adopted an eclectic approach to determine explanatory variables. Our basic specification related the currency composition share of China's foreign exchange reserves to its lagged currency share, bilateral trade, foreign debt and the currency confidence. The results are obtained by the panel regressions with cross-section weighted standard errors.

The basic model was constructed as follows:

$$\begin{aligned} Currency\_Share_{it} = {} & \beta_0 + \beta_1 \times Currency\_Share_{it-1} + \beta_2 \times Export\_Ratio_{it} \\ & + \beta_3 \times Import\_Ratio_{it} + \beta_4 \times Currency\_Confidence_{it} \\ & + \beta_5 \times External\_Debt_{it} + \varepsilon_{it} \end{aligned} \tag{5.1}$$

Notably, our basic equation is consistent with both earlier research and contemporary opinions. But it is important to note that we include the foreign debt as a basic explanatory variable to account for the payment demand. Traditionally, foreign exchange reserves are considered to be a cushion for trade payments or the repayment of foreign debts, especially in developing countries with fragile access to international financial markets and growing foreign debts. Thus, borrowing more foreign debts with a country requires a larger relative share of relevant foreign assets in total reserves. In other words, it is reasonable to expect that as China increased its foreign debts in a certain currency, the State Administration of Foreign Exchange would increase the holding of that currency assets as reserves to meet the payment demand in the future.

5.1.3 Other Factors

In addition to those key factors, many other factors may influence the decision of currency

composition. First, investment returns could be a powerful influential factor. To preserve and increase the value of reserves are the two most important goals of reserve management. The risk-averse reserve managing entity will pursue higher returns when facing similar risk conditions. Thus, the relative gain should positively correlate to the currency share of foreign exchange reserves. In order to enhance the explanatory ability, we also introduced the explanatory variable to reflect the different currency investment returns, which were represented by 10-year government bond yields.

Second, the stability of currency value in domestic economy may be as important as exchange rate stability in international economy. Devereux and Shi (2013) find that the use of a currency will collapse and countries may adopt another currency as the reserve currency if inflation goes too high. In the meantime, as Chinn and Frankel (2007) point out, inflation is also considered as an alternative proxy of exchange rate change against the SDR basket to indicate the confidence in the value of reserve currency. Thus, in order to address concerns about the impact of macroeconomic stability on reserve currency composition, we included the CPI inflation rate to reflect the macroeconomic stability of reserve currency issuing countries.

Third, it may be disputable whether the change of foreign exchange rate is the best measure to reflect the latent influence of exchange rate variation on the relative status of primary international currencies. In order to address these concerns, we also included exchange rate volatility as another additional variable.

Fourth, foreign direct investment (FDI) may be also an important influential factor. Although the structure of international trade and foreign debt acting as the best measure of external payments have been considered in numerous literatures, FDI in China has increased considerably in the last decade with the rapid development of domestic economy and the reform of foreign economic policy. Outward FDI flows had reached 12.31 billion dollars by the end of 2014 (Figure 5-2). FDI has played more and more important roles in the balance of payments. To better reflect the needs of external payments, we also include the FDI as an alternative proxy variable.

Finally, the development of financial market may correlate to the currency composition evolution. The larger and more liquid a country's financial markets, the more attractive its currency being used for the purpose of foreign exchange intervention by other countries (Eichengreen, 1998). Eichengreen (2011) argues that the 'size, stability and liquidity' of financial markets are important pre-conditions for a currency to play a role as a reserve currency. Thus, in order to further check the robustness, we also included the financial market development variable as previous studies (Hartmann and Issuing, 2002; Papaioannou and Portes, 2008) did.

5.2 Empirical Results

According to our previous estimation, the U.S. dollar, the euro, the pound sterling and the Japanese yen were still four dominant currencies in China's foreign exchange reserves. By the end of 2015Q1, China held about 63.6% of its reserves in the U.S. dollar, 19.6% in the euro, 3.09% in the Japanese yen, 4.89% in the pound sterling. Obviously, compared to the U.S. dollar and the euro, the value shares of the Japanese yen and the pound sterling in China's foreign exchange reserve holdings are relatively small.

In order to analyze the determinants of relative adjustment between the U.S. dollar and the euro, we first estimated the two-currency group (the U.S. dollar and the euro) regression using the quarterly data from 2003Q2 to 2015Q1 obtained through the Constrained Least Squares. Furthermore, given that the State Administration of Foreign Exchange started to publish the quarterly data of foreign debt composition in primary international currencies since 2010, we only built our basic regressions including all four influential factors from 2010Q1 to 2015Q1. Then, in further investigations, we look into the four-currency group (the U.S. dollar, the euro, the pound sterling and the Japanese yen) ranging from 2003Q2 to 2015Q1 without including the external debt variable[25]. Moreover, due to the unavailability of the quarterly data on FDI and financial market development, we could only estimate the regressions including these two additional variables using the annual data from 2004 to 2014. Accordingly, the results might not be as convincing as other regression results because of the shorter time span. Thus they will be reported in Appendix 2 for reference only.

5.2.1 Empirical Results about the Two-currency Group

Table 5-1 and Table 5-2 summarize the regression results for two-currency group with and without the external debt variable, respectively.

Column (1) in Table 5-1 and Table 5-2 illustrates the results of the basic regression specification. The results were basically consistent with what was found in the previous literatures even though some differences existed. What we found was that the regression coefficients of the lagged relative currency shares, exports, confidence in reserve currencies and external debts were statistically significant while the variable of imports was statistically insignificant.

In order to enhance the explanatory ability, we gradually added more potential determinants of currency composition decision, such as the exchange rate volatility, CPI inflation and long term bond yields, to the basic regression specification and obtained the results from column (2) to column (5). The expanded results showed that all of the qualitative conclusion remained

[25] The data descriptions and sources are reported in Appendix 1.

unchanged. In particular, the coefficients on the lagged currency share, exports, confidence in reserve currencies and external debts were similar to those obtained in the basic regression.

However, as for other newly added explanatory variables, all of them were insignificant. This finding means that in comparison with traditional influential factors the relatively stable domestic purchasing power and relatively high asset returns are not critical elements when the State Administration of Foreign Exchange decides the currency composition of huge foreign exchange reserves.

Specifically, the coefficient on lagged currency share was significantly positive and larger than 0.82, which confirms the existence of strong inertial effect in currency composition. This finding shows that compared with frequent adjustment the State Administration of Foreign Exchange prefers to keep the stability of the currency composition of foreign exchange reserves.

Furthermore, the coefficient on exports was positive and statistically significant while the coefficient on imports was statistically insignificant. Apparently, the trade factor did influence the currency composition management. Yet the influence of exports was quite different from that of imports. Comparatively speaking, the exports lead to the inflow of foreign currency while the imports lead to the outflow of foreign currency. Our finding shows that the State Administration of Foreign Exchange would raise the relative holdings of U.S. dollar denominated assets if China exported more goods to the United States. Also the State Administration of Foreign Exchange paid more attention to the exports than to the imports. In comparison, the coefficients on exports in Table 5-2 were larger than those on other explanatory variables, which shows that the export is still the most important influential factor in the currency composition decision of China's foreign exchange reserves.

In the meantime, the influence of foreign exchange rate were more complex. Although mixed results were reported in previous studies, our findings were consistent with Eichengreen *et al.* (2016). The coefficient on the confidence in reserve currencies, represented by the three-year average change rate of currency value against the SDR basket, was negative and statistically significant at least 1% level, which is in accordance with the theoretical expectation. However, the foreign exchange rate volatility estimated from GARCH model was insignificant although its regression coefficients were also negative. Based on what we found, the confidence in the value of reserve currency is indeed an important inducement of currency composition adjustment. When some kind of international currency shows explicit depreciation trends, the State Administration of Foreign Exchange tends to decrease those assets denominated in that currency and seeks to chase after more stable currencies. Also this finding indicates that as a strategic investor the State Administration of Foreign Exchange focuses on the long term variation trends of reserve currencies rather than their short term exchange rate volatilities.

Moreover, another point of interest is that the coefficient on foreign debts was negative and statistically significant, which seems not to be in accordance with the theoretical expectation. Intuitively, we expected a positive sign for the estimated coefficients on the variable of foreign debts as most previous studies did. This unanticipated results may be attributed to two reasons: one is that the data we use here is the ratio of foreign debts denominated in different currencies to the aggregate foreign debts which also include those foreign debts denominated in renminbi. According to the newly released data of foreign debts, by the end of 2016Q1, renminbi denominated foreign debts reach 605.3 billion dollars but drop by 199.4 billion dollars compared with the same period last year. Including renminbi denominated foreign debts may mislead our calculation about the composition of foreign debts. The other is that the State Administration of Foreign Exchange might try to seek for foreign debt composition arbitrage rather than asset-liability collaborative management. Theoretically, increasing the foreign debt denominated in the currency with low interest rate and depreciation trend will benefit the debtor. China may positively pursue this strategy and thus cut off the link between the composition of foreign assets and foreign debts. Figure 5-3 illustrates that the although the scale of foreign debts experienced a rapid growth since 2003 reaching 959.51 billion dollars by the end of 2014, the ratio of aggregate foreign debts to the exports of goods, services and income (especially the ratio of foreign debts to gross national income) does not rise up along with the piling up of foreign debts. The risk implied in foreign debts is not high and controllable in the short run. Thus, it is reasonable to believe that as a rational managing entity the State Administration of Foreign Exchange has conducted foreign debt composition arbitrage.

On the whole, empirical results are consistent with theoretical expectation. Inertia, exports, foreign debts and the foreign exchange rate variation are important influential factors when deciding the currency composition of foreign exchange reserves. In addition, it is worth noting that the adjusted R^2 in all of regressions are about 0.99 and D.W. statistics are around 2, which shows us statistically satisfactory results.

5.2.2 Empirical Results about the Four-currency Group

In addition to the two currency group model, we also extended the regression model to the four currency group situation. The empirical results are reported in Table 5-3. The most important finding is that there were no significant differences between the two currency group results and the four currency group results and the main results were robust.

In addition to the similarity of the results, one point of interest is that the coefficient on the imports became positive and statistically significant, which suggests that the composition of imports did influence the currency composition decision of China's foreign exchange reserves in

a broader dimension. In fact, the asymmetry between import trade relation and export trade relation may influence the currency composition decision. Figure 5-4 and Figure 5-5 illustrates that as China's two important trade partners the exports to the United Stated and to the euro-zone dominated in China's aggregate exports. On the contrary, the imports from these two countries, especially from the United Stated, were less than that from Japan. As China's another important trading partner, imports from Japan occupied a rather high proportion even though it has begun to decline since 2011. Thus, it is reasonable for the State Administration of Foreign Exchange to focus on the composition of imports in the four currency group.

5.3 Summary

The panel regressions obtain not only basically consistent empirical results as previous literatures find but also some interesting new findings. Those traditional factors, such as the inertia of currency use and confidence in the value of reserve currency, strongly affect the currency composition decision of China's foreign exchange reserves. In the meantime, the composition of foreign debts negatively influences the currency composition decision of China's foreign exchange reserves. What was found shows that compared with the payment demand of foreign debts the State Administration of Foreign Exchange puts more attention to the balance management of foreign debts given the low risks implied in the current foreign debt scale so far. In addition, China's specific import and export trading structures lead to different regression results, which shows that the State Administration of Foreign Exchange emphasizes the export structure in managing the shares of the U.S. dollar and the euro while also pays attention to the import structure when managing the most important four reserve currencies.

Chapter 6. Conclusions

Under the circumstance of open economy, foreign exchange reserve management constitutes the important part of foreign asset management for the sovereign state. As for China, the unceasingly accumulated foreign exchange reserves have become a burden. In this thesis, we explored the macroeconomic impacts of China's foreign exchange reserve accumulation and estimated the latent currency composition of China's foreign exchange reserve as well as discussed determinants of currency composition adjustment. Some interesting findings were detected.

First, foreign exchange reserve accumulation only had a significant positive impact on the base money, which means excessive foreign exchange reserves are not helpful for economic growth. As far as the sterilization intervention, the People's Bank of China frequently offset the effects of reserve accumulation, even though this operation became less efficient over time. However, due to the simplified theory model and regression equation, we have provided no further robustness checks about the macroeconomic impact of reserve accumulation and sterilization efficiency. Thus, future work will build a dynamic stochastic general equilibrium model (DSGE) in which the central bank's budget constraint and foreign exchange reserves could be included to analyze the effect of reserve accumulation.

Second, China maintained a stable currency composition: the U.S. dollar, the euro, the pound sterling and the Japanese yen were still four dominant reserve currencies. Overall, China did not significantly diversify its foreign exchange reserves out of the U.S. dollar to other international currencies. However, a downtrend of U.S. dollar share during the subprime crisis and a uptrend of it since 2011 were found. As a rational asset manager, the State Administration of Foreign Exchange tries to alternatively take the portfolio diversification strategy and portfolio rebalance strategy rather than stick to either one of them. The European sovereign debt crisis did concern China and thus the State Administration of Foreign Exchange began to decrease the shares of the euro and the pound sterling since 2010. The total share of four dominant currencies significantly decreased from 2008 to 2012, which reveals that China has started to pay more attention to the emerging international currencies. Especially, China may have introduced the Canadian dollar and the Australian dollar as alternatives to the pound sterling and the Japanese yen, respectively. By the end of 2015Q1, China held about 63.6% of its reserves in the U.S. dollar, 19.6% in the euro, 3.09% in the Japanese yen, 4.89% in the pound sterling, 2.22% in the Canadian dollar, 2.03%

in the Australian dollar and 0.09% in the Swiss franc. Before 2014Q3, the first derivative of the U.S. dollar was always positive while those of other currencies were always negative and vice versa after 2014Q4. Apparently, diversifying out of the U.S. dollar was not always decreasing the portfolio risk of foreign exchange reserves. The decrease of euro share during European sovereign debt crisis may not contribute much to the management of foreign exchange reserves. With respect to the absolute values of derivatives, all of them declined rapidly in 2012 and the absolute values of emerging international currencies were larger than those of traditional reserve currencies. Thus, the introduction of the Canadian dollar and the Australian dollar as alternatives of the pound sterling and the Japanese yen, respectively, may improve the management of China's foreign exchange reserves. Nevertheless, the currency composition management of China's foreign exchange reserves were still relatively effective.

Although we have estimated the possible currency composition of China's foreign exchange reserves, it is unable to remove the impact of other non-trading factors other than exchange rate fluctuation and interest rate variation on the non-purchase change of foreign exchange reserves. In order to obtain more robust results, future work will try to start from decomposing the change of foreign exchange reserves more specifically and revisit relevant themes. Moreover, empirical research on determinants of the currency composition of China's foreign exchange reserves should also be conducted based on our estimated results. In terms of reserve management, an important component of the reserve management strategy is to decide on the appropriate degree of diversification with the aim of improving the risk-return profile of the portfolio. This necessarily involves making a trade-off between risk and return in the context of setting reserve management priorities, which will be another priority of future works.

Third, we found that traditional factors, such as *the inertia of currency use* and *the confidence in the value of reserve currency*, strongly affect the currency composition decision of China's foreign exchange reserves. In the meantime, *the composition of foreign debts* negatively influences the currency composition decision of China's foreign exchange reserves. Compared with the payment demand of foreign debts, the State Administration of Foreign Exchange might put more attention to the balance management of foreign debts given the low risks implied in the current foreign debt scale so far. In addition, the State Administration of Foreign Exchange emphasizes the relative change of export structure in managing the shares of the U.S. dollar and the euro while also pays attention to the change of import structure when managing the most important four reserve currencies.

Although possible determinants of the currency composition of China's foreign exchange reserves were detected, we cannot provide more accurate estimation results including other important influential factors, such as Foreign Direct Investment (FDI) and financial market

development. Moreover, even though exchange rate volatility has little impact on the currency composition decision of China's foreign exchange reserves in our regressions, it is important to note that the exchange rate volatility is assumed to be exogenous in our regression equation. Many researchers emphasize that foreign exchange reserves may be important macroeconomic management tool to conduct foreign exchange intervention in order to maintain the stability of managed floating exchange rate regime. Especially, since the middle of 2014, the debate on whether China conducted foreign exchange interventions to reduce excess volatility in foreign exchange rate has been of particular interest. In fact, if foreign exchange interventions frequently occurred and significantly affected the foreign exchange rate, the variable of exchange rate volatility would become endogenous. Thus, it is important and meaningful to analyze China's foreign exchange intervention policy in the future work.

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Figures and Tables

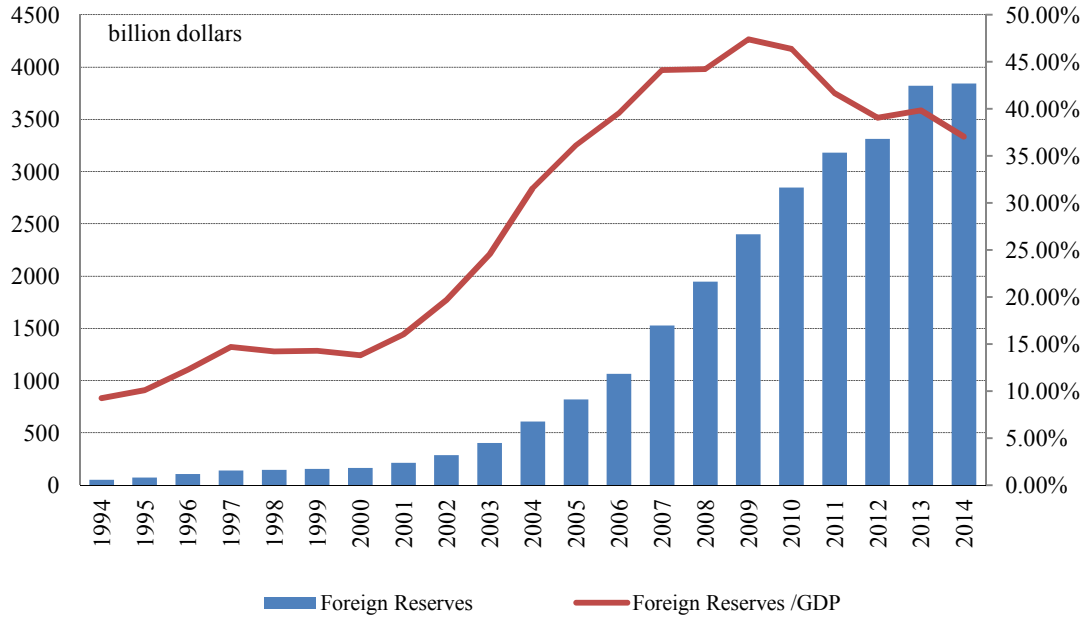


Figure 1-1. China's foreign exchange reserves, 1994-2014

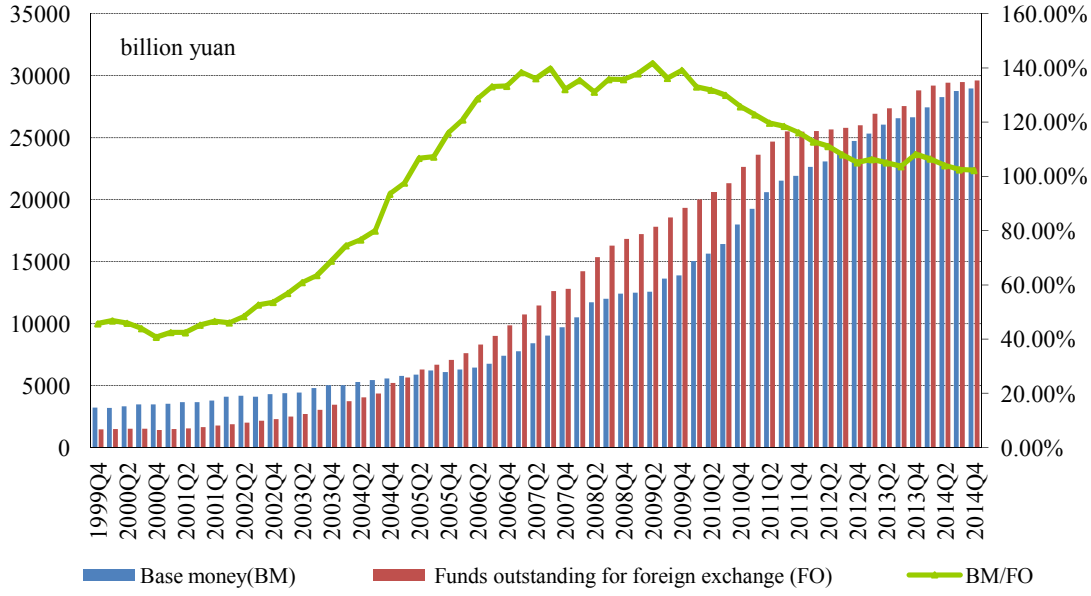


Figure 1-2. China's funds outstanding for foreign exchange and base money, 1999-2014

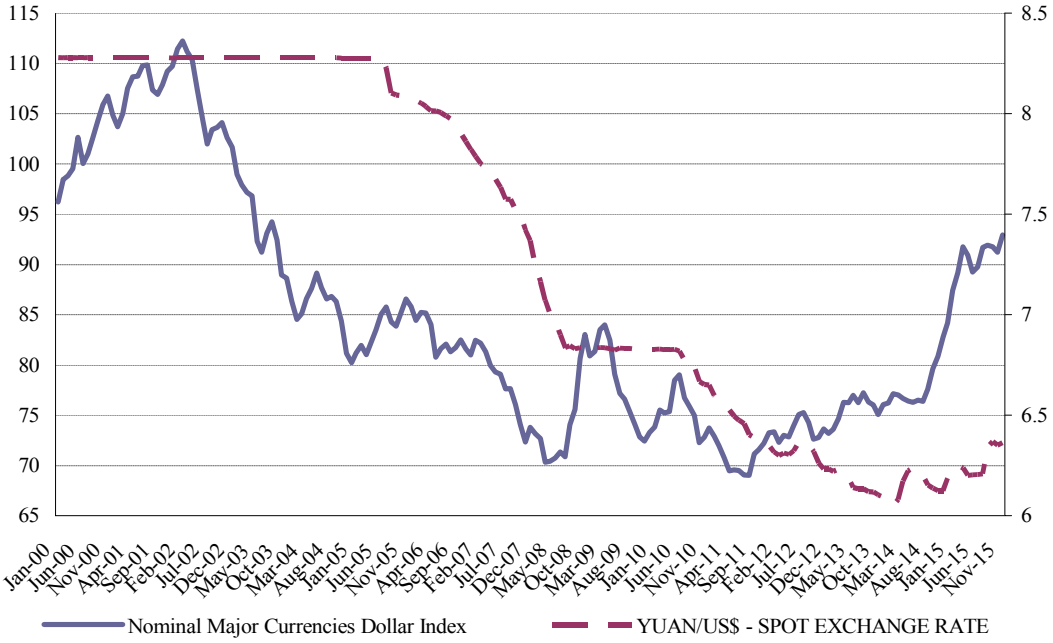


Figure 1-3. Exchange rate of U.S. dollar

Table 3-1. Deterministic Trend Tests

Variables	Constant	Slope	*t*-statistics
Foreign Exchange Reserves	4.7816	0.0047***	2.9707
Funds Outstanding for Foreign Exchange	4.8156	0.0051***	2.6493
Base Money	4.7744	0.0055***	3.1935
Domestic Credit	4.4254	0.0021**	2.1078
Real Added Value of Industrial Output	3.7263	0.0042***	10.7339
CPI	2.0210	0.0010***	3.7038
Real Effective Exchange Rate	1.9297	0.0015**	2.3473

Note: ** represents significance in 95% level, *** represents significance in 99% level.

Table3-2. Unit-root Tests

Variables	KPSS Test Statistics	ADF Test Statistics
Foreign Exchange Reserves	0.1180	-4.0161** (0.0126)
Funds Outstanding for Foreign Exchange	0.1094	-4.0359** (0.0113)
Base Money	0.1032	-4.0144** (0.0189)
Domestic Credit	0.1111	-4.0377*** (0.0091)
Real Added Value of Industrial Output	0.1076	-4.0003** (0.0201)
CPI	0.1061	-4.1165*** (0.0038)
Real Effective Exchange Rate	0.0993	-3.8785** (0.0332)

Note: KPSS test asymptotic critical values are: 1% level, 0.2160; 5% level, 0.1460; 10% level, 0.1190. *p* values are in the bracket. ** represents significance in 95% level, *** represents significance in 99% level.

Table 3-3. Identifying Sign Restrictions

	Foreign Exchange Reserves	Funds Outstanding for Foreign Exchange	Base Money	Domestic Credit	Real Added Value of Industrial Output	CPI	Real Effective Exchange Rate
Business Cycle					+		
Monetary Policy			+	+		+	
External Shock	+				+		-
Foreign Exchange Reserve Accumulation	+	+					

Note: this table shows the sign restrictions on the impulse responses for each identified shock. A "+" ("-")indicates the impulse response of the variable in question is restricted to be positive (negative) for eight quarters following the shock. A blank entry means that no restrictions have been imposed.

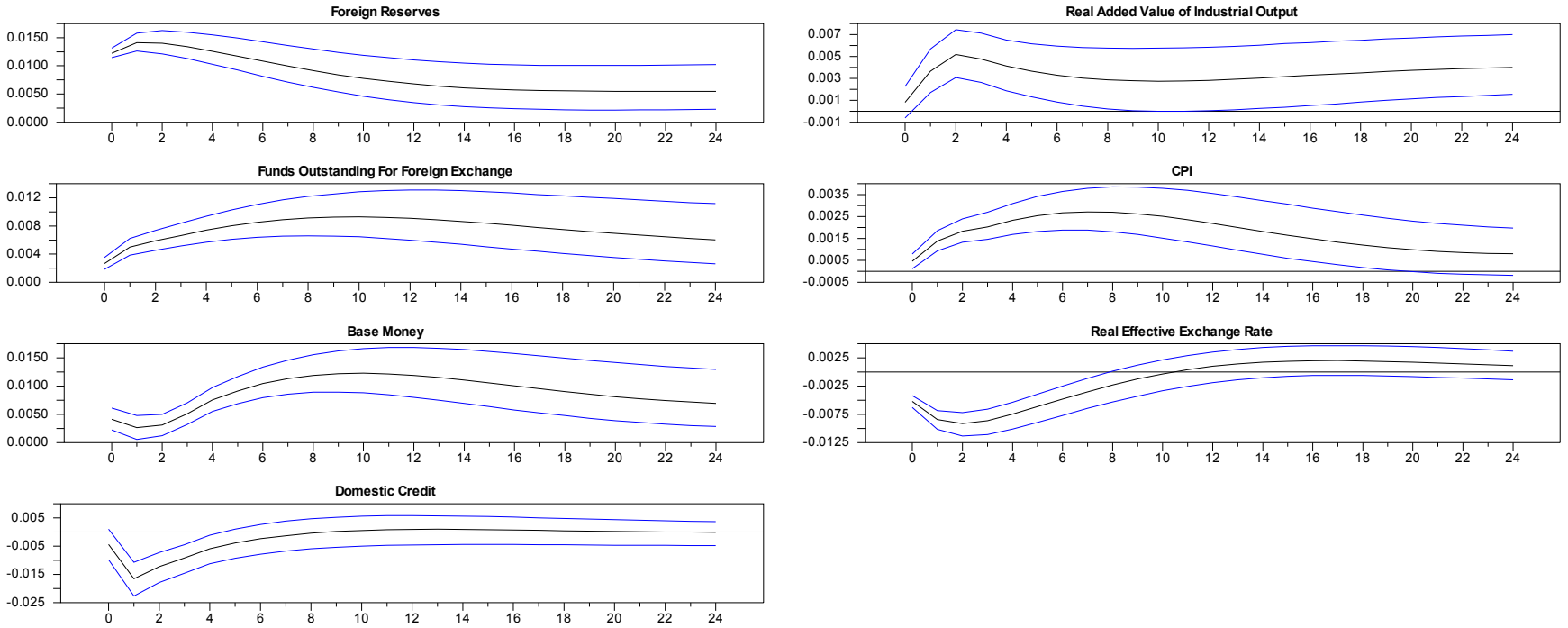
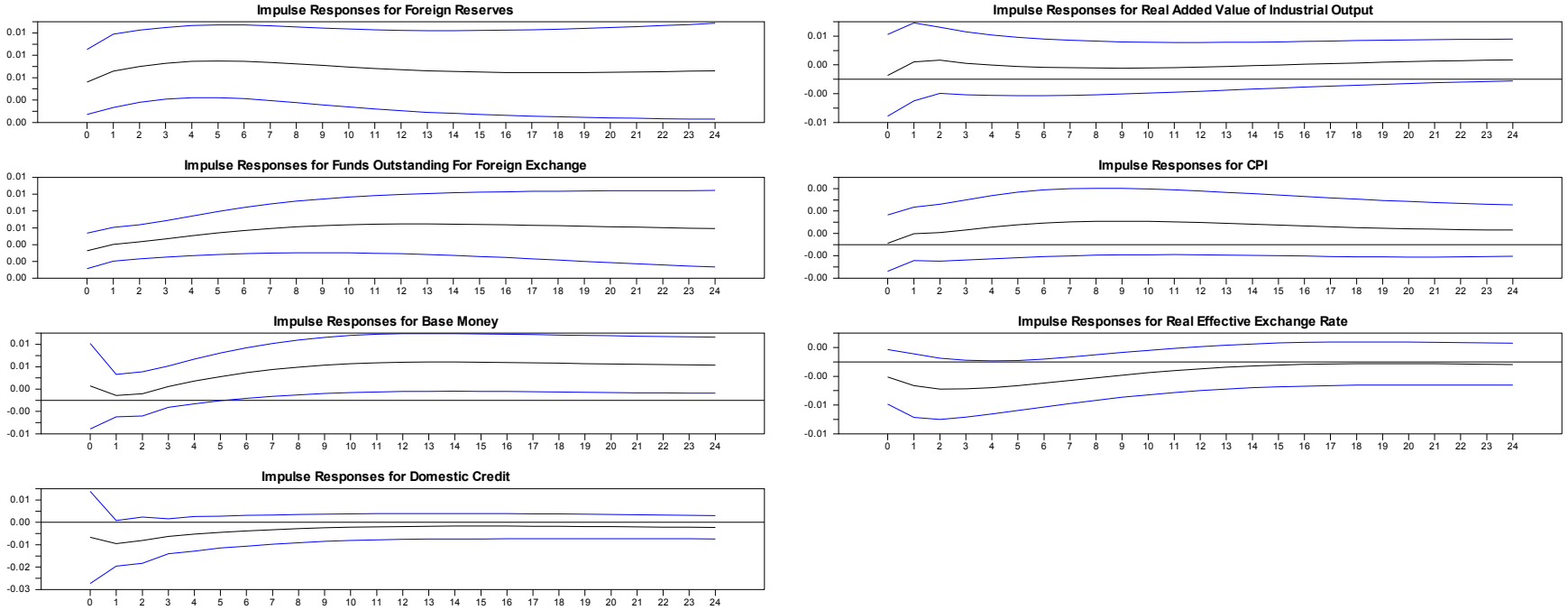


Figure 3-1. Traditional Impulse Responses to Reserve Accumulation Shock



Impulse Responses with Pure-Sign Approach

Figure 3-2. Impulse Responses to Reserve Accumulation Shock

***Nkeep*=10000, *nstep*=24, *Kmax*=8**

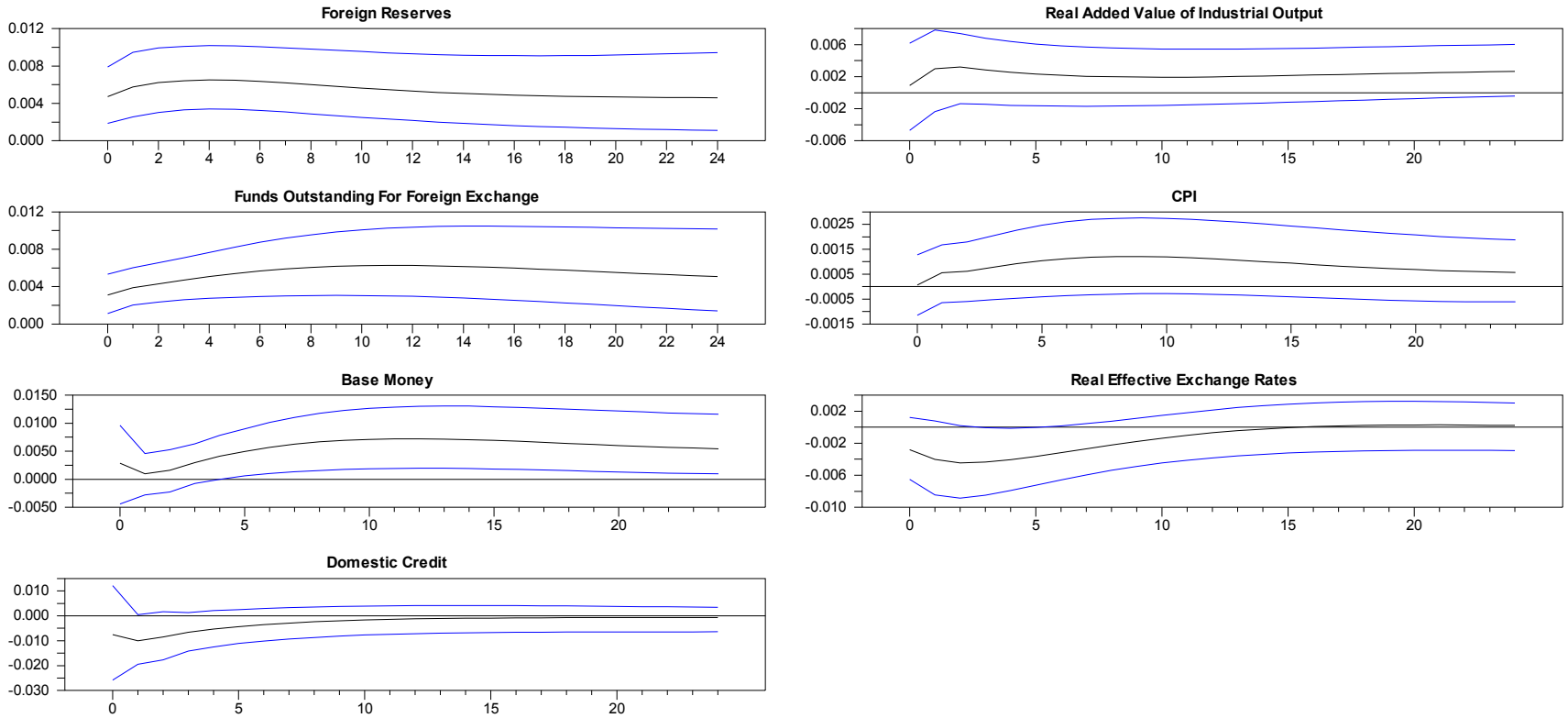


Figure 3-3. Impulse Responses to Reserve Accumulation Shock filtering out business cycle shock, monetary shock and external shock identified by the Pure-sign-restriction Approach

***Nkeep*=10000, *nstep*=24, *Kmax*=8**

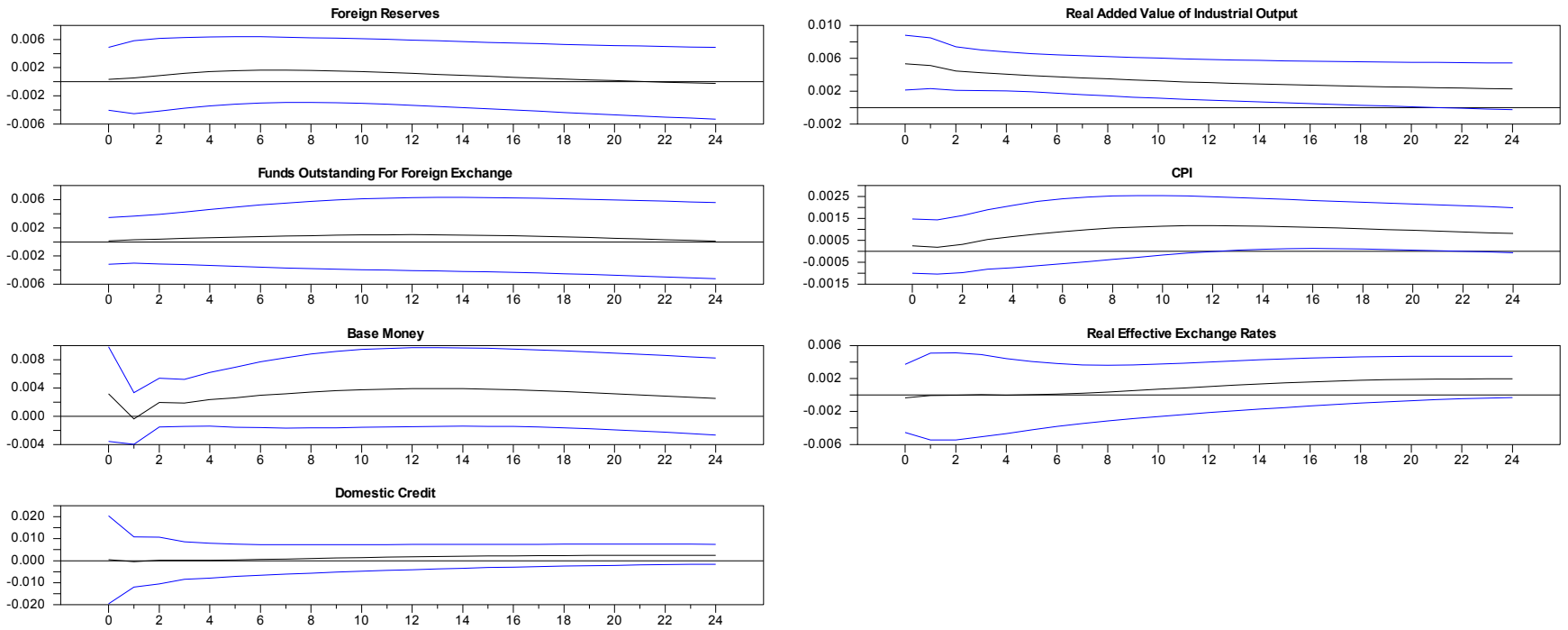


Figure 3-4. Impulse Responses to Business Cycle Shock identified by the Pure-sign-restriction Approach

***Nkeep*=10000, *nstep*=24, *Kmax*=8**

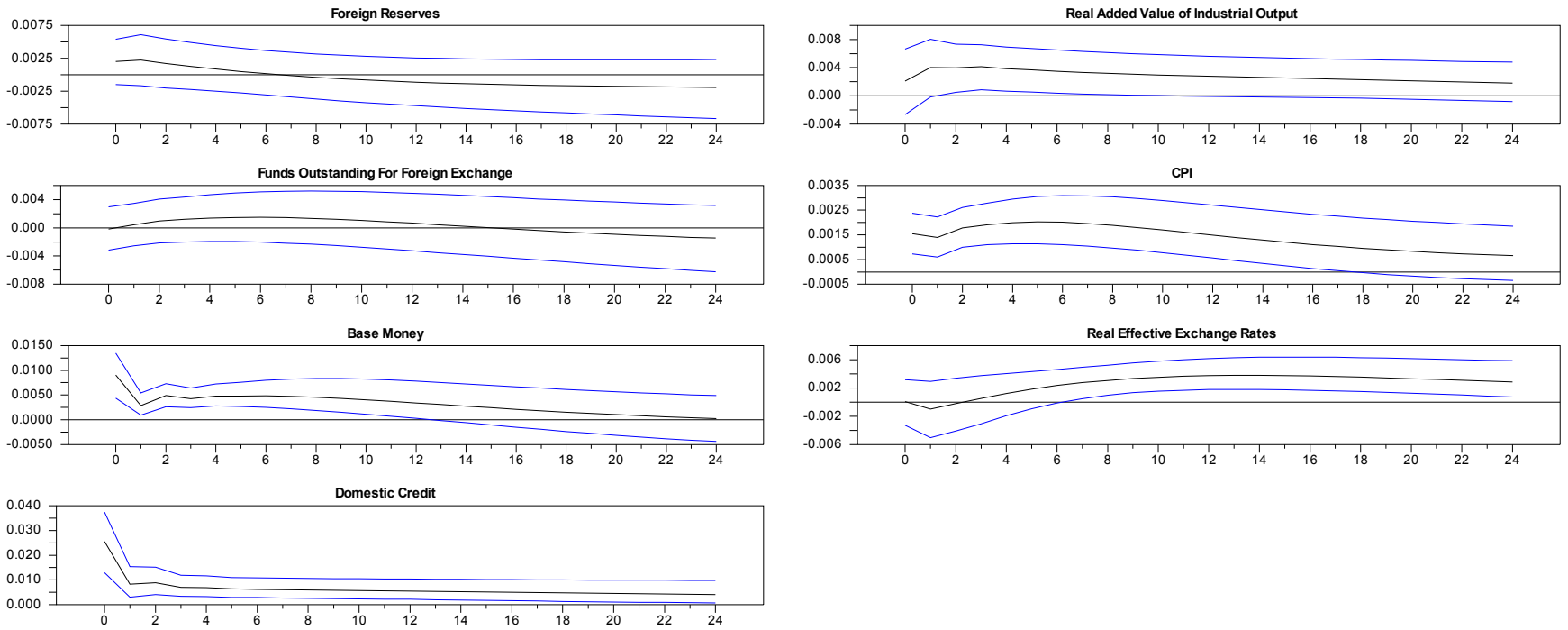


Figure 3-5. Impulse Responses to Monetary Policy Shock identified by the Pure-sign-restriction Approach

***Nkeep*=10000, *nstep*=24, *Kmax*=8**

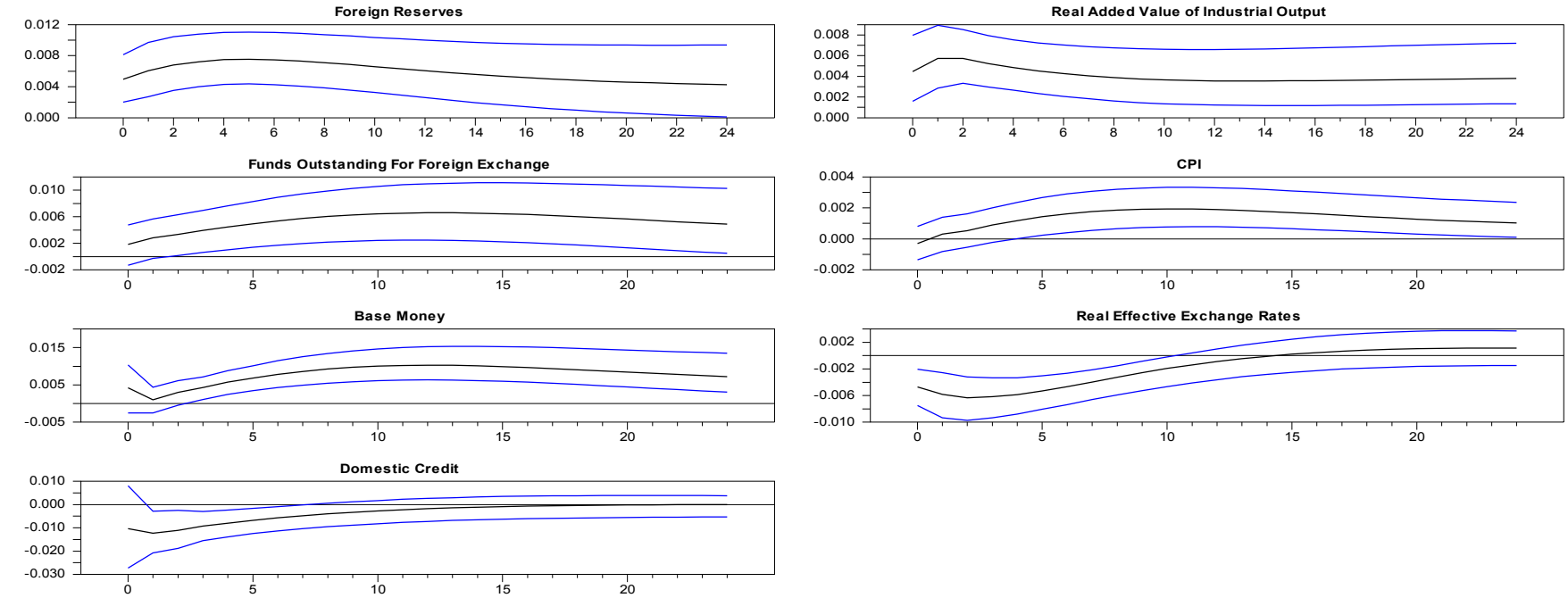


Figure 3-6. Impulse Responses to External Shock identified by the Pure-sign-restriction Approach

***Nkeep*=10000, *nstep*=24, *Kmax*=8**

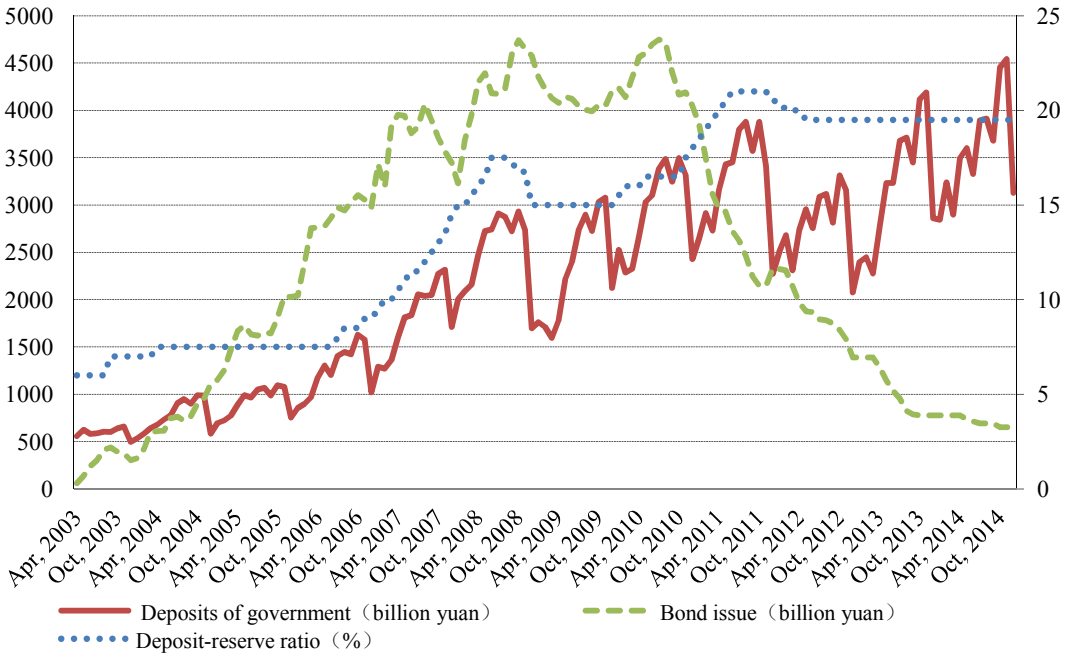


Figure 3-7. The primary sterilization intervention policy in China

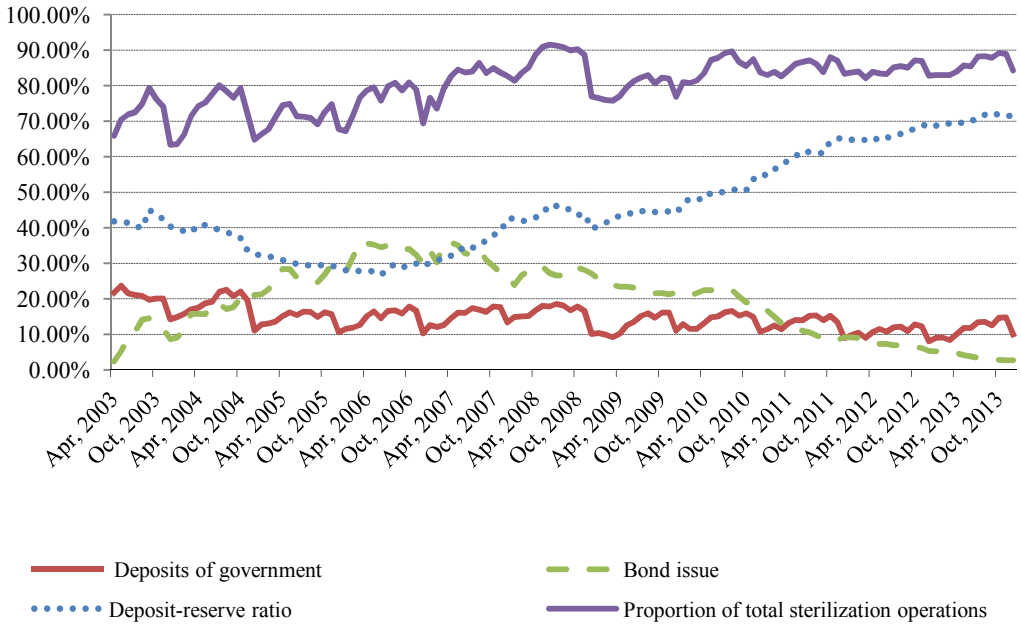


Figure 3-8. The proportion of sterilization in funds outstanding for foreign exchange

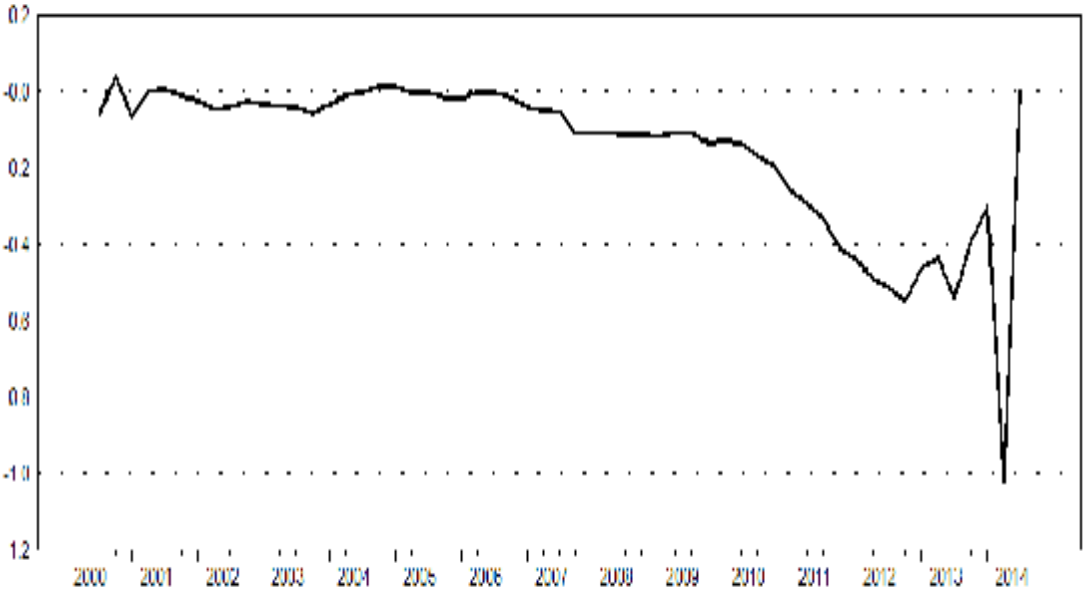


Figure 3-9. Sterilization coefficients from 40-quarter rolling regression

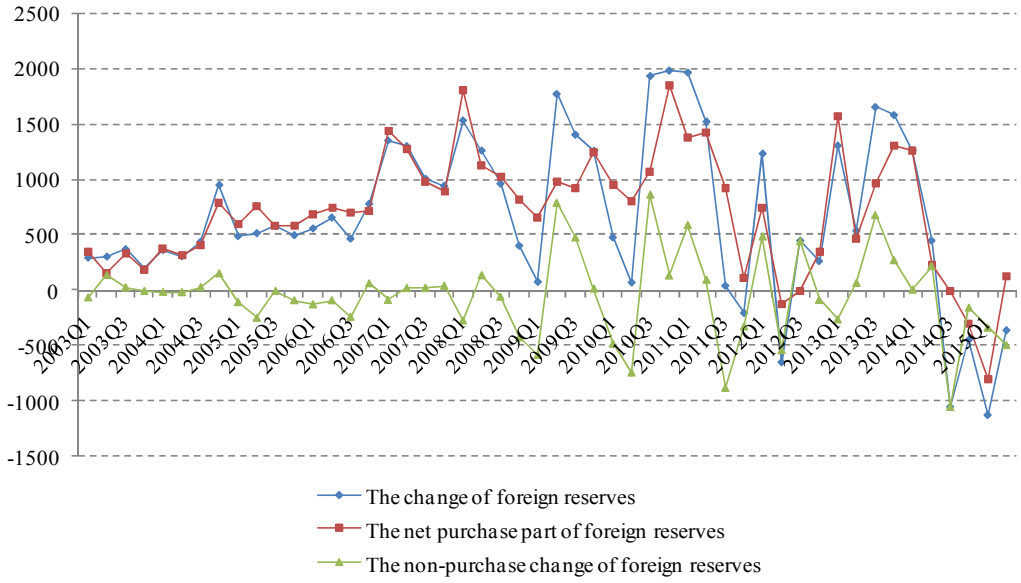


Figure 4-1. The value change of foreign exchange reserves and its composition (a hundred million dollars)

Table 4-1. China's foreign exchange reserves and its constitution (Jun. 2015 - Sep.2015)

	Foreign exchange reserves (FR)	Securities		Total currency and deposits	
		Claims	Ratio in FR	Claims	Ratio in FR
Jun., 2015	36938.38	36817.78	99.67%	120.60	0.33%
Jul., 2015	36513.10	36307.98	99.44%	205.11	0.56%
Aug., 2015	35573.81	35352.99	99.38%	220.82	0.62%
Sep., 2015	35141.20	34899.68	99.31%	241.52	0.69%

Source: the State Administration of Foreign Exchange. Unit: a hundred million dollars.

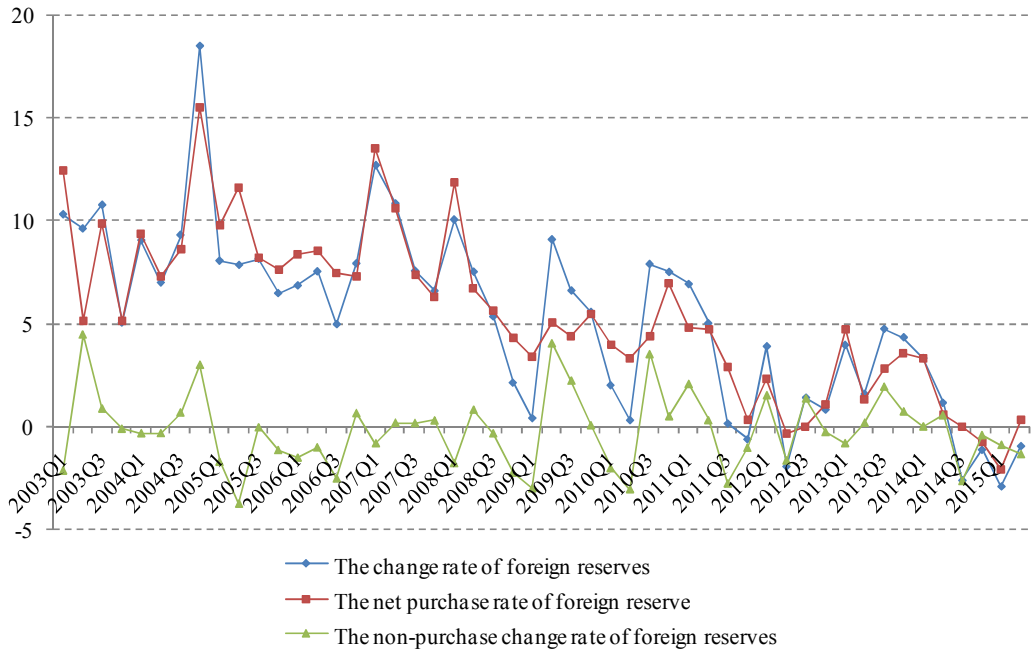


Figure 4-2. The change rate of foreign exchange reserves and its composition (%)

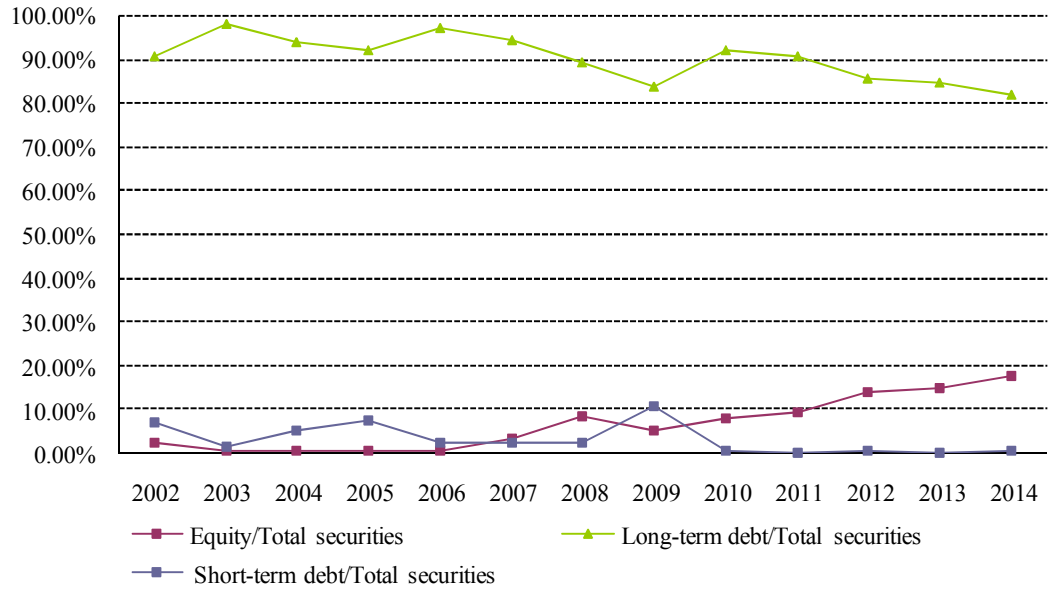


Figure 4-3. The composition of China's holdings of U.S. Securities

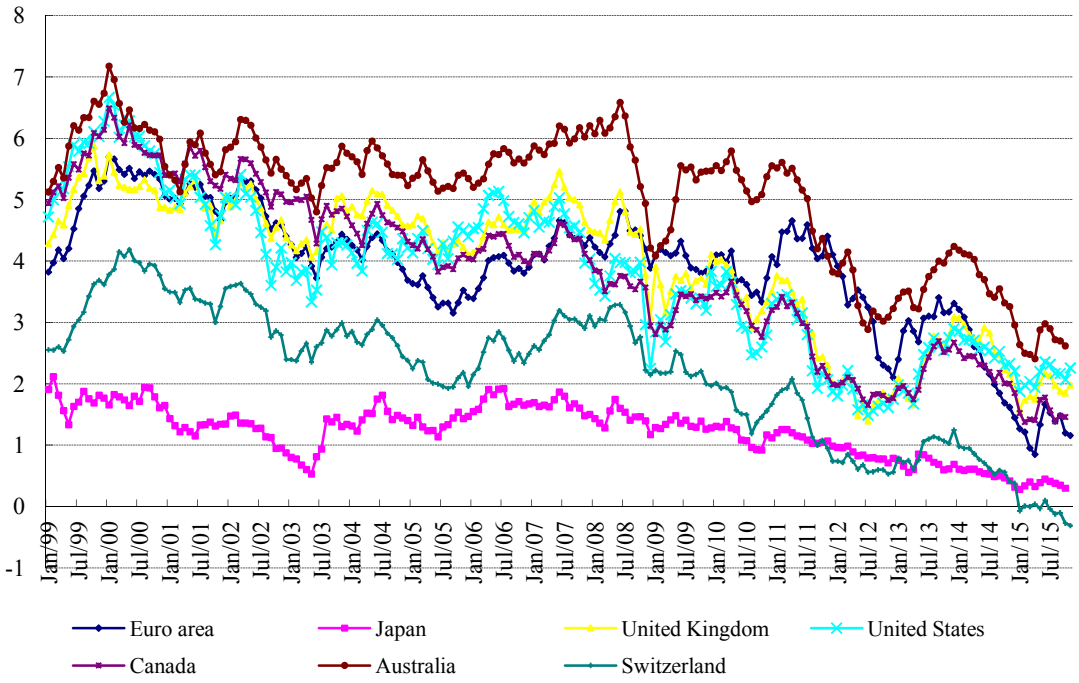


Figure 4-4. Nominal 10-year benchmarked government bond yields (%)

Table 4-2. Descriptive statistics of real 10-year benchmarked government bond yields

	USD	GBP	JPY	CHF	CAD	AUD	EUR
Mean	0.3001	0.3263	0.2326	0.3635	0.3797	0.5435	0.4575
Median	0.2979	0.3740	0.2555	0.3964	0.3952	0.5013	0.5574
Maximum	3.5820	1.3775	1.5654	1.8928	2.3381	1.5174	1.7114
Minimum	-1.2221	-0.8076	-2.3669	-0.8538	-1.1397	-0.6325	-1.0345
Std. Dev.	0.7645	0.5555	0.5669	0.6561	0.6115	0.4174	0.6035
Skewness	1.4679	-0.0538	-1.6467	0.2299	0.2254	-0.0392	-0.3599
Kurtosis	8.1321	2.3812	10.0755	2.2748	3.9972	3.6211	2.3576
Jarque-Bera	75.7418	0.8546	131.9694	1.5976	2.5950	0.8492	2.0164
Probability	0.0000	0.6523	0.0000	0.4499	0.2732	0.6540	0.3649
Sum	15.6047	16.9685	12.0969	18.9035	19.7433	28.2605	23.7888
Sum Sq. Dev.	29.8052	15.7364	16.3915	21.9516	19.0723	8.8873	18.5738
Observations	52	52	52	52	52	52	52

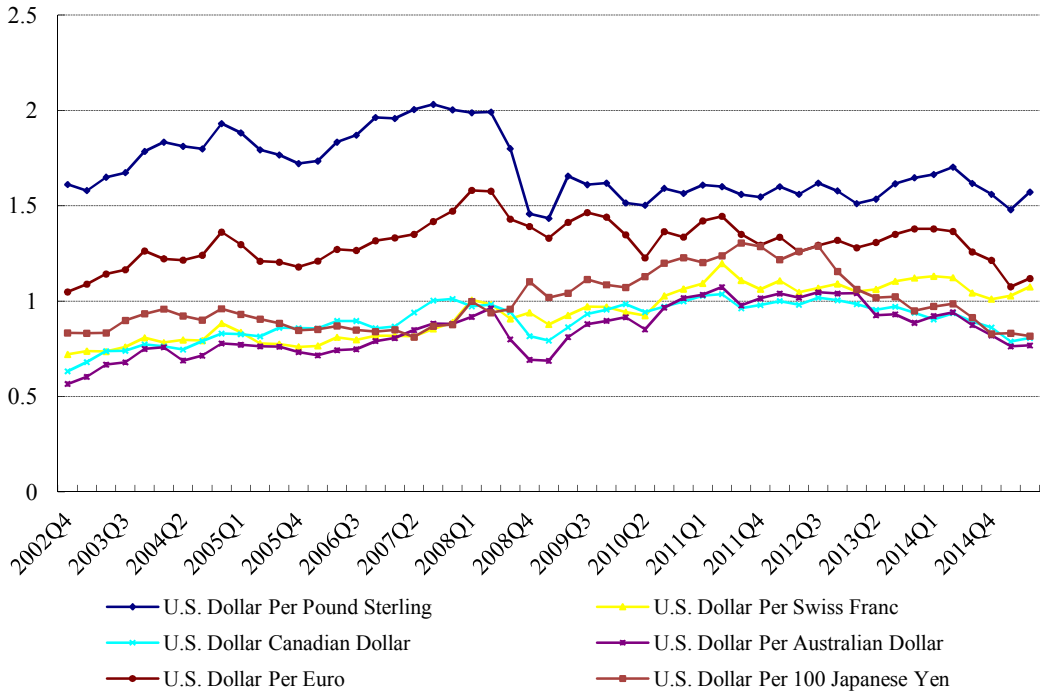


Figure 4-5. Spot exchange rates of primary currencies against U.S. dollar

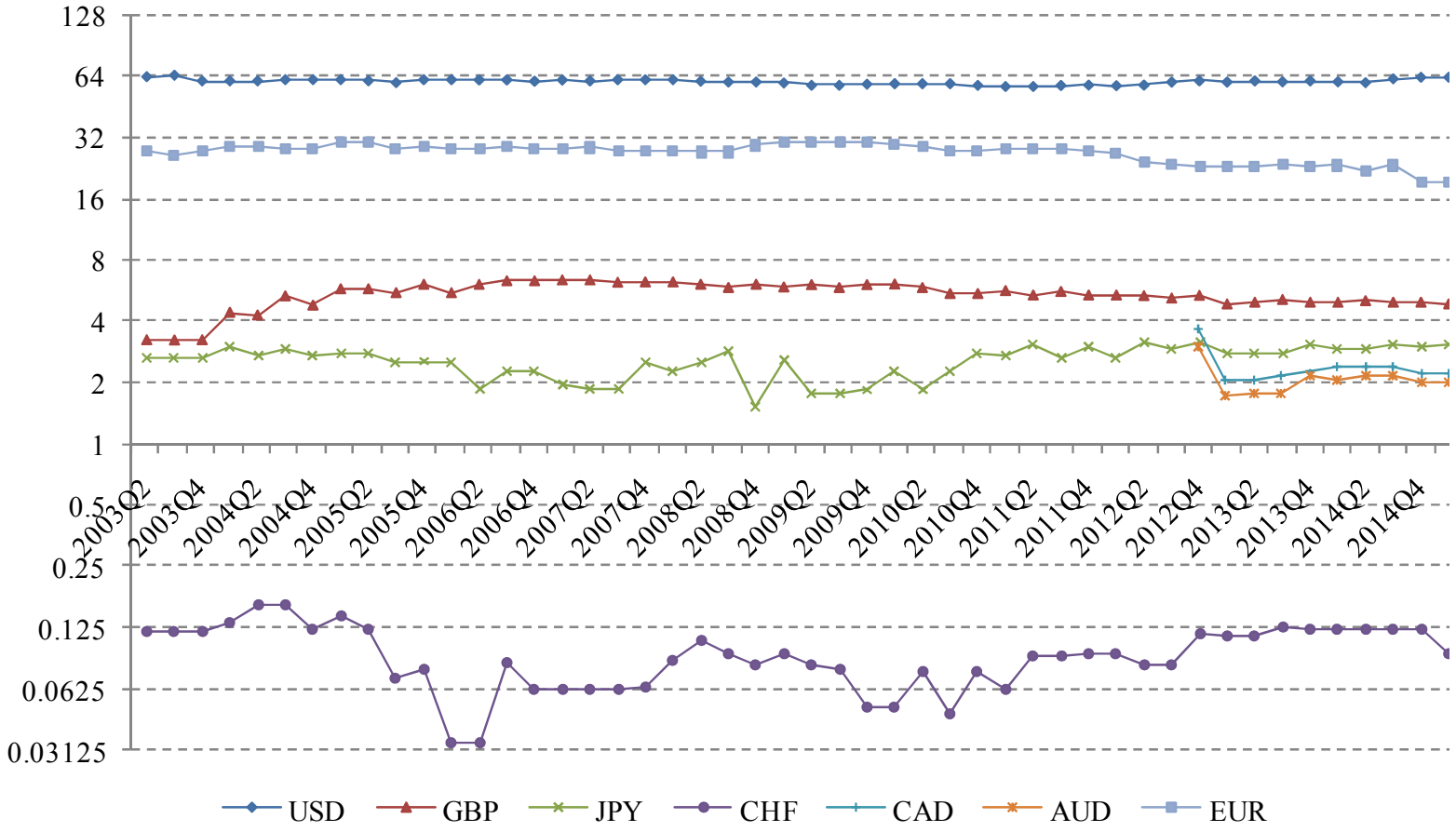


Figure 4-6. The estimated currency composition of China's foreign exchange reserves (%)

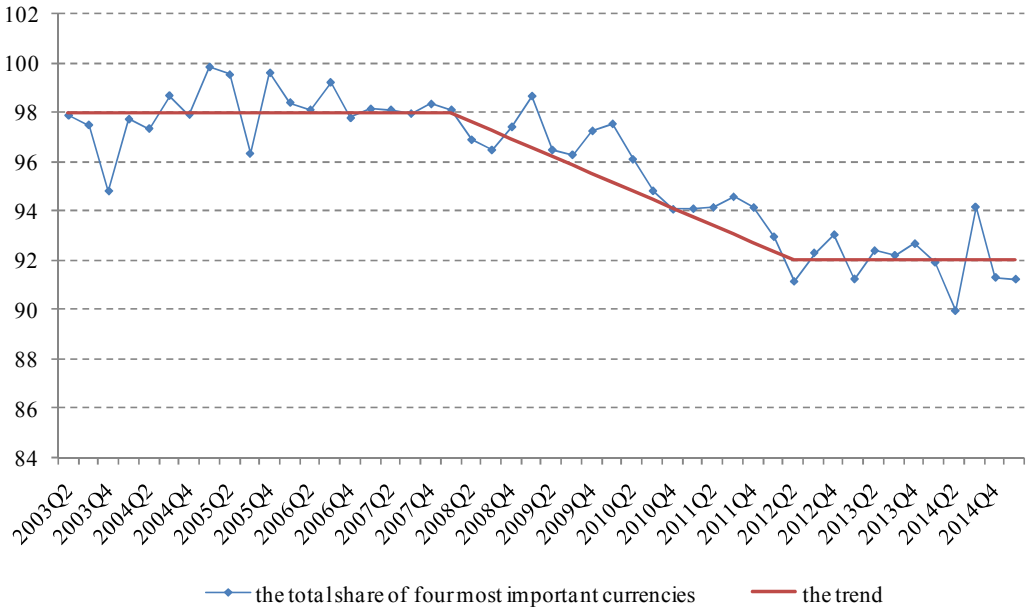


Figure 4-7. The total share of four most important currencies and its segmented trend (%)

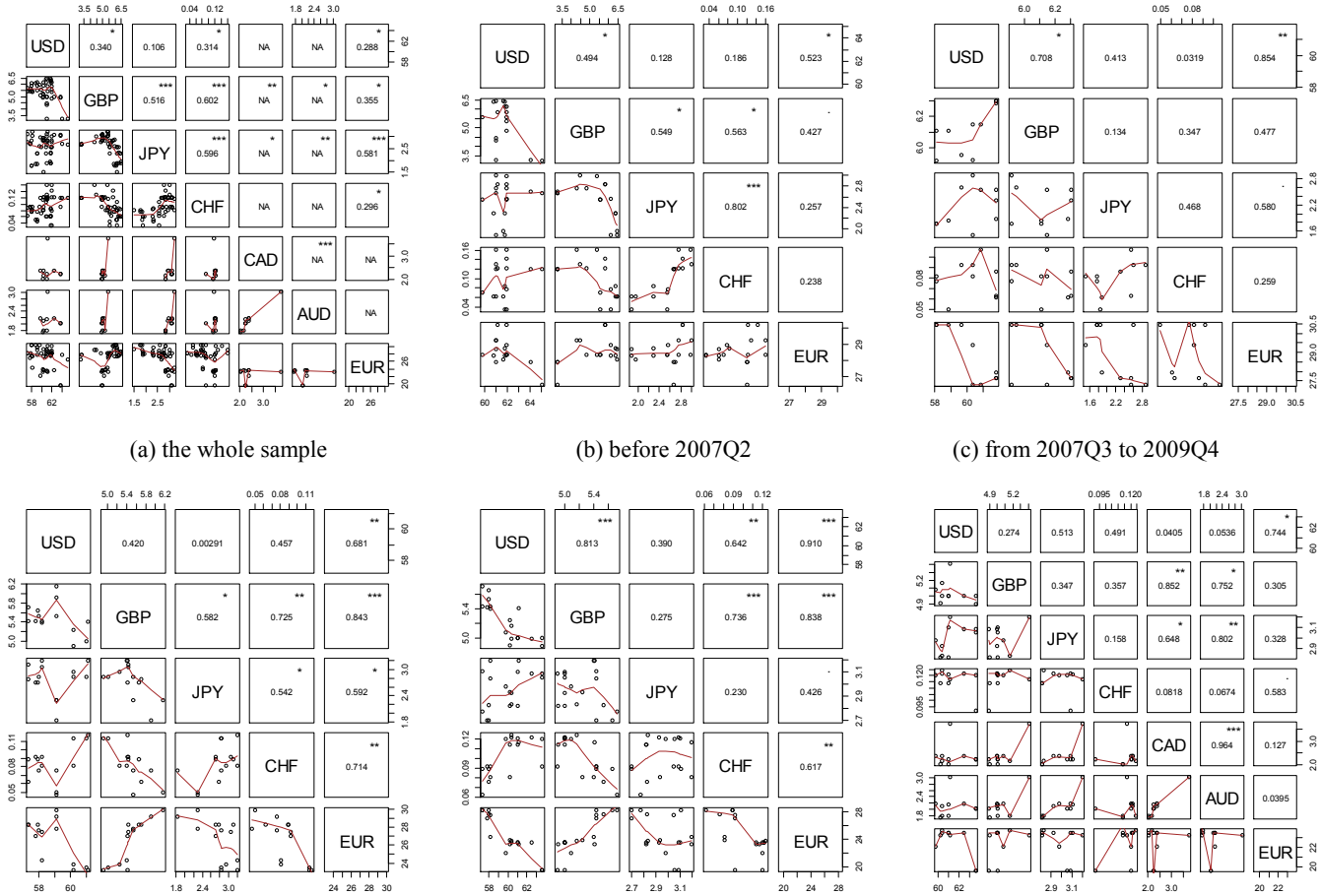
Table 4-3. Descriptive statistics about the estimated currency composition

	USD	EUR	GBP	JPY	CAD	AUD	CHF
Mean	60.5702	27.1331	5.4711	2.5931	2.3833	2.0992	0.0932
Median	60.9200	27.9784	5.5545	2.6990	2.2399	2.0662	0.0907
Maximum	65.0517	30.4585	6.4567	3.1948	3.7279	2.9202	0.1604
Minimum	57.3315	19.6174	3.2406	1.5166	2.0490	1.7507	0.0337
Std. Dev.	1.7988	2.7778	0.7949	0.4471	0.4884	0.3648	0.0307
Skewness	0.0741	-1.0789	-1.2453	-0.7611	2.3469	1.6235	0.1073
Kurtosis	2.6969	3.3884	4.5352	2.5021	7.1520	5.2637	2.4312
Jarque-Bera	0.2276	9.6136	17.1202	5.1296	16.3630	6.5281	0.7392
Probability	0.8924	0.0082	0.0002	0.0769	0.0003	0.0382	0.6910
Sum	2907.3680	1302.3890	262.6108	124.4692	23.8334	20.9921	4.4715
Sum Sq. Dev.	152.0768	362.6567	29.6960	9.3951	2.1472	1.1980	0.0442
Coefficient of Variance	0.0297	0.1024	0.1453	0.1724	0.2049	0.1738	0.3294

Table 4-4. Deterministic trend test for the value shares of primary currencies

	the whole sample			before 2007Q2			from 2007Q3 to 2009Q4			from 2010Q1 to 2013Q4			from 2010Q4 to 2015Q1		
	Intercept	Slop	t-stat	Intercept	Slop	t-stat	Intercept	Slop	t-stat	Intercept	Slop	t-stat	Intercept	Slop	t-stat
U.S. dollar	64.0473	-0.0092	-0.0607	64.2262	-0.1881	-0.6019	62.1194	-0.2992**	-2.0741	58.9966	0.1269	0.6371	57.6681	0.3300	1.4506
Euro	28.0410	-0.1755	-1.1582	27.8133	0.0521	0.2217	27.9074	0.0215	0.1136	30.3506	-0.4275**	-2.2443	28.1601	-0.4746**	-2.3929
pound sterling	3.2144	0.0351	0.5456	3.0491	0.2004***	3.2753	6.3707	-0.0520***	-2.9091	5.9616	-0.0623***	-7.3776	5.5657	-0.0370***	-2.8916
Japanese yen	2.6883	0.0083	0.2827	2.7473	-0.0508*	-1.8794	1.9155	0.0475	1.1069	2.2500	0.0533	1.0960	2.8095	0.0153	0.7479
Swiss franc	0.1206	-0.0006	-0.2519	0.1236	-0.0037	-0.5842	0.0593	0.0019	0.5913	0.0508	0.0045***	9.5376	0.0751	0.0009	0.2908

Note: *** represents significant at 1% level, ** represents significant at 5% level, and * represents significant at 10% level.



(a) the whole sample

(b) before 2007Q2

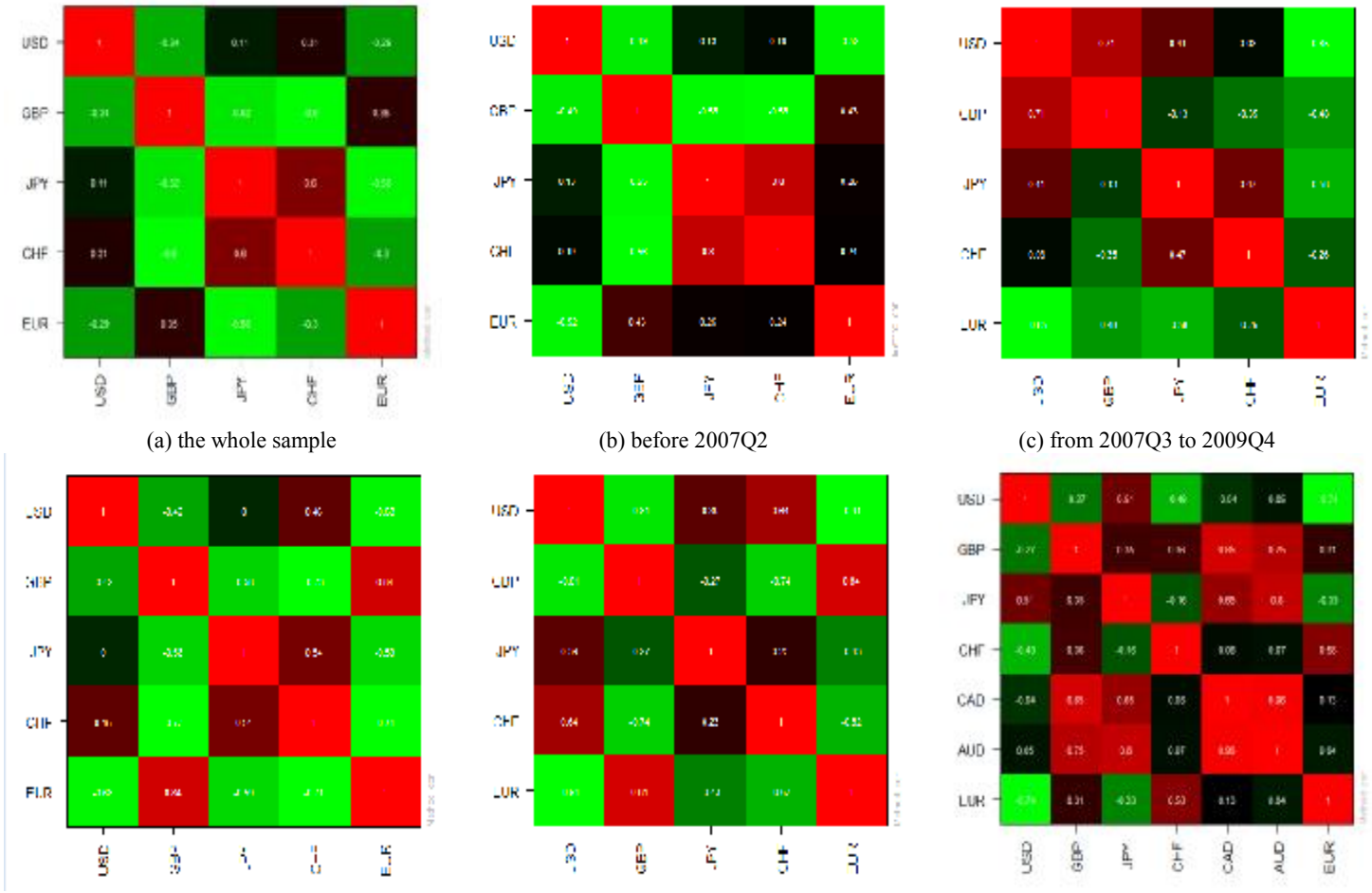
(c) from 2007Q3 to 2009Q4

(d) from 2010Q1 to 2013Q4

(e) since 2010Q4

(f) from 2012Q4 to 2015Q1

Figure 4-8. Scatter plots in combination with Pearson correlation tests. The plot represents a graphical view of correlations in combination with pairwise correlation tests. The lower off-diagonal panel displays a scatter plot combined with a locally-weighted polynomial regression fit. The upper off-diagonal panel shows the results returned from the correlation test. The diagonal panel shows the names of primary currencies.



(a) the whole sample (b) before 2007Q2 (c) from 2007Q3 to 2009Q4

(d) from 2010Q1 to 2013Q4 (e) since 2010Q4 (f) from 2012Q4 to 2015Q1

Figure 4-9. Image plots of Pearson correlations. The plot shows a symmetric colored image with default settings. The numbers represent values for Pearson's correlation coefficient.

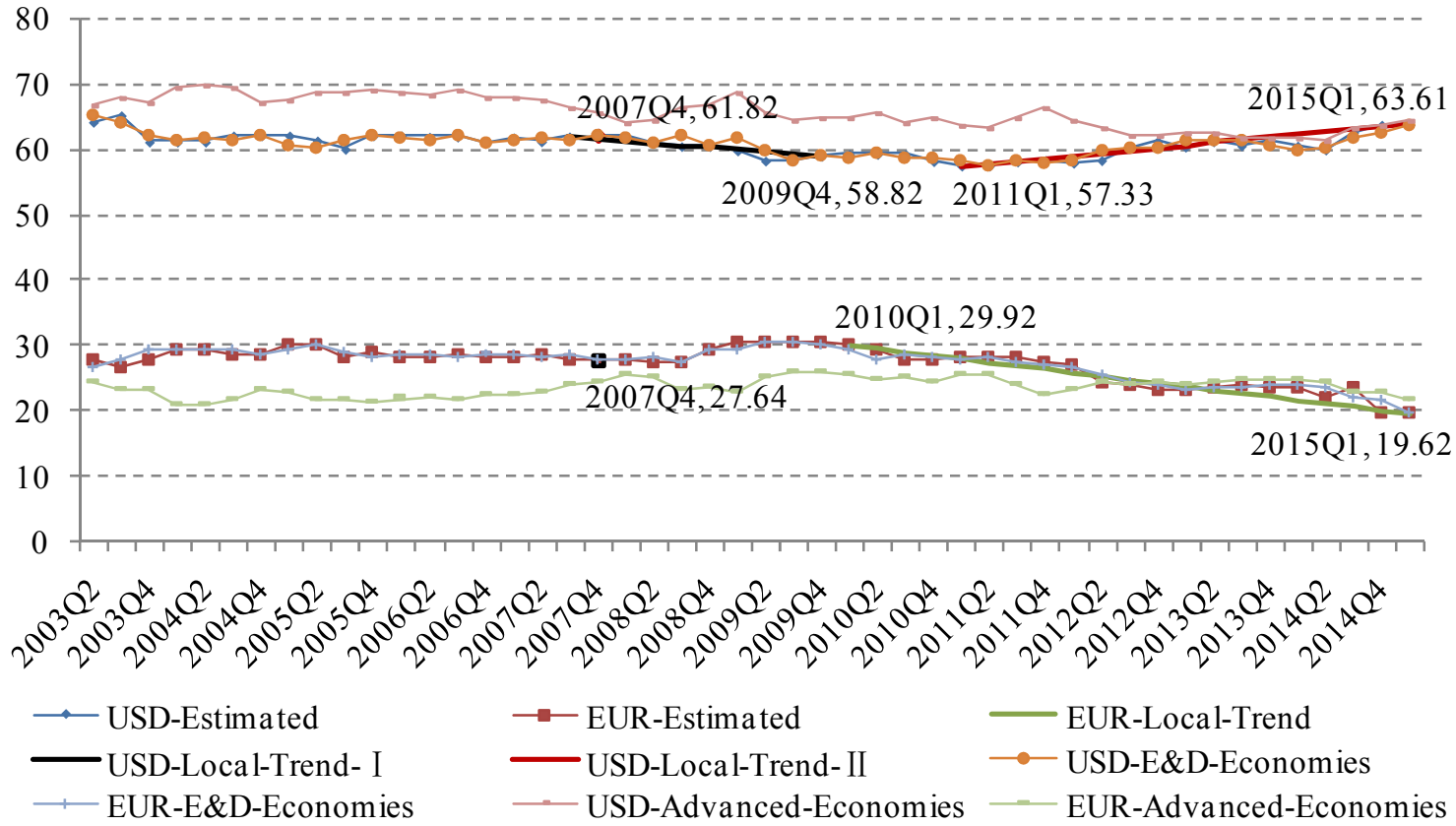


Figure 4-10. The estimated value shares of the U.S. dollar and the euro, their local trends and the corresponding shares of emerging and developing economies and advanced economies reported in the IMF COFER. Unit: %. E&D-Economies represents the emerging-and-developing-economies. USD-Local-Trend-Ⅰ refers to the segmented trend from 2007Q3 to 2009Q4, in which the slope is -0.2992 significantly at 5% level. USD-Local-Trend-Ⅱ denotes the segmented trend from 2011Q1 to 2015Q1, in which the slope is 0.4184 significantly at 10% level. EUR-Local-Trend represents the segmented trend from 2010Q1 to 2015Q1, in which the slope is -0.5153 significantly at 5% level.

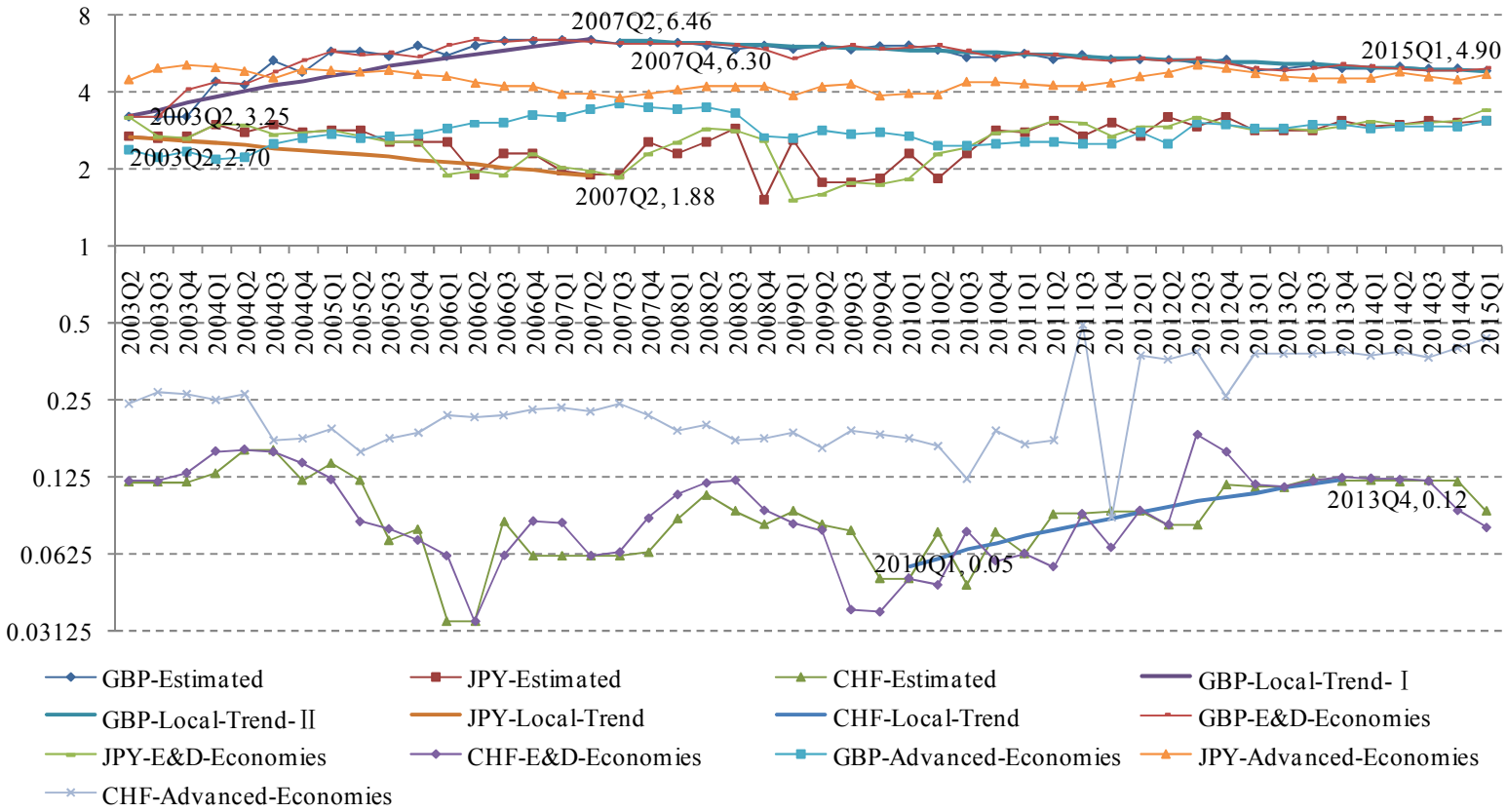


Figure 4-11. The estimated value shares of the pound sterling, the Japanese yen, the Swiss franc, their local trends and the corresponding shares of emerging and developing economies and advanced economies reported in the IMF COFER. Unit: %. E&D-Economies represents the emerging-and-developing-economies. GBP-Local-Trend-Ⅰ denotes the segmented trend before 2007Q2, in which the slope is 0.2004 significantly at 1% level. GBP-Local-Trend-Ⅱ denotes the segmented trend after 2007Q3, in which the slope is -0.0506 significantly at 1% level. JPY-Local-Trend refers to the segmented trend before 2007Q2, in which the slope is -0.0508 significantly at 10% level. CHF-Local-Trend refers to the segmented trend from 2010Q1 to 2013Q4, in which the slope is 0.0045 significantly at 1% level.

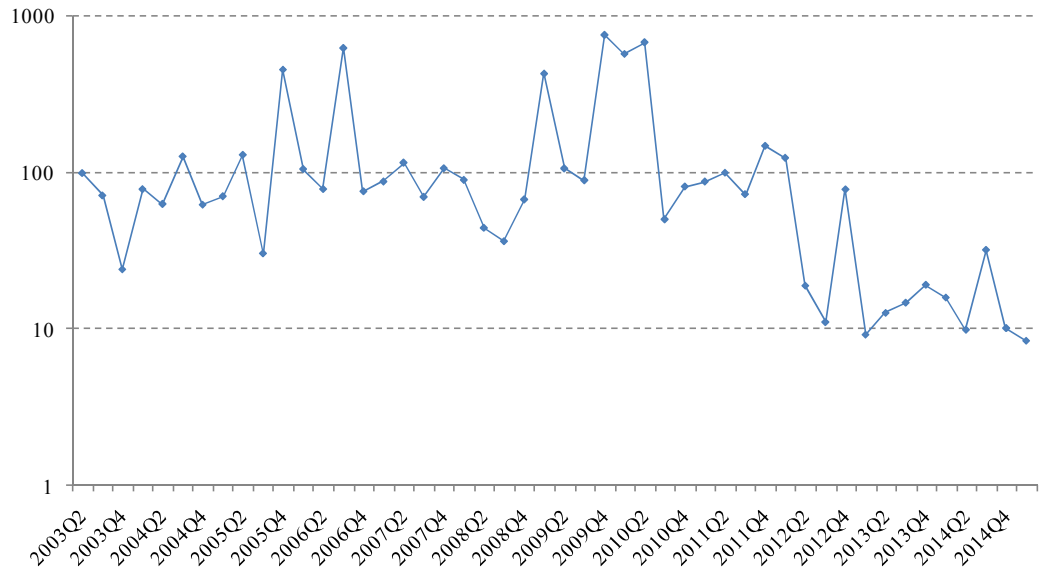


Figure 4-12. The proportion of the difference between the holding period returns based on estimated currency composition and the portfolio adjustment profit/loss to the absolute of holding period returns based on estimated currency composition. Unit: %. A smaller value below 100 represents a higher proportion of portfolio adjustment profit. A value above 100 implies that the portfolio adjustment causes the net loss.

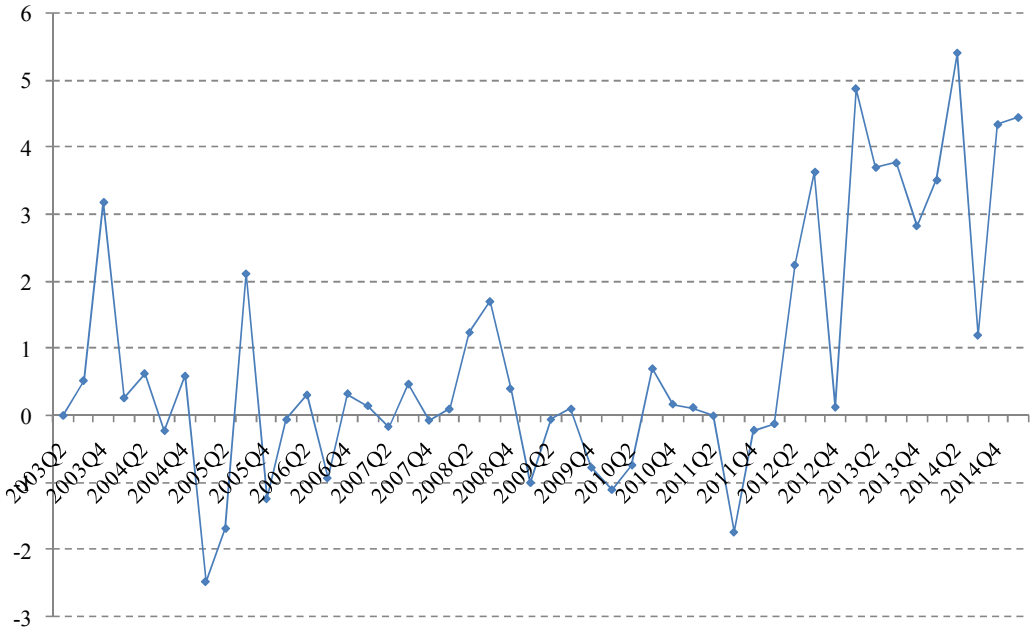


Figure 4-13. The estimated net profit/loss rate from portfolio adjustment (Unit: $\times 10^{-4}$)

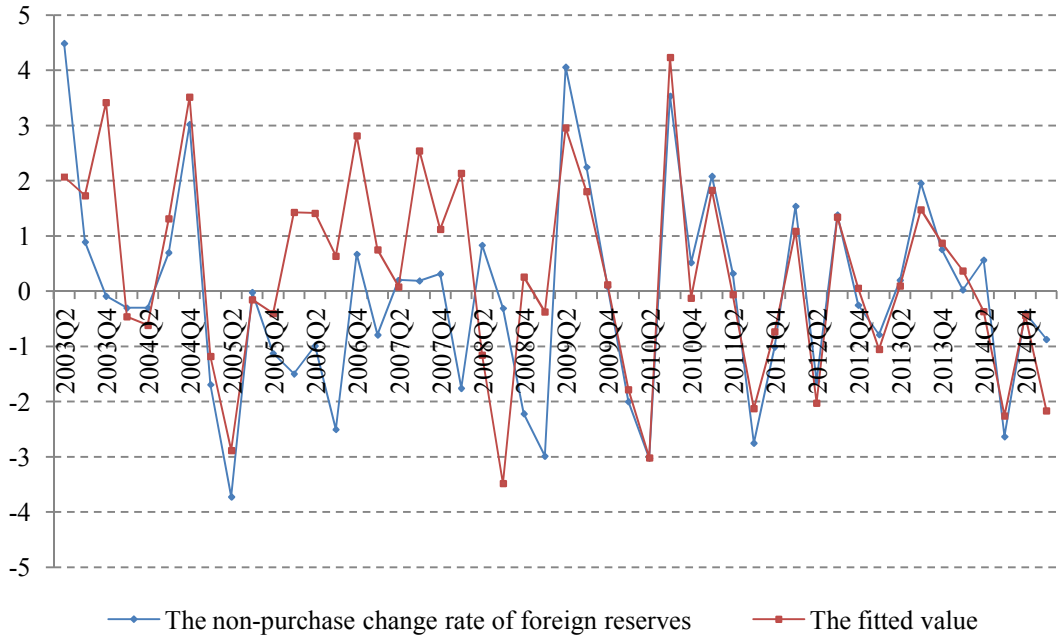
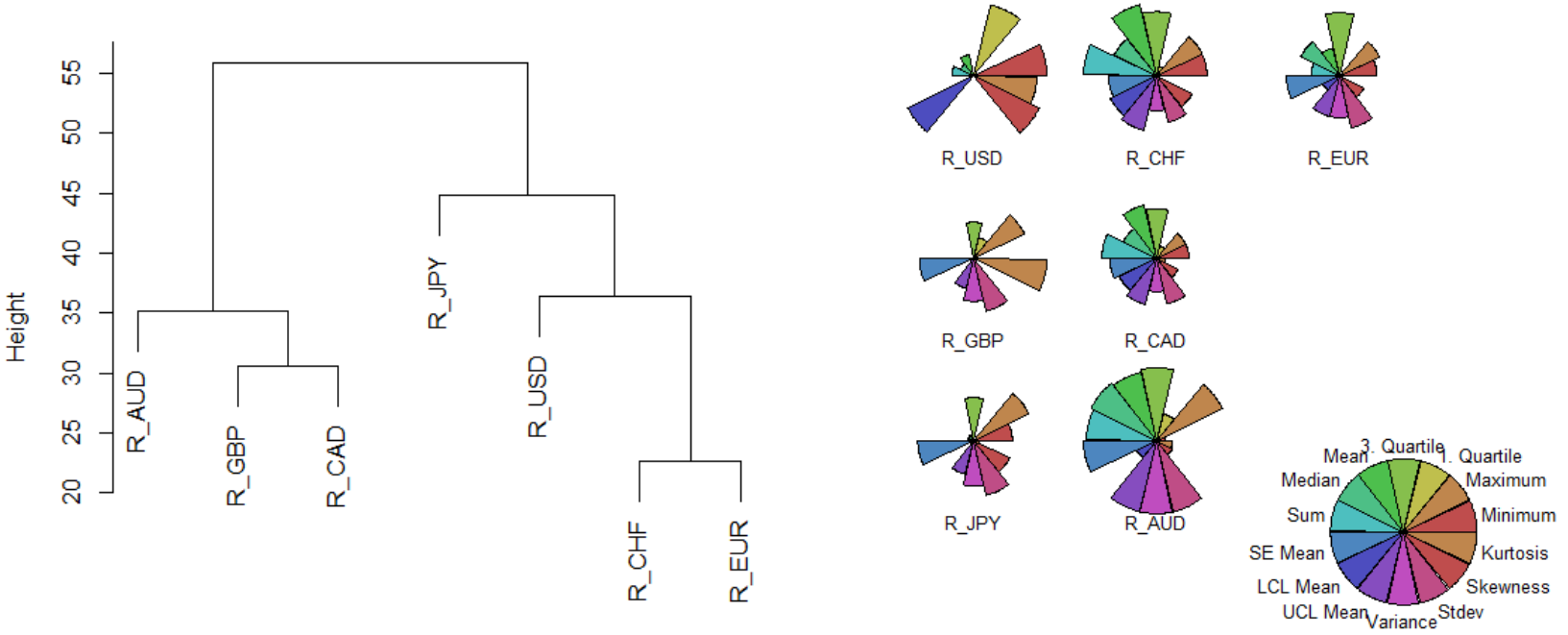


Figure 4-14. The non-purchase change rate of foreign exchange reserves and its fitted value (%)



(a) Cluster Dendrogram

(b) Returns Statistics

Figure 4-15. Hierarchical clustering of the real returns of primary currencies and their segment plots of basic return statistics

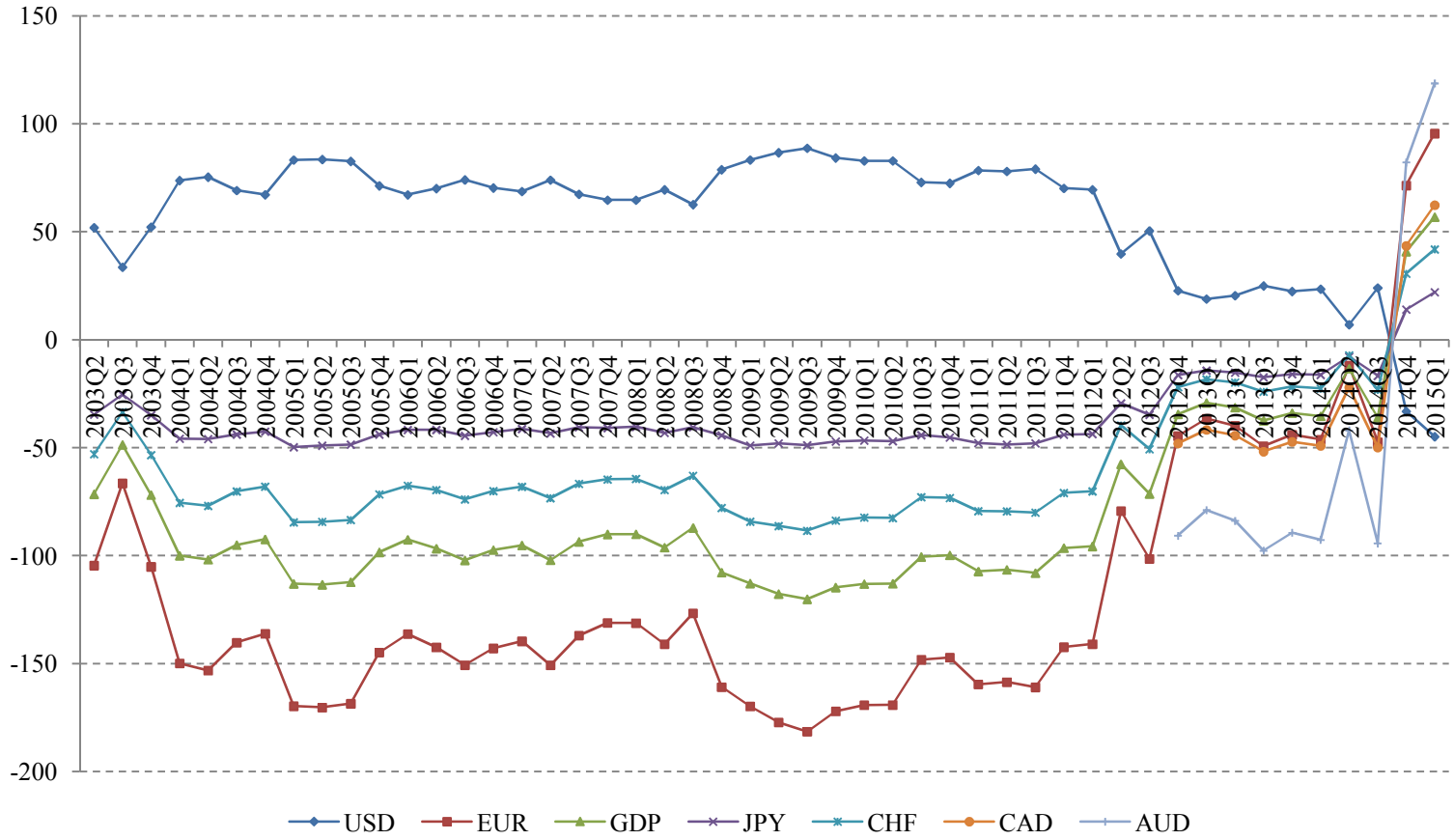


Figure 4-16. The first derivatives of foreign reserve portfolio variance with respect to the corresponding share change of different currencies

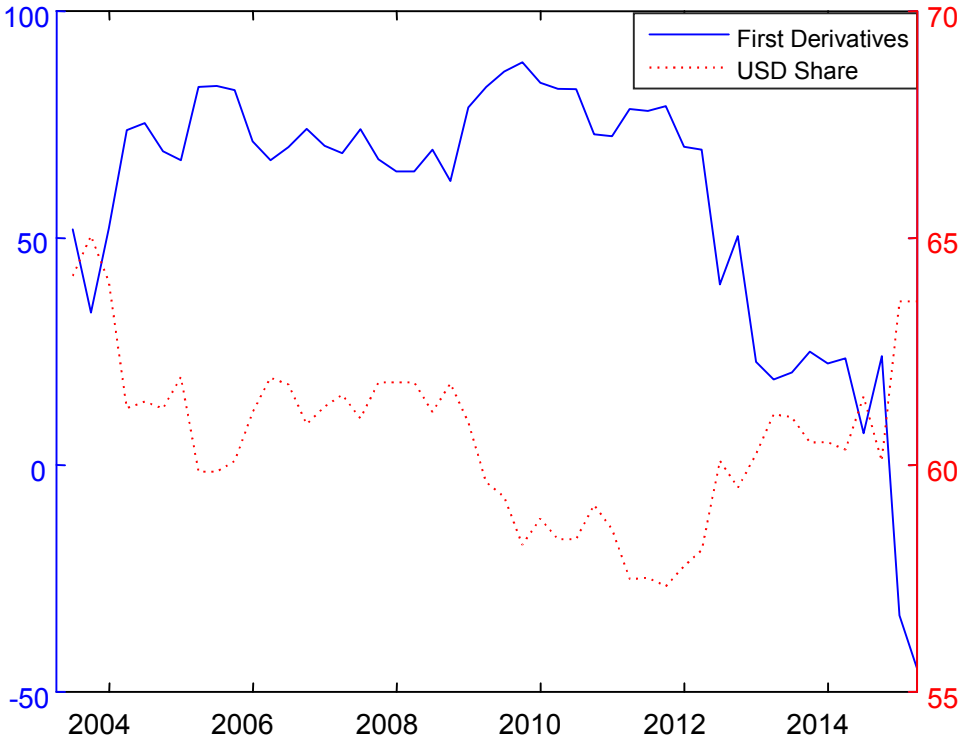


Figure 4-17. The first derivative of the U.S. dollar and its estimated value share

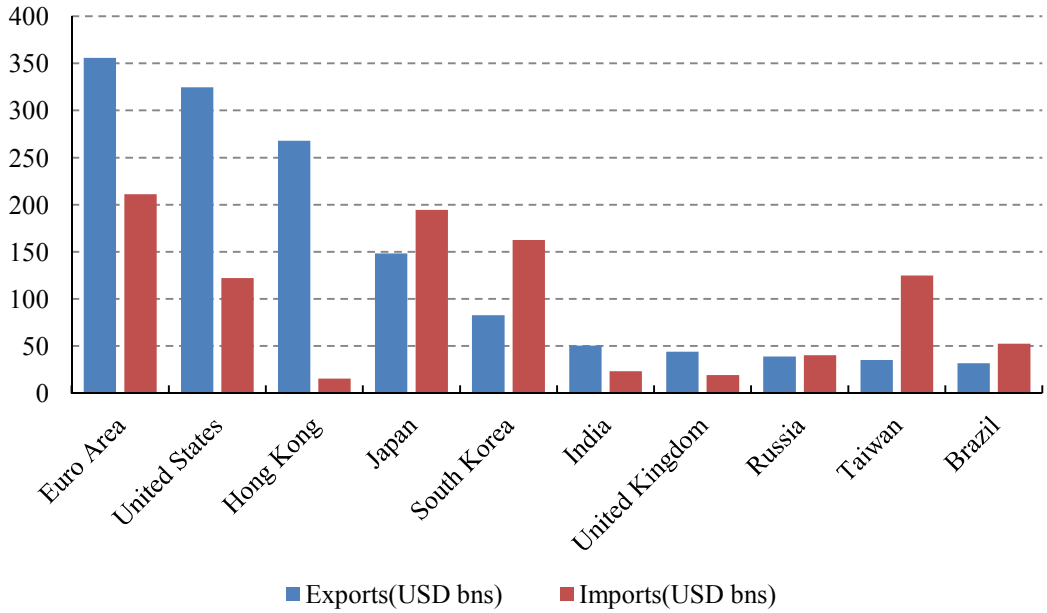


Figure 5-1. The imports and exports of primary trading partners with China in 2011.

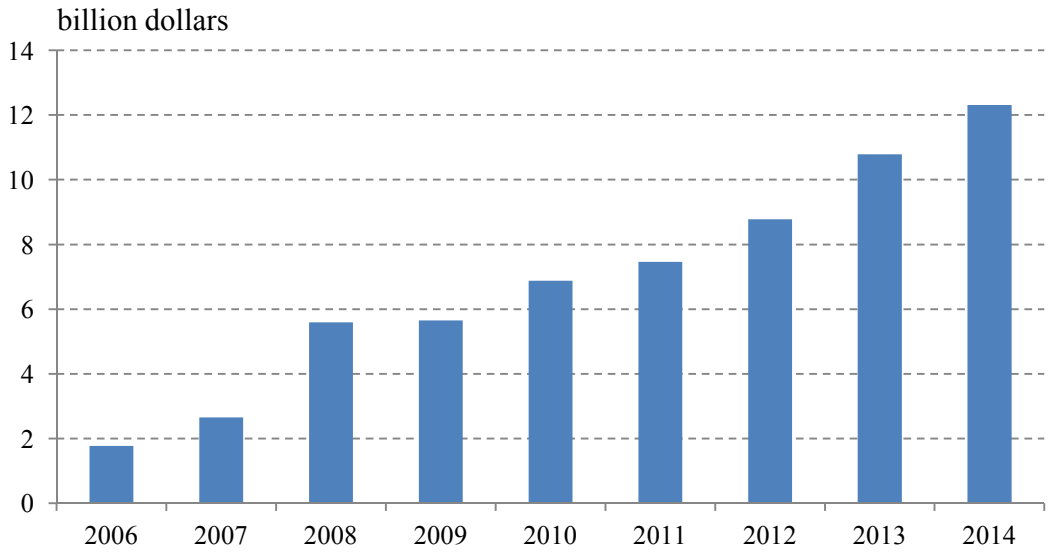


Figure 5-2. China's outward FDI flows

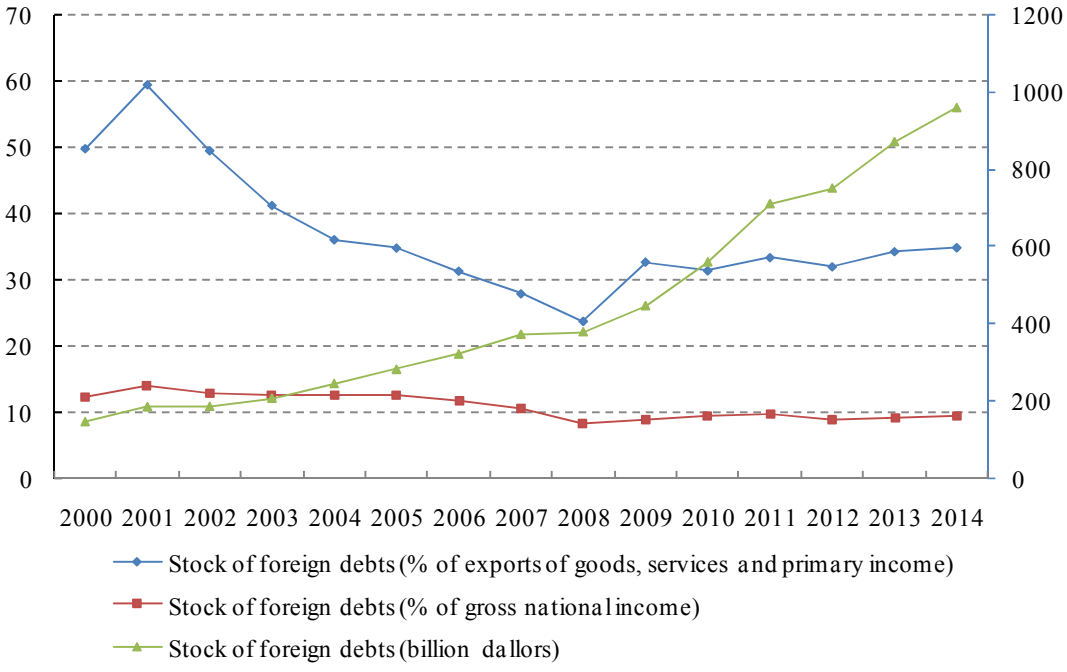


Figure 5-3. China's foreign debts from 2000 to 2014

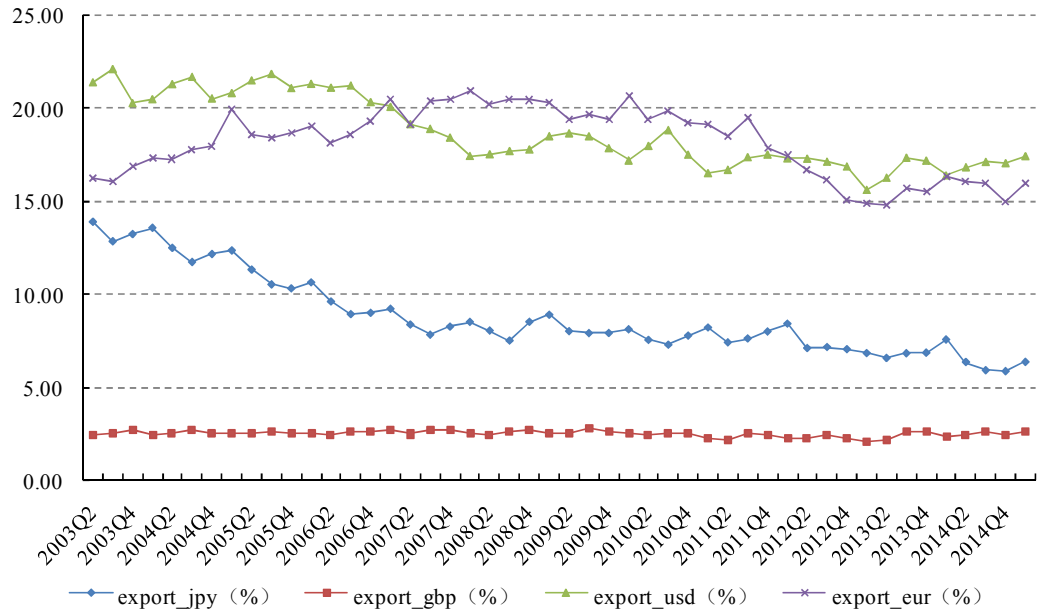


Figure 5-4. The share of exports to main currency issuing countries in China's total exports

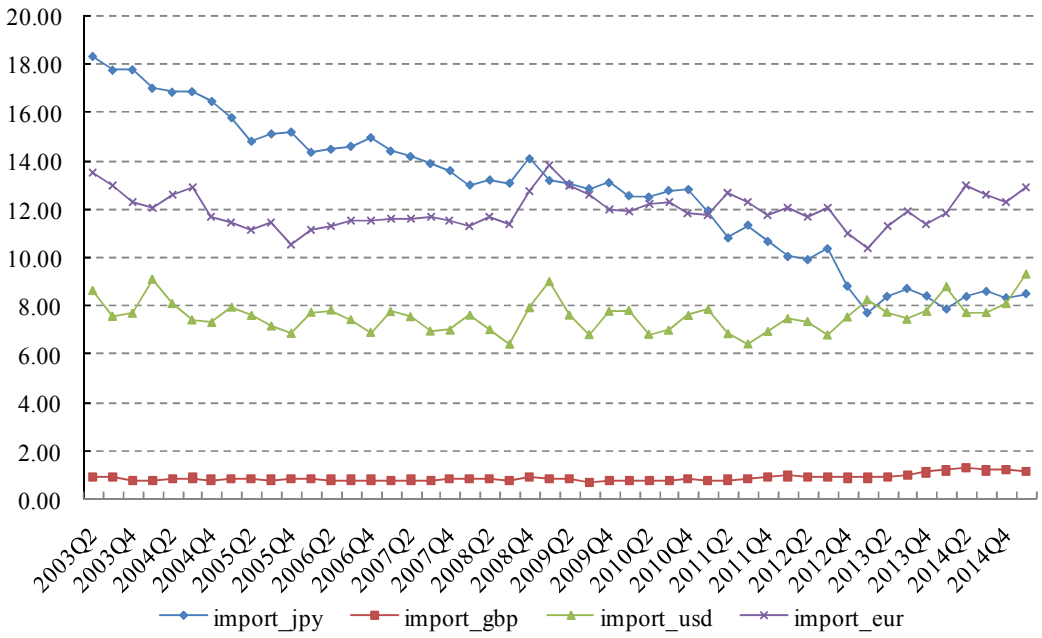


Figure 5-5. The share of imports from main currency issuing countries in China's total imports

Table 5-1. Panel regression results for the two-currency group (without foreign debts）

	(1)	(2)	(3)	(4)	(5)
Constant	0.8551	1.2698	0.9743	1.5502	2.2377
Inertia	0.8368***	0.8255***	0.8404***	0.8320***	0.8228***
Exports	0.3322**	0.3333**	0.3247**	0.2866**	0.2702**
Imports	-0.0238	0.0063	0.0180	-0.0997	-0.0362
Confidence	-0.0594***	-0.0571***	-0.0571***	-0.0632***	-0.0590***
FX volatility		-214.5134			-233.5049
Inflation			-0.4626		-0.5117
Bond yields				0.3113	0.3750
Currency effects	Yes	Yes	Yes	Yes	Yes
Time effects	Yes	Yes	Yes	Yes	Yes
Observations	95	95	95	95	95
Adjusted R^2	0.9941	0.9940	0.9942	0.9941	0.9941
D.W. statistic	2.3768	2.3587	2.2858	2.4163	2.3016

Notes: this table reports the fixed effect estimations of two-currency group where reserve currency shares are regressed on traditional and additional determinants over the full sample ranging from 2003Q2 to 2015Q1. The results are obtained based on cross-section weighted standard errors. *** represents significant at 1%, ** represents significant at 5%, * represents significant at 10%.

Table 5-2. Panel regression results for two-currency system (with foreign debts)

	(1)	(2)	(3)	(4)	(5)
Constant	-5.3348**	-5.0898**	-4.8547**	-5.1049*	-4.4449
Inertia	0.8147***	0.8089***	0.8492***	0.7682***	0.8476***
Exports	0.9653***	0.9607***	0.8676***	1.0157***	0.8458**
Imports	-0.3365	-0.3162	-0.3573	-0.2964	-0.3319
Confidence	-0.1034***	-0.1047***	-0.0957***	-0.1022***	-0.0968***
Foreign debts	-0.1285***	-0.1290***	-0.1235**	-0.1229***	-0.1240**
FX volatility		-106.0969			-158.9459
Inflation			-0.2145		-0.2402
Bond yields				0.1777	-0.0112
Currency effects	Yes	Yes	Yes	Yes	Yes
Time effects	Yes	Yes	Yes	Yes	Yes
Observations	40	40	40	40	40
Adjusted R^2	0.9991	0.9991	0.9991	0.9934	0.9989
D.W. statistic	2.8187	2.8517	2.7244	2.6264	2.7521

Notes: this table reports the fixed effect estimations of two-currency group where the reserve currency shares are regressed on traditional and additional determinants over the period from 2010Q1 to 2015Q1. The results are obtained based on cross-section weighted standard errors. *** represents significant at 1%, ** represents significant at 5%, * represents significant at 10%.

Table 5-3. Panel regression results for four-currency group (without external debt）

	(1)	(2)	(3)	(4)	(5)
Constant	2.1326	2.1292	2.2845	1.4069	1.5587
Inertia	0.8495***	0.8495***	0.8518***	0.8453***	0.8474***
Exports	0.1913***	0.1916***	0.1904***	0.1782**	0.1778**
Imports	-0.1242**	-0.1244**	-0.1259**	-0.0911	-0.0930
Confidence	-0.0130***	-0.0130***	-0.0123**	-0.0127***	-0.0121**
FX volatility		0.0002			0.0002
Inflation			-0.0593		-0.0562
Bond yields				0.2380	0.2373
Currency effects	Yes	Yes	Yes	Yes	Yes
Time effects	Yes	Yes	Yes	Yes	Yes
Observations	189	189	189	189	189
Adjusted R^2	0.9985	0.9985	0.9985	0.9985	0.9985
D.W. statistic	1.6312	1.6317	1.6196	1.6474	1.6354

Notes: this table reports the fixed effect estimations of four-currency group where reserve currency shares are regressed on traditional and additional determinants over the full sample ranging from 2003Q2 to 2015Q1. The results are obtained based on cross-section weighted standard errors. *** represents significant at 1%, ** represents significant at 5%, * represents significant at 10%.

Appendix

Appendix 1. Data Descriptions and Sources

Variables	Descriptions	Source
Reserve currency shares	Four dominant currencies in China's foreign exchange reserves-- the U.S. dollar, euro, Japanese yen and pound sterling are considered.	Estimated by the author
Exports	The share of exports from China to reserve currency issuing countries in China's total exports.	CEIC database
Imports	The share of imports from reserve currency issuing country to China in China's total imports.	CEIC database
Confidence in reserve currencies	This is calculated as the average change rate of the value of the currency against the special drawing right (SDR) basket over the preceding three years.	International Monetary Fund
Foreign debts	For the quarterly data, this is the ratio of individual foreign currency denominated long-term public and publicly-guaranteed foreign debts to China's aggregate foreign debts (including renminbi denominated and foreign currency denominated foreign debts). For the annual data, this is the ratio of individual foreign currency denominated long-term public and publicly-guaranteed foreign debts to China's aggregate foreign debts.	The quarterly data come from CEIC database. The annual data come from The World Bank.
Inflation	Consumer Price Index (2010=100)	CEIC database
FX volatility	This is estimated from GARCH models using the foreign exchange rate against SDR basket.	International Monetary Fund
Bond yields	10 year government bond yields	Organization for Economic Cooperation and Development
FDI	China's outward foreign direct investment	CEIC database
Financial depth	SM cap./GDP and SM turnover ratio represents the ratio of stock market capitalization to GDP as well as the stock market turnover ratio, respectively.	The World Bank (Global Financial Development)

Appendix 2. Panel regression results for four-currency group（annual data, with foreign debts）

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Constant	4.7467	4.0926	4.2044	4.6623	4.4326	4.1727	4.7202
Inertia	0.6532***	0.6543***	0.5589**	0.6554***	0.6446***	0.6729***	0.6510***
Exports	0.3811	0.4346*	0.4926	0.3933	0.3685	0.3890	0.3866
Imports	-0.5329***	-0.5827***	-0.4754*	-0.5537***	-0.5459**	-0.4960**	-0.5347***
Confidence	-0.0225**	-0.0230**	-0.0312*	-0.0204**	-0.0218**	-0.0268**	-0.0226**
External debts	0.1354**	0.1466**	0.1491*	0.1376**	0.1356**	0.1237*	0.1365**
FX volatility		0.0170					
Inflation			0.3752				
Bond yields				0.0355			
FDI					0.1270		
SM cap./GDP						0.0069	
SM turnover ratio							0.0009
Currency effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	44	44	44	44	44	44	44
Adjusted R^2	0.9981	0.9981	0.9981	0.9981	0.9981	0.9981	0.9980
D.W. statistic	2.0665	2.1542	2.2312	2.0511	2.0622	2.0804	2.0599

Notes: The table reports the fixed effect estimates of our basic equation where the reserve currency shares are regressed on the traditional and additional determinants over the period from 2004 to 2014. And it is estimated using cross-section weighted standard errors *** significant at 1%, ** significant at 5%, * significant at 10%.