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Jiao Wang

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AUTHOR AFFILIATION: Ph.D. Candidate in economics at Crawford School of Public Policy, the Australian National University

CONTACT: jiao.wang@anu.edu.au

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PAFTAD International Secretariat
Crawford School of Public Policy
College of Asia and the Pacific
The Australian National University
Canberra ACT 0200 Australia

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Jiao Wang†

The Australian National University

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Abstract

This paper assesses the effectiveness and the mechanism of monetary sterilization in China by applying VAR models. It finds that over the periods of 2002-2012, the People's Bank of China has achieved a degree of overall effectiveness at 80 per cent in its sterilization operations. It also finds that the sterilization mechanism did evolve over time. Among the three policy instruments, issuing central bank bills was frequently adopted before the Global Financial Crisis while raising reserve requirements was more relied on in the post-crisis time. Reduction of domestic asset holdings served as a regular policy instrument over the entire estimated period. Given its sterilizing contribution and time length in active use, the administrative approach of raising reserve requirements is found to be the most intensively used one. This paper provides evidence that there exists a working link between the PBoC's balance sheet and the domestic monetary conditions and suggests that the monetary authority in China needs to pay close attention to the impact of its balance sheet expansion, on both domestic economy and the international society.

JEL codes: E51, E52, E58

Keywords: Effectiveness of Monetary Sterilization; Sterilization Mechanism; VAR; PBoC; Balance Sheet; China

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†Jiao Wang is Ph.D. Candidate in economics at Crawford School of Public Policy, the Australian National University. Email: jiao.wang@anu.edu.au.

1 Introduction

China has frequently encountered large capital inflows since the Asian financial crisis. This has forced the People's Bank of China (PBoC) to intervene in the foreign exchange market in order to stabilize its exchange rate, by purchasing U.S. dollars and selling renminbi. To avoid involuntary liquidity expansion induced by the intervention, the PBoC may have to undertake sterilization actions aimed at stabilizing the base money.

The PBoC has three instruments available: reducing domestic asset holdings, issuing central bank bills and raising reserve requirements to its commercial banks. The first two are market-oriented activities while the last is administrative in nature. Each of these actions leads to a withdrawal of renminbi liquidity back to the central bank from the market. These instruments might be applied separately or jointly, and the combination can change over time.

The effectiveness of the PBoC's monetary sterilization has been an important subject of policy discussion. Some economists attribute rising inflation pressure during the second half of the 2000s to ineffective sterilization or involuntary monetary expansion. The view that intervention in the foreign exchange market eventually leads to partial loss of monetary policy independence is shared by monetary policymarkers.

This paper analyzes the mechanism of sterilization effort during the past decade in China. It asks three specific questions: (1) what was the overall degree of effectiveness of the PBoC's monetary sterilization? (2) of the three sterilization instruments, which ones were more heavily used? (3) did the sterilization mechanism evolve over time?

I address the above questions by applying the vector autoregression (VAR) approach, following Moreno (1996) and He et al (2005), among others. I first construct a four-variable VAR model to explore the lagged effects of shocks to net foreign assets (NFA) on net domestic assets (NDA) and domestic monetary conditions: money supply (M2) and interbank interest rate (IR). The ordering of Cholesky decomposition assumes that shocks to net foreign assets are exogenous to the model. Secondly a five-variable VAR model is constructed to examine the impulse responses of domestic asset holdings (DA), central bank bills (CB), reserve requirements (RR) on the balance sheet, and money supply (M2) to shocks to net domestic assets (NDA). In the second model, innovations in NDA are assumed to be exogenous.

The analyses unveil some important findings. One, the central bank of China has achieved an overall degree of effectiveness at 80 per cent in its sterilization operations over the years 2002–2012. Two, over the full estimated period, reduction of domestic asset holdings and raising reserve requirements on average made equally more contributions to the overall sterilization than issuing central bank bills did. And three, the sterilization mechanism did evolve over time. Before the Global Financial Crisis, the PBoC relied on reducing domestic assets and issuing central bank bills to achieve its sterilization targets. After the crisis, it replaced central bank bills issuing with reserve requirements in its actions. Given its relatively short period of time in use and large proportion of contribu-

tion it made, raising reserve requirements was the most intensively used policy tool by the PBoC among the three. Finally, there exists a working link between the PBoC's balance sheet and domestic monetary conditions. A balance sheet expansion can be effectively transmitted to the economy, causing liquidity expansion and short-term interest rate to rise.

This study makes a two-fold contribution to the literature. One is providing new evidence of a working transmission mechanism from the balance sheet of the PBoC to the domestic monetary conditions, which is found absent in the earlier studies.[1] Two is decomposing the contributions made by each of the three instruments, from which evolvements in sterilization mechanism are successfully identified.[2]

The remainder of this paper is organized as follows: Section 2 introduces the background of intervention and sterilization in China and raises the research questions; section 3 reviews related studies in the literature of monetary sterilization and suggests the potential contribution of this paper; section 4 sets out the models and reports the main findings, followed by section 5 with concluding remarks.

2 Intervention, Sterilization and the PBoC

Empirical analysis on monetary sterilization is based on two identities. First, the balance of payments identity implies that the sum of the current and the capital account balance equals the change in the foreign assets of a central bank. Consider an economy in which the current account is balanced initially. If the expected returns on this economy's domestic assets are larger than the expected returns on other countries' assets, then there is a tendency for capital inflows in a foreign currency (U.S. dollar, for instance). This induces an appreciation pressure on this country's currency. If the central bank of the country wants to stabilize the exchange rate from appreciation, it will intervene in the foreign exchange market by buying U.S. dollars. The outcome is positive capital inflows and accumulations of foreign assets on its balance sheet. Therefore changes in foreign assets of the central bank reflect the balance of payments conditions of a country and its exchange rate policies (Moreno 1996).

Second, on a simple version of a central bank balance sheet, changes in reserve money (H) are equal to the difference between changes in its assets and its liabilities, which essentially equals the sum of changes in net foreign assets (NFA) and net domestic assets (NDA) of the central bank:

$$\Delta Assets - \Delta Liabilities = \Delta H$$

since

[1] See, for instance, He et al (2005).

[2] Most of the studies on monetary sterilization in China have only focused on estimating the overall effectiveness by applying various econometric method, without examining how the effectiveness has been achieved or through which instruments.

$$Assets = FA + DA, \text{ and } Liabilities = FL + DL$$

then

$$\Delta(FA + DA) - \Delta(FL + DL) = \Delta H$$

that is

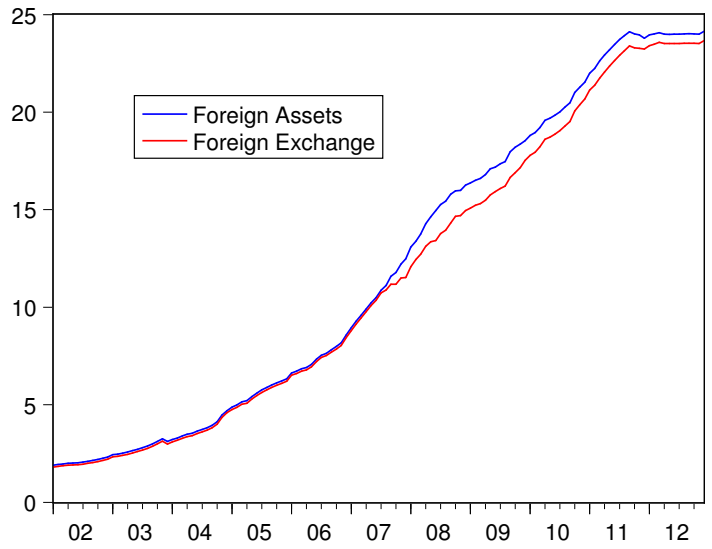
$$\Delta NFA + \Delta NDA = \Delta H$$

where Δ is first-difference operator. Therefore, changes in the net foreign assets or net domestic assets of the central bank could affect the level of reserve money. A policy attempt to prevent changes in net foreign assets from affecting the level of reserve money by implementing offsetting changes in net domestic assets is know as sterilization.

Over the past decades, China has frequently encountered large capital inflows induced by a number of reasons: policy-oriented foreign direct investment (FDI) inflows since the mid-1990s, persistent interest rate differential-driven arbitrage investment since 2000, expectation of renminbi appreciation, etc. The enormous cross-border capital movements put huge appreciation pressure on the currency and the PBoC had to intervene in the foreign exchange market, by buying U.S. dollars and selling renminbi, in order to stabilize the exchange rate. Consequently, its foreign exchange has soared in the past ten years and expanded the foreign assets simultaneously[3] (Figure 1).

[3]On the PBoC balance sheet items under foreign assets are foreign reserves and monetary gold. Monetary gold remains steady over the past decades, leaving the foreign assets move closely with foreign reserves.

Figure 1: Foreign Assets and Foreign Exchange on the Balance Sheet, 2002 – 2012, Yuan trillion.



Source: Survey and Statistics, the PBoC.

The huge accumulation of the foreign assets, if not neutralized, would largely raise the level of money base. To avoid the undesirable money base expansion, the PBoC has steadily conducted sterilization operations, namely, implementing offsetting reduction of its net domestic assets, over the past decade. Three policy instruments were available for achieving the operation target: (1) reducing domestic asset holdings, (2) Open Market Operations (OMOs), i.e. issuing central bank bills, and (3) raising reserve requirements (or RRRs). On the PBoC's balance sheet, domestic asset holdings are measured by the sum of claims on government, claims on other depository corporation, financial corporations and non-financial corporations and other assets. OMOs are represented by bond issue item and reserve requirements are measured by deposits of other depository corporations (see Table 1 for a standard structure of the PBoC balance sheet). Figure 2 plots these policy instrument variables and displays different moving patterns. Reserve requirements seem to have a persistent upward trend over time while domestic assets rise slowly. Central bank bills, however, climb rapidly before around 2010 and then fall steadily afterwards.

The effectiveness of the PBoC's sterilization operations has been an important subject of policy discussion. The extent to which the injected liquidity was left unsterilized in the market will directly affect the inflation rate and the level of money base, both of which are the PBoC's major policy targets (He and Pauwels 2008). Some economists attribute rising inflation pressure during

the second half of the 2000s to ineffective sterilization or involuntary monetary expansion (Huang et al 2012). The view that intervention in the foreign exchange market eventually leads to partial loss of monetary policy independence is shared by monetary policymarkers.[4] That being said, it is natural to start with examining the ex post effectiveness of monetary sterilization over the past decade and its impact on domestic monetary condition. Specifically this paper asks three questions: (1) what was the overall degree of effectiveness of the PBoC's monetary sterilization? (2) of the three sterilization instruments, which ones were more heavily used? (3) did the sterilization mechanism evolve over time?

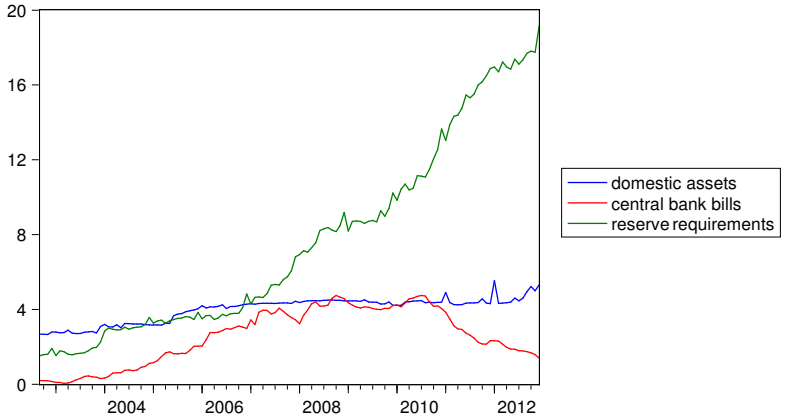
Table 1: Balance Sheet of Monetary Authority in China, March 2013, Yuan trillion

Assets		Liabilities	
Foreign Assets	25.4	Reserve Money	25.4
foreign exchange	*24.6*	*currency issue*	*6.1*
monetary gold	*0.07*	*deposits of other depository corporations*	*19.2*
other foreign assets	*0.7*	Deposits of financial corporations	
Claims on government	1.5	excluded from reserve money	0.1
of which: central government	*1.5*	Bond issue	1.4
Claims on other depository corporations	1.1	Foreign liabilities	0.1
Claims on other financial corporations	1.0	Deposits of government	2.3
Claims on non-financial sector	0	Own capital	0.02
Other assets	0.8	Other liabilities	0.6
Total Assets	**29.9**	**Total Liabilities**	**29.9**

Source: Survey and Statistics, the PBoC and author estimates.

[4]For instance, during a lecture at the Peking University on 1 June, 2011, Deputy Governor of the PBoC, Yi Gang, admitted that the central bank's sterilization operation was not completely effective and the Bank partially lost monetary policy independence.

Figure 2: Variables as Sterilization Instruments, Yuan trillion.



Source: Survey and Statistics, the PBoC and author estimates.

3 Literature Review

There are two basic approaches in the literature of monetary sterilization. The first one is a structural approach initiated by Cumby and Obstfeld (1981). By running linear ordinary least squares (OLS) regression on a central bank's reaction function, in which changes in net domestic assets is dependent variable, changes in net foreign assets and a set of macro variables are explanatory variables, this approach estimates the sterilization coefficient of changes in net foreign assets, which reflects the effectiveness of sterilization. If it equals minus one, the sterilization is complete as every one yuan increase in net foreign assets is neutralized by the same amount of reduction of net domestic assets, leaving the money base unaffected; if it equals zero, then the sterilization is null and increases in net foreign assets will affect the base money directly and by the same amount. Applications of this framework include, among others, Kim (1995) for sterilization actions in South Korea, Brissimis et al (2002) for Germany, Ouyang et al. (2007) and Wang (2010) for China.

The second approach is constructing vector autoregression (VAR) models to explore the lagged effects of shocks to net foreign assets on net domestic assets and domestic monetary conditions. VAR models have been widely used in studying macro variables and their interactions since Sims' seminal work (1980). Moreno (1996) among others, first adopts the reduced form VAR models for investigating monetary sterilization. Christensen (2004), He et al (2005), Cavoli & Rajan (2006) follow the similar frameworks to analyze the impact of capital flows on the wider economy.

This paper follows the VAR model from He et al (2005) to examine the effectiveness of monetary sterilization in China and the impact on domestic

monetary conditions. In addition, this paper develops another VAR model to estimate sterilization contributions made by each of the three policy instruments and to identify possible evolvements in the sterilization mechanism. To this end, this paper makes a two-fold contribution to the literature. First, in estimating the impact of sterilization on domestic monetary conditions, this paper provides evidence that there exists a working link between the central bank balance sheet and the wider economy in China, which was not at work before 2004 (He et al 2005)[5], and shows that the balance sheet expansion in China has the characteristic of accommodative monetary policies in developed countries, such as the united States and Japan, in terms of affecting domestic monetary conditions. Second, this paper takes a step further to decompose individual contributions made by the three policy tools and identifies evolvement in the sterilization mechanism. This finding may help to better understand the sterilization behaviors of the central bank of China over time.

4 Methodology

4.1 Model (1)

4.1.1 Model Specification

I construct the first model following He et al (2005) to examine the overall effectiveness of PBoC's sterilization and the impact of shocks to balance sheet on domestic liquidity conditions. The model contains four variables and their dynamics, specified as:

$$\Delta NFA_t = c_1 + \sum_{i=1}^{T} \beta_{11i} \Delta NFA_{t-i} + \sum_{i=1}^{T} \beta_{12i} \Delta NDA_{t-i} + \sum_{i=1}^{T} \beta_{13i} DLM2_{t-i} + \sum_{i=1}^{T} \beta_{14i} \Delta IR_{t-i} + \varepsilon_{1t}$$

$$\Delta NDA_t = c_2 + \sum_{i=1}^{T} \beta_{21i} \Delta NFA_{t-i} + \sum_{i=1}^{T} \beta_{22i} \Delta NDA_{t-i} + \sum_{i=1}^{T} \beta_{23i} DLM2_{t-i} + \sum_{i=1}^{T} \beta_{24i} \Delta IR_{t-i} + \varepsilon_{2t}$$

$$DLM2_t = c_3 + \sum_{i=1}^{T} \beta_{31i} \Delta NFA_{t-i} + \sum_{i=1}^{T} \beta_{32i} \Delta NDA_{t-i} + \sum_{i=1}^{T} \beta_{33i} DLM2_{t-i} + \sum_{i=1}^{T} \beta_{34i} \Delta IR_{t-i} + \varepsilon_{3t}$$

$$\Delta IR_t = c_4 + \sum_{i=1}^{T} \beta_{41i} \Delta NFA_{t-i} + \sum_{i=1}^{T} \beta_{42i} \Delta NDA_{t-i} + \sum_{i=1}^{T} \beta_{43i} DLM2_{t-i} + \sum_{i=1}^{T} \beta_{44i} \Delta IR_{t-i} + \varepsilon_{4t} \tag{1}$$

where NFA denotes net foreign assets, NDA denotes net domestic assets, $M2$ measures domestic credit, and IR denotes interbank lending interest rate. Δ is first difference operator while DL is log-difference operator. In the four-variable VAR model, domestic liquidity condition is measured in growth rate while net

[5] In their paper, He et al find no significant response from domestic credit to capital flows and argue that it might indicate a broken link between the central bank's balance sheet and domestic credit and raise a fundamental issue of how an impulse response from the PBoC's operating targets can be transmitted to its intermediate targets (p. 13, 2005).

foreign assets, net domestic assets and short-term interest rate are in form of first-difference.

The four-variable model is in a reduced form, which allows contemporaneous interactions among residuals from the four equations. To identify the underlying orthogonal shocks of the system, I employ the Cholesky decomposition of the variance-covariance matrix from the reduced form VAR, with the ordering of $\{\Delta NFA,\ \Delta NDA,\ DLM2,\ \Delta IR\}$. This ordering is based on observations that changes of net foreign assets are mainly induced by foreign exchange market intervention to stabilize the exchange rate of yuan so shocks to ΔNFA are external to the system. The PBoC adjusts its net domestic asset holdings in response to the rapid accumulation of net foreign assets to stabilize the base money so ΔNDA enters the model in second order. Shocks to the central bank's balance sheet are transmitted to domestic monetary conditions, contemporaneously affecting money supply and interest rate, and thus $DLM2$ and ΔIR are in the last two orders. As there is not strong economic underpinnings determining the contemporaneous relation between money supply and short-term interest rates, I also estimate the model (1) with the ordering of $\{\Delta NFA,\ \Delta NDA,\ \Delta IR,\ DLM2\}$. The results show that position interchanges between $DLM2$ and $\triangle IR$ do not change the effects of shocks to net foreign assets on net domestic assets and the two monetary indicators.

4.1.2 Data

I use monthly data from 2002m9 to 2012m12 for estimation[6]. NFA and NDA data are calculated definition based on the official release of Balance Sheet statistics at Survey and Statistics of the PBoC website. Data for M2 are obtained from the International Financial Statistics, the International Monetary Fund. For IR data, I use China Interbank Offered Rates (CHIBOR) for the period before 2006m10 and Shanghai Interbank Offered Rates (SHIBOR) for the period after, both of which are from CEIC.

4.1.3 Stationarity, Lag Length and Structural Change

I first conduct unit root tests for the four variables to check whether stationarity conditions are satisfied. Augmented Dickey-Fuller unit root test results are reported in Table 2. All variables are I(1).

[6]In the second model, I use central bank bills statistics for estimation, which was not available until 2002m9. For consistency of estimation, I choose 2002m9 as the first period for all variables included in the two models.

Table 2: Augmented Dickey-Fuller Unit Root Test (H_0: variable has a unit root.)

Test for unit root	Exogenous Variables	Lag length	ADF test statistic
in Level			
NFA	Constant	2	-0.302
NDA	Constant	0	-0.263
log(M2)	Constant, Linear Trend	3	-2.520
IR	Constant	2	-2.180
in First Difference			
NFA	Constant	1	-3.486*
NDA	Constant	0	-11.894**
log(M2)	Constant, Linear Trend	4	-5.562**
IR	Constant	1	-13.082**

Notes: (*) indicates 5% significance level. (**) indicates 1% significance level.

Two criteria are considered in selecting the appropriate lag length for VAR models: Akaike Information Criterion (AIC) suggests lag lengths of four while Schwarz Baynesian Information Criterion (BIC) suggests lag lengths of two. A formal Likelihood Ratio test is conducted to choose between those two and VAR(4) is eventually chosen for estimates. Lag length selection criteria and hypothesis tests are reported in Appendix A and B, respectively.

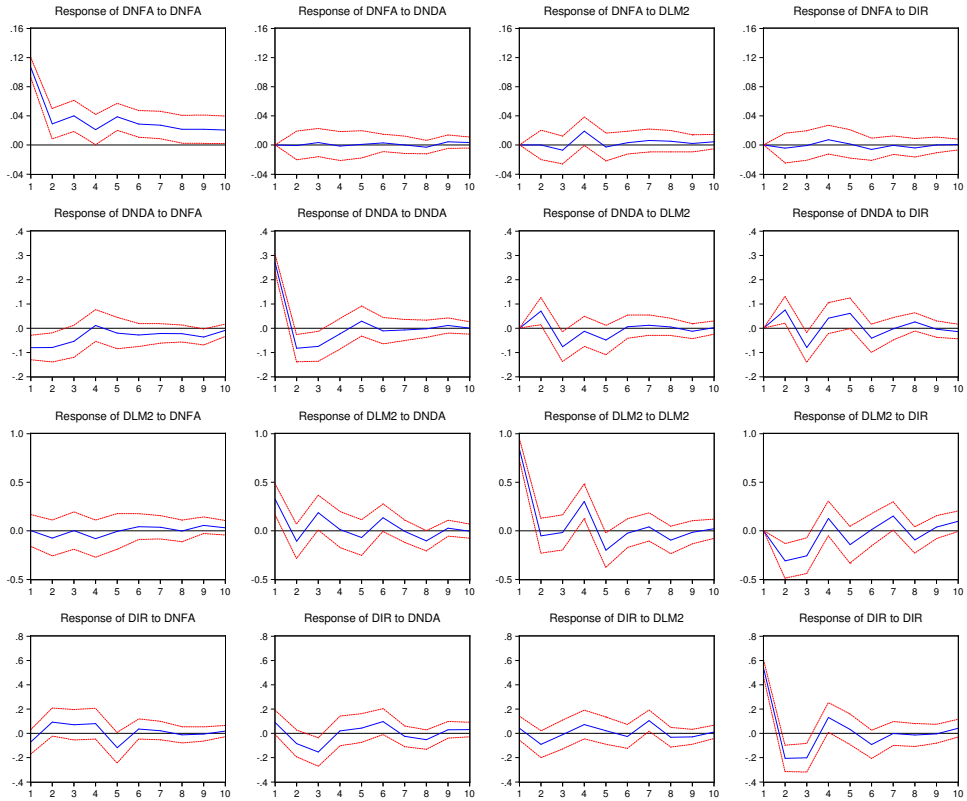
Before turning to impulse response analysis, I consider the possibility of structural changes. Over the period of 2002m09 – 2012m12, there are two possible structural break points. One is in July 2005, when the Chinese government announced to adopt a new exchange rate regime, which may potentially alter the sterilizing behavior of the PBoC and hence the operational effectiveness. The other is in October 2008, when the Global Financial Crisis hit the East Asia economies and central banks in Asia started to impose capital controls and financial restrictions to isolate the economy from the crisis. Appendix C reports the hypothesis tests. Based on the test statistics, there is not enough evidence to reject the null hypothesis and hence I conclude that there is no structural changes in 2005m7 and 2008m12, tested at 5% significance level. This result sends an important message suggesting that the PBoC has been quite consistent in terms of the effectiveness of monetary sterilization in the past decade.[7]

4.1.4 Impulse Responses Analysis

Figure 3 reports the impulse responses of the four variables to different one standard deviation shocks with 2 standard error bands over 10 periods (months).

[7]Within the scope of this paper, it is not clear whether the consistency in the degree of sterilization effectiveness is an intended policy target of the PBoC.

Figure 3: Impulse Responses to Different Shocks, Model (1), 2002m9 – 2012m12.



Based on Figure 3, responses of DNDA to shocks to DNFA in the first two months are statistically significant. A shock of 1 unit increase in net foreign assets would cause a decline of net domestic assets by approximately 0.8 unit within one month, suggesting that for every RMB 1 yuan injected into the domestic liquidity market due to the PBoC's foreign exchange market intervention, 0.8 yuan is effectively sterilized (mopped up from the market back to the bank). Therefore the overall degree of effectiveness of the PBoC's sterilization is 80 per cent and the action was quickly implemented within one month. Combining the hypothesis test results of no structural change in model (1) in the previous section, it is sensible to conclude that the PBoC has kept its sterilization effectiveness at 80 per cent consistently over the past decade.

Impulse responses of DLM2 and DIR to shocks to DNFA, however, are overall insignificant. The results could be interpreted as a sensible outcome of successful sterilization operations, insulating domestic monetary conditions from liquidity expansion shocks. Or it might be an indicator that there is a missing link be-

tween the central bank's balance sheet and domestic monetary conditions, as argued by He et al (2005). Which interpretation is more plausible? Impulse responses of DLM2 and DIR to shocks to DNDA may give some insights to this question. From Figure 3, an expansionary shock to net domestic assets exerts a positive and strong impact on money supply while, to a lesser extent, affects short-term interest rate within one month.[8] It means that balance sheet expansion, at least on net domestic asset side, is effectively transmitted to domestic credit market, causing liquidity expansion and monetary tightening. Therefore, the insignificant impact of changes in net foreign assets on DLM2 and DIR is more likely to be a result of effective sterilization operations, than a missing transmission channel from the central bank's balance sheet to the market.

Is 80 per cent of the effectiveness is the PBoC's initial target or a passive outcome of trying to stabilize the level of money base? It is difficult to answer this question within the scope of this paper but maybe it is a good research topic to work on in the future. As far as this paper concerns, 80 per cent is the revealed effectiveness of the PBoC's sterilization operations and the insignificant responses of domestic monetary conditions to shocks to net foreign assets suggest quite a success of the PBoC in insulating the economy from excessive liquidity expansion.

4.2 Model (2)

4.2.1 Model specification

In the next stage, I construct another VAR model to decompose contributions of individual instruments used in sterilization operation and to investigate possible evolvement, if any, of sterilization mechanism. To this end, a five-variable VAR model is specified as

$$\Delta NDA_t = \alpha_1 + \sum_{i=1}^{T} \theta_{11i} \Delta NDA_{t-i} + \sum_{i=1}^{T} \theta_{12i} \Delta DA_{t-i} + \sum_{i=1}^{T} \theta_{13i} \Delta CB_{t-i} + \sum_{i=1}^{T} \theta_{14i} \Delta RR_{t-i} + \sum_{i=1}^{T} \theta_{15i} DLM2_{t-i} + \gamma_1 \Delta NFA_{t-1} + u_{1t}$$

$$\Delta DA_t = \alpha_2 + \sum_{i=1}^{T} \theta_{21i} \Delta NDA_{t-i} + \sum_{i=1}^{T} \theta_{22i} \Delta DA_{t-i} + \sum_{i=1}^{T} \theta_{23i} \Delta CB_{t-i} + \sum_{i=1}^{T} \theta_{24i} \Delta RR_{t-i} + \sum_{i=1}^{T} \theta_{25i} DLM2_{t-i} + \gamma_2 \Delta NFA_{t-1} + u_{2t}$$

$$\Delta CB_t = \alpha_3 + \sum_{i=1}^{T} \theta_{31i} \Delta NDA_{t-i} + \sum_{i=1}^{T} \theta_{32i} \Delta DA_{t-i} + \sum_{i=1}^{T} \theta_{33i} \Delta CB_{t-i} + \sum_{i=1}^{T} \theta_{34i} \Delta RR_{t-i} + \sum_{i=1}^{T} \theta_{35i} DLM2_{t-i} + \gamma_3 \Delta NFA_{t-1} + u_{3t}$$

$$\Delta RR_t = \alpha_4 + \sum_{i=1}^{T} \theta_{41i} \Delta NDA_{t-i} + \sum_{i=1}^{T} \theta_{42i} \Delta DA_{t-i} + \sum_{i=1}^{T} \theta_{43i} \Delta CB_{t-i} + \sum_{i=1}^{T} \theta_{44i} \Delta RR_{t-i} + \sum_{i=1}^{T} \theta_{45i} DLM2_{t-i} + \gamma_4 \Delta NFA_{t-1} + u_{4t}$$

[8] Nevertheless, it is necessary to point out that responses of interbank interest rate to DNDA shocks are not unambiguously significant as the lower 2 S.E. limit in the first month touches zero. The results might be improved if using the latest data. As interest rate controls were gradually removed along the way of interest rate reform in China, short-term interest rates may respond more significantly.

$$DLM2_t = \alpha_5 + \sum_{i=1}^{T} \theta_{51i} \Delta NDA_{t-i} + \sum_{i=1}^{T} \theta_{52i} \Delta DA_{t-i} + \sum_{i=1}^{T} \theta_{53i} \Delta CB_{t-i} + \sum_{i=1}^{T} \theta_{54i} \Delta RR_{t-i} + \sum_{i=1}^{T} \theta_{55i} DLM2_{t-i} + \gamma_5 \Delta NFA_{t-1} + u_{5t} \tag{2}$$

where NFA denotes net foreign assets, NDA denotes net domestic assets, DA denotes domestic assets, RR denotes reserve requirements, CB denotes central bank bills and bonds issued, $M2$ denotes money supply. Δ is first-difference operator and DL is log-difference operator. Constants and one lag of ΔNFA are exogenous variables in each equation.

The five-equation system is in reduced form with error terms contemporaneously interacting with each other. Cholesky decomposition is again adopted to transform the reduced form system into structural form with only orthogonal shocks. The ordering is given as $\{\Delta NDA,\ \Delta DA,\ \Delta CB,\ \Delta RR,\ DLM2\}$. As discussed in previous section, the PBoC adjusts its net domestic asset holdings to absorb excessive liquidity brought in by its foreign exchange market intervention so ΔNDA is determined by variables external to Model (2). ΔNDA is ordered first. The PBoC achieves its sterilization target by using one or more of the three instruments: reduction of own domestic assets (ΔDA), issuing central bank bills (ΔCB), and raising reserve requirement ratios to the commercial banks (ΔRR). Therefore, changes of these three variables are affected by shocks to net domestic assets and are ordered second to fourth[9]. $DLM2$ is included in this model, representing domestic liquidity condition, and is affected contemporaneously by all the other variables. I order it last.

One lag of net foreign asset changes is included in Model (2) as exogenous variables. The accumulation of foreign assets is the root cause of changes in net domestic assets and adoption of sterilization instruments so net foreign asset is likely to be statistically significant in predicting the other variables. To test the predictability, I conduct a Granger Causality test, reported in Appendix F, and find that ΔNFA does Granger Causes each of the four variables in the system, at 5% significance level.

[9]The exact ordering among the three sterilization variables is subject to reality of monetary sterilization and open for discussion. Generally speaking, a central bank would initially reduce its domestic assets in response of rapid foreign assets accumulation. Open Market Operations (OMO) are commonly used by central banks in advanced economies while administrative approach, i.e. raising reserve requirement ratios is another policy practice adopted by a lot of monetary authorities in emerging countries, including China. Since monetary sterilization is a relatively new policy practice for emerging economies, comparing to advanced economies, I order ΔDA and ΔCB before ΔRR in model (2). For robustness check, I also estimate model (2) using orderings of (2a) $\{\Delta NDA,\ \Delta DA,\ \Delta RR,\ \Delta CB,\ DLM2\}$, and (2b) $\{\Delta NDA,\ \Delta RR,\ \Delta CB,\ \Delta DA,\ DLM2\}$. The results are quite similar with those of model (2) and are reported in Figure 10 and Figure 11, Appendix G. As shown in the section below, a structural break in December 2008 is identified so model (2) is also estimated using data before and after the structural break. To further check the robustness of my model specification, I estimate model (2a) and (2b) using subsample data and the high similarity of impulse responses between (2), (2a) and (2b) remains. Therefore, the results of model (2) is robust.

4.2.2 Data

Monthly data from 2002m9 to 2012m12 are used in the model. Data for M2 are obtained from the International Financial Statistics, the International Monetary Fund. Data for NFA and NDA are obtained in the same way as in Section 4.1.2 and DA, CB and RR are all from the official release of Balance Sheet statistics at Survey and Statistics of the PBoC website, as explained in Section 2.

4.2.3 Stationarity, Lag Length and Structural Change

Unit root tests[10] for DA, CB and RR are reported in Table 3. All variables in model (2) satisfy stationarity conditions. Based on AIC, lag lengths of three are chosen for estimation (Appendix D)[11]. I also conduct structural change tests for model (2) to identify possible structural break points: July 2005 and December 2008, and based on the results, there exists a structural break in 2008m12, tested at 5% significance level (Appendix E).

Table 3: Augmented Dickey-Fuller Unit Root Test (H_0: variable has a unit root.)

Test for unit root	Exogenous Variables	Lag length	ADF test statistic
in Level			
DA	Constant	2	-1.092
CB	Constant	1	-1.393
RR	Constant, Linear Trend	3	-0.901
in First Difference			
DA	Constant	1	-12.320**
CB	Constant	0	-7.892**
RR	Constant, Linear Trend	2	-5.788**

Notes: * indicates 5% significance level. ** indicates 1% significance level.

4.2.4 Impulse Response Analysis

Impulse responses to shocks to DNDA over full sample period are reported in Figure 4. To save space, impulse responses to different shocks are reported in Appendix G. From Figure 4, over the full sample period all three sterilization variables respond significantly within 2 S.E. bands in the first month. In response to one S.D. innovations in NDA accumulation, DDA increases by about

[10] Unit root tests for NDA and log(M2) are in Table 2, Section 4.1.3.

[11] I didn't do formal LR tests in choosing lag lengths for model (2) because SIC suggests a static model (lag=0). In addition, in estimating time-series models, it is a rule of thumb to use AIC for the purpose of good fitness and exclusion of serial correlations in error terms. LR test results for model (1) supports the rule.

0.06 unit, DCB and DRR decreases by around 0.04 unit and 0.06 unit, respectively. Note that impulse responses in Figure 4 are derived to a positive one S.D. innovations in DNDA so it is the opposite situation of reality, where the central bank uses NDA reduction to achieve its sterilization target. Therefore, if responding to a negative shock to DNDA, DDA would fall while DCB and DRR would rise by 0.06, 0.04 and 0.06 unit, respectively. Each of the two policy stances, reduction of domestic asset holdings and raising RRRs, makes 37.5 per cent of contributions to the overall effectiveness of sterilization, while OMOs, i.e. issuing central bank bills takes up the rest of 25 per cent contribution.

Impulse responses to innovations in DNDA in two subsamples are shown in Figure 5 and 6 (responses to different shocks are reported in Appendix G). Before 2008, only DDA and DCB reacted significantly to shocks to DNDA (Figure 5). During that period central bank bills issuing made more contribution to the neutralization success than reduction of domestic asset holdings. After 2008, however, policy stances that responded significantly to net domestic assets shocks were DDA and DRR (Figure 6), indicating an evolvement of sterilization mechanism in China. This finding is also observed by others (see, for example, Wang and Hu 2011).

Figure 4: Impulse Responses to Shocks to DNDA, Model (2), 2002m9 – 2012m12.

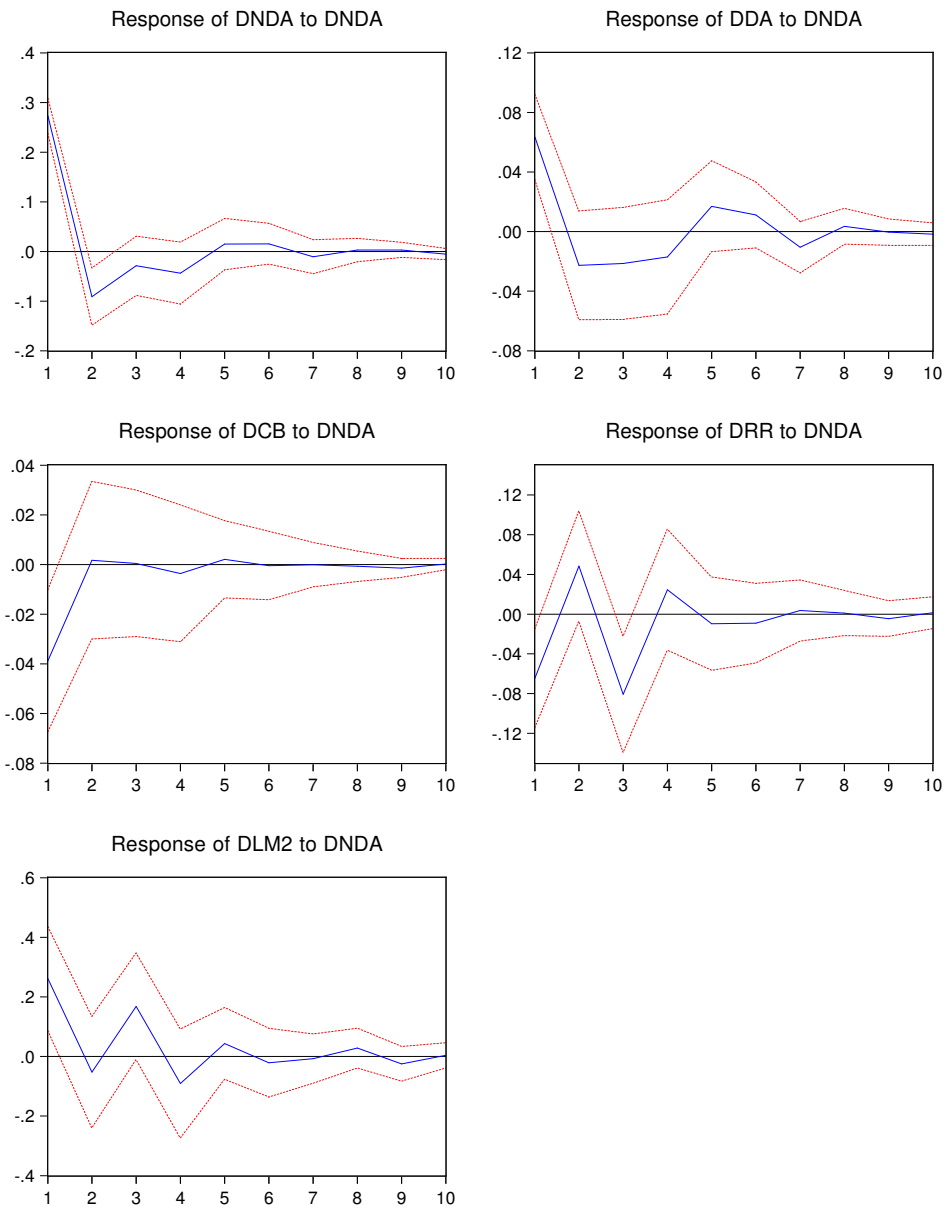


Figure 5: Impulse Responses to Shocks to DNDA, Model (2), 2002m9 – 2008m12

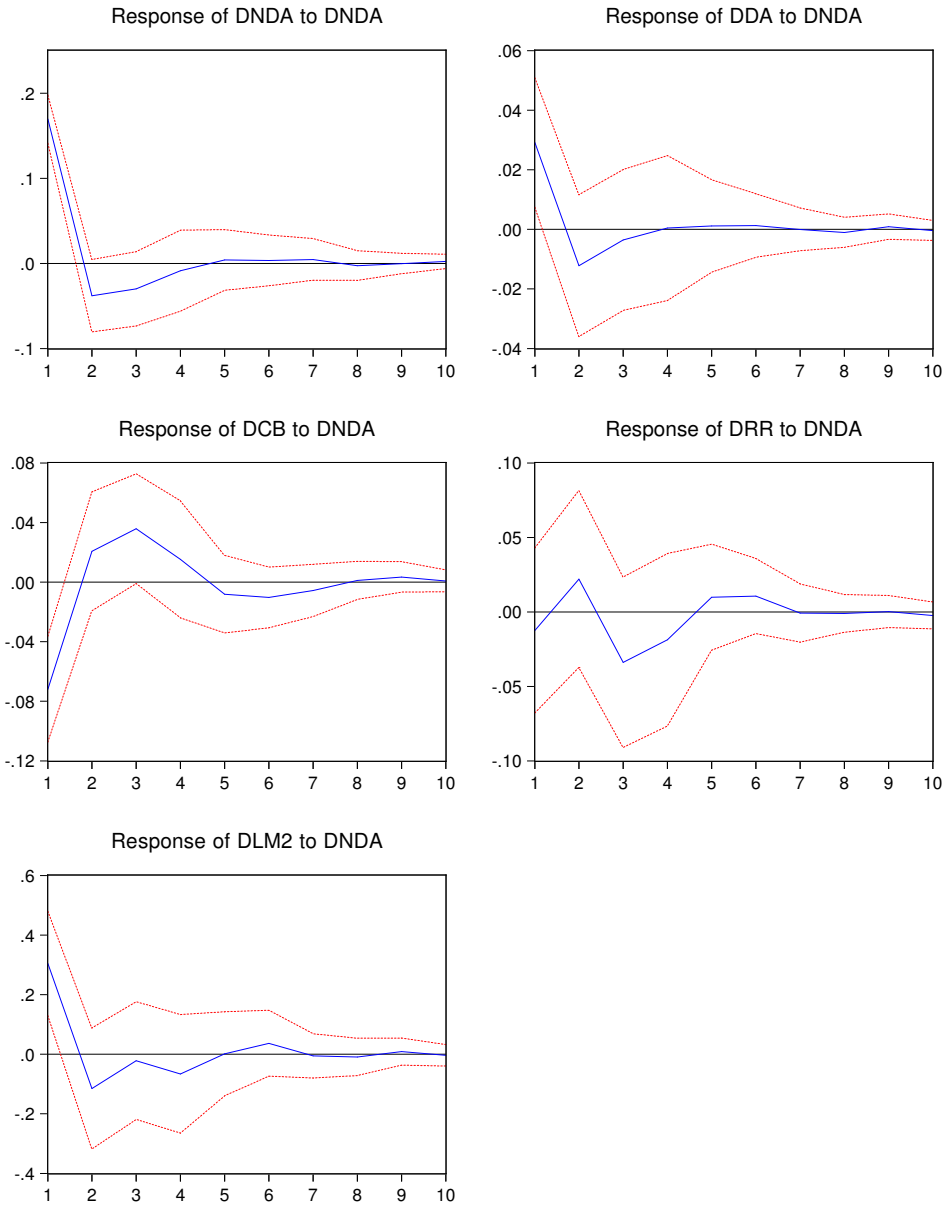
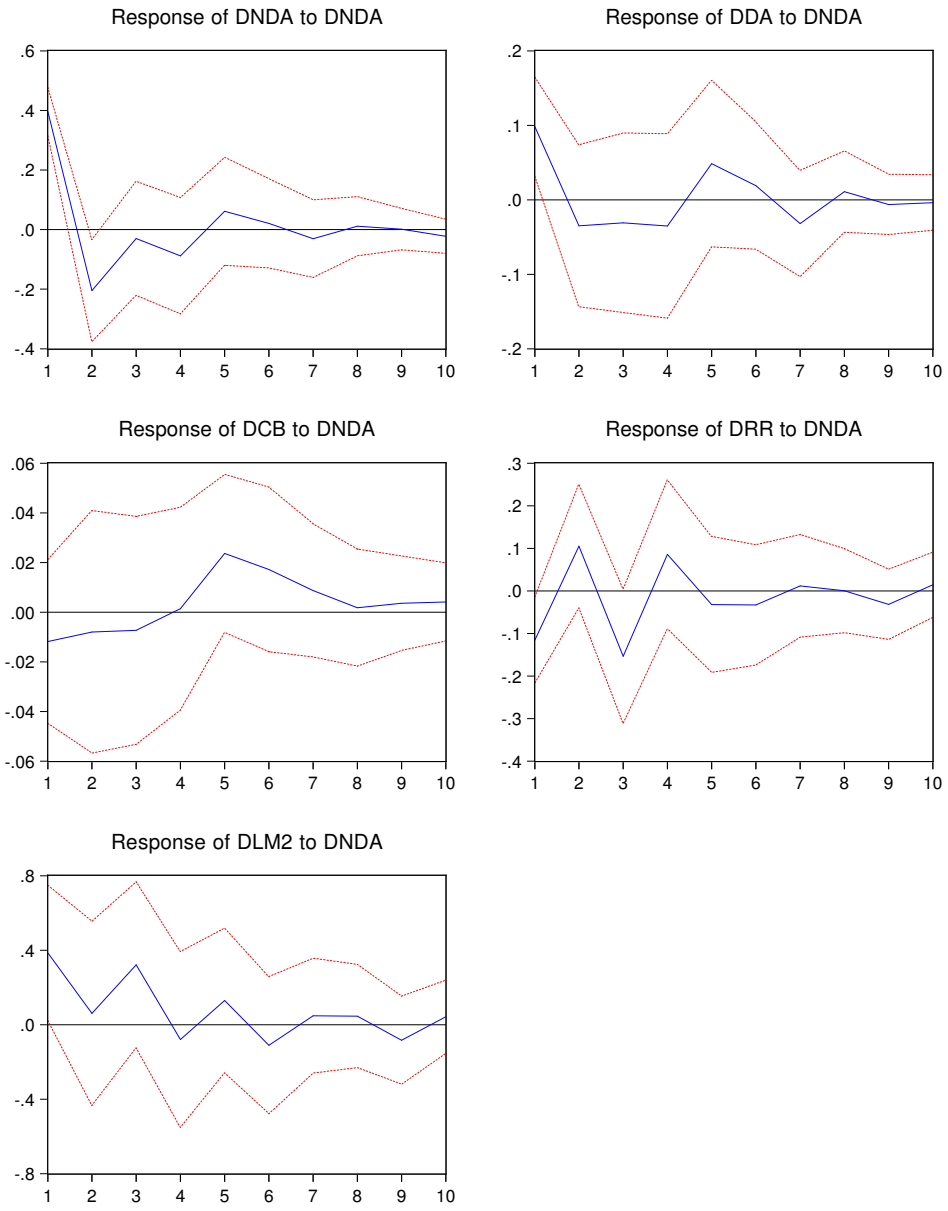


Figure 6: Impulse Responses to Shocks to DNDA, Model (2), 2009m1 – 2012m12.



Overall, the PBoC reserves the reduction of domestic assets as a regular stance of sterilization. It frequently undertakes OMOs to neutralize the market

before the Global Financial Crisis in 2008 and more heavily relied on raising RRRs in the post-crisis period. Given the fact that it on average takes up as much contribution as reduction of asset holdings but was not effectively in use until 2009, this administrative approach is the most intensively used policy instrument among the three.

Since there is technically no 'ceiling' on the ratio, the RRRs will probably continue to hike (Wang and Hu 2011). Nevertheless, some economists argue that raising RRRs to achieve sterilization target is essentially a cost-sharing mechanism, namely, the central bank passes some of the sterilization costs to its commercial banks and to households, because returns on reserve requirements and household deposits are very low. As China pushes forward the interest rate reform and capital account liberalization, costs of such administrative approach would eventually matter in the PBoC's sterilization actions.

5 Conclusions

This paper applies the VAR approach to examine the effectiveness and mechanism of monetary sterilization in China from September 2002 to December 2012. The PBoC has achieved an 80 per cent of overall effectiveness in its sterilization operations. For every 1 yuan of liquidity injection due to foreign exchange market intervention, 0.8 yuan is effectively neutralized from the market over the past decade. This paper finds that sterilization mechanism evolves over time. The PBoC achieves its sterilization targets by reducing holdings of domestic assets and issuing central bank bills before the Global Financial Crisis while relies on reduction holdings of domestic assets and raising reserve requirements in the past five years. Given their sterilization contributions and periods of time effectively in use, of the three, the administrative approach is the most intensively used policy instrument. This paper also provides evidence that there exists a working transmission channel from the PBoC balance sheet to domestic monetary conditions, a link that was missing in the first half of the 2000s, suggested by others' studies.

The findings of this study raise important policy implications. First, the PBoC confronts a loss of monetary policy independence as it has been occupied by the frequent sterilization operations. Second, the administrative approach passes the sterilization costs to the commercial banks and the households, causing potential welfare loss unaccounted. Third, the PBoC balance sheet expansion, at least from the domestic asset side, has the common characteristic of an accommodative monetary policy, and so the monetary authority in China needs to pay close attention to its impact on both domestic economy and the international society.

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Appendix

A. Lag Order Selection Criteria for Model (1)

Endogenous variables: DNFA DNDA DLM2 DIR Exogenous variables: C Sample: 2002M09 2012M12						
Lag	LogL	LR	FPE	AIC	SC	HQ
0	-247.4558	NA	0.000865	4.298390	4.392823	4.336729
1	-204.3236	82.5780	0.000544	3.8346	4.3068	4.0263
2	-164.0299	74.3883	0.000359	3.4193	4.2692*	3.7644
3	-142.4641	38.3393	0.000328	3.3242	4.5518	3.8226
4	-119.4769	39.2943	0.000292*	3.2047*	4.8101	3.8564
5	-104.7405	24.1827	0.000301	3.2263	5.2094	4.0314
6	-87.98539	26.3500	0.000300	3.2134	5.5743	4.1719

* indicates lag order selected by the criterion
LR: sequential modified LR test statistic (each test at 5% level)
FPE: Final prediction error
AIC: Akaike information criterion
SC: Schwarz information criterion
HQ: Hannan-Quinn information criterion

B. Likelihood Ratio (LR) Test for Model (1)

Based on the lag length selection criteria, VAR(4) is selected by AIC while VAR(2) is selected by BIC. A formal LR test is conducted below and according to the test statistic VAR(4) is chosen.

$H_0 : VAR(2)$ is appropriate for Model (1)

$H_1 : VAR(4)$ is appropriate for Model (1)

Estimate the unrestricted model and the restricted model separately, and get the determinants of residual covariance as

$$\hat{\Omega}_U = 8.83 \times 10^{-5}$$

$$\hat{\Omega}_R = 0.000188$$

respectively.

The test stat. is calculated as

$$\begin{aligned} LR &= dofc \times \left(ln \mid \hat{\Omega}_R \mid - ln \mid \hat{\Omega}_U \mid \right) \\ &= (119 - 17) \times \left(ln\,(0.000188) - ln\left(8.83 \times 10^{-5}\right)\right) \\ &= 77.082 \end{aligned}$$

The 5% critical value is

$$\chi^2_{4^2 \times 2,.05} = 46.194$$

Decision rule: we reject H_0 if $LR > \chi^2_{k^2q,\alpha}$

Since

$$LR = 77.082 > \chi^2_{4^2\times 2,.05} = 46.194$$

we reject the null hypothesis and conclude that VAR(4) is more appropriate, tested at 5% significance level.

C. Structural Change Tests for Model (1)

Suppose there is a structural change in 2005m7. The constants in each equation of Model (1) would be different before and after 2005m7, written in matrix form, that is

$$Y_t = AX_t + Ddummy1_t + u_t$$

with

$$dummy1_t = \begin{cases} 0 & if\, t \leqslant 2005m7 \\ 1 & otherwise \end{cases}$$

where AX_t is the matrix form of dynamics of endogenous variables and their coefficients, D is the coefficient matrix of dummy variables.

Formal test:

$H_0: \quad D = 0$ (no structual change)

$H_1: \quad D \neq 0$ (at least one coefficient of dummy variables is not equal to zero)

Estimate the unrestricted model and restricted model to get the determinants of residual covariance:

$$\hat{\Omega}_U = 8.65 \times 10^{-5}$$

$$\hat{\Omega}_R = 8.83 \times 10^{-5}$$

The test stat. is given by

$$LR = dofc \times \Big(ln \mid \hat{\Omega}_R \mid - ln \mid \hat{\Omega}_U \mid \Big) = (119-18) \times \big(ln \left(8.83 \times 10^{-5}\right) - ln \left(8.65 \times 10^{-5}\right) \big) = 2.080$$

The critical value is

$$\chi^2_{4,.05} = 9.488$$

Since $LR = 2.080 < \chi^2_{4,.05} = 9.488$, we fail to reject the null hypothesis and conclude that there is no structural change in 2005m7 in model (1), tested at 5% significance level.

Suppose there is a structural change in December 2008, induced by the Global Financial Crisis. Repeat the test steps above by constructing another dummy variable,

$$dummy2_t = \begin{cases} 0 & if\, t \leqslant 2008m12 \\ 1 & otherwise \end{cases}$$

and estimate both unrestricted model and restricted model to get the determinants of residual variance-covariance as

$$\hat{\Omega}_U = 8.39 \times 10^{-5}$$

$$\hat{\Omega}_R = 8.83 \times 10^{-5}$$

Note that $\hat{\Omega}_R$ is the same as above because the restricted model is Model (1) in both cases. Calculate the test stat.

$$LR = dofc \times \Big(ln \mid \hat{\Omega}_R \mid - ln \mid \hat{\Omega}_U \mid \Big) = (119-18) \times \big(ln \left(8.83 \times 10^{-5}\right) - ln \left(8.39 \times 10^{-5}\right) \big) = 2.163$$

Since $LR = 2.163 < \chi^2_{4,.05} = 9.488$, we fail to reject the null hypothesis and conclude that there is no structural change in 2008m12 in model (1), tested at 5% significance level.

D. Lag Order Selection Criteria for Model (2)

Endogenous variables: DNDA DDA DCB DRRDT DLM2
Exogenous variables: C DNFA(-1)
Sample: 2002M09 2012M12

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-134.0129	NA	7.90e-06	2.440896	2.675700*	2.536234
1	-84.64304	92.88226	5.23e-06	2.027848	2.849661	2.361529*
2	-49.14934	63.76834	4.39e-06	1.849989	3.258812	2.422012
3	-19.50021	50.75529	4.09e-06*	1.771190*	3.767022	2.581557
4	3.832232	37.96465*	4.25e-06	1.799454	4.382295	2.848164
5	26.43149	34.85648	4.52e-06	1.840144	5.009995	3.127197

* indicates lag order selected by the criterion
LR: sequential modified LR test statistic (each test at 5% level)
FPE: Final prediction error
AIC: Akaike information criterion
SC: Schwarz information criterion
HQ: Hannan-Quinn information criterion

E. Structural Change Test for Model (2)

Structural change tests for model (2) have the same procedure with the one for model (1). Dummy variables are added into model (2) as another exogenous variable when constructing unrestricted model. Model (2) itself is restricted model in the tests. $dummy1$ and $dummy2$ are used for testing structural change in 2005m7 and 2008m12, respectively.

Suppose there is a structural break in 2005m7, I estimate the unrestricted model and restricted model to get the determinant of residual covariance matrix, given as

$$\hat{\Omega}_U = 9.09 \times 10^{-7}$$

$$\hat{\Omega}_R = 9.52 \times 10^{-7}$$

The test stat. is given as

$$LR = dofc \times \Big(ln \mid \hat{\Omega}_R \mid - ln \mid \hat{\Omega}_U \mid \Big) = (120-18) \times \big(ln \left(9.52 \times 10^{-7}\right) - ln \left(9.09 \times 10^{-7}\right) \big) = 4.714$$

while the critical value is

$$\chi^2_{5,.05} = 11.07$$

Since $LR = 4.714 < \chi^2_{5,.05} = 11.07$, we fail to reject the null hypothesis and conclude that there is no structural change in 2005m7, tested at 5% significance level.

Suppose 2008m12 is a structural break point for model (2). Repeat the test procedure using $dummy2$ in the unrestricted model. Estimating it gives a new determinant of residual covariance matrix as

$$\hat{\Omega}_U = 7.97 \times 10^{-7}$$

and a new value for test stat.

$$LR = dofc \times \Big(ln \mid \hat{\Omega}_R \mid - ln \mid \hat{\Omega}_U \mid \Big) = (120-18) \times \big(ln \left(9.52 \times 10^{-7}\right) - ln \left(7.97 \times 10^{-7}\right) \big) = 18.126$$

Since $LR = 18.126 > \chi^2_{5,.05} = 11.07$, we reject the null hypothesis and then conclude that there is a structural change point in 2008m12, tested at 5% significance level.

F. Granger Causality Test for Model (2)

This test is conducted to see whether lags of ΔNFA Granger Cause the other variables in model (2).

$H_0 : \Delta NFA_{t-1} \overset{GC}{\nrightarrow}$ the other variables

$H_1 : \Delta NFA_{t-1} \overset{GC}{\longrightarrow}$ the other variables

The Unrestricted model is (2), with

$$\hat{\Omega}_U = 9.52 \times 10^{-7}$$

The Restricted model with

$$\hat{\Omega}_R = 1.29 \times 10^{-6}$$

The test stat. is given as

$$LR = dofc \times \Big(ln \mid \hat{\Omega}_R \mid - ln \mid \hat{\Omega}_U \mid \Big) = (120-17) \times \big(ln \left(1.29 \times 10^{-6}\right) - ln \left(9.52 \times 10^{-7}\right) \big) = 31.298$$

The critical value is

$$\chi^2_{3,.05} = 7.815$$

Since $LR = 31.298 > \chi^2_{3,.05} = 7.815$, we reject the null hypothesis and conclude that one lag of ΔNFA does GCs the other variables in model (2), tested at 5% significance level.

G. Impulse Responses

Figure 7: Impulse Responses to Different Shocks, Model (2), 2002m9 – 2012m12.

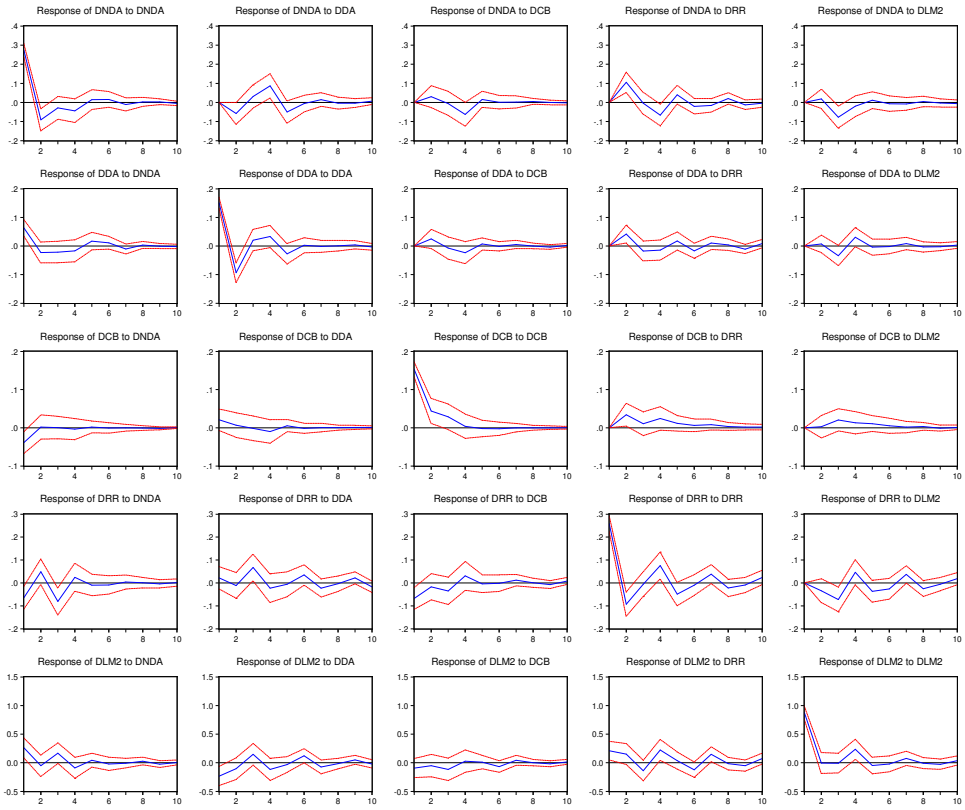

Figure 8: Impulse Responses to Different Shocks, Model (2), 2002m9 – 2008m12.

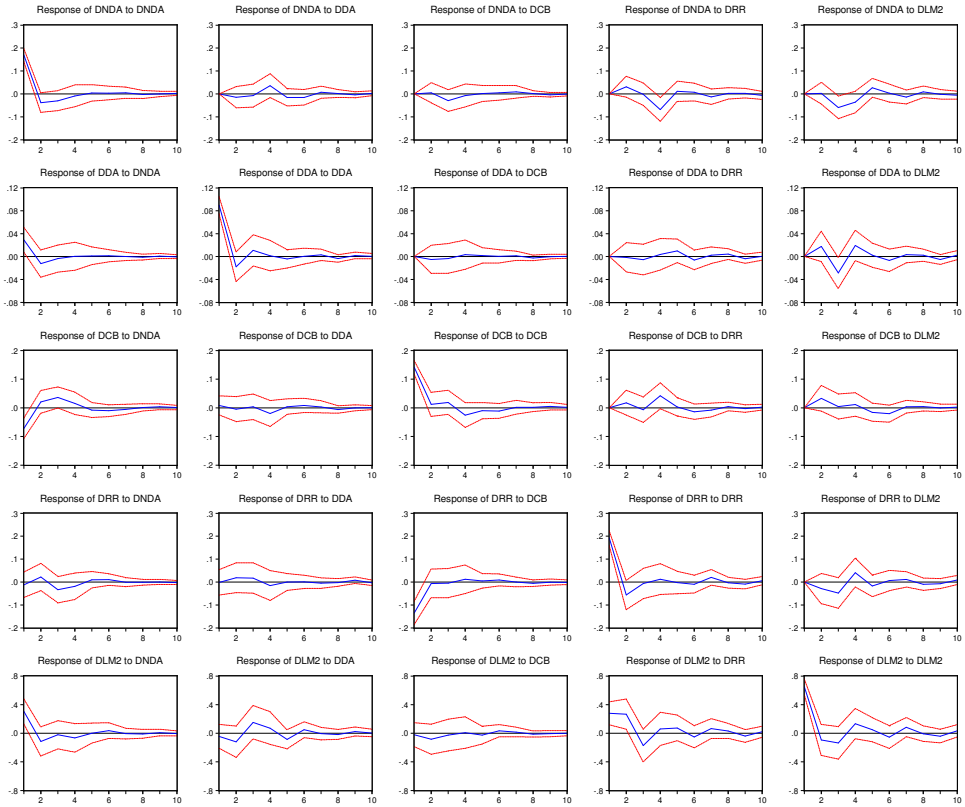

Figure 9: Impulse Responses to Different Shocks, Model (2), 2009m1 – 2012m12.

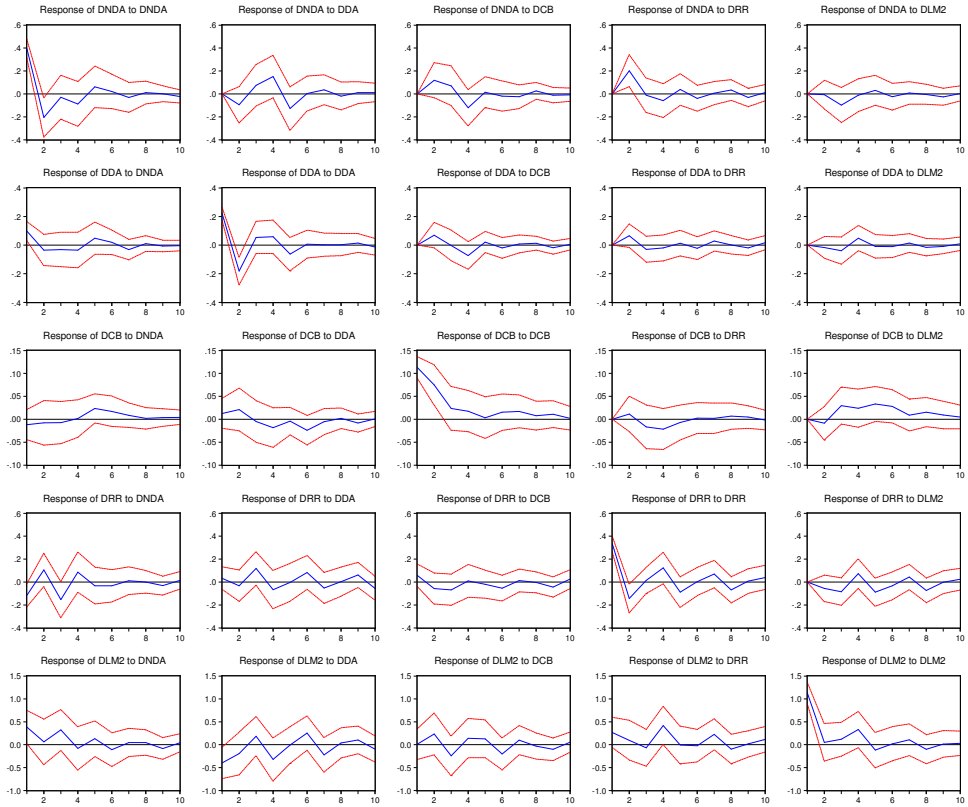

Figure 10: Impulse Responses to Different Shocks, Model (2a), 2002m9 – 2012m12.

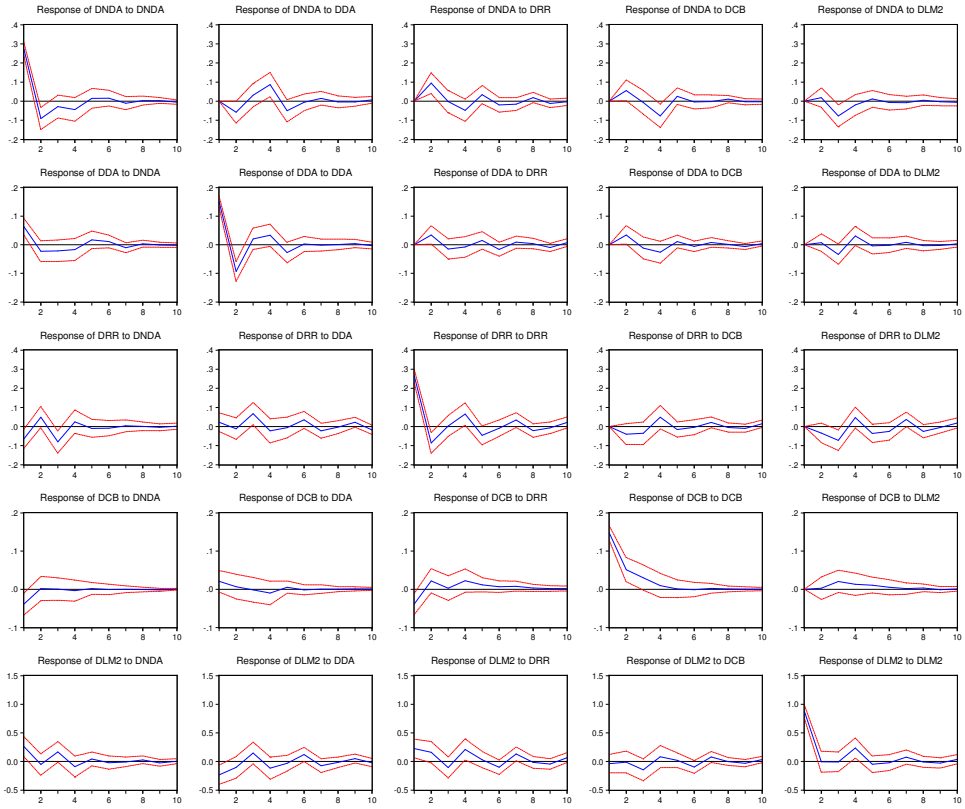
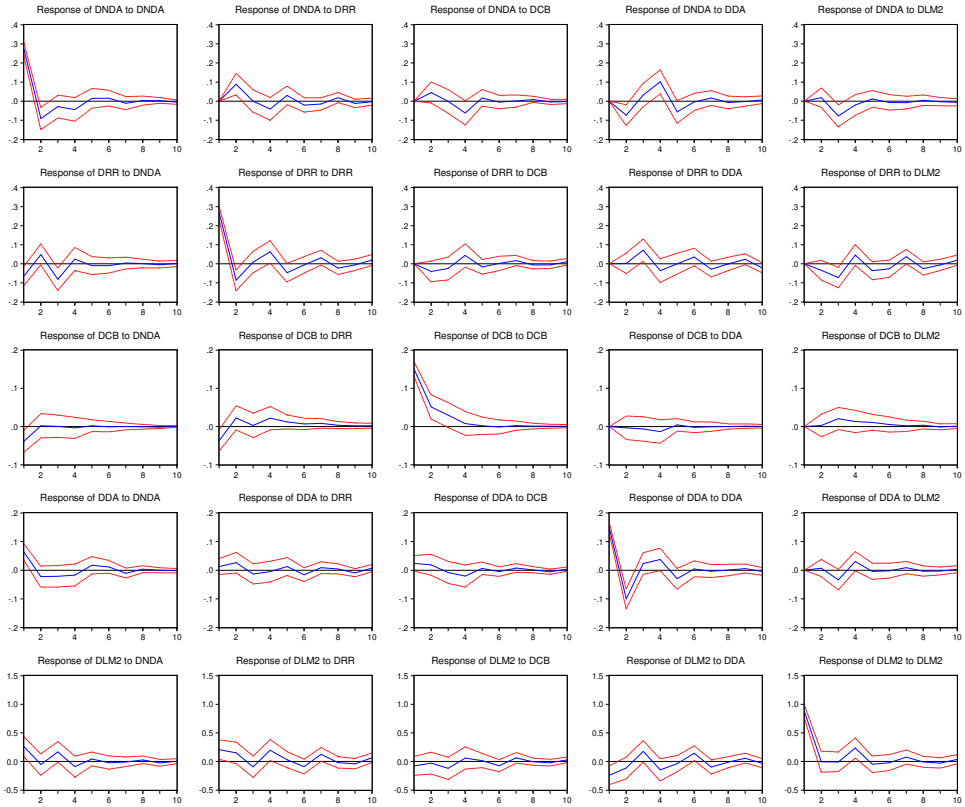
Figure 11: Impulse Responses to Different Shocks, Model (2b), 2002m9 – 2012m12.