THREE ESSAYS ON CHINA'S INTERBANK MONEY MARKET: ITS INTERACTIONS WITH THE CENTRAL BANK, THE EXCHANGE-BASED MONEY MARKET AND THE OFFSHORE RENMINBI MONEY MARKET

A Dissertation

by

RUOXI LU

Submitted to the Office of Graduate and Professional Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Chair of Committee,	David J. Leatham
Co-Chair of Committee,	David A. Bessler
Committee Members,	Ximing Wu
	Rebekka M. Dudensing
Head of Department,	C. Parr Rosson III

August 2017

Major Subject: Agricultural Economics

ABSTRACT

This dissertation consists of three essays that focus on China's interbank money market. The first essay is an empirical examination of the responses of China's short-term interbank interest rates to the People's Bank of China (PBOC)'s policy instruments, and how these responses were affected by structural changes. The results indicate that the interbank interest rates responded to policy instruments differently following three structural changes related to the 2007-08 global financial crisis and major operational changes by the PBOC in 2011 and 2013. The results also suggest that there were significant discrepancies between the Shanghai Interbank Offered Rate (SHIBOR) and the interbank repo rate's responses to policy instruments.

The second essay is an empirical assessment of the transmission of liquidity shocks between China's interbank money market that supplies liquidity to the banking sector and China's exchange-based money market that supplies liquidity to the stock market, based on the co-movements of interest rate spreads in these two markets. The segmentation between the two money markets was supposed to prevent the transmission of liquidity shocks between China's banking sector and stock market during liquidity-related market events. However, the results in this study suggest that the trading and financing activities in the two money markets allowed liquidity shocks to circumvent the market segmentation during two recent market events, including the rollercoaster ride of China's stock market in 2014-15 and the cash crunch in China's banking sector in mid-2013.

The third essay is an attempt to infer how China's monetary policymakers may have handled the famous monetary policy trilemma based on an empirical exploration of the interactions between the onshore and offshore renminbi interbank interest rates. The results suggest that, during most of the last three to four years, the monetary policymaking of the PBOC has been bounded by the trilemma like the central banks in the other major economies, with the exception of a 15-month period since May 2014. The results also suggest that the PBOC may have switched their priorities among the three components of the trilemma several times in recent years in responses to different market environments.

TABLE OF CONTENTS

Page

ABSTRACT ii

TABLE OF CONTENTS iv

LIST OF FIGURES...vi

LIST OF TABLES viii

CHAPTER I INTRODUCTION 1

CHAPTER II THE EFFECTS OF STRUCTURAL CHANGES ON THE INTERACTION BETWEEN SHORT-TERM INTERBANK INTEREST RATES IN CHINA AND THE POLICY INSTRUMENTS OF CHINA'S CENTRAL BANK 4

2.1 Introduction 4
2.2 Background..7
2.3 Empirical Analysis 10
2.4 Results 19
2.5 Summary and Policy Implications...41

CHAPTER III THE TRANSMISSION OF LIQUIDITY SHOCKS INTO AND OUT OF CHINA'S BANKING SECTOR VIA CHINA'S SEGMENTED MONEY MARKET: EVIDENCE FROM RECENT MARKET EVENTS 45

3.1 Introduction 45
3.2 Background..46
3.3 Methodology...56
3.4 Empirical Results..65
3.5 Conclusion 84

CHAPTER IV THE INTERACTION BETWEEN THE ONSHORE AND OFFSHORE RENMINBI INTERBANK INTEREST RATES AND ITS IMPLICATIONS ON THE TRILEMMA CHALLENGE FOR CHINA'S MONETARY AUTHORITY 87

4.1 Introduction 87
4.2 Background..91
4.3 Methodology...98
4.4 Empirical Results..110

4.5 Conclusion and Policy Implications 127

CHAPTER V SUMMARY 131

REFERENCES 134

LIST OF FIGURES

Page

Figure 2.1. Interbank interest rate series 11

Figure 2.2. Selective monetary instruments 13

Figure 2.3. EMFP for overnight SHIBOR 20

Figure 2.4. EMFP for overnight repo rate 20

Figure 2.5. EMFP for 7-day SHIBOR 20

Figure 2.6. EMFP for 7-day repo rate 21

Figure 2.7. EMFP for individual parameters (overnight SHIBOR) 22

Figure 2.8. EMFP for individual parameters (overnight repo rate) 22

Figure 2.9. EMFP for individual parameters (7-day SHIBOR) 23

Figure 2.10. EMFP for individual parameters (7-day repo rate) 23

Figure 2.11. The four periods separated by structural changes 27

Figure 2.12. Daily market turnover: overnight vs. 7-day interbank lending 37

Figure 2.13. Daily market turnover: overnight vs. 7-day repos 37

Figure 2.14. Overnight SHIBOR-repo spread vs. deposit benchmark rate 38

Figure 2.15. 7-day SHIBOR-repo spread vs. deposit benchmark rate 38

Figure 3.1. China's segmented money market and how it connects different traders and assets 51

Figure 3.2. Weekly averages of the six daily interest rates 60

Figure 3.3. The five interest rate spreads as liquidity measures 60

Figure 3.4. The six liquidity co-movements to be measured by the empirical model 61

Figure 3.5. The co-moveMent of funding liquidity between the banking sector and stock traders 68

Figure 3.6. The co-movement between the funding liquidity of the banking sector and the market liquidity of major short-term debt securities in the interbank money market 68

Figure 3.7. CSI 300 Index between July 2013 and April 2016 71

Figure 3.8. Co-movement 1 between July 2013 and April 2016 72

Figure 3.9. Co-movement 2 between July 2013 and April 2016 72

Figure 3.10. Co-movement 2 based on PFB between July 2012 and May 2014 79

Figure 3.11. Co-movement 2 based on CP between July 2012 and May 2014 79

Figure 3.12. Co-movement 1 between July 2012 and May 2014 80

Figure 3.13. CSI 300 Index between July 2012 and May 2014 80

Figure 4.1. Fed funds effective rate vs. the USD Libor rates with overnight and 1-week maturities 95

Figure 4.2. CNY SHIBOR and repo fixing rates vs. CNH HIBOR of overnight maturity 95

Figure 4.3. CNY SHIBOR and repo fixing rates vs. CNH HIBOR of 1-week maturity 96

Figure 4.4. Interest rate data 109

Figure 4.5. CNH-CNY interest rate spread 110

Figure 4.6. CNH exchange rate 110

Figure 4.7. Structural breaks and the shifts in the mean CNH-CNY interest rate spread 112

Figure 4.8. The calculated volatility measure of the CNH/USD exchange rate 124

LIST OF TABLES

Page

Table 2.1. Regulatory and operational changes on the PBOC's instruments 10

Table 2.2. Dates of structural break points...26

Table 2.3. Optimal settings for the ARMA-EGARCH models..................................27

Table 2.4. Parameter estimates for the ARMA-EGARCH models of overnight SHIBOR rates. 29

Table 2.5. Parameter estimates for the ARMA-EGARCH models of overnight repo rates 30

Table 2.6. Parameter estimates for the ARMA-EGARCH models of 7-day SHIBOR rates..31

Table 2.7. Parameter estimates for the ARMA-EGARCH models of 7-day repo rates 32

Table 2.8. Comparison of parameter estimates across 4 periods 34

Table 2.9. Comparison of parameter estimates across 4 periods 35

Table 3.1. Parameter estimates of the penta-variate AR(1)-DCC(1,1)-GARCH(1,1) system 66

Table 4.1. Orders of integration 120

Table 4.2. Optimal lag orders for the VAR models in each period...........................121

Table 4.3. The results of the Granger causality tests in each period..........................122

Table 4.4. Optimal lag orders for the VAR models in each period...........................125

Table 4.5. The results of the Granger causality tests in each period..........................125

Table 4.6. The parameter estimates for the VAR models in Periods 3 and 5 126

Table 4.7. The attainment of the three components of the monetary policy trilemma 128

CHAPTER I

INTRODUCTION

The interbank money market refers to the component of a country's financial system mainly reserved for banks and other financial institutions to lend and borrow short-term funds, as well as buy and sell short-term credit instruments with maturities typically of one year or less among each other. The interbank money market serves several crucial functions in a modern financial system. First, it enables the banks with liquidity shortage to borrow funds from the banks with liquidity surplus in order to meet their obligations and reserve requirements. Meanwhile, the transactions in the interbank money market determine the interbank interest rates that are typically used as benchmarks to price all other debts. Furthermore, the interbank money market provides a medium for the central bank to target and intervene the market interest rates. Additionally, the interbank money market has increasingly become a major funding source for long-term debts, as securitized banking takes over the traditional form of banking.

The gradual liberalization of China's financial system since the 1990s has brought about a booming interbank money market in China. Although the liberalization is still a work-in-progress, the interbank money market in China has already occupied a key position in China's financial system after two decades of rapid development and expansion. The interbank money market now determines the benchmark interest rates being used for all bond issuances in China, after the interest rates of bonds were liberalized from government controls. The interbank money market also allows the investors in China's stock market to be indirectly financed by funds from the banking sector, after the non-bank financial institutions with presence in China's stock market were granted access to the interbank money market. In addition, the interbank money market provides a gateway for foreign intuitional investors to invest their offshore renminbi holdings back to the onshore market as well as to obtain renminbi financing from the onshore market, after the interbank money market became the first market to be opened up to foreign investors.

The evolving interbank money market in China raises concerns on the following three important policy questions.

1. As the benchmark interest rates in China transition from being specified by the government to being determined by the interbank money market, is the People's Bank of China (PBOC), China's central bank, still able to effectively manage the market interest rates with its existing policy instruments?
2. Does the expanding interbank money market in China makes it more likely for liquidity shocks to transmit between China's closely guarded banking sector and China's volatile stock market, despite the prohibition for banks to directly access the stock market?
3. Does the increasing interconnectivity between the onshore and offshore renminbi money markets affect the effectiveness of the PBOC's capital controls and its handling of the famous monetary policy trilemma?

In this dissertation, I address the three policy questions above with three separated essays contained in Chapters II, III and IV, respectively. In Chapter II, I empirically examine the responses of China's short-term interbank interest rates to the PBOC's policy instruments, as well as how these responses were affected by structural changes. This study extends the previous literature on the interaction between the interbank interest rate and the monetary policy instruments in China by incorporating new data and considering the impact of structural changes in the interest rate model for the first time. In Chapter III, I empirically assess the transmission of liquidity shocks between China's interbank money market that supplies liquidity to the banking sector and China's exchange-based money market that supplies liquidity to the stock market, based on the co-movements of interest rate spreads in these two markets. This study is the first empirical assessment of the transmission of liquidity shocks though money market transactions in China. In Chapter IV, I infer how China's monetary policymakers may have handled the monetary policy trilemma based on an empirical exploration of the interactions between the onshore and offshore renminbi interbank interest rates. This study is made possible for the first time by the June 2013 launch of the previously inexistent benchmark interbank interest rate for the offshore renminbi and over three years of data accumulation since its launch. In the end, my findings are summarized in Chapter V.

CHAPTER II

THE EFFECTS OF STRUCTURAL CHANGES ON THE INTERACTION BETWEEN SHORT-TERM INTERBANK INTEREST RATES IN CHINA AND THE POLICY INSTRUMENTS OF CHINA'S CENTRAL BANK

2.1 Introduction

A central bank's ability to implement monetary policies relies crucially on its ability to control market interest rates. For major developed economies, the interactions between short-term interbank interest rates and the central banks' open market operations (OMOs) enable their central banks to anchor the short end of the yield curve and guide the market interest rates. For example, in the U.S., the federal funds rate is targeted by the Federal Reserve (the Fed) and maintained at around the target level by its OMOs. In the Eurozone, the Eonia and Euribor, two major interbank reference rates, closely track the interest rates of the European Central Bank (ECB)'s main refinancing operations (MROs). Previous studies generally agree that the Fed and the ECB's monetary interventions via OMOs effectively move the short-term interbank interest rates in their respective markets. Bernanke and Blinder (1992) argued that the federal funds rate sensitively recorded shocks to the supply of bank reserves, making it a good indicator for monetary policy. Hamilton (1996) found overwhelming evidence for liquidity effect in the federal funds market, which enabled the Fed to change the interest rate on a daily basis. Bartolini, Bertola and Prati (2002) proposed a model of interbank money market volatility with an explicit role for central bank intervention and periodic reserve requirements, which was consistent with the empirical patterns of the federal funds rate. Moschitz (2004) revealed that most of the predictable patterns in the mean and volatility of the overnight interbank interest rate in the Eurozone were related to the ECB's monetary policy implementation. However, these assessments are not necessarily applicable to China's interbank interest rate and its central bank's monetary interventions. According to Prati, Bartolini and Bertola (2003), many key features of the U.S. federal funds rate's behavior were not robust to different institutional details and styles of central bank interventions in other major industrial countries.

China's interest rate liberalization is still a work-in-progress. When China completes its transition from a government-specified interest rate system to a market-based system in the future, the short-term interbank interest rate in China will likely take on a more central role in market interest rate determination and monetary policy implementation, similar to its counterparts in the U.S. and the Eurozone. In this scenario, the ability to control the interbank interest rate with OMOs and reserve requirement will be critical for the PBOC to effectively conduct monetary policies. However, according to previous empirical studies based on pre-2011 data (Porter and Xu, 2009; He and Wang, 2012), China's interbank interest rate was mainly responsive to the benchmark interest rates for bank deposits and loans administratively set by the PBOC, but not significantly responsive or only slightly responsive to the PBOC's market liquidity interventions via OMOs and changes in the reserve requirement ratio (RRR). Unless the PBOC's regulatory and operational changes after these studies led to structural change(s) in the interbank interest rate that strengthened its interactions with the PBOC's liquidity interventions and weakened its dependence on the PBOC's non-market-determined policy benchmark rates, it would be hard to convince the policy makers to control market interest rates only with market based measures without resorting to the policy benchmark rates. Therefore, the primary motivation of this paper is to investigate if there exist structural breaks in the interbank interest rate series that coincides with the PBOC's major regulatory operational changes since 2011, and to empirically verify if China's interbank interest rate reacted differently to the PBOC's policy instruments after the structural breaks in a way that favors the use of market based interest rate interventions over more traditional administrative measures.

Besides updating and amending the earlier empirical findings on China's interbank interest rate, we also intend to extend the coverage of previous studies to Shanghai Interbank Offered Rate (SHIBOR), a new interbank reference rate introduced in October 2006 as China's equivalent of Libor but yet to be thoroughly studied, possibly due to its short history and limited sample size. Unlike the interbank repo rate, the main subject in previous studies such as Porter and Xu (2009), SHIBOR is an unsecured rate for credit based interbank lending rather than a collateral rate, and is based on quotes rather than actual transactions.[1] In recent years, although interbank repo rates are still commonly used to price floating rate notes (Zhou, Li and Sun, 2013), SHIBOR has become the main reference rate for fixed rate corporate bonds and commercial papers (PBOC, 2015a), making it an important subject for new studies on China's interbank interest rate.

[1] "About Shibor" on Shibor official website: http://www.shibor.org/shibor/web/html/index_e.html [in Chinese]

In this paper, we choose the overnight and 7-day SHIBOR and interbank repo rates as the subjects of our analysis, because the overnight and 7-day maturities are the most liquid types on both the secured and unsecured interbank markets[2]. Based on the empirical behaviors of these four rates, we specifically address the following research questions: 1. Were there one or more structural changes in China's interbank interest rate? If so, were they related to any of the regulatory and operational changes of the PBOC since 2011? 2. Was China's interbank interest rate significantly responsive to PBOC's main policy instruments, namely the policy benchmark rates, OMOs and RRR? How did these responses vary across structural changes in terms of significance and magnitude? 3. Are the answers to Questions 1 and 2 consistent across the four types of interbank interest rates?

2.2 Background

Before presenting the detailed analysis and the results, we would like to first provide a brief background on the status quo of China's interest rate system, the theoretical basis on how the interbank interest rate may react to the PBOC's policy instruments under the current system, and the PBOC's recent regulatory and operational changes that might have led to structural changes in the empirical behavior of the interbank interest rate.

2.2.1 China's dual-track interest rate system

Although China already has a liquid interbank market, the role of interbank interest rate as a market benchmark has been largely limited to the money market and the bond

[2] Measured by the daily turnover for each maturity in these two markets (Source: CEIC Data)

market. The PBOC issues a separated set of benchmark interest rates for bank loans and deposits, and confines the actual deposit and loan rates offered by banks with a deposit rate ceiling and a lending rate floor set in proportion to the respective benchmark rate. Unlike the Fed, the PBOC does not explicitly target a short-term interbank interest rate when conducting OMOs. Besides setting the benchmark rates for the banks and routine OMOs, the PBOC frequently changes RRR to manage market liquidity, which is unusual among major economies (Ma, Yan and Liu, 2011). In addition, the PBOC use window guidance, a form of persuasion tactic, to set loan growth target for individual banks, which could also impact the market interest rate (Chen, Chen and Gerlach, 2011). However, since window guidance is directed to individual banks and is not usually observable, our study will focus only on the impact of the PBOC's benchmark rates, OMOs and RRR.

2.2.2 The PBOC's policy instruments as the determinants of interbank interest rate

The theoretical connections between the interbank interest rate and the PBOC's official benchmark rates, RRR and OMOs were established by Porter and Xu (2009) based on Freixas and Rochet (2008)'s microeconomic framework of banking. Their model assumes a competitive market of N price-taking banks maximizing profits by choosing the optimal deposits, loans, bond holdings (assumed to be inelastically supplied by the government) and positions on the interbank market in each period subjected to reserve requirement and their own liquidity preferences. The competitive equilibrium is characterized by the clearing conditions of loan market, savings market and interbank market. At equilibrium, interbank interest rate is a function of deposit and loan interest rates (which are assumed to follow the PBOC benchmark rates), RRR (which is set by the PBOC), and the issuance of government bonds (which can be considered a form of OMO). Chen, Chen and Gerlach (2011) and He and Wang (2012) further modified Porter and Xu (2009)'s model to account for the impact of window guidance and money flows between banking sector and the bond market, respectively. The predictions of these models varied with model types and assumptions. For example, assuming the deposit rate ceiling was binding as commonly believed, Porter and Xu (2009) and Chen, Chen and Gerlach (2011) predicted negative impact of deposit benchmark rate on the interbank interest rate, but He and Wang (2012) predicted otherwise. For RRR to have positive impact on the interbank interest rate, Porter and Xu (2009)'s model required sufficient liquidity preferences of the banks and Chen, Chen and Gerlach (2011)'s model required a loan target level for banks set by the PBOC.

2.2.3 Policy factors that could lead to structural changes

The major regulatory and operational changes on the three major policy instruments since 2008 are listed in Table 2.1. As the restrictions on the bank interest rates were gradually loosened by the PBOCs, the actual rates offered by the banks may have been able to move closer to the competitive equilibrium without hitting the deposit rate ceiling or lending rate floor, making the restrictions non-binding. Meanwhile, the variable reserve requirement may force banks to have a higher liquidity preference, thereby making the impact of RRR on the interbank interest rate more positive, based on Porter and Xu

(2009)'s assessment. In addition, the creation of new OMO tools might finally make OMOs a significant determinant of the interbank interest rate.

Restrictions on deposit and loan interest rates	Reserve requirement	Open market operations
The PBOC lowered the lending rate floor for banks on • Jul-2012: from 0.9x lending benchmark rate to 0.7x • Jul-2013: lending rate floor removed	The PBOC started enforcing two RRRs since Sep-2008 • Small and medium sized financial institutions to have a lower RRR than large national banks	Between 2004 and 2013, the PBOC conducted OMOs with • Central bank bills (CB) with 3-month to 3-year maturities • Repos and reversed repos with 7-day to 6-month maturities
The PBOC raised the deposit rate ceiling for banks on • Jun-2012: from 1.0x deposit benchmark rate to 1.1x • Nov-2014: from 1.1x to 1.2x • Mar-2015: from 1.2x to 1.3x	The PBOC adopted a variable reserve requirement scheme in the beginning of 2011 • The RRR for a specific financial institution depends on a set of financial health metrics specified by the PBOC on top of the standard RRR	Since the Short-term Liquidity Operations (SLO) was introduced in 2013, the PBOC conducted OMOs with • CBs • Repos and reversed repos • SLOs with 1-day to 6-day maturities

Table 2.1. Regulatory and operational changes on the PBOC's instruments. (Source: PBOC 2009, 2012, 2013, 2014, 2015b, 2015c, CEIC)

2.3 Empirical Analysis

2.3.1 The data

2.3.1.1 Interbank interest rate

The overnight and 7-day SHIBOR and interbank repo rates data were collected from the National Interbank Funding Center (NIBFC) (Figure 2.1).

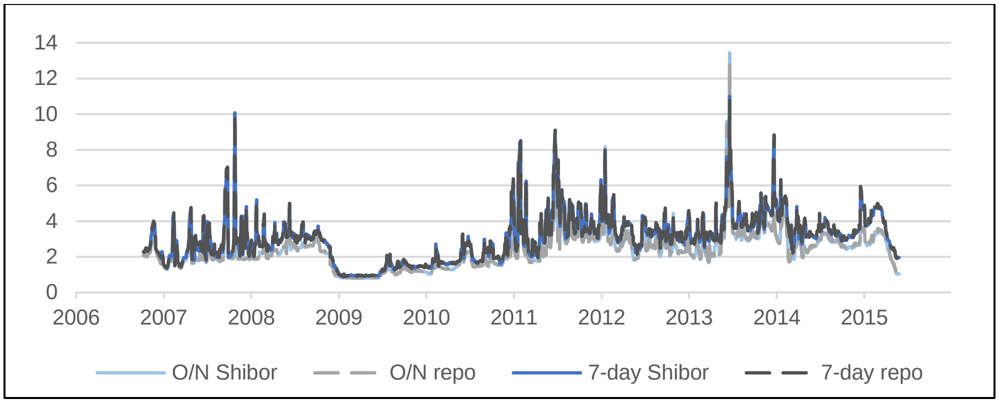

Figure 2.1. Interbank interest rate series (Source: NIBFC)

The repo fixing rates used in this study were published daily based on the medium rates for all transactions between 9am-11am on each trading day for each repo type, respectively. In comparison, the daily SHIBOR quotes for different maturities are calculated by averaging all the rate quotes (excluding the highest and lowest two) offered by a preselected group of banks with high credit ratings. The SHIBOR quotation group consists of 18 major domestic and foreign commercial banks operating in China, which are either primary dealers of the PBOC's OMOs or market makers in the FX market[3]. The four interbank rate series are modeled separately for the period between October 9, 2006 (when SHIBOR was introduced) and May 29, 2015 (when the database was last accessed by the authors). Although the repo rate and SHIBOR with the same maturity generally move closely together, many factors could lead to non-trivial differences between their movements. For example, the access to the unsecured interbank lending market is more restrictive than the interbank repo market, making some of the participants in the repo market unable to trade in the unsecured market (Cassola and Porter, 2013).

[3] "About Shibor" on Shibor official website: http://www.shibor.org/shibor/web/html/index_e.html [in Chinese]

2.3.1.2 The PBOC's monetary instruments

The variable representing the PBOC benchmark rates in our study is the 3-month deposit benchmark rate collected from the PBOC's website[4], which has the shortest term among the PBOC's fixed-term deposit benchmark rates. In our empirical models, only the deposit benchmark rate is included but not the loan benchmark rate. Such arrangement is to avoid a potential multicollinearity problem for the interest rate models, due to the fact that the PBOC almost always changed the deposit and loan benchmark rate simultaneously. However, this situation also makes it difficult to interpret the impact of the deposit benchmark rate in the models, because any movements in the interbank market associated with changes in the deposit benchmark rate could actually be the combined impact from both the deposit and loan benchmark rates. The current and historical RRRs are also obtained from the PBOC's website[5]. There have been two different RRRs since the PBOC's start enforcing the 2-tier reserve requirement in 2008, but only the RRR for the large financial institutions is used in this study to avoid multicollinearity. The PBOC's open market operations data are collected from CEIC's China Premium Database[6]. The final OMO variable used in this study is measured by daily net liquidity drain by the PBOC, calculated as the sum of the PBOC's CB and repo (including SLO) issuance of all maturities, plus the total expiring reversed repo (including SLO), minus the total expiring CB and repo, and minus the total reversed repo issuance for each trading day. The three PBOC-controlled variables are visualized in Figure 2.2.

[4] http://www.pbc.gov.cn/zhengcehuobisi/125207/125213/125440/125838/125888/2968982/index.html [in Chinese]
[5] http://www.pbc.gov.cn/zhengcehuobisi/125207/125213/125434/125798/17085/index1.html [in Chinese]
[6] http://www.ceicdata.com/en/countries/china

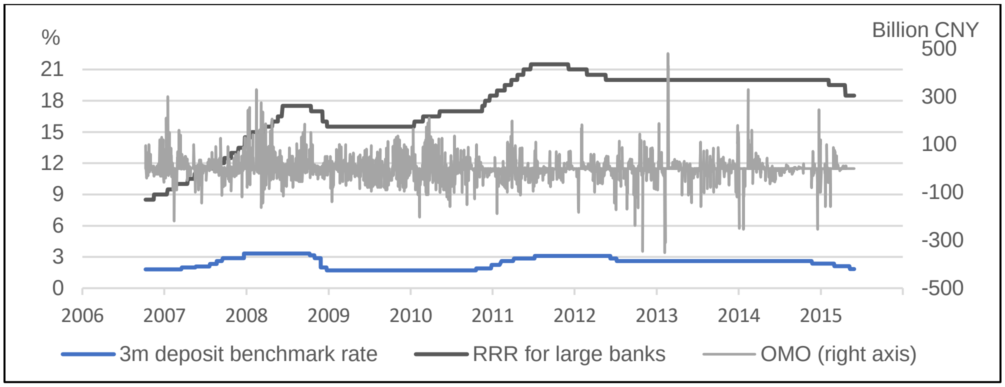

Figure 2.2. Selective monetary instruments (Source: PBOC, CEIC)

2.3.1.3 Other exogenous variables

The short time horizon of the interest rate data and the added dimensions associated with structural changes limit the number of variables that can be reliably estimated. The only additional variable besides the interest rate and policy variables in our model is a dummy variable for the trading days before the Chinese New Year in each year. The enormous cash need during this traditional festival is believed to have caused major liquidity drains from the banking system in the business days immediately before the official holidays. Such phenomenon has been acknowledged by the PBOC, which usually pledged sufficient liquidity supply to the banking system before the holidays (PBOC, 2010; 2015a).

2.3.2 The empirical model for interbank interest rate

This paper follows the tradition of Hamilton (1996), Bartolini, Bertola and Prati (2002), Prati, Bartolini and Bertola (2003), Moschitz (2004) and Porter and Xu (2009) to model the conditional mean of the interbank interest rate as an autoregressive process and its conditional variance as an exponential GARCH (EGARCH) process introduced by Nelson (1991). Using EGARCH instead of standard GARCH allows asymmetric volatility responses to the positive and negative changes of the interbank rate. The variables representing the PBOC's policy instruments enter the mean and variance equations as exogenous variables. The AR(p)-EGARCH(m,s) system is specified as

Mean equation:

$$r_t = \mu_t + \varepsilon_t \tag{2.1}$$

$$\mu_t = \phi_0 + \sum_{i=1}^{p} \phi_i \, r_{t-i} + b_1 r_{d,t} + b_2 RRR_{L,t} + b_3 OMO_t + b_4 Precny_t \tag{2.2}$$

Variance equation:

$$\varepsilon_t = v_t \sqrt{h_t} \tag{2.3}$$

$$\ln(h_t) = \omega_t + \sum_{k=1}^{m} \alpha_i \frac{|\varepsilon_{t-k}| + \gamma_k \varepsilon_{t-k}}{\sqrt{h_{t-k}}} + \sum_{n=1}^{s} \beta_n \ln(h_{t-n}) \tag{2.4}$$

$$\omega_t = \omega_0 + c_1 \Delta r_{d,t}^{+} + c_2 \Delta r_{d,t}^{-} + c_3 RRR_{L,t} + c_4 OMO_t + c_5 Precny_t \tag{2.5}$$

In the mean equation, r_t is the selected interbank interest rate and μ_t is the conditional expectation $E(r_t | r_{t-1}, \dots, r_{t-p}, r_{d,t}, RRR_{L,t}, OMO_t\ Precny_t)$, where $r_{d,t}$ is the 3-month deposit benchmark rate at time t, $RRR_{L,t}$ is the RRR for large banks at time t, OMO_t is the net liquidity drain by the PBOC at time t and $Precny_t$ is the dummy variable for the last five trading days before the Chinese New Year. In the variance equation, h_t is the conditional variance of the innovations ε_t, given that v_t is an iid random variable with zero mean and unit variance. $\Delta r_{d,t}^{+}$ is the change of 3-month deposit benchmark rate at time t if the change is positive, while $\Delta r_{d,t}^{-}$ is the change of 3-month deposit benchmark rate at time t if the change is negative. Separating rate hikes and rate drops is to account for the scenario that any policy rate change decision could induce market volatility regardless of the direction of change. Also, it is reasonable to assume that the magnitude of policy rate changes is more relevant to the market volatility than the level of policy rates. Equation (2.4) is the standard formulation of an EGARCH(m, s) model except for the time varying ω_t, which is adjusted for the impact of policy variables and the Chinese New Year. A distributional assumption for v_t is required to fit the AR-EGARCH model using maximum likelihood estimation (MLE). Several previous studies, such as Prati, Bartolini and Bertola (2003) and Porter and Xu (2009) used Student-t distribution. But in our preliminary analysis on the current data, the innovation distribution seems to have more leptokurtosis and fatter tails than a Student-t distribution, which coheres well with the generalized error distribution (GED) as originally suggested by Nelson (1991).

2.3.3 The test for structural changes

The structural change test focuses on the mean equation specified in Section 2.3.2, because our main concern is the implication of structural changes on the ability of the PBOC's policy instruments in guiding the level of interbank interest rate. The linear model to be tested for structural change is formed by combining Equations (2.1) and (2.2):

$$r_t = \phi_0 + \sum_{i=1}^{p} \phi_i \, r_{t-i} + b_1 r_{d,t} + b_2 RRR_{L,t} + b_3 OMO_t + b_4 Precny_t + \varepsilon_t \tag{2.6}$$

We define a (p+5)-dimensional parameter

$$\boldsymbol{\theta}_t = (\phi_{0,t}, \phi_{1,t}, \dots, \phi_{p,t}, b_{1,t}, b_{2,t}, b_{3,t}, b_{4,t}) \tag{2.7}$$

and a (p+5)-dimensional observation

$$\boldsymbol{Y}_t = (r_t, r_{t-1}, \dots, r_{t-p}, r_{d,t}, RRR_{L,t}, OMO_t, Precny_t) \tag{2.8}$$

Under the assumption that for each observation $\boldsymbol{Y}_t$ at time t, there is a parameter $\boldsymbol{\theta}_t$ such that the autoregression model specified by Equation (2.6) holds, the null hypothesis for no structural changes in the model can be stated as

H_0: $\boldsymbol{\theta}_t = \boldsymbol{\theta} \quad \forall\, t$ where $\boldsymbol{\theta}$ is a constant.

Testing the null hypothesis requires a method that's flexible enough for multiple structural changes at unspecific times, efficient enough to deal with the multiple dimensions of the parameter, compatible with MLE, and also consistent even when heteroscedasticity and serial correlation is presented in ε_t. The generalized M-fluctuation test introduced by Zeileis and Hornik (2003) seems to be an ideal fit for the task. The structural change test in this study is performed following the procedures specified by Zeileis (2005, 2006). The test is based on a full-sample M-estimator defined as

$$\sum_{t=1}^{n} \psi\left(\boldsymbol{Y}_t, \widehat{\boldsymbol{\theta}}\right) = 0 \tag{2.9}$$

where $\psi(\cdot)$ is an M-estimation score function, in this case a maximum likelihood (ML) score function, with zero expectation at the true parameters. Under the null hypothesis, $E\left(\psi\left(\boldsymbol{Y}_t, \widehat{\boldsymbol{\theta}}\right)\right) = 0$, any systematic deviation from the null can be captured using a cumulative sum (CUSUM) process of the scores:

$$W_n(\tau) = n^{-1/2} \sum_{t=1}^{\lfloor n\tau \rfloor} \psi\left(\boldsymbol{Y}_t, \widehat{\boldsymbol{\theta}}\right) \tag{2.10}$$

in which $\tau \in [0, 1]$ is the relative location in the sample period. $\tau = 0$ represents the start date of the sample and $\tau = 1$ represents the end date of the sample. The decorrelated empirical fluctuation process of the model can be written as

$$efp(\tau) = \hat{\boldsymbol{J}}^{-1/2} W_n(\tau) \tag{2.11}$$

in which $\hat{\boldsymbol{J}}$ is the estimator of the asymptotic covariance matrix of the scores ψ. Different types of covariance estimators can be used for $\hat{\boldsymbol{J}}$. Considering the explicit assumption of heteroskedasticity in Section 2.3.2 and possible serial correlation in the innovations of the AR(p) model, a kernel based heteroskedasticity and autocorrelation consistent (HAC) estimator for covariance matrix (Andrews, 1991) is used in this study. Based on a functional central limit theorem (FCLT), it can be shown that the empirical fluctuation process converges to a Brownian bridge.

$$efp(\cdot) \overset{\mathrm{d}}{\to} W^0(\cdot) \tag{2.12}$$

Equation (2.12) provides the probabilistic basis for using the empirical M-fluctuation process specified by Equation (2.11) to visually inspect the instabilities of parameter estimates in Equation (2.6) over time. To enable significance testing for parameter instabilities, Zeileis and Hornik (2003) specified a scalar function $\lambda(efp)$ to aggregate the $efp(\cdot)$ into a single test statistic and also provide the methods to obtain the asymptotic critical values.

If the existence of structural changes is confirmed by the test, a dating procedure to identify the time of structural breaks is needed for segmenting the data and comparing parameter estimates before and after each structural change. For this purpose, the RSS-based dating technique specified in Bai and Perron (2003), which is insensitive to error variance, is performed after the M-fluctuation test. Suppose there are m breakpoints in the data, the full-sample residual sum of squares is given by

$$RSS(t_1, t_2, \dots, t_m) = \sum_{i=1}^{m+1} rss(t_{i-1}, t_i) \tag{2.13}$$

where $(t_1, t_2, \dots, t_m)$ are the breakpoints, $rss(t_{i-1}, t_i)$ is the minimal residual sum of squares in the segment between t_{i-1} and t_i, assuming $t_0 = 0$ and $t_{m+1} = n$. According to Bai and Perron (2003), a dynamic programming algorithm can be used to optimize Equation (2.13) and select optimal break dates $(t_1, t_2, \dots, t_m)$ for each given m. Then the optimal number of breakpoints m can be chosen by Schwarz's Bayesian Information Criterion (BIC) if the maximum of m is specified.

2.3.4 Estimation strategies

Before the empirical model in Section 2.3.2 is estimated, the structural change analysis specified in Section 2.3.3 is performed on each of the four interest rate series to verify the existence of structural changes in the mean equation and to determine the specific dates of these changes. Based on these dates, the data is partitioned into segments before and after structural changes, and the AR-EGARCH model is estimated for each interest rate series separately for each segment.

The structural change analysis starts with unit root tests. If no unit roots are detected in the interest rate series, the interest rate levels are then used directly in the AR(p) model specified in (6). For each interest rate series, the order of the AR(p) model is chosen as a $\mathrm{p} \in [0, 5]$ that minimize the BIC of the model. Limiting the maximum p to the length of a typical trading week is to maintain parsimony of the model used for structural change test. After the model is specified, the visualization of parameter instabilities by empirical M-fluctuation process as well as the testing and dating of structural changes can be performed on each interest rate series. And then the dates of structural changes can be used to partition the data.

The AR(p)-EGARCH(m, s) model for each rate type in each segment is estimated by maximizing a single likelihood function instead of first estimating the AR portion then fit the EGARCH portion with AR residuals. The preliminary attempts to fit the AR-EGARCH models reveal high order serial correlation in the AR residuals which could not be eliminated by including more lags in the mean equations. As a remedy to this issue, the original AR(p)-EGARCH(m, s) model is extended to an ARMA(p, q)-EGARCH(m, s) model. The optimal (p, q, m, s) is determined by fitting the models with all possible (p, q, m, s) combinations that satisfy the following restrictions: $\mathrm{p}, \mathrm{q} \in (0,1, \dots, \mathrm{p}^*)$ and $\mathrm{m}, \mathrm{s} \in (1, 2)$ where p^* is the order used in the structural break test, and finding the (p, q, m, s) combination that results in the lowest BIC.

2.4 Results

2.4.1 Structural changes and their dates

The structural change analysis supports the existence of multiple structural changes in China's interbank interest rate and their linkages to the PBOC's regulatory and operational changes on policy instruments. The tests for structural changes are based on the level of interest rates, because both the augmented Dickey-Fuller test and Phillips-Perron test reject unit roots in all the four interbank interest rate series. The models selected based on minimum BIC are AR(3) for overnight SHIBOR and overnight repo rates, and AR(2) for 7-day SHIBOR and 7-day repo rates, respectively. The empirical M-fluctuation process (EMFP) for parameters in each of these four models are calculated based on Equation (2.11) and plotted against a 5% asymptotic critical value. Figure 2.3-2.6 shows the aggregated $efp(\cdot)$ for all parameters in each model.

Figure 2.3. EMFP for overnight SHIBOR (Aggregated test statistic = 2.78, p-value = 0.000)

Figure 2.4. EMFP for overnight repo rate (Aggregated test statistic = 2.78, p-value = 0.000)

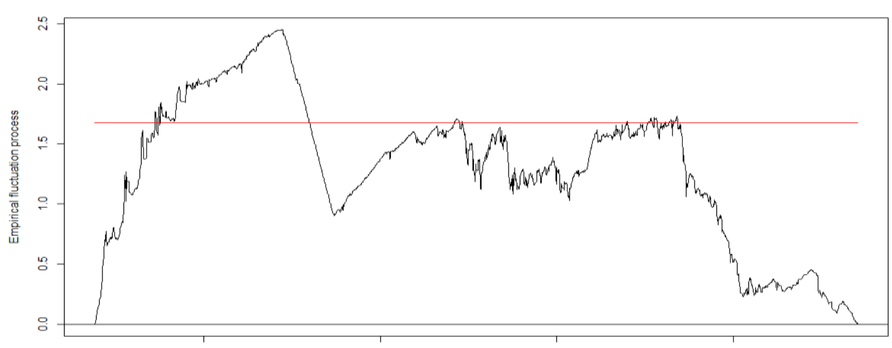

Figure 2.5. EMFP for 7-day SHIBOR (Aggregated test statistic = 2.45, p-value = 0.000)

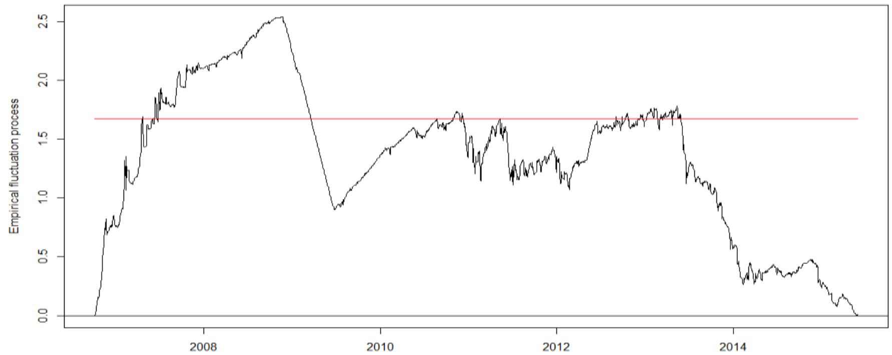

Figure 2.6. EMFP for 7-day repo rate (Aggregated test statistic = 2.54, p-value = 0.000)

The EMFPs reveal significant parameter instabilities in the models of all the four interbank interest rates, because each EMFPs spikes above its 5% critical values multiple times over the sample period, which are signals for structural changes. The aggregate M-fluctuation test statistics for the four interest rate models all reject the hypothesis of no structural changes at 5% significance level, further confirming the existence of structural changes in these models. If the two spikes between late 2010 and early 2011 in the EMFPs of the 7-day rates are considered a single structural change point, then the overnight rates and the 7-day rates share the first two structural changes, one between late 2007 and early 2008 and the other between late 2010 and early 2011. The 7-day rates had another structural change at around mid-2013, which is not captured by the EMFPs of the overnight rates. Disaggregating the EMFPs for each right-hand-side variables in Equation (2.6) reveals further insights on the linkages between the structural changes and the policy related variables. Figure 2.7-2.10 shows the variable-specific EMFPs for the four interbank interest rate models.

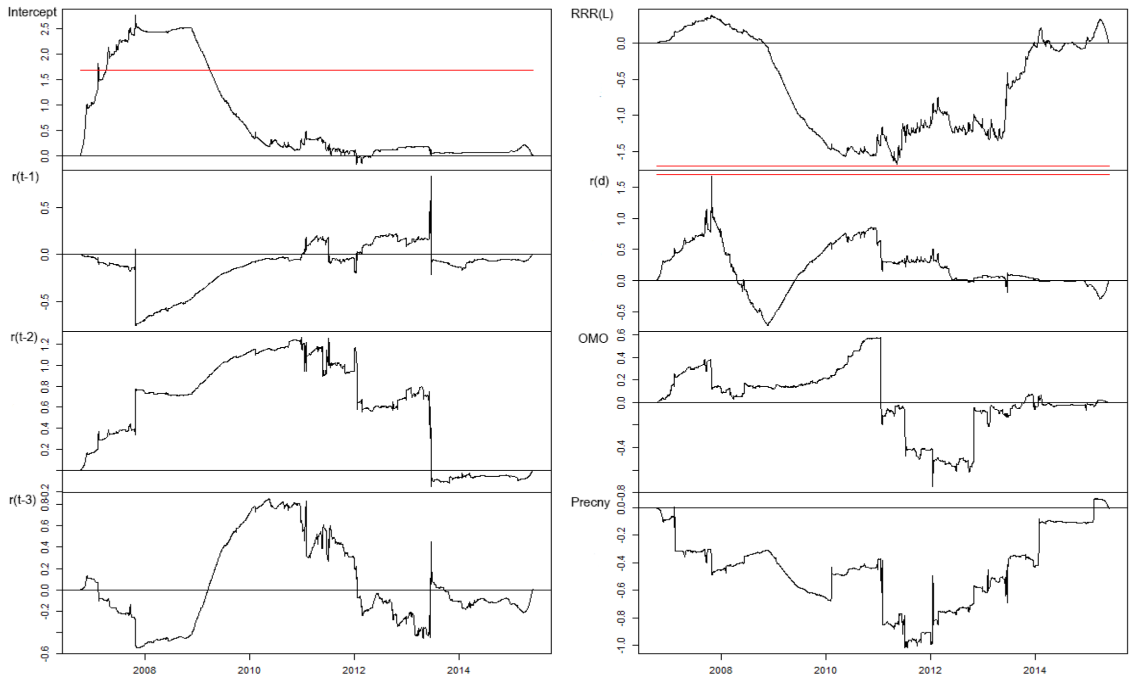

Figure 2.7. EMFP for individual parameters (overnight SHIBOR)

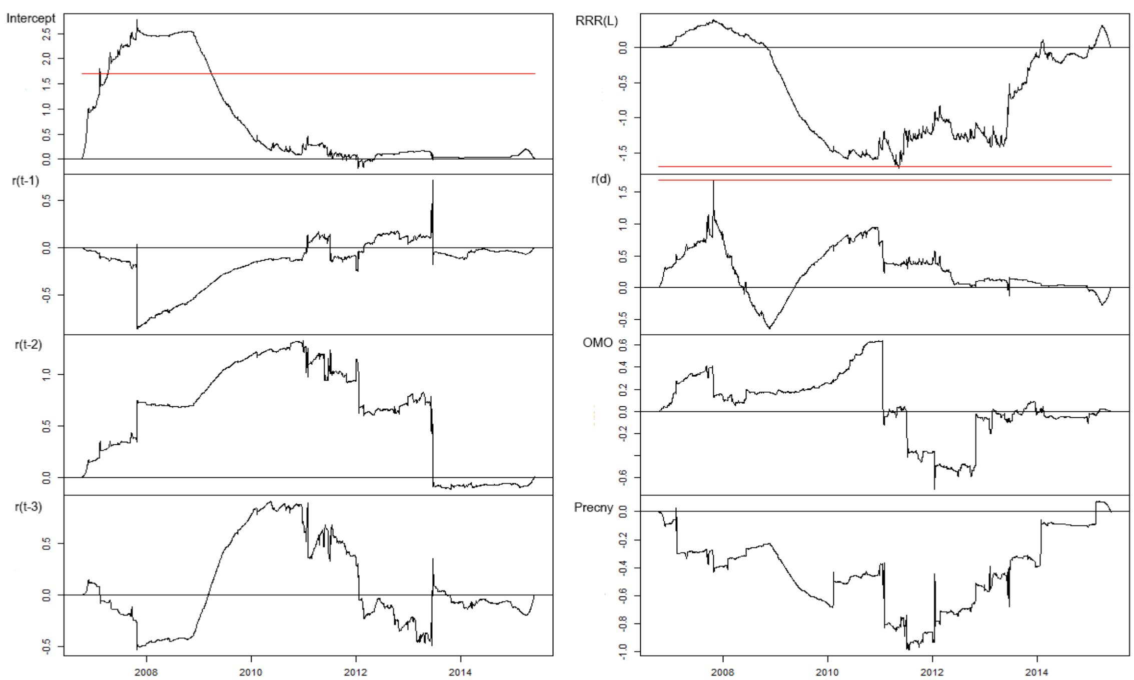

Figure 2.8. EMFP for individual parameters (overnight repo rate)

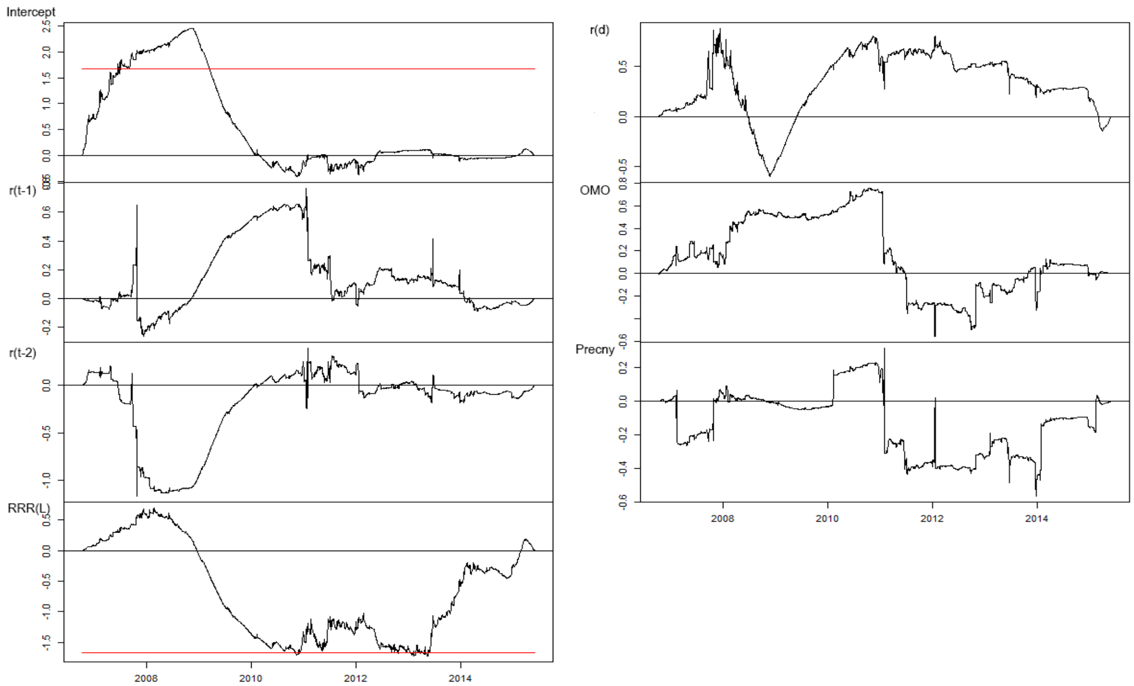

Figure 2.9. EMFP for individual parameters (7-day SHIBOR)

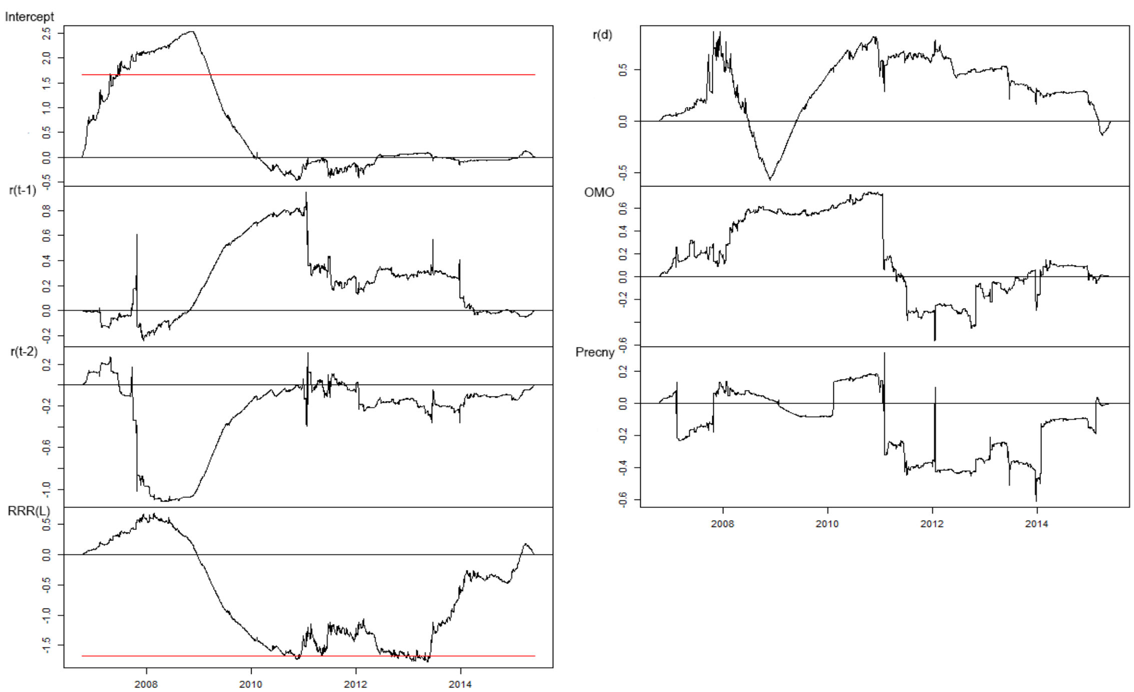

Figure 2.10. EMFP for individual parameters (7-day repo rate)

It appears that, during the sample period, significant parameter shifts took place at the intercept and the RRR variables in the models for all the four interest rates. In addition, the models for the overnight night rates experienced significant parameter shift at the benchmark deposit rate variable in late 2007. The shift in the intercept between late 2007 and early 2008 seems to suggest that an exogenous factor outside of the PBOC's control had moved the unconditional means of the interbank interest rates in 2008. Judging from the timing, this factor could either be the market reaction to the global financial crisis or the market reaction to government's stimulus via means other than monetary instruments following the financial crisis. The structural changes between late 2010 and early 2011 as well as in 2013 were dominated by the changes on how the interbank interest rates responded to RRR, indicating that the PBOC might have played a role in these structural changes. As described in Section 2.2, the PBOC began enforcing the variable reserve requirement scheme described in early 2011, possibly driving up the banks' liquidity preferences and making them more sensitive to RRR changes. Besides, prior to the implementation of variable reserve requirement, the PBOC organized two symposia on China's credit market conditions in November and December 2010 respectively. At these symposia, the PBOC officials pressed financial institutions to maintain "appropriate" credit growth and enhance risk management capability (PBOC, 2011). These measures could all contribute to a structural change in the interbank interest rates between late 2010 and early 2011. There were no apparent regulatory changes by the PBOC in 2013, but the timing of the mid-2013 structural change in the 7-day rates coincides with the "SHIBOR shock"[7] which took place on June 20, 2013, when the 7-day SHIBOR and repo skyrocketed to double digit, a level previously unseen in the rates' history. Multiple news reports speculated that the short-lived cash crunch in the interbank market was caused by the PBOC temporarily withholding liquidity provision to the banks to curb credit growth and to punish those that provided too much credit to the market, particularly through off-balance-sheet lending (The Economist, 2013; Reuters, 2013). But such an intention has not been explicitly acknowledged by the PBOC. Nevertheless, this event could also shift the liquidity demand of the banks in the interbank market and alter how the interbank rates react to changes in RRR.

In comparison, there is no evidence that the parameters on the deposit benchmark rate and OMO variables were changed at the time when the PBOC's raised deposit rate ceiling or introduced new OMO instruments. Thus, if the interbank rates reacted strongly to changes in the deposit benchmark rate before 2011, such reaction would likely remain strong in 2015. If the interbank rates did not change much with the OMOs before 2011, they would likely remain unresponsive to OMOs in 2015.

The exact dates of the structural changes in the AR(p) models are determined by following the Bai and Perron (2003) procedure. In order to maintain sufficient sample size in each segment for the relatively large number of parameters, the maximum number of break points is set to 5 and the minimum number of observations in each segment is set to 200 in the optimization algorithm. The optimal number of break points and break dates for each interbank interest rate is listed in Table 2.2.

[7] A term used in the title of *The Economist* article on this event.

Rate Type	No. of Break Points	Break Dates		
Overnight SHIBOR	2		1/24/2011	6/14/2013
Overnight Repo	2		1/17/2011	6/14/2013
7-day SHIBOR	3	6/4/2008	1/24/2011	6/8/2013
7-day Repo	3	6/4/2008	1/24/2011	6/8/2013

Table 2.2. Dates of structural break points

There is a slight difference in the dates of the break points in 2011 and in 2013 across the four interbank rates. But since the break dates in the same year are well within each other's 95% confidence interval, the timing of the structural changes in 2011 and in 2013 for the four rates are considered the same. Meanwhile, the number of breaks and the break dates are generally consistent with what was suggested by the empirical M-fluctuation process. The only exception is that the dating algorithm finds the 2013 break point more significant than the 2008 break point for the overnight rates, while the EMFP shows otherwise. If instead the dating algorithm is forced to search for the optimal break dates for three breaks in the models of the overnight rates, the resulting break dates would be nearly identical to the ones found in the 7-day rates. For the convenience of cross comparison, the data of all the four interbank interest rates are partitioned into four sample periods based on the break dates in the 7-day rates. The four periods are specified as 10/9/2006 to 6/3/2008 for Period 1, 6/4/2008 to 1/21/2011 for Period 2, 1/24/2011 to 6/7/2013 for Period 3, and 6/8/2013 to 5/29/2015 for Period 4, which are visualized in Figure 2.11. The empirical behavior of the interbank interest rates is noticeably different across the four periods in the figure. How much differently they react to each policy variable before and after each structural change is further examined by the ARMA-EGARCH models fitted separately for each rate type and each period.

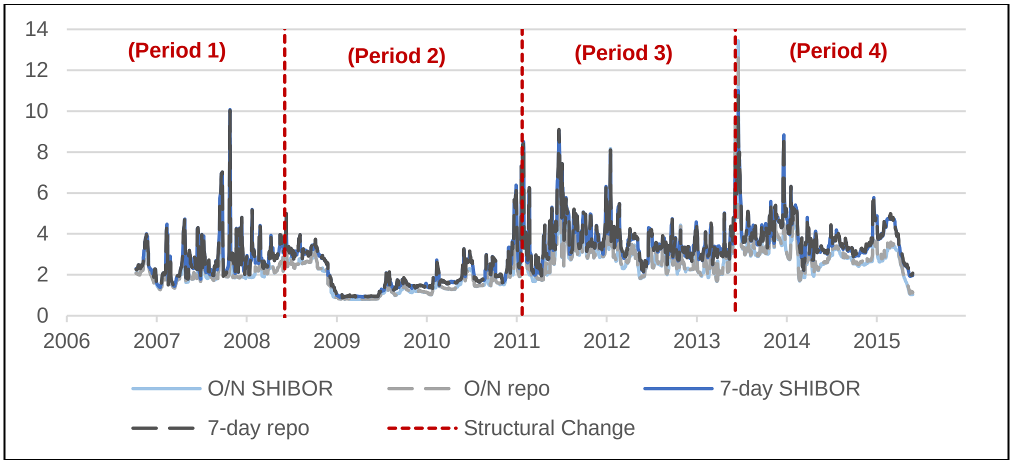

Figure 2.11. The four periods separated by structural changes (Source: authors, NIBFC)

2.4.2 Results of ARMA-EGARCH models for interbank interest rates

2.4.2.1 Model fitting

The optimal sets of (p, q, m, s) in the ARMA(p, q)-EGARCH(m, s) models in the four periods defined in Section 2.4.1 are selected based on the criteria specified in Section 2.3.4 and listed in Table 2.3.

Rate Type	Period 1	Period 2	Period 3	Period 4
Overnight SHIBOR	ARMA(2,0)-EGARCH(1,2)	ARMA(1,3)-EGARCH(1,1)	ARMA(1,1)-EGARCH(1,1)	ARMA(2,0)-EGARCH(1,1)
Overnight Repo	ARMA(3,0)-EGARCH(1,1)	ARMA(2,1)-EGARCH(1,1)	ARMA(2,3)-EGARCH(1,1)	ARMA(2,1)-EGARCH(1,1)
7-day SHIBOR	ARMA(2,2)-EGARCH(1,1)	ARMA(1,0)-EGARCH(1,1)	ARMA(2,0)-EGARCH(1,1)	ARMA(2,1)-EGARCH(1,2)
7-day Repo	ARMA(2,0)-EGARCH(1,1)	ARMA(1,0)-EGARCH(1,1)	ARMA(1,0)-EGARCH(1,2)	ARMA(2,1)-EGARCH(1,1)

Table 2.3. Optimal settings for the ARMA-EGARCH models

The parameter estimates of these models fitted by MLE with generalized error distribution are listed in Table 2.4-2.7. Because the deposit benchmark rate only changed in one direction in period 1 and period 4, $\Delta r_{d,t}^{-}$ is excluded from the models for Period 1 and $\Delta r_{d,t}^{+}$ is excluded from the models for Period 4. In these 16 models, most of the ARMA and GARCH parameters are statistically significant at 1% level, confirming that serial correlation and volatility clustering are widely presented in all the four interbank interest rate series. The parameter γ that captures asymmetric volatility response in the EGARCH proportion is also significantly positive in all models in Period 1, 2 and 4, suggesting that the volatility of the interbank interest rates increased more when the interbank rates rose than when the rates dropped. But the sign of γ is not consistent across rates in Period 3.

Overnight SHIBOR

Mean Equation	**Period 1**	**Period 2**	**Period 3**	**Period 4**
$intercept$	2.125 *** (0.011)	-6.546 *** (0.014)	0.176 *** (0.015)	-2.679 *** (0.027)
r_{t-1}	1.234 *** (0.003)	0.992 *** (0.001)	0.997 *** (0.004)	1.351 *** (0.001)
r_{t-2}	-0.230 *** (0.001)			-0.357 *** (0.000)
ε_{t-1}		0.007 *** (0.000)	0.063 *** (0.002)	
ε_{t-2}		0.010 *** (0.000)		
ε_{t-3}		0.014 *** (0.000)		
$r_{d,t}$	**0.063 ***** (0.001)	**0.729 ***** (0.003)	**1.022 ***** (0.019)	**0.179 ***** (0.002)
$RRR_{L,t}$	**-0.016 ***** (0.000)	**0.396 ***** (0.001)	**-0.030 ***** (0.001)	**0.219 ***** (0.000)
OMO_t	**0.000 ***** (0.000)	**0.000** (0.000)	**0.000 **** (0.000)	**0.000 ***** (0.000)
$Precny_t$	-0.001 (0.008)	0.002 *** (0.000)	0.138 *** (0.002)	0.099 *** (0.002)
Variance Equation	**Period 1**	**Period 2**	**Period 3**	**Period 4**
ω_0	-0.505 * (0.263)	-4.173 *** (1.188)	-2.867 *** (0.005)	3.299 *** (0.003)
α_1	0.375 *** (0.128)	0.168 * (0.095)	0.612 *** (0.061)	0.286 *** (0.033)
β_1	0.738 *** (0.261)	0.893 *** (0.029)	0.893 *** (0.000)	0.973 *** (0.001)
β_2	0.131 (0.239)			
γ_1	0.702 *** (0.186)	0.604 *** (0.126)	0.041 *** (0.010)	0.105 *** (0.033)
$RRR_{L,t}$	**0.002** (0.020)	**0.217 ***** (0.064)	**0.123 ***** (0.001)	**-0.173 ***** (0.000)
OMO_t	**-0.004 *** (0.002)	**-0.004 ***** (0.001)	**-0.008 ***** (0.001)	**0.001** (0.001)
$Precny_t$	0.147 (0.344)	1.297 *** (0.444)	-0.028 (0.128)	0.076 (0.120)
$\Delta r_{d,t}^{+}$	**8.907 **** (4.128)	**-3.290** (6.095)	**13.693 ***** (3.385)	
$\Delta r_{d,t}^{-}$		**-1.156** (2.216)	**6.991** (5.609)	**13.209 ***** (1.754)

Table 2.4. Parameter estimates for the ARMA-EGARCH models of overnight SHIBOR rates. (*: significant at 10%, **: significant at 5%, *: significant at 1%, standard errors in parentheses)**

Overnight Repo

Mean Equation	Period 1	Period 2	Period 3	Period 4
$\boldsymbol{intercept}$	1.826 *** (0.010)	-3.689 *** (0.127)	5.562 *** (0.042)	3.530 *** (0.045)
$\boldsymbol{r_{t-1}}$	1.284 *** (0.002)	0.980 *** (0.003)	0.874 *** (0.001)	1.498 *** (0.001)
$\boldsymbol{r_{t-2}}$	-0.172 *** (0.001)	0.017 *** (0.001)	0.126 *** (0.000)	-0.498 *** (0.001)
$\boldsymbol{r_{t-3}}$	-0.110 *** (0.001)			
$\boldsymbol{\varepsilon_{t-1}}$		0.016 *** (0.002)	0.166 *** (0.002)	-0.209 *** (0.007)
$\boldsymbol{\varepsilon_{t-2}}$			0.059 *** (0.001)	
$\boldsymbol{\varepsilon_{t-3}}$			0.051 *** (0.001)	
$\boldsymbol{r_{d,t}}$	**0.074 ***** (0.001)	**0.793 ***** (0.031)	**-0.026 ***** (0.002)	**-0.274 ***** (0.005)
$\boldsymbol{RRR_{L,t}}$	**0.013 ***** (0.000)	**0.203 ***** (0.007)	**-0.035 ***** (0.001)	**0.235 ***** (0.002)
$\boldsymbol{OMO_t}$	**0.000 ***** (0.000)	**0.000** (0.000)	**0.000 ***** (0.000)	**0.000** (0.000)
$\boldsymbol{Precny_t}$	-0.016 *** (0.000)	0.002 *** (0.000)	0.165 *** (0.004)	0.006 (0.009)
Variance Equation	**Period 1**	**Period 2**	**Period 3**	**Period 4**
$\boldsymbol{\omega_0}$	-0.679 ** (0.278)	-4.150 (2.583)	-2.015 *** (0.341)	-1.259 (2.150)
$\boldsymbol{\alpha_1}$	0.333 *** (0.128)	0.124 (0.116)	0.467 *** (0.133)	0.193 * (0.113)
$\boldsymbol{\beta_1}$	0.851 *** (0.036)	0.883 *** (0.098)	0.900 *** (0.027)	0.884 *** (0.043)
$\boldsymbol{\gamma_1}$	0.759 *** (0.180)	0.651 ** (0.284)	0.094 (0.163)	0.394 ** (0.154)
$\boldsymbol{RRR_{L,t}}$	**0.014** (0.021)	**0.213 *** (0.129)	**0.083 ***** (0.018)	**0.040** (0.103)
$\boldsymbol{OMO_t}$	**-0.006 ***** (0.002)	**-0.004 **** (0.002)	**-0.007 ***** (0.002)	**0.001** (0.002)
$\boldsymbol{Precny_t}$	0.129 (0.290)	1.617 * (0.909)	0.281 * (0.164)	0.192 (0.273)
$\boldsymbol{\Delta r^{+}_{d,t}}$	**9.678 ***** (3.478)	**0.737** (6.252)	**9.641 **** (3.805)	
$\boldsymbol{\Delta r^{-}_{d,t}}$		**-4.578 *** (2.474)	**2.852** (4.216)	**1.778** (3.825)

Table 2.5. Parameter estimates for the ARMA-EGARCH models of overnight repo rates

7-day SHIBOR

Mean Equation	Period 1	Period 2	Period 3	Period 4
$intercept$	1.118 *** (0.004)	-0.238 *** (0.010)	2.746 *** (0.001)	4.441 *** (0.060)
r_{t-1}	0.900 *** (0.001)	0.993 *** (0.002)	1.066 *** (0.000)	1.426 *** (0.001)
r_{t-2}	0.112 *** (0.001)		-0.071 *** (0.000)	-0.426 *** (0.001)
ε_{t-1}	0.255 *** (0.002)			-0.085 *** (0.004)
ε_{t-2}	0.054 *** (0.001)			
$r_{d,t}$	**0.802 ***** (0.002)	**0.609 ***** (0.008)	**0.993 ***** (0.001)	**0.178 ***** (0.007)
$RRR_{L,t}$	**-0.031 ***** (0.000)	**0.007 ***** (0.000)	**0.026 ***** (0.000)	**0.087 ***** (0.002)
OMO_t	**0.000 ***** (0.000)	**0.000 ***** (0.000)	**0.000 ***** (0.000)	**0.000 ***** (0.000)
$Precny_t$	-0.074 *** (0.002)	-0.029 *** (0.002)	0.029 (0.072)	-0.003 *** (0.000)
Variance Equation	**Period 1**	**Period 2**	**Period 3**	**Period 4**
ω_0	-0.776 *** (0.298)	-3.149 *** (0.903)	-0.348 *** (0.000)	-4.125 (2.994)
α_1	0.337 *** (0.106)	0.227 *** (0.060)	0.469 *** (0.000)	0.220 ** (0.099)
β_1	0.985 *** (0.169)	0.922 *** (0.021)	0.969 *** (0.000)	0.586 *** (0.129)
β_2	-0.109 (0.168)			0.297 ** (0.131)
γ_1	0.432 ** (0.202)	0.582 *** (0.105)	-0.224 *** (0.000)	0.932 *** (0.149)
$RRR_{L,t}$	**0.048 **** (0.020)	**0.166 ***** (0.050)	**0.012 ***** (0.000)	**0.186** (0.147)
OMO_t	**-0.006 ***** (0.002)	**-0.001** (0.001)	**-0.001 ***** (0.000)	**-0.003** (0.002)
$Precny_t$	0.101 (0.283)	0.850 *** (0.302)	0.115 *** (0.001)	-0.252 (0.390)
$\Delta r_{d,t}^{+}$	**-1.049** (2.831)	**-3.923** (4.419)	**4.560 ***** (0.002)	
$\Delta r_{d,t}^{-}$		**-1.608** (1.593)	**5.016 ***** (0.273)	**4.889** (4.803)

Table 2.6. Parameter estimates for the ARMA-EGARCH models of 7-day SHIBOR rates

7-day Repo

Mean Equation	**Period 1**	**Period 2**	**Period 3**	**Period 4**
$intercept$	0.889 *** (0.010)	0.323 *** (0.017)	-0.073 *** (0.007)	4.214 *** (0.082)
r_{t-1}	1.120 *** (0.003)	0.994 *** (0.003)	0.989 *** (0.001)	1.703 *** (0.000)
r_{t-2}	-0.107 *** (0.001)			-0.705 *** (0.001)
ε_{t-1}				-0.609 *** (0.009)
$r_{d,t}$	**0.857 ***** (0.007)	**0.590 ***** (0.010)	**1.100 ***** (0.001)	**0.094 ***** (0.005)
$RRR_{L,t}$	**-0.019 ***** (0.000)	**-0.015 ***** (0.001)	**0.036 ***** (0.000)	**0.121 ***** (0.003)
OMO_t	**0.000** (0.000)	**0.000 ***** (0.000)	**0.000 **** (0.000)	**0.000 ***** (0.000)
$Precny_t$	-0.054 (0.041)	-0.040 *** (0.001)	0.047 * (0.025)	0.145 *** (0.007)
Variance Equation	**Period 1**	**Period 2**	**Period 3**	**Period 4**
ω_0	-0.538 *** (0.208)	-2.980 *** (0.921)	-0.248 *** (0.000)	-0.568 (1.445)
α_1	0.361 *** (0.103)	0.241 *** (0.060)	0.397 *** (0.000)	0.383 *** (0.052)
β_1	0.867 *** (0.041)	0.912 *** (0.024)	1.000 *** (0.000)	0.904 *** (0.023)
β_2			-0.022 *** (0.000)	
γ_1	0.305 ** (0.152)	0.592 *** (0.112)	-0.174 *** (0.000)	0.450 *** (0.058)
$RRR_{L,t}$	**0.027 *** (0.016)	**0.154 ***** (0.050)	**0.008 ***** (0.000)	**0.014** (0.071)
OMO_t	**-0.008 ***** (0.002)	**-0.001** (0.001)	**0.000 ***** (0.000)	**0.001** (0.001)
$Precny_t$	0.074 (0.271)	0.593 * (0.316)	0.082 *** (0.001)	-0.112 (0.289)
$\Delta r_{d,t}^{+}$	**2.429** (2.976)	**-1.026** (3.957)	**3.364 ***** (0.014)	
$\Delta r_{d,t}^{-}$		**-1.171** (1.593)	**4.220 ***** (0.329)	**0.587** (3.041)

Table 2.7. Parameter estimates for the ARMA-EGARCH models of 7-day repo rates

2.4.2.2 An overview on the interactions between the interbank rates and policy instruments

The fitted mean equations in Table 2.4-2.7 confirm that the deposit benchmark rate and RRR both had statistically significant and sizable impact on the level of the four interbank rates, but the deposit benchmark rate had much higher magnitude of impact among the two in most periods. With the exception of overnight repo rate, the impact of the deposit benchmark rate and RRR was positive over the whole sample. Although the parameters of the OMO variable are also statistically significant, their sizes are too small to make OMO an economically significant determinant of the interbank interest rates.

The fitted variance equations show that only in some periods changing the deposit benchmark rate and RRR has significant impact on the volatility of the interbank rates. In these periods, changing the deposit benchmark rate and raising RRR both increased the interbank interest rate volatility, with the exceptions of overnight repo in Period 2 and overnight SHIBOR in Period 4. But the volatility impact of changing the deposit benchmark rate was more pronounced than changing RRR. Liquidity drains by OMOs generally had a small negative impact on the interest rate volatility, which seems to support the claim in previous studies that OMOs were mainly used by the PBOC to smooth the market.

2.4.2.3 The impact of structural changes

The fitted ARMA-EGARCH models confirm that the sign and magnitude of the parameters for the policy variables varied across the 4 periods, consistent with the findings from the structural change analysis. Meanwhile, several additional parameter changes not captured by the EMFPs are also presented in the results.

Impact on how the interbank interest rates react to the benchmark deposit rate

The parameter shift for the deposit benchmark rate variable in the mean equations of the overnight SHIBOR and repo rates between Period 1 and Period 2 (see Table 2.8) is exactly what was indicated in the EMFPs in Figure 2.7 and 2.8.

Explanatory Variable: 3-month deposit benchmark rate				
Dependent Variable	**Period 1**	**Period 2**	**Period 3**	**Period 4**
Overnight SHIBOR	0.063	0.729	1.022	0.179
Overnight repo	0.074	0.793	-0.026	-0.274
7-day SHIBOR	0.802	0.609	0.993	0.178
7-day repo	0.857	0.590	1.100	0.094

Table 2.8. Comparison of parameter estimates across 4 periods

Before the 2008 structural change, each percentage point change in the deposit benchmark rate would contribute only a small change in the overnight rates. But afterwards, it would lead to a 70-80 basis points change. In comparison, the 7-day rates were very responsive to deposit benchmark rate in both Period 1 and Period 2. The second major change in the parameter of the deposit benchmark rate happened between Period 3 and Period 4, which was not picked up by the EMFPs. After the structural change in 2013, all the interbank rates (except for overnight repo) became much less responsive to the deposit benchmark rate. The average change in the interbank rates for each percent change in the deposit benchmark rate dropped from around 100 basis points in Period 3 to less than 20 basis points in Period 4. It is likely that interest rate liberalization measures in Period 4 weakened the linkages between the policy rates and the market rates. One may recall that the PBOC removed the lending rate floor in July 2013 and relaxed the deposit rate ceiling in November 2014 and March 2015.

Impact on how the interbank interest rates react to RRR

The patterns of parameter change for the RRR variable in the mean equations are different between the overnight rates and the 7-day rates (see Table 2.9).

Explanatory Variable: reserve requirement ratio				
Dependent Variable	**Period 1**	**Period 2**	**Period 3**	**Period 4**
Overnight SHIBOR	-0.016	0.396	-0.030	0.219
Overnight repo	0.013	0.203	-0.035	0.235
7-day SHIBOR	-0.031	0.007	0.026	0.087
7-day repo	-0.019	-0.015	0.036	0.121

Table 2.9. Comparison of parameter estimates across 4 periods

The impact of one percentage point increase in RRR on the overnight rates was low in Period 1 and Period 3 but high in Period 2 and Period 4. In comparison, the impact of one percent increase in RRR on the 7-day rates continuously increased from -2 to -3 basis points in Period 1 to around +10 basis points in Period 4. Considering that RRR were usually changed by less or equal to 0.5 percent increments, only in Period 4 changing RRR had a noticeable impact on the level of the 7-day interbank interest rates. These results suggest that only after the June 2013 “SHIBOR shock”, RRR started to play a major role in the movements of all the four interbank interest rates.

2.4.2.4 Discrepancies across different rate types in their reactions to policy variables

The ARMA-EGARCH models confirm that the empirical behaviors and reactions to the three policy instruments are not consistent across the four rates, and the parameter variations across rate types are seemingly associated with the three structural changes.

Overnight rates vs. 7-day rates

The discrepancies between the overnight rates and 7-day rates mainly appeared in Period 1 and Period 2. In Period 1, the levels of the overnight rates were not very responsive to the deposit benchmark rate but their volatility was greatly affected by the changes in the deposit benchmark rate. On the contrary, the levels of the 7-day rates had significant co-movement with the deposit benchmark rate in Period 1 but their volatility did not react much to the changes in the benchmark rate. After the structural change in 2008, this inconsistency disappeared. Meanwhile, the overnight rates' responses to RRR increased significantly in Period 2, despite the 7-day rates' small responses to RRR in the same period. Based on these observations, whatever caused the structural change in mid-2008 seems to have led to a closer tie between the overnight rates and the PBOC's policy instruments. Figures 2.12 and 2.13 give a possible explanation on what might have facilitated the closer tie. Especially for the repo market, the daily turnover of overnight lending started increasing sharply in mid-2008, dramatically widening the gap between the daily turnovers of overnight lending and 7-day lending in the following years. As the overnight market became much more liquid in Period 2, the overnight rates would likely become more responsive to market information and the PBOC's policy actions. The growing popularity among banks in using overnight borrowing rather than longer term borrowing for liquidity needs could be an indication of higher perceived counterparty risk in the banking sector in the aftermath of the global financial crisis.

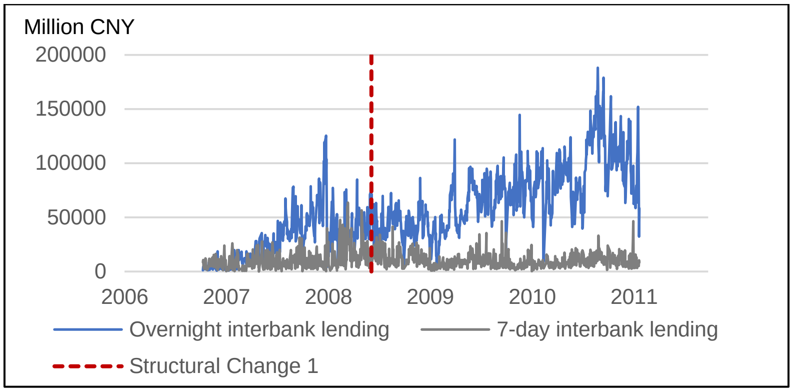

Figure 2.12. Daily market turnover: overnight vs. 7-day interbank lending (Source: CEIC)

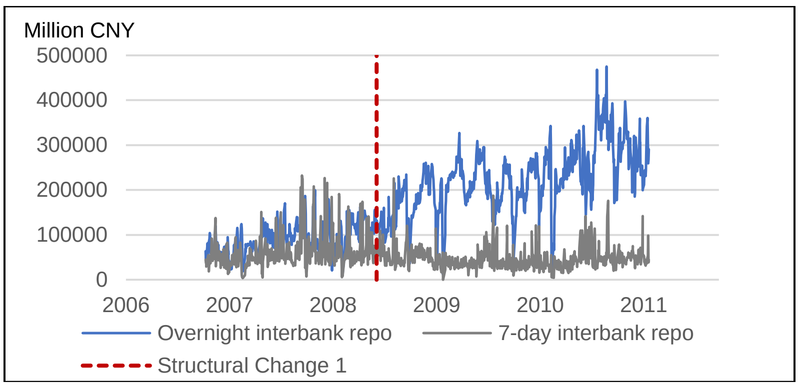

Figure 2.13. Daily market turnover: overnight vs. 7-day repos (Source: CEIC)

SHIBOR vs. interbank repo rate

The results in Section 2.4.2.3 suggest that the overnight SHIBOR and repo rates would move in opposite directions amid changes in the deposit benchmark rates in Period 3 and Period 4, and the 7-day SHIBOR would change twice as much as the 7-day repo rate when the deposit benchmark rate was changed in Period 4. Thus, the SHIBOR and repo rates of the same maturity could converge, cross or diverge when the PBOC changed the deposit benchmark rate in these periods. Intuitively, the SHIBOR should always exceed the repo rate with the same maturity by a risk premium, because the SHIBOR is an unsecured rate. But in our sample, the overnight SHIBOR was lower than the overnight repo rate on most trading days (except for the first few months after the SHIBOR was launched in 2006), and the 7-day SHIBOR was often lower than 7-day repo rate in Period 4. Figures 2.14 and 2.15 visualizes the overnight and 7-day SHIBOR-repo spreads vs. deposit benchmark rate.

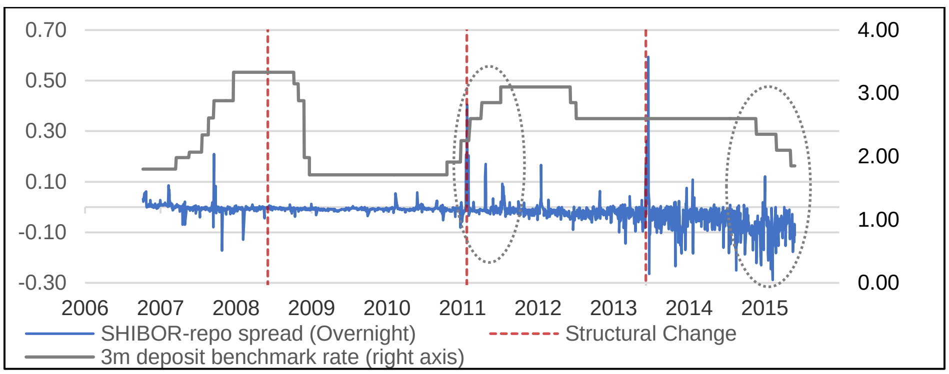

Figure 2.14. Overnight SHIBOR-repo spread vs. deposit benchmark rate (Source: authors, PBOC)

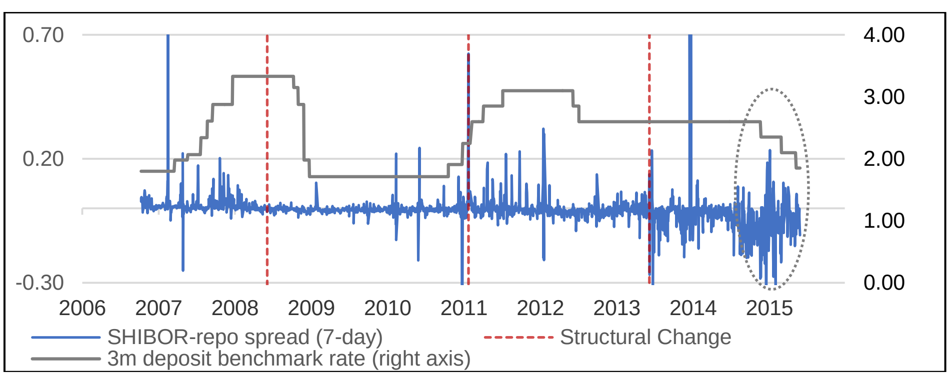

Figure 2.15. 7-day SHIBOR-repo spread vs. deposit benchmark rate (Source: authors, PBOC)

In Figure 2.14, the three raises in the deposit benchmark rate in Period 3 coincided with the three spikes in the overnight SHIBOR-repo spread. Meanwhile, each drop in the deposit benchmark rate in Period 3 and 4 was accompanied by a widened and persistent negative SHIBOR-repo spread, particularly in late 2014 and early 2015. The 7-day SHIBOR-repo spread (Figure 2.15) was less affected by the deposit benchmark rate in Period 3, but became rather negative when the deposit benchmark rate was lowered in Period 4.

The widening negative spread between the SHIBOR and repo rates in recent years is puzzling. A plausible conjecture for its cause is the market segmentation between the secured and unsecured interbank markets and the market power of large state-owned commercial banks being compounded by the structural changes in 2011 and 2013. The negative SHIBOR-repo spread could not have been sustainable if banks could freely arbitrage between the secured and unsecured interbank markets. In reality, some borrowers on the repo market, such as smaller regional bank and non-bank institutions that usually have tighter liquidity positions than the large banks, might have been restricted from borrowing in the unsecured market, thereby creating an imbalance of liquidity demand in the two markets. Such imbalance could be amplified when the market was tighten by the PBOC, leading to an even wider gap between SHIBOR and the repo rates, which was exactly what happened after the structural changes in early 2011 and mid-2013. The widened liquidity demand gap between the secured and unsecured markets following the 2011 structural change might also enable large state-owned banks to exert market power to borrow low from the unsecured market and lend at a higher rate in the repo market with minimal risk. According to the data provided in Cassola and Porter (2013), large state-owned banks became net borrowers on the unsecured market since the first quarter in 2011 but maintain their net lenders role on the repo market, while the other banks became net lenders on the unsecured market since 2011 but remained net borrowers on the repo market. The timing of the switch coincides with the structural change in early 2011. The presumed market power of the large national banks could also explain why the SHIBOR-repo spread became more negative when the deposit benchmark rate was lowered. The dominance of large banks in the deposit market might force small banks to compete with them using higher deposit rates, making the demand clearing deposit rate higher for small banks than large banks. Lowering the deposit benchmark rate would make it more difficult for small banks to meet their demand for deposits than large banks, because the lower deposit rate ceiling will squeeze their room to raise rates above large banks'. As a result, the smaller banks might seek additional financing from the repo market if the unsecured interbank market was off-limits to them, in turn driving up the repo rates.

In addition, alternative investment opportunities and deteriorating quality of the repo collateral pool could also contribute to the increasingly negative SHIBOR-repo spread in Period 3 and Period 4. Fan and Zhang (2007) explained the interest rate discrepancy in China's interbank repo market and exchange-traded repo market based on different alternative investment opportunities of the funds raised in these two markets. A similar case could be made for the discrepancy between the unsecured and secured interbank markets. Chu, Wen and He (2010) reported increasing use of discounted short-term bills and corporate medium-term notes as collateral for interbank repos, which could lead to higher risk in the interbank repo market.

2.5 Summary and Policy Implications

2.5.1 Major findings

Section 2.4 provides detailed answers to our research questions. The empirical results indicate 2-3 structural changes in the SHIBOR and interbank repo rates at June 2008, January 2011 and June 2013 respectively. The structural change in 2008 was likely related to the 2007-2008 global financial crisis, while the structural changes in 2011 and 2013 could be attributed to the PBOC's announced or unannounced operational changes during these years. The four interbank interest rates reacted differently to the PBOC's deposit benchmark rate and RRR adjustments following each structural change, but remained unresponsive to OMOs even after the most recent structural change, except for their volatility. Following the structural break in June 2013, the linkage between the interbank rates and the deposit benchmark rate weakened and the linkage between the interbank rate and RRR strengthened. The discrepancies between the overnight rates and the 7-day rates in terms of their reactions to the policy instruments mainly presented before the January 2011 structural change, while the discrepancies between SHIBOR and the repo rates of the same maturity mainly appeared after the January 2011 structural change. Particularly since the 2013 structural change, the negative spread between SHIBOR and the repo rates widened whenever the deposit benchmark rate was lower by the PBOC.

2.5.2 Key implications for policy makers

a. Any insights provided by empirical studies on China's interbank interest rate based on pre-2011 data should be viewed with caution in guiding current or future policies due to structural changes.

b. The PBOC's benchmark interest rates seem to be an effective tool to guide the interbank interest rate, but their impact dropped significantly following the relaxing of restrictions on the interest rates of bank loans and deposits. As the PBOC eventually raises the deposit rate ceiling to an extent that it is no longer a binding restriction for banks, the deposit benchmark rate might become obsolete, which is a sign of progress for the transition of the interest system. It also means that the PBOC will have to rely more on the remaining instruments such as RRR and OMOs to maintain control over the short-term interest bank interest rates. Currently, RRR seems to be the preferable instrument to guide the interbank interest rate, because the interbank interest rate became more responsive to changes in RRR since the implementation of variable reserve requirement in 2011 and the "SHIBOR shock" in 2013. Yet, using RRR as the primary instrument to influence the interbank interest rate has its own limitations. According to Ma, Yan and Liu (2011), the range the PBOC can adjust RRR depends heavily on the scale of its foreign exchange interventions, because RRR is its main foreign exchange sterilization tool. Meanwhile, according to the same study, increasing RRR adds cost to financial intermediation, because it is an implicit tax burden imposed on banks. In order for OMOs to become a price signal for the interbank market rather than merely a remedy for market volatility, the PBOC may need to explicitly specify a rate target for its OMOs. For example, it can choose a SHIBOR rate of a specific maturity as its target rate. He and Wang (2012) found that certain market interest rates were responsive to the PBOC's repo issuance rates. Yet, it is difficult to use the interest rate on the PBOC-issued repos as a direct price signal, because the PBOC repos have different maturities and their rates can be determined by either a price auction based on a preset quantity or a quantity auction based on a preset interest rate.

c. The 7-day SHIBOR and interbank repo rates seem to be preferable to the overnight rates for the role of market benchmark rates. After the structural change in January 2011, the 7-day rates generally moved in the same direction as the PBOC's policy instruments, making them better signals for the PBOC's policy intentions. However, the rather high volatility in the 7-day rates might make them too noisy to serve as benchmark rates, which demands further attention from the PBOC.

d. The widening negative spread between SHIBOR and the repo rates as well as the discrepancies between their responses to adjustments in the deposit benchmark rate after the structural changes in 2011 and 2013 signaled increased market segmentation between two interbank markets as well as strengthened market power of the large state-owned banks. This situation could be a threat to China's finance sector and a complication for the PBOC's monetary transmission via interest rate channel. The negative risk premium of the SHIBOR over the repo rate indicated that the risks in the two interbank markets were not priced correctly, potentially resulting in extensive price distortions among the debts and financial assets that track the SHIBOR or repo rates. Meanwhile, substantially different or even opposite reactions between SHIBOR and repo rates to the deposit benchmark rate adjustments since 2011 suggested that the PBOC's price signals might be transmitted unevenly in the two interbank markets, making it more difficult for the PBOC to achieve its policy goal with the benchmark rate instrument. Cassola and Porter (2013) suggested that removing the divisions in the bond market, strengthening existing standing facilities and liberalizing financial prices could address the anomalies between the unsecured and secured rates. There are also other potential measures to eliminate the interbank market segmentation and counter the market power of large banks, such as allowing more financial institutions to participate in the unsecured market and removing the deposit rate ceiling for small regional banks before doing so for the large national banks.

CHAPTER III

THE TRANSMISSION OF LIQUIDITY SHOCKS INTO AND OUT OF CHINA'S BANKING SECTOR VIA CHINA'S SEGMENTED MONEY MARKET: EVIDENCE FROM RECENT MARKET EVENTS

3.1 Introduction

This study is largely inspired by the studies that documented how liquidity shocks were transmitted via transactions in the U.S. money market during the 2007 U.S. subprime crisis, such as Brunnermeier (2009) and Gorton and Metrick (2012). Compared to the U.S., the financial system in China is generally perceived to be less interconnected due to various degrees of market segmentation and policy restrictions. However, in recent years, the booming money market transactions, such as repurchase agreements (repo), among banks and other institutional investors may have created pathways that can circumvent the segmentation and restrictions, and allow liquidity shocks to spread between China's closely guarded banking sector[8] and the rest of its financial system during liquidity-related financial market events. The existence of such pathways could threaten the overall stability of China's financial system, but this has not been covered in the previous literature. Therefore, the primary objective of this paper is to provide an anatomy of the pathways created by money market transactions in China that are capable of transmitting liquidity shocks into and out of China's banking sector, and to empirically assess how these pathways have functioned over the last five years. Specifically, we want to examine their

[8] The banking sector in China does not include investment banks, which are called securities firms in China.

involvement in two of the most dramatic financial market events that took place in China during this period, namely the rollercoaster ride in China's stock market between late-2014 and mid-2015 and the “SHIBOR Shock”, a short-lived but severe cash crunch in China's banking sector in mid-2013. Given the fact that China's banking sector has always been strictly prohibited from trading the in the stock market, these two market events provide an the ideal opportunity to explore whether or not a liquidity shock originated from a market inaccessible by the banks could affect the liquidity condition of banking sector via the money market, and whether or not a liquidity shock originated from the banking sector could affect the liquidity condition of a market that the banks do not have direct access to via the money market.

3.2 Background

Before presenting the methodology and results, we first provide a detailed background on how money market transactions create transmission paths for liquidity shocks across financial assets and financial institutions and how they may function differently in China due to China's unique market structure. To avoid ambiguity, we explicitly specify the realm of money market in this paper as the wholesale credit market for short-term debt securities and credit instruments with maturities of one year or less.

3.2.1 The transmission paths for liquidity shocks created by money market transactions

The money market's ability to transmit liquidity shocks across different parts of a financial system stems from its role as the central hub for short-term liquidity. In a modern financial system, the money market provides a venue for institutional investors to keep their cash in highly liquid and relatively safe short-term assets, such as treasury bills and commercial papers, and earn better interest rates than cash positions. At the same time, the money market provides institutional investors a platform to borrow short-term funds from each other with collateralized and uncollateralized instruments, such as repurchase agreements (repos) and call loans, in order to support the crucial functions in their day-to-day operations. For example, financial institutions raise funds from the money market to finance securitized lending; wholesale investors obtain funds from the money market to make leveraged trades; brokerage firms borrow from the money market to finance the margins they provide to retail investors; and commercial banks trade their reserve cash with each other in the money market to satisfy their capital and reserve requirements imposed by regulators.

Following Brunnermeier and Pedersen (2009), we consider the term liquidity in two different aspects: the market liquidity of assets, i.e. the ease with which they are traded, and the funding liquidity of traders, i.e. the ease with which they can obtain funding. Based on these two aspects of liquidity, we characterize the transmission paths of liquidity shocks facilitated by money market transactions into three types: 1. the co-movement of funding illiquidity between lenders and borrowers; 2. the co-movement between the market illiquidity of assets and the funding illiquidity of their traders; and 3. the co-movement of market illiquidity across multiple assets. These three types of transmission paths often function together and reinforce each other.

It is obvious that when a trader (e.g. a financial institution) is hit by a funding liquidity problem, the funding liquidity of the other traders it finances will also be tighten. Meanwhile, the market liquidity of multiple assets in the trader's portfolio will likely be negatively affected as well, because the trader may be forced to liquidate part of the portfolio to cope with the liquidity issue. However, in order for a liquidity shock originated from the market illiquidity of an asset to affect the funding liquidity of its traders, and for a local shock originally affecting only a few assets and traders to spread out and affect the whole financial system via the money market, the market participants need to be substantially reliant on levered funds from the money market via repos, margins and other instruments. According to Brunnermeier and Pederson (2009), increasing market illiquidity of an asset leads to its increasing price volatility, which in turn drives up the repo haircut[9] or margin requirement for the asset to be used as collateral, because the repo haircut or margin requirement of an asset is adjusted based on volatility. Suppose a trader invests in an asset and uses it as repo (or margin) collateral to borrow short-term funds. It can then use the funds to replenish its cash position, to make new trades and to finance other traders. When the asset used as collateral is hit by a liquidity shock, its repo haircut (or margin requirement) rises, forcing the trader to raise new funds from the money market and to withdraw its financing to other traders, subsequently reducing the funds available for other traders. This interaction between market liquidity and funding liquidity created by repo transaction (or margin trade) allows the liquidity shock to transmit from an asset to multiple traders. When the funding liquidity of these traders is worsen to an extent that

[9] Repo haircut is the difference between the market value of repo collateral and the amount of funds obtained by repo

they are no longer able borrow new funds from the money market, they are then forced to fire-sale their asset holdings, in turn driving up the market illiquidity of multiple assets simultaneously. Furthermore, if these affected assets are also used as repo (or margin) collateral by other traders, then the liquidity shock will be transmitted to these traders and the assets in their portfolios as well, ultimately resulting in system-wide illiquidity contagion. In fact, if we replace the initially affected asset and the traders in this hypothetical example by the asset-backed commercial papers (ABCPs) tied to subprime mortgages and the Wall Street banks, respectively, our example becomes a partial illustration of how the initial problem in the subprime mortgage market was able to affect the liquidity of assets and financial institutions seemingly unrelated to subprime mortgage, and eventually led to a system-wide liquidity crunch during the 2007 subprime crisis. This is documented with more details in Brunnermeier (2009) and Gorton and Metrick (2012).

From the above illustration, it is straightforward to infer that the three types of illiquidity co-movements among different assets and market participants will strengthen when a liquidity shock spreads among them, and will weaken once their market/funding liquidity improves, which is supported by Brunnermeier and Pederson's (2009) theoretical model and empirically shown to hold during the 2007 subprime crisis by Frank, Gonzalez-Hermosillo and Hesse (2008). Therefore, if we can specify the empirical measures for the funding illiquidity levels of major entities engaging in money market transactions in China, as well as the market illiquidity levels of major assets being traded in or financed by the money market in China, we can then explore how liquidity shocks are transmitted among them by tracking the strength of co-movements among these illiquidity measures.

3.2.2 The obstructed transmission paths in China's segmented money market

According to the assessment in Section 3.2.1, if we ignore the restrictions and segmentation in China's financial system, there are three potential paths through which money market transactions can transmit liquidity shocks between the banking sector and the stock market in China: 1. through the interaction between the funding illiquidity of the banking sector and the funding illiquidity of stock traders, if the banks provide financing to stock traders via the money market; 2. through the interaction between the funding illiquidity of the banking sector and the market illiquidity of equity assets, if the banks trade stocks with funds borrowed from the money market; 3. and through the interaction between the market illiquidity of stocks and the market illiquidity of assets used by banks as collateral to borrow from the money market. However, in reality, the second path is nonexistent because the banks in China are barred from trading in the stock market, and the third path is severely obstructed by the segmentation in China's money market, leaving the first path the most susceptible for transmitting liquidity shocks between the banking sector and the stock market. In the rest of this subsection, we explain in detail why this is the case and discuss how China's money market structure affects how we conduct our analysis.

Based on China's money market structure, we visualize how China's banking sector interacts with other traders via financing and trading activities in China's segmented money market with Figure 3.1.

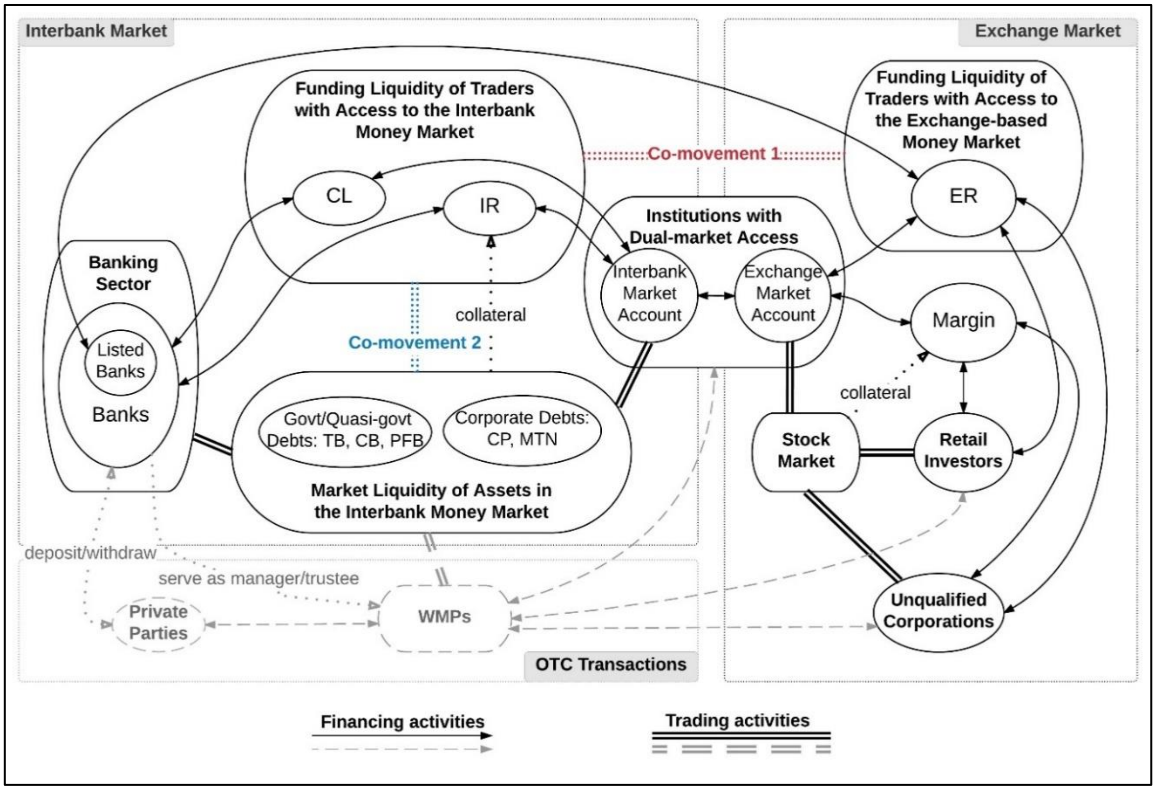

Figure 3.1. China's segmented money market and how it connects different traders and assets (Source: authors)

Because the money market is a submarket within the overall credit market, the segmentation in China's money market is a direct result of the artificial division of China's credit market into two parts: the interbank credit market mainly reserved for banks and institutional investors, and the exchanged-based credit market mainly reserved for investors with access to China's two stock exchanges, which was previously described by Fan and Zhang (2007). Although the interconnectivity between the two markets has been greatly improved over the years, several major restrictions remain in place. With the exception of the 16 publicly listed commercial banks, no other banks are allowed to trade in the exchange market. Even for the 16 banks, the access to the exchange market has been partial, because they were prohibited from conducting exchange-based repo (ER) transactions until July, 2014 and are still prohibited from trading stocks and convertible bonds. On the other hand, the interbank credit market is generally off-limits to retail investors. Currently, only non-bank institutions, such as insurance companies, securities firms, fund management companies and qualified corporations can have relatively unrestricted access to the two markets, in the sense that they can have accounts in both markets, can trade securities (including stocks) and borrow funds in both markets, and can transfer funds and certain debt securities between their accounts in the two markets, albeit with cumbersome procedures and delays. Under the current market setting, the banks can still supply funds to the stock market by financing non-bank institutional investors in the interbank and exchange-based money markets, despite the market segmentation.

Along with the differentiated market access for different participant types, the security types in the two markets are also differentiated. Almost all short-term debt securities in the realm of money market are exclusively traded in the interbank money market, except for the short-term treasury bonds (TBs) that are occasionally issued in the exchange market. The major security types in the interbank money market include short-term TBs, short-term policy financial bonds (PFBs), which is a popular type of quasi-government bonds issued by government-backed policy banks, short-term central bank bills (CBs) used by the PBOC as an open market operation tool, and short-term corporate debts in the forms of commercial papers (CPs) and medium-term notes (MTNs). Because these securities cannot be traded in or transferred into the exchange market, where stocks are traded, they cannot be held in the same portfolio with stocks. As a result, the direct interaction between their market liquidity and the market liquidity of stocks are significantly limited.

In addition, the funding sources for participants in the two money markets are also differentiated. There are two main funding sources in the interbank money market. Most of the institutions with access to this market can borrow with interbank repos (IRs) collateralized by interbank market assets. Qualified institutions can also obtain short-term funds from the interbank call loan (CL) market, an uncollateralized market mainly created for banks to trade their cash reserves with each other in order to satisfy the reserve requirement set by the PBOC, similar to the function of the Federal Funds market. The CL market also shares some commonalities with the Eurodollar market, because its benchmark interest rate SHIBOR is determined by a board of banks like the Libor, and not targeted by the central bank. In practice, non-bank institutions and smaller regional banks may find it difficult to borrow from the CL market due to its high credit requirement, thus having to rely more on the IR market for funding needs. This is evident by Cassola and Porter (2013)'s finding that small banks are usually net borrowers in the IR market but net lenders in the CL market, while the opposite is true for large national banks. In the exchange-based money market, traders can finance with ERs collateralized by credit assets in the exchange market. However, this funding source comes with significant restrictions, particularly for the retail investors. First, repo collaterals are difficult to accumulate in the exchange market, because exchange-based bonds are largely held by major financial institutions. Secondly, there are stringent requirements for retail investors to borrow with repo, such as having at least 500 thousand yuan in net asset value and a track record of active bond trading.

Given all the restrictions in China's public financial markets, the over-the-counter (OTC) "wealth-management products"[10] (WMPs) become an important supplement to them, because the regulators do not prohibit certain financial innovations by the banks through WMPs. For example, a bank can create a WMP funded by private parties, including many of its depositors, to finance the margins provided by securities firms to their customers. The off-balance-sheet status of these WMPs allows the banks to supply extra funds to the exchange-based credit and stock markets, skirting the reserve and capital requirements imposed on their balance-sheets and the restrictions in the public markets. Due to the non-standard nature of WMPs and their limited data availability, we do not explicitly account for their impact in this study. However, the transmission of liquidity shocks via WMPs could be partially captured by our analysis based on data from the two public money markets, because the WMPs are partially funded by the banking sector, and some of traders financed by WMPs might have access to the public money markets at the same time.

The Co-movements 1 and 2 highlighted in Figure 3.1 are the main focus in the rest of this paper. Co-movement 1 represents the co-movement between the funding liquidity of traders funded by the interbank money market and the funding liquidity of traders funded by the exchange-based money market. It can be viewed as a proxy for the interaction between the funding liquidity conditions of the banking sector and the stock

[10] A term used in China to represent uninsured financial products sold by banks and other financial institutions.

traders, which is the primary transmission path for liquidity shocks between the banking sector and the stock market as we have discussed. We expect Co-movement 1 to strengthen when a liquidity shock affects either side of the market segmentation and drives up cross-market fund movements. Co-movement 2 represents the co-movement between the funding liquidity of traders funded by the interbank money market and the market liquidity of short-term assets traded and used as repo collateral in the interbank money market. Although Co-movement 2 is not a major transmission path for shocks between the banking sector and the stock market, its strength can serve as a key indicator for the stress level at the banking sector. Because the short-term debt securities in the interbank market do not have direct interaction with stocks, their market liquidity is expected to be mainly affected by the funding liquidity of their traders, who are most likely the banks being confined in the interbank market and having no access to the other short-term assets. Adding the fact that short-term debt securities are the easiest to liquidate in a credit market, we expect Co-movement 2 to rise sharply when the funding of the banks are tightened to a point that they have to sell a substantial amount assets to deal with cash shortage. In summary, strengthening Co-movement 1 is an indication that the funding liquidity of the banking sector is more closely tied to the funding liquidity of stock traders, while strengthening Co-movement 2 is a confirmation that a liquidity shock capable of affecting the stability of the banking sector has taken place. If Co-movements 1 and 2 strengthen at the same time, it is a strong evidence that either a liquidity shock originated from the stock market is being transmitted into the banking sector, or a liquidity shock originated from the banking sector is being transmitted into the stock market.

3.3 Methodology

In order to examine the two types of liquidity/illiquidity co-movements described in Section 3.2, we need to specify empirical measures for the funding liquidity of traders in China's interbank money market and exchange-based money market, as well as the market liquidity of assets in the interbank money market. We then need to construct a model to capture the co-movements among these liquidity measures. In the next three subsections, we detail our liquidity measures, our data and our empirical model.

3.3.1 Measuring funding liquidity and market liquidity

For traders in the interbank money market, we use two variants of liquidity measures to represent their funding liquidity, one based on IR and one based on CL. The measure based on IR is more representative of the funding liquidity of small regional banks and non-bank institutions in the interbank money market, because they are more likely to be able to borrow in the IR market than the CL market as mentioned in Section 3.2.2. The measure based on CL is more representative of the funding liquidity of large national banks. For traders in the exchange-based money market, we use the liquidity measure of ER to represent their funding liquidity. We also include two variants of liquidity measures of assets in the interbank money market, one based on PFB and one based on CP. The measure based on PFB is more representative of the market liquidity of short-term government debts, while the measure based on CP is more representative of the market liquidity of short-term corporate debts.

We specify our liquidity measures in a way that is consistent with Brunnermeier and Pederson (2009)'s theoretical model and similar measures in the U.S. market. In Brunnermeier and Pederson's (2009) model, the illiquidity level of a security is represented by the absolute deviation of its market price from its fundamental value. Because the prices of debt securities are usually quoted in interest rates rather than prices, it is more convenient for us to measure the price deviations for debt securities based on interest rate spreads. An example of such rate spread is the Libor-OIS spread, which is used in numerous studies on the 2007 U.S. subprime crisis as a proxy for risk and liquidity condition in the money market (see Frank, Gonzalez-Hermosillo and Hesse (2008), Brunnermeier (2009) and Gorton and Metrick (2012)). The Libor-OIS spread is the difference between the U.S. Dollar Libor rate, a reference interest rate for unsecured interbank lending of Eurodollar, and the fixed rate for Overnight Indexed Swap (OIS) that tracks the Fed Funds effective rate. It can be considered the premium of a bank's borrowing cost in the money market over a baseline rate subjected to little risk and liquidity concerns. It seems straightforward for us to adopt a Chinese equivalent to the Libor-OIS spread, i.e. the difference between SHIBOR and the fixed rate of an overnight interest rate swap (IRS) similar to the OIS, as the measure of illiquidity for CLs in China. However, there are two potential issues with this approach. First, the roles of Libor-OIS spread and its Chinese equivalent as liquidity measures can be complicated by the impact of credit risk on Libor and SHIBOR, due to their nature as unsecured rates. Both Frank and Hesse (2009) and Smith (2012) have shown that Libor-OIS spread contains a component for liquidity risk (i.e. the risk of solvent counterparties having unexpected cash constraints to meet obligations) as well as a component for credit risk (i.e. the risk of loss due to insolvency of counterparties). Yet, because major banks in China are perceived to be backed by the government against insolvency because of their major or partial government ownership, the credit risk component in a SHIBOR-based spread is likely trivial. Secondly, the availability of China's IRS rate data is rather spotty due to infrequent IRS transactions in China, making the SHIBOR-OIS spread impractical. To circumvent this issue, we use the spread between SHIBOR and the TB yield instead. The SHIBOR-TB spread can be considered the Chinese equivalent to the TED spread, i.e. the difference between Libor and the U.S. Treasury bill (T-bill) yield, which is commonly used analogously to the Libor-OIS spread.

Similarly, we use the IR-TB spread, ER-TB spread, CP-TB spread and PFB-TB spread to represent the illiquidity levels of IRs, ERs, CPs and PFBs, respectively. Most of these rate spreads have their counterparts in studies on the U.S. market. The IR-TB and ER-TB spreads are comparable to the U.S. Repo-Tbill spread suggested by Bai, Krishnamurthy and Weymuller (2016) as a preferred measure for the liquidity condition in the U.S. banking sector. The CP-TB spread in China is an imperfect equivalent to the U.S. ABCP-Tbill spread used by Frank, Gonzalez-Hermosillo and Hesse (2008) as a measure of liquidity condition in the U.S. ABCP market. Unlike the ABCPs in the U.S., the CPs in China are all non-asset-backed variants, thus are not protected against credit risk. To minimize the impact of credit risk, we specifically use the yield of AAA-rated CP to calculate the CP-TB spread. The PFB-TB spread is unique to the Chinese market. The PFBs are quasi-government bonds issued by the government-designated policy banks to support large public projects, such as infrastructure projects, while the TBs are directly issued by the government. Unlike certain short-term TBs that can be traded in both markets, the short-term PFBs are only traded in the interbank market, and are generally priced with a premium over TBs. According to Wan (2006), the difference in pricing between PFB and TB is not only attributed to their liquidity difference but also attributed to the difference in tax policies for their interest returns. To remedy this issue, we explicitly account for the impact of tax differences in our model.

3.3.2 The data

The five rate spreads specified in Section 3.3.1 are calculated from the weekly averages of six daily interest rates with 1-month maturity for the period between June 17, 2011, the earliest date when all the six rates are available, and April 8, 2016. Our original data consists of 1-month SHIBOR published by NIBFC, the weighted average 1-month interbank repo rate and the 1-month CP, PFB and TB yields collected from CEIC Data, and the daily closing rate of the standardized exchange repo GC028 listed in Shanghai Stock Exchange. We specifically choose the 1-month maturity to maximize data availability, because repos with maturities over a month are infrequent in China, while the PFBs and TBs with less than a month maturities are nonexistent. We also use weekly averages to eliminate excess noise in the daily data, which may be caused by the day of week liquidity effect and the routine open market operations by the PBOC. The six interest rates and the calculated 1-month rate spreads are displayed in Figure 3.2 and Figure 3.3 respectively.

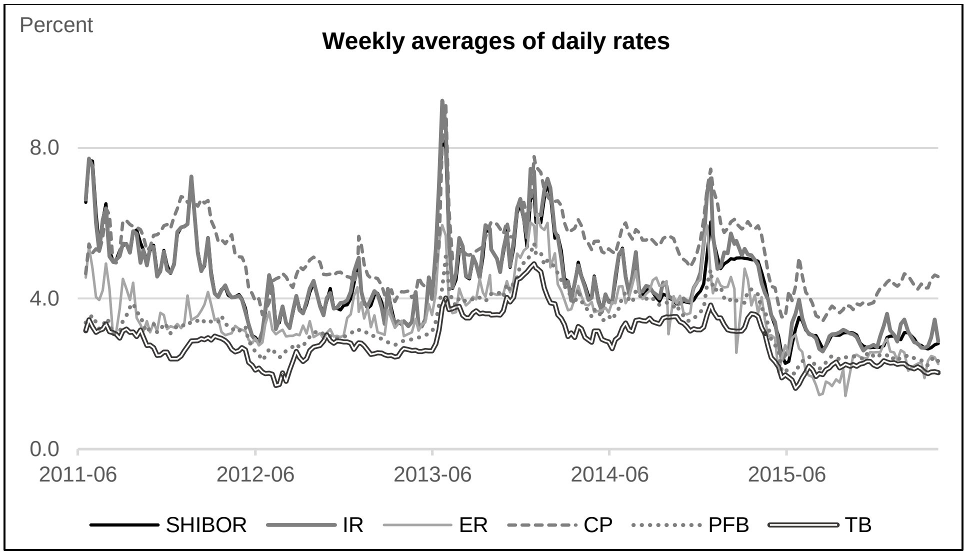

Figure 3.2. Weekly averages of the six daily interest rates (Source: CEIC Data, NIBFC, Sohu Finance)

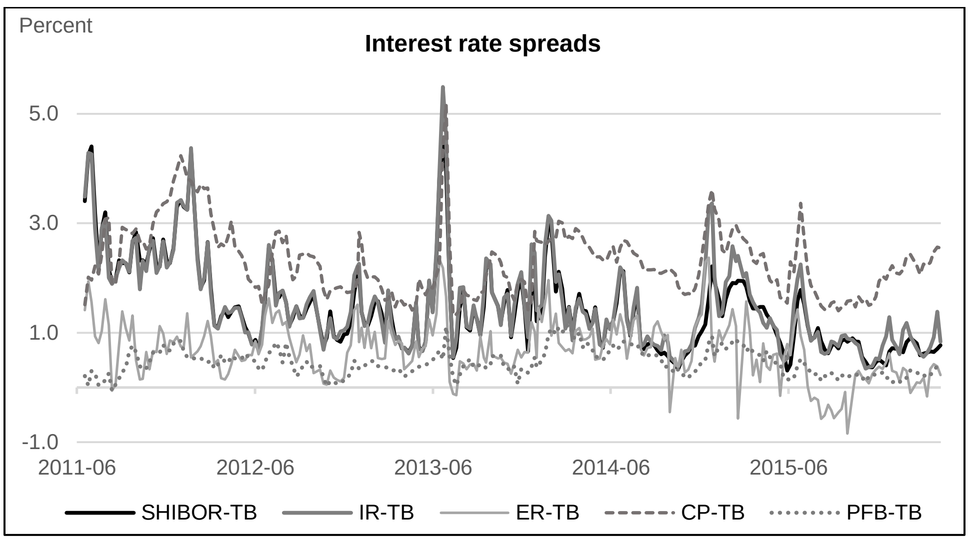

Figure 3.3. The five interest rate spreads as liquidity measures (Source: authors)

According to Figure 3.2, the TB yield is generally the lowest among the six interest rates while the CP yield is generally the highest, which is consistent with their risk and liquidity characteristics. Meanwhile, the difference between SHIBOR and IR rates is very small, suggesting the credit risk component in SHIBOR is indeed trivial. In Figure 3.3, our liquidity measures (i.e. the illiquidity levels represented by the rate spreads) fluctuate violently with a range up to 500 basis points, which is unusual among similar rate spreads in the U.S.

3.3.3 Modelling the co-movements of liquidity measures

Because we adopt two variants of funding liquidity measures as well as two variants of market liquidity measures for the interbank money market, our model is tasked to measure six variants of liquidity co-movements rather than two, including two versions of Co-movement 1 and four versions of Co-movement 2. The six variants of liquidity co-movements are visualized in Figure 3.4.

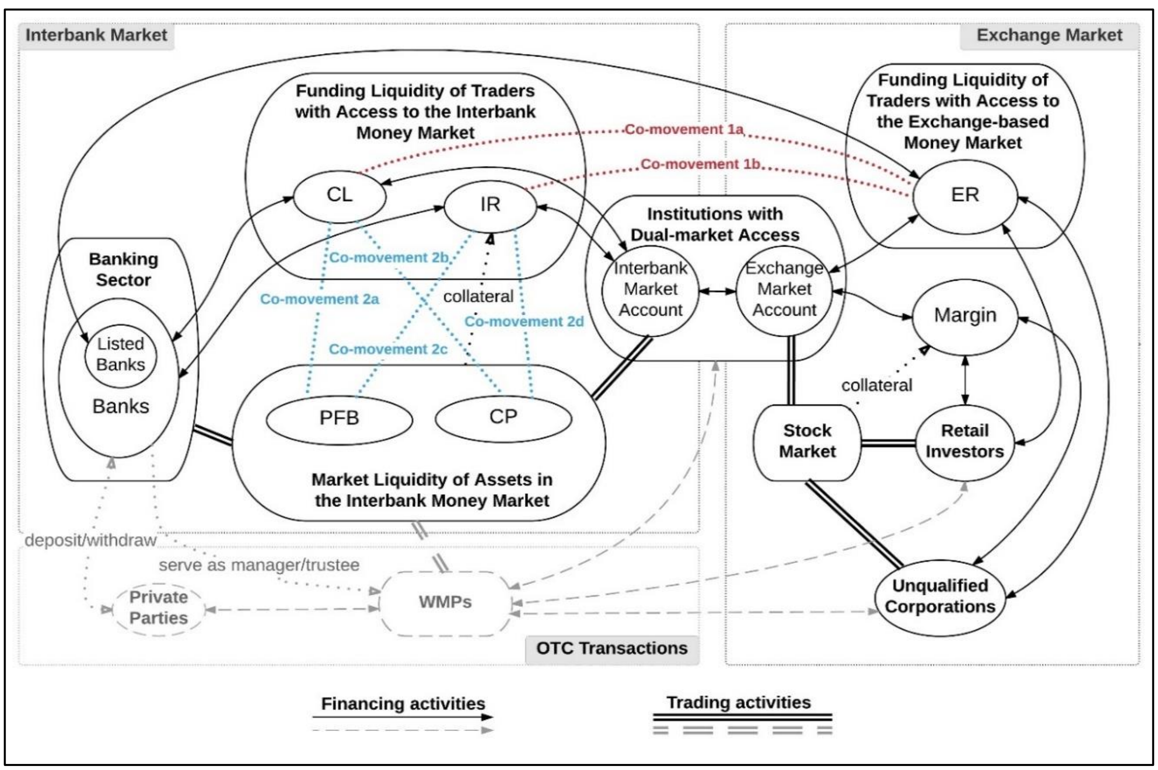

Figure 3.4. The six liquidity co-movements to be measured by the empirical model (Source: authors)

In Brunnermeier and Pederson (2009)'s theoretical model, the co-movement between the liquidity conditions of two securities is represented by the covariance of the liquidity measures of these two securities. Based on this concept, the co-movements among the five liquidity measures in this study are represented by their covariance matrix or correlation matrix, which can be viewed as the covariance matrix adjusted for individual volatilities. Obviously, the six co-movements highlighted in Figure 3.4 are elements in the correlation matrix. By adopting this concept, our task then becomes estimating the time-varying correlation matrix among the five liquidity measures. A multivariate volatility model, such as the Dynamic Conditional Correlation (DCC) model specified by Engle (2002), seems to be ideal for the task. In fact, a modified DCC-GARCH model has already been used by Frank, Gonzales-Hermosillo and Hesse (2008) to empirically examine the spillovers of liquidity shocks during the 2007 subprime crisis. The DCC-GARCH model and similar time-varying correlation multivariate GARCH models have also been used to study the other aspects of cross-market and cross-asset co-movements, such as the co-movements in returns and volatilities. For example, Chiang, Joen and Li (2007) study the cross-market financial contagion among Asian markets based on a DCC-GARCH model of stock returns. Yang, Zhou and Wang (2009) document the time-varying correlation between stock and bond market returns in the U.S. for the past 150 years using a smooth transition multivariate GARCH model. Arouri, Jouini and Nguyen (2011) examine the volatility transmission between oil and stock markets in Europe and the U.S. using a VAR-GARCH model.

Most of these studies use multiple bivariate models to estimate the time-varying correlation for each pair of assets or markets. Instead of following their approach, we estimate the time-varying correlation matrix of the five liquidity measures with a single penta-variate DCC-GARCH model. We expect the six co-movements to interact with each other, so we estimate them together in one model. In our model, the conditional means of the five rate spreads are assumed to follow an AR(1) process and the conditional covariance matrix is assumed to follow a multivariate DCC(1, 1)-GARCH(1, 1) process. The AR(1) model for the PFB-TB spread include an additional variable to account for the impact of different tax policies for PFB and TB. The mean equations for the interest rate spreads are specified as

$$x_{i,t} = \mu_i + \phi_i x_{i,t-1} + r_{i,t}\,, \quad i = 1, 2, 3, 4 \tag{3.1}$$

$$x_{5,t} = \mu_5 + \phi_5 x_{5,t-1} + \tau B_t + r_{5,t} \tag{3.2}$$

$$r_{i,t} = \sqrt{h_{i,t}}\,\varepsilon_{i,t}\,, \quad i = 1, 2, 3, 4, 5 \tag{3.3}$$

where $x_{1,t}$ is the SHIBOR-TB spread, $x_{2,t}$ is the IR-TB spread, $x_{3,t}$ is the ER-TB spread, $x_{4,t}$ is the CP-TB spread, $x_{5,t}$ is the PFB-TB spread, B_t is the 1-month TB yield, $h_{i,t}$ is the conditional variance of innovations, and $\varepsilon_{i,t}$ is a standardized disturbance with mean zero and variance one. The intuition behind using the TB yield variable to capture the impact of tax difference is straightforward. Suppose PFB has comparable risk and liquidity characteristics as TB, but its interest payment is taxable as opposed to the tax-free TB, the theoretical interest rate for PFB $I_{5,t}$ should satisfy the following relationship $I_{5,t} = 1/(1-T) * B_t$ where T is the tax rate. In this case, $x_{5,t} = I_{5,t} - B_t = T/(1-T) * B_t$. Thus, the difference between $I_{5,t}$ and B_t contributed by tax difference should be proportional to the yield of TB. The reason for not using a specific tax rate T to directly calculate $T/(1-T)$ is because tax policies regarding interest payments from PFBs differ for different type of institutions. In this case, estimating $T/(1-T)$ with a parameter τ is a preferable approach to approximate the average impact of tax across different types of institutions.

Our DCC(1, 1)-GARCH(1, 1) model for the conditional correlations is specified based on Engle (2002)'s formulation. But unlike the original model, we assume that the innovation vector $\boldsymbol{r_t} = \left[r_{1,t}, r_{2,t}, r_{3,t}, r_{4,t}, r_{5,t}\right]'$ follows a multivariate Student's t distribution instead of a multivariate normal distribution to account for fat tails. Suppose we define the covariance of the innovation as $\boldsymbol{H_t} = \boldsymbol{D_t R_t D_t}$ where $\boldsymbol{D_t} = diag\{\sqrt{h_{i,t}}\}$ and $\boldsymbol{R_t}$ is the time varying correlation matrix. Our DCC model can be specified as

$$\boldsymbol{r_t}| =_{\boldsymbol{t-1}} \sim \boldsymbol{t}(\boldsymbol{0}, \boldsymbol{D_t R_t D_t}) \tag{3.4}$$

$$\boldsymbol{D_t^2} = diag\{\omega_i\} + diag\{\kappa_i\} \circ \boldsymbol{r_{t-1} r'_{t-1}} + diag\{\lambda_i\} \circ \boldsymbol{D_{t-1}^2}, i = 1, 2, 3, 4, 5 \tag{3.5}$$

$$\boldsymbol{\varepsilon_t} = \boldsymbol{D_t^{-1} r_t} \tag{3.6}$$

$$\boldsymbol{Q_t} = (1 - \alpha - \beta)\boldsymbol{S} + \alpha \boldsymbol{\varepsilon_{t-1} \varepsilon'_{t-1}} + \beta \boldsymbol{Q_{t-1}} \tag{3.7}$$

$$\boldsymbol{R_t} = diag\{\boldsymbol{Q_t}\}^{-1/2} \boldsymbol{Q_t} diag\{\boldsymbol{Q_t}\}^{-1/2} \tag{3.8}$$

$$\boldsymbol{S} = \boldsymbol{E}[\boldsymbol{\varepsilon_t \varepsilon'_t}] \tag{3.9}$$

where $\boldsymbol{\varepsilon_t} = \lfloor \varepsilon_{i,t} \rfloor$, $\boldsymbol{Q_t} = \lfloor q_{i,j,t} \rfloor$, $\boldsymbol{R_t} = \lfloor \rho_{i,j,t} \rfloor$, $\{\omega_\mathrm{i}, \kappa_i, \lambda_i, \alpha, \beta\}$ are the parameters to be estimated and $\circ$ denotes Hadamard product. Equation (3.5) governs the GARCH process and Equation (3.7) governs the DCC process. Equation (3.7) can be interpreted as a GARCH(1,1) process for the conditional correlation matrix. Each element of $\boldsymbol{Q_t}$ satisfies

$q_{i,j,t} = \bar{\rho}_{i,j} + \alpha\left(\varepsilon_{i,t-1}\varepsilon_{j,t-1} - \bar{\rho}_{i,j}\right) + \beta\left(q_{i,j,t-1} - \bar{\rho}_{i,j}\right)$ with $\bar{\rho}_{i,j}$ being the unconditional correlation between $\varepsilon_{i,t}$ and $\varepsilon_{j,t}$.

Based on the assumption of Student's t distribution in Equation (3.4), we construct the likelihood function of the whole AR-DCC-GARCH system specified in Equations (3.1)-(3.9), and jointly estimate the AR parameters $\{\mu_i, \phi_i, \tau\}$, the DCC-GARCH parameters $\{\omega_i, \kappa_i, \lambda_i, \alpha, \beta\}$ and the shape parameters of the Student's t distribution with the Quasi-Maximum Likelihood (QML) procedure specified in Engle (2002).

3.4 Empirical Results

In this section, we present the results from our model, explore the six variants of liquidity co-movements represented by the estimated conditional correlations, and discuss what these co-movements tell us about the transmission of liquidity shocks into and out of China's banking sector in the last five years, particularly during the two market events mentioned in Section 3.1.

3.4.1 Model fitting and parameter estimates

Before our model is estimated by the QML procedure, the five interest rate spreads are tested for stationarity by the augmented Dickey-Fuller test and the Phillips-Perron test. Neither tests support the existence of unit roots in the five series, so the levels of the rate spreads are directly used to fit the model. The QML results are tabulated in Table 3.1.

	SHIBOR-TB	IR-TB	ER-TB	CP-TB	PFB-TB
Conditional Mean: AR(1)					
$\boldsymbol{\mu_i}$	0.914***	1.052***	0.636***	1.764***	0.947***
	(0.132)	(0.133)	(0.090)	(0.464)	(0.347)
$\boldsymbol{\phi_i}$	0.888***	0.816***	0.735***	0.948***	0.944***
	(0.033)	(0.039)	(0.055)	(0.038)	(0.027)
$\boldsymbol{\tau}$					-0.224*
					(0.128)
Conditional Variance: GARCH(1, 1)					
$\boldsymbol{\omega_i}$	0.006	0.024**	0.016	0.029**	0.002
	(0.005)	(0.011)	(0.017)	(0.013)	(0.002)
$\boldsymbol{\kappa_i}$	0.432***	0.526***	0.125	0.756**	0.316**
	(0.098)	(0.157)	(0.084)	(0.354)	(0.143)
$\boldsymbol{\lambda_i}$	0.567***	0.473***	0.768***	0.243***	0.575***
	(0.094)	(0.084)	(0.171)	(0.079)	(0.155)
Conditional Correlation: DCC(1, 1)					
$\boldsymbol{\alpha}$	0.033** (0.017)				
$\boldsymbol{\beta}$	0.945*** (0.038)				

Table 3.1. Parameter estimates of the penta-variate AR(1)-DCC(1,1)-GARCH(1,1) system
***: significant at 10% level; **: significant at 5% level; ***: significant at 1% level**

The empirical behaviors of the five rate spreads are well summarized by our model because most of the parameters are statistically significant at 5% level, including the serial correlation in conditional means, the volatility clustering in conditional variances and the fluctuations in conditional correlations. However, the negative parameter for the tax factor in the PFB-TB spread is puzzling. According to Section 3.3.3, the difference between the yields of PFB and TB contributed by the tax factor should be proportional to the TB yield. Given a positive tax rate, when the yield of TB increased, the tax related component in the PFB-TB spread should increase rather than decrease as suggested by the negative τ. One possible explanation for the negative τ is that higher yields in the credit market might have changed the composition of market participants in the credit market. According to Zhao (2015), the interest returns from PFBs are taxable for most financial institutions but tax-free for fund management companies. When yields in the credit market increased, fund management companies might invest more in credit assets including PFBs. As a result, tax-free investors might constitute a larger proportion of PFB holders when yields were high, thereby lowering the average tax rate for PFB investors as well as the required premium of the PFB yield over the TB yield to offset the difference in tax.

3.4.2 The liquidity co-movements measured by conditional correlations

The two versions of Co-movement 1 and four versions of Co-movement 2 represented by the estimated conditional correlations among our liquidity measures are visualized in Figures 3.5 and 3.6, respectively. Before presenting the details, it is worth noting that each date marked on the figures is either a Friday or the last trading day in a week if it is not Friday, due to the fact that we use weekly averages of daily rates to estimate our model.

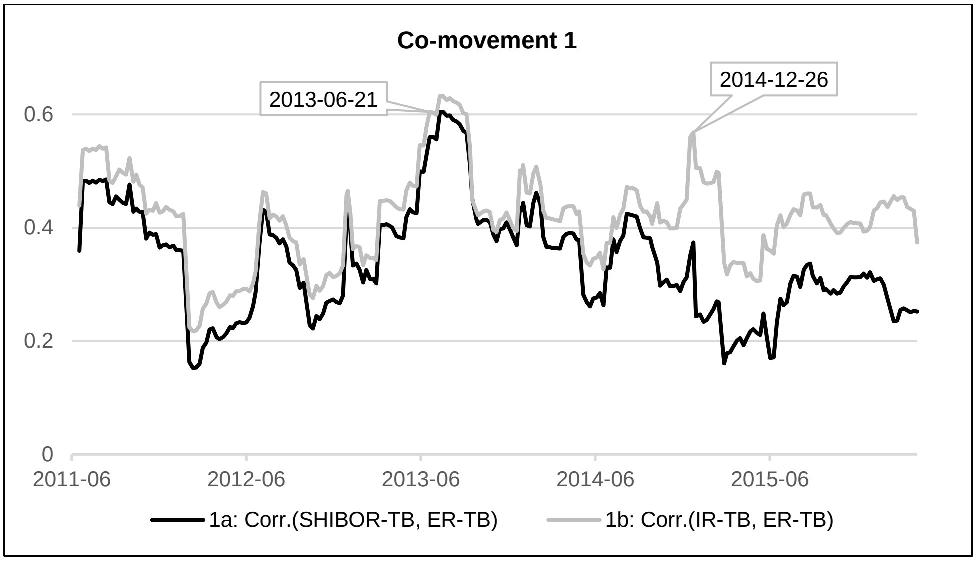

Figure 3.5. The co-movement of funding liquidity between the banking sector and stock traders (Source: authors)

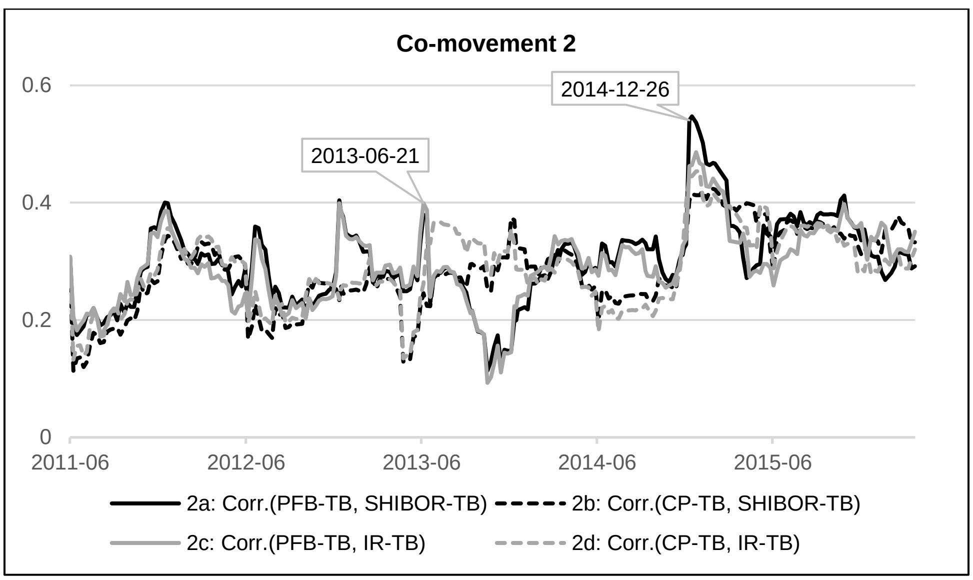

Figure 3.6. The co-movement between the funding liquidity of the banking sector and the market liquidity of major short-term debt securities in the interbank money market (Source: authors)

The two sets of empirical correlations estimated by our DCC model are all positive over the whole sample period, ranging from around 0.1 at the low points to over 0.6 at the high points. These fluctuating positive correlations suggest that the co-movements among our liquidity measures are substantial, and their strength varies much during the sample period, which is consistent with what we have expected. Meanwhile, from Figures 3.5 and 3.6, we notice a few distinct features[11] in the patterns of the liquidity co-movements in close proximity to the timing of the two market events in focus. The most prominent feature in Co-movement 1 (i.e. the cross-market funding liquidity co-movement) is the peak of its strength around mid-2013, which is close to the timing of the "SHIBOR Shock" that took place in the week ending on June 21, 2013. There is a second peak in the strength of Co-movement 1 based on IR (Co-movement 1b in Figure 3.5) around the end of 2014, which is in the middle of a period of drastic stock market movements. But the same peak is much less noticeable in Co-movement 1 based on CL (Co-movement 1a in Figure 3.5), and the gap between the two versions of Co-movement 1 seems to have widen significantly shortly before the peak and remain wider than it used to be ever since. The most prominent feature in Co-movement 2 (i.e. the co-movement of funding liquidity and market liquidity in the interbank market) is the spike in its strength around the end of 2014, which is captured by all the four versions of its empirical measures (see Figure 3.6). The timing of the spike coincides with the second peak in Co-movement 1b that we have suspected to be related to the stock market event. There is also a minor spike in the strength of Co-movement 2 around the time of the "SHIBOR Shock", but it is less standout compared to the first peak in Co-movement 1. In addition, the versions of Co-movement 2 based on PFB (Co-

[11] The distinct features in the liquidity co-movements discussed in Sections 3.4.2 and 3.4.3 are robust for different starting dates of our sample. For example, even if we estimate our model based on a shortened data set from 2012 onward and recreate Figures 3.5 and 3.6, we will still see the same distinct features in the new figures.

movement 2a and 2c in Figure 3.6) and based on CP (Co-movements 2b and 2d in Figure 3.6) alternate in strength before and after the "SHIBOR Shock". These patterns and features have important implications on the transmission of liquidity shocks during the two market events in focus, which are discussed in Section 3.4.3.

3.4.3 The transmission of liquidity shocks during the two market events

By examining the liquidity co-movements captured by our empirical model in conjunction with the regulatory actions and policy changes surrounding the two market events (i.e. the rollercoaster ride in China's stock market between late-2014 and mid-2015 and the "SHIBOR Shock" in June, 2013), we are able to better understand how the liquidity shocks related to the two market events were transmitted between China's banking sector and stock market via money market transactions. Our findings strongly suggest that liquidity shocks can be transmitted both ways between the banking sector and the stock market via the money market, and the transmission of shocks can be affected by various decisions of China's policy makers. Our narratives on the two events are presented separately in Section 3.4.3.1 and Section 3.4.3.2.

3.4.3.1 The rollercoaster ride of China's stock market in 2014-2015

The dramatic movements in China's stock market between late-2014 and mid-2015 are illustrated by the CSI 300 Index in Figure 3.7. The two types of liquidity co-movements corresponding to the period of Figure 3.7 are shown in Figures 3.8 and 3.9. The CSI 300 Index a major stock index in China that tracks the performance of 300 stocks listed in Shanghai Stock Exchange and Shenzhen Stock Exchange. In this study, we specifically focus on the period between October, 2014, when the CSI 300 index rose above 2500 points for the first time since May, 2013, and June, 2015, when the index eventually reached above 5300 points but quickly collapsed back to the 3000-4000-point range. The patterns shown in Figures 3.7, 3.8 and 3.9 clearly indicate that there was a stock-market-related liquidity shock affecting the banking sector via the money market in late-2014. Surprisingly, however, this shock seems to be related to the heating-up of the stock market rather than the collapse of the stock market.

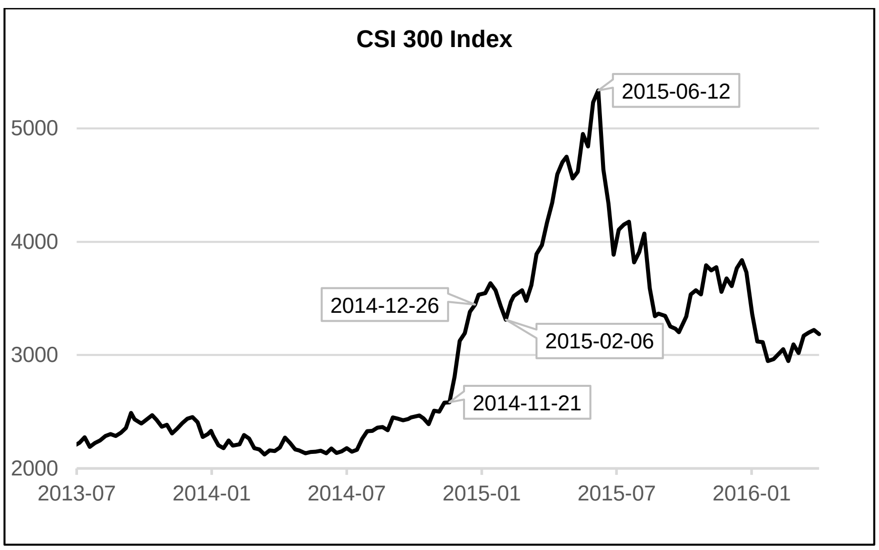

Figure 3.7. CSI 300 Index between July 2013 and April 2016 (Source: CEIC)

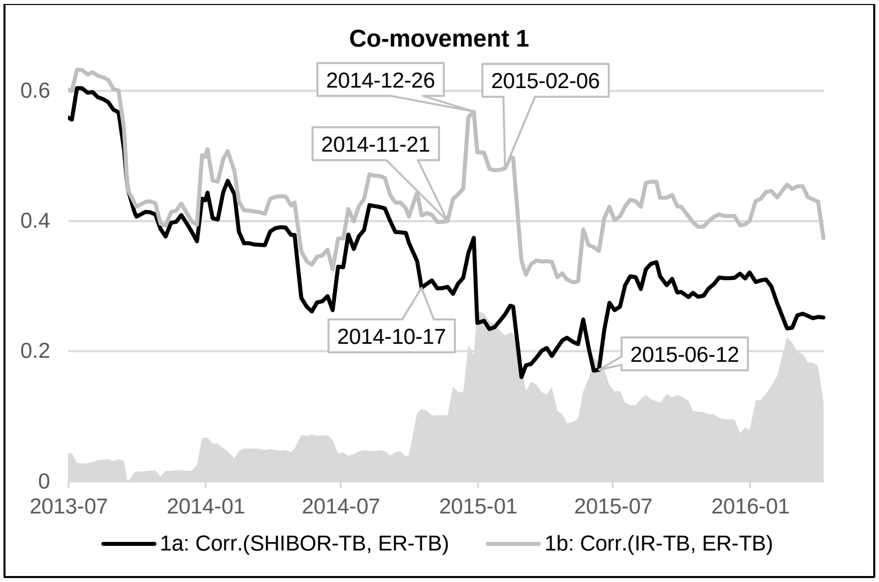

Figure 3.8. Co-movement 1 between July 2013 and April 2016. Shadow shows the different between the two versions (Source: authors)

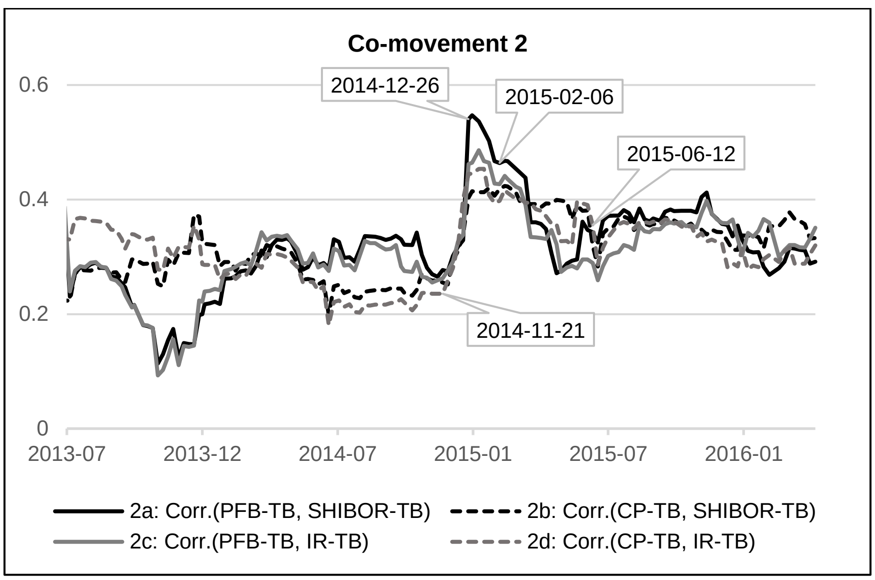

Figure 3.9. Co-movement 2 between July 2013 and April 2016 (Source: authors)

As we have discussed at the end of Section 3.2.2, strengthening Co-movement 1 is a sign that the funding liquidity of traders in the interbank market is more closely tied to the funding liquidity of traders in the stock exchanges; strengthening Co-movement 2 is a sign that the funding liquidity in the banking sector is drying up; and the two co-movements strengthening at the same time is a double confirmation that there is a liquidity shock being transmitted between the banking sector and the exchange market. From Figures 3.7, 3.8 and 3.9, we indeed observe that, between the week ended on November 21, 2014 and the end of 2014, both Co-movement 1 and Co-movement 2 strengthened sharply while the CSI 300 Index skyrocketed from around 2600 points to around 3400 points, which is a strong indication that a liquidity shock related to the stock market had affected the funding liquidity of the banking sector through the money market during that period. It is unlikely that the shock being transmitted was originated from a problem in the stock market, because otherwise the stock market would not have gone up so quickly at the same time. Instead, we conjecture that it was due to the funds in the exchange market being all tied-up in equity assets in the white-hot stock market, drying up the funds available for the further financing of stock traders. The funding illiquidity in the exchange market was transmitted into the interbank market when traders with dual-market access started bringing funds from the interbank market to the exchange market in response to the growing funding constraint in the exchange market, driving up Co-movement 1. As the funding condition in the interbank market tightened up, the banking sector might have been forced to recoup cash by liquidating some assets in interbank market, subsequently driving up Co-movement 2.

The patterns of the two co-movements and their correspondence with the timing of two major policy changes in October and November, 2014, respectively, suggest that the policy makers might have played an important role in the initiation and transmission of the liquidity shock, because they made it easier for stock traders to access funds in the banking sector and provided incentive for them to borrow more. As mentioned in Section 3.4.2, the gap between the versions of Co-movement 1 based on CL (1a) and based on IR (1b) widens notably since October, 2014 (see Figure 3.8). This shift in the mean difference between Co-movements 1a and 1b is also confirmed by a structural break testing and dating procedure specified in Bai and Perron (2003)[12]. The most likely contributor of this shift is a new rule issued by the PBOC on October 17, 2014[13], which allowed qualified non-financial corporations with at least 30 million yuan in net assets to access the interbank credit market. This policy change lowered the barriers between the two money markets and provided new funding opportunities for many commercial entities that previously only had access to funds in the exchange market. Given that these newcomers to the interbank market were more likely to borrow from the IR market rather than the unsecured CL market mainly reserved for high-credit financial institutions, the cross-market flows of funds carried by them should mainly take place between the two repo markets. Thus, we expect the cross-market liquidity co-movement based on IR to strengthen relative to the cross-market liquidity co-movement based on CL following the new rule, which is indeed what we see in Figure 3.8. Meanwhile, the turning point of Co-movements 1 and 2 at around November 21, 2014 is also not a coincidence. On November 22, 2014, the PBOC lowered the benchmark interest rates in China for the first time since 2012[14], signaling major monetary easing and providing a strong incentive for more

[12] The detailed structural break testing and dating procedure and results are available upon request from the author.
[13] http://www.pbc.gov.cn/zhengcehuobisi/125207/125227/125963/2810732/index.html [in Chinese]
[14] http://www.pbc.gov.cn/zhengcehuobisi/125207/125213/125440/125835/2892213/index.html [in Chinese]

borrowing. Following the rate change, the strength of Co-movements 1 and 2 immediately jumped up, reflecting tightening funding liquidity conditions in both money markets, while the upward movement in the CSI 300 Index started to accelerate. This is a substantial evidence that funds were leaving the banking sector via the interbank money market, being brought into the exchange market by entities with dual-market access, and being invested in the stock market. The much stronger reaction in Co-movement 1b compared to Co-movement 1a (see Figure 3.8) is again an indication that the liquidity drain from the banking sector mainly took place in the IR market. In summary, our empirical results suggest that the policy change in October widened the money-market-based pathway for funds to flow between the banking sector and the exchange market, then the rate change in November triggered a major outflow of funds from the banking sector to the stock market via money market transactions.

The timing of the alleviation and dissipation of the liquidity stress, as implied by the sharp drops in the strength of the two liquidity co-movements at the end of 2014 and mid-2015 (see Figures 3.8 and 3.9), is also consistent with two policy decisions that aimed to release liquidity into the banking sector. During the week ending on December 26, 2014, the PBOC injected more than 300 billion yuan into the banking sector via Short-term Liquidity Operations (SLOs)[15], which was a temporary relief for the funding illiquidity in the banking sector. On February 4, 2014, the PBOC lowered the reserve requirement ratio (RRR) for all banks for 0.5%, which was the first RRR adjustment since May, 2012[16] and

[15] http://www.pbc.gov.cn/zhengcehuobisi/125207/125213/125431/125478/2810439/index.html [in Chinese]
[16] http://www.pbc.gov.cn/zhengcehuobisi/125207/125213/125434/125798/2875174/index.html [in Chinese]

a major relaxation of the funding constraint faced by the banking sector. This decision meant that an amount equal to 0.5% of all the renminbi deposits in China were freed up from the banking sector's mandatory reserves held by the central bank, which was a huge amount, considering the fact that the total renminbi deposit balance in China was over 100 trillion yuan at the end of the first quarter in 2015 (PBOC, 2015d). The RRR change was followed by a sharp drop in the strength of both Co-movements 1 and 2, as well as a new round of rally in the stock market after a brief pull-back in January, suggesting that the liquidity conditions were quickly improving over the board.

The above narrative based on our empirical results and their coordination with market and policy events demonstrates that the two types of liquidity co-movements estimated by our model are capable of capturing the transmission and dissipation of liquidity shocks between China's banking sector and stock market via its segmented money market. During the rapid downfall of the stock market after its peak on June 12, 2015 (see Figure 3.7), the liquidity co-movements displayed in Figures 3.8 and 3.9 again showed signs of illiquidity being transmitted between the two money markets and into the banking sector. Co-movement 1 strengthened immediately after June 12, 2014 and Co-movement 2 followed suit a week later. However, the reactions of Co-movements 1 and 2, particularly Co-movement 2, in the aftermath of the stock market collapse were much milder compared to the one-month period before the end of 2014, suggesting that the funding condition of the banking sector were not severely hampered by the violent downturn in the stock market. Based on this observation, we suspect that the retail investors restricted from borrowing in the two money markets and their financing activities via OTC funding channels (refer to Figure 3.4) subjected to much less regulatory restrictions might have played a major role in the finale of the stock market rally before it ended in mid-June. In this case, the margin calls triggered by the freefalling equity prices would mainly affect the funding liquidity of traders not reliant on funds from the two money markets and their creditors not directly financed by the banking sector, thus diverting the transmission of liquidity shock away from the two public money markets and limiting how much shock could be captured by Co-movements 1 and 2. Our conjecture is supported by a report from China Securities Regulatory Commission (CSRC) [17] issued in 2015, which stated that the number of new accounts in China's stock market opened in the first quarter of 2015 grew by over 400% quarter-over-quarter, and over 90% of these new accounts had a net asset value less than 500 thousand yuan, the legal minimum for margin accounts set by the CSRC. This report confirms that most of the new investors entering the stock market in early 2015 were indeed small retail investors that did not even have indirect access to funds in the two money markets via margins provided by their brokers, and would have to resort to OTC funding sources if they wanted to add leverage to their portfolios. Therefore, it is important to understand and monitor the transmission of liquidity shocks via OTC transactions outside of the two public money markets in order to prevent unexpected illiquidity contagion not reflected by the fluctuations in the public markets. A future study on this specific subject is needed once more data on China's OTC market becomes available.

[17] http://www.csrc.gov.cn/pub/newsite/tzzbh1/tbtzzjy/tbfxff/201504/t20150428_275686.html [in Chinese]

3.4.3.2 The "SHIBOR Shock"

The "SHIBOR Shock" was a short-lived cash crunch in China's interbank money market that took place around mid-June in 2013 and reached its climax on June 20, 2013, when the SHIBOR rates shot up to record high levels. For example, the overnight SHIBOR jumped from 7.66% on June 19 to 13.44% on June 20, an unimaginable level for an overnight interbank rate. There was no official account for the event, but the media attributed it to the shortage of funds in the banking sector since early June and the PBOC temporarily withholding its liquidity provision to banks aiming to curb excess credit expansion (The Economist 2013a, 2013b). If this was indeed the case, then the liquidity shock was clearly originated from the banking sector, and would be reflected in strengthening Co-movement 2 (i.e. the co-movement between the funding liquidity and market liquidity in the interbank market) around the time of the "SHIBOR Shock". Meanwhile, if this liquidity shock was transmitted from the banking sector to exchange-based traders by money market transactions and eventually affected the liquidity in the stock market, Co-movement 1 (i.e. the cross-market funding liquidity co-movement) would also strengthen, and the stock market performance would be negatively affected around the time of the shock. All these features are confirmed by the patterns of the liquidity co-movements estimated by our model between May, 2013 and July, 2013 and the CSI 300 Index during the same period, which are displayed in Figures 3.10-3.13. Therefore, our empirical results provide strong evidences that a liquidity shock originated from the banking sector can be transmitted into the stock market via money market transactions. By further examining patterns of the liquidity co-movements surrounding the event, we are able to not only provide a narrative on the spreading of the "SHIBOR Shock", but also help verify some of the claims made by the media regarding what might have caused the liquidity shortage in the first place and how the banking sector and policy makers responded to the "SHIBOR Shock".

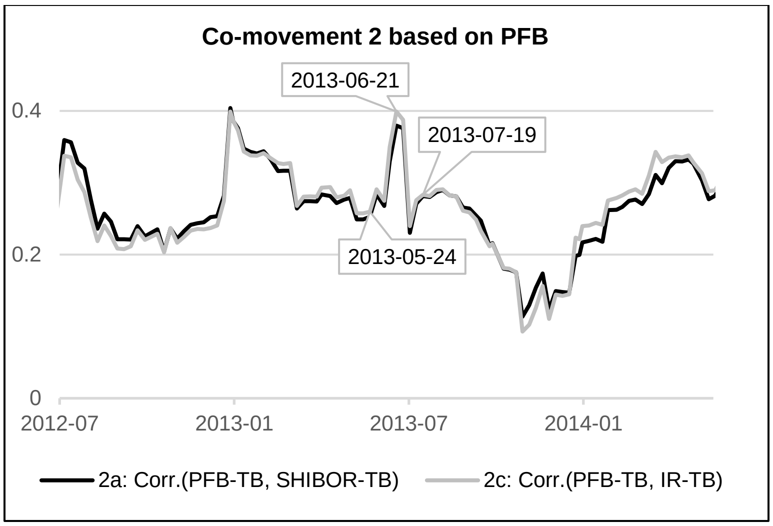

Figure 3.10. Co-movement 2 based on PFB between July 2012 and May 2014 (Source: authors)

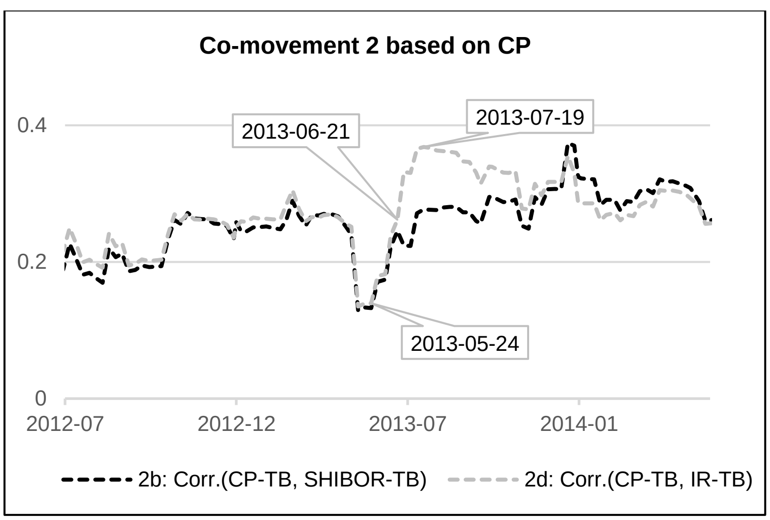

Figure 3.11. Co-movement 2 based on CP between July 2012 and May 2014 (Source: authors)

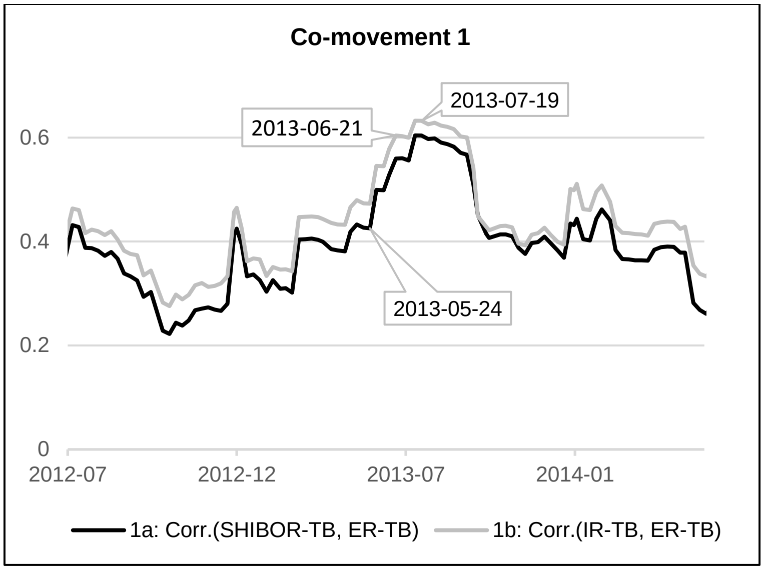

Figure 3.12. Co-movement 1 between July 2012 and May 2014 (Source: authors)

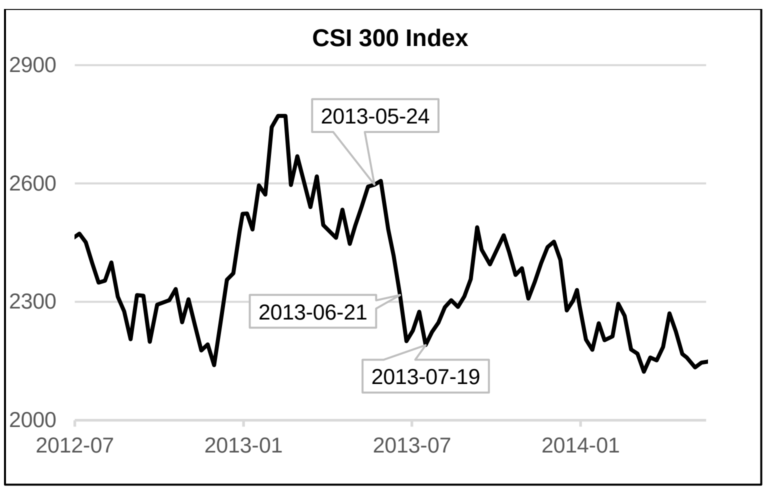

Figure 3.13. CSI 300 Index between July 2012 and May 2014 (Source: CEIC)

The liquidity co-movements shown in Figures 3.10-3.12 seem to suggest that the funding condition in the banking sector started tightening rapidly since late May. Media reports speculated that the PBOC actually knew about the situation and reacted to it, but its reaction was the opposite of what the banks expected. According to a leaked statement from a private PBOC meeting, the PBOC was alarmed by an apparent surge in lending in the first ten days in June, when the banks in China added almost 1 trillion yuan to their loan books, more than they typically lend in a whole month; and the PBOC concluded that some banks were expecting a fresh government stimulus and had “positioned themselves in advance” (The Economist, 2013b). The same article commented that the PBOC might have misread the banks' intentions, because 70% of in the 1 trillion yuan in new loans were short-term discounted bills intended to facilitate transactions between commercial enterprises, which were likely smuggled off balance-sheets at smaller banks and only resurfaced in early June after the regulator tightened up accounting at these banks. However, our results suggest that the PBOC's opinion had its own merit. Even if the new loans were mainly discounted bills, it appeared that the banks did stretched their balance-sheets to finance these bills, which happened as early as in May. Our liquidity measure for CP is a good proxy for the liquidity of discounted bills, because they are both short-term corporate loans serving similar purposes. We separate the versions of Co-movement 2 based on PFB (i.e. Co-movements 2a and 2c) and the versions based on CP (i.e. Co-movement 2b and 2d) into two figures to show the discrepancies between them before the “SHIBOR Shock” and afterwards. By only looking at the CP versions Co-movement 2 (see Figure 3.11), we may think that the funding constraint for the banking sector were suddenly relaxed in early May, 2013, because the strength of Co-movements 2b and 2d dropped to the lowest level since late 2011 at that time (refer to Figure 3.6). Yet, when we look at the PFB versions of Co-movement 2 for the same period (see Figure 3.10), we cannot find obvious clues for the major improvement of the funding condition in the banking sector. This could happen if the banks continued to make it easier for companies to borrow short-term funds from them (i.e. improving liquidity of CPs) despite their funding liquidity were not improved (i.e. the liquidity of IRs and CLs not improved) and they did not want to buy more low-interest PFBs (i.e. the liquidity of PFBs not improved), hence the much weakened Co-movements 2b and 2d but relatively stable Co-movements 2a and 2c in May, 2013.

The liquidity co-movements also reveal that the transmission of the liquidity shock originated from the banking sector continued beyond the "SHIBOR Shock" and lasted well into July, 2013. The commonalities and differences in the patterns of different types/versions of the liquidity co-movements during and after the "SHIBOR Shock" provide strong indications that the banks changed their preferences and behaviors in response to the "SHIBOR Shock". All four versions of Co-movement 2 strengthened sharply during the 2-3 weeks before June 21, 2013, but their movements started to differ significantly since the "SHIBOR Shock" (see Figures 3.10-3.12). If we only look at the Co-movement 2 based on PFB (see Figure 3.10), we are inclined to think that the "SHIBOR Shock" quickly dissipated and merely had a transient impact. However, the co-movements shown in Figures 3.11 and 3.12 seem to tell a different story, in which the illiquidity in the banking sector continued to intensify and being transmitted into the exchange market until late July. This apparent discrepancy can be explained by a phenomenon called "flight to quality", a term coined by Brunnermeier and Pederson (2009). In our case, flight to quality means that, when funding becomes scarce for the banks, they will favor safer and more liquid assets and will prioritize their cutback on assets with higher volatility. It also means that the market liquidity of assets with higher volatility will be more sensitive to changes in the funding liquidity of the banks, i.e. the versions of Co-movement 2 based on assets with higher volatility would be stronger than the versions of Co-movement 2 based on assets with lower volatility. Although the "SHIBOR Shock" was temporarily eased when the PBOC provided liquidity support for selected banks by June 25, 2013[18], the liquidity pressure was still high in the banking sector, because there was no monetary stimulus in sight from the PBOC and the banks could no longer retain the mindset that PBOC would back them up whenever they were short of liquidity. This was the ideal setup for the flight to safety phenomenon to appear. Facing the persistent liquidity pressure, the banks preferred to hold more of their assets in PFBs rather than CPs, because the PFB was much less volatile than the CP (see Figure 3.2) and risk-free. In this case, even if they no longer needed to fire-sale their assets, they might continue to sell their CP holdings while buying PFBs. Therefore, it is not surprising to see that the CP-based versions of Co-movement 2 (see Figure 3.11) had been stronger than the PFB-based versions of Co-movement 2 (see Figure 3.10) for close to six months after the "SHIBOR Shock". We also notice from Figure 3.11 that the difference in strength between Co-movement 2b (i.e. the liquidity co-movement between CP and CL, the major funding source for large banks) and Co-movement 2d (i.e. the liquidity co-movement between CP and IR, the major funding source for small banks) was substantially wider during the five months after the "SHIBOR Shock" than the rest of the sample period. We consider it an indication that the flight to safety phenomenon was more pronounced for

[18] http://www.pbc.gov.cn/goutongjiaoliu/113456/113469/2868130/index.html [in Chinese]

small banks than large banks, possibly due to CPs and other short-term corporate loans having more weights in the assets of small banks than large banks prior to the “SHIBOR Shock”. Similar to the versions of Co-movement 2 based on CP, the strength of Co-movement 1 continued to rise after the “SHIBOR Shock” until it reached its highest point in history in mid-July (see Figure 3.12). We suspect it was driven by the banks pulling back the funds they previously supplied to traders with dual-market access, including institutional investors in the stock market, in order to cope with the liquidity pressure, because the CSI 300 Index had been dropping since early June until reaching its lowest point in 2013 in mid-July, some 15% lower than the beginning of June (see Figure 3.13). These fund movements can be attributed to the flight-to-safety phenomenon as well, because the banks may have preferred to hold more cash and safe assets such as PFBs and TBs in the interbank market than financing the traders with exposure to the riskier and more volatile exchange market. In summary, by assessing the estimated liquidity co-movements before, during and after the “SHIBOR Shock”, we are not only able to verify the transmission of liquidity shock from the banking sector to the stock market via money market transactions, but also able to provide important insights on the involvement of the policy makers in the build-up of this event and the reactions of the banking sector in the aftermath of this event.

3.5 Conclusion

In this study, we conduct the first empirical examination of the transmission paths for liquidity shocks created by money-market-based financing and trading activities in

China. We find strong evidences that liquidity shocks can indeed be transmitted back and forth between China's banking sector and a part of the financial system that it does not have direct access to, such as the stock market, via the money market in China, despite the regulatory restrictions imposed on the banks and the segmentation existed in China's money market. We are able to unveil these evidences by first creating an array of empirical measures for the funding liquidity of the banking sector in the interbank money market, the funding liquidity of stock traders in the exchange-based money market, as well as the market liquidity of short-term credit assets, then modelling the co-movements among them with a multivariate DCC-GARCH model. The results from our empirical model enable us to better understand how liquidity shocks were transmitted across different parts of China's financial system during the rollercoaster ride of China's stock market between late-2014 and mid-2015 and the “SHIBOR Shock” in mid-2013. They also provide us important insights on the crucial roles played by China's banking sector and policy makers during these two events.

What we have found in this study can be regarded as both a testimony for the improved interconnectivity between China's interbank market and exchange market, and a warning sign for the potential risk associated with it. It can serve as a strong reminder for China's policy makers and market participants that money market transactions are capable of allowing a liquidity shock to circumvent various regulatory restrictions and segmentations in China's financial system and result in a widespread illiquidity contagion, thus presenting a major threat to the overall stability of China's financial system. Therefore, it is important for the policy makers and regulators in China to closely monitor how funds are flowing through the two money markets in China to prevent a system-wide liquidity crisis like the one that took place in the U.S. in 2007. It is also important for the entities engaged in money market transactions in China, particularly the banking sector, to prepare for the unexpected illiquidity contagion associated with trading and financing in the money market.

CHAPTER IV

THE INTERACTION BETWEEN THE ONSHORE AND OFFSHORE RENMINBI INTERBANK INTEREST RATES AND ITS IMPLICATIONS ON THE TRILEMMA CHALLENGE FOR CHINA'S MONETARY AUTHORITY

4.1 Introduction

The terms "onshore" and "offshore" are seldom associated with a major currency, except for the Chinese renminbi. The onshore renminbi (CNY) refers to the renminbi circulating within the border of Mainland China while the offshore renminbi (CNH) refers to the renminbi circulating outside the border of Mainland China. The distinction between the two highlights the segmentation between the markets of CNY and CNH and the tight control on cross-border flows of the renminbi imposed by China's financial regulators. In recent years, the internationalization of the renminbi and its emergence as a major world currency has facilitated growing research interest on the CNH and its interaction with the CNY. However, the current literature on CNH is still rather limited and largely centers on the aspect of its exchange rate. For example, Funke et al. (2015) assess the factors contributing to the CNH-CNY pricing differential based on their exchange rates with the U.S. dollar (USD). The lack of interest rate aspect in the literature of CNH could be due to the absence of a benchmark interest rate for the CNH money market before 2013. With the launch of CNH HIBOR in June 2013 by the Treasury Markets Association (TMA) of Hong Kong and over three years of data accumulation since then, it is finally feasible for us to empirically examine the CNH-CNY interaction from the perspective of their market interest rates and provide previously unattainable insights on the decision-making of China's monetary policy maker based on the empirically findings. This new possibility motivates the current study.

So why are we interested in the interaction between the market interest rates of the CNH and the CNY, specifically the interaction between their short-term interbank interest rates? The main reason is that this interaction can shed light on how China's monetary policymakers deal with the famous "impossible trinity" or "trilemma" problem first elaborated by Mundell (1963). The "trilemma" refers to a fundamental challenge in monetary policymaking, which states that exchange rate stability, financial market openness, and monetary policy autonomy cannot be achieved simultaneously in an open economy, even though all these three properties are highly attractive operational goals for monetary authorities around the world. After China's monetary policymakers started liberalizing the exchange rate of the renminbi, gradually opening up the domestic financial market and modernizing their monetary instruments a few years back, they would inevitably face the trilemma challenge in the process. According to Kawai and Liu (2015), unlike many countries that choose to achieve two of the three properties while compromising the third one, China adopts an intermediate combination of the three properties and chooses the level of attainment of each of these properties according to their policy objectives. Based on this observation, we suspect that the monetary authority in China may have been actively adjusting how it approaches the trilemma amid varying market conditions and changing policy priorities over the years instead of following a single regime. The newly available benchmark interbank interest rate data for the CNH allows us to empirically examine how the PBOC prioritized among the three aspects of the trilemma overtime.

There are three ways the CNH interbank interest rate can inform us about how the PBOC approaches the trilemma. First, the CNH-CNY interest rate spread is a direct indicator for the strength of capital controls in China, a major factor that hinders the openness of China's financial market. Given the fact that the CNY and the CNH are essentially the same currency separated by the border, a large difference between the interest rates of CNY and CNH cannot sustain if the cross-border flows of the renminbi currency is unrestricted, because any substantial divergence between the two interest rates will be offset by arbitrage activities. Therefore, a persistent gap between the two interest rates that cannot be explained by transaction costs or the fundamental differences between the two markets is a strong indication for capital controls in effect. Any major shift in the size of the gap can be viewed as a signal for tightened or loosened capital controls. Secondly, the interactions between the CNY and the CNH interbank interest rates can tell us whether or not the PBOC's policymaking is affected by the decisions of foreign central banks. Short-term interbank interest rates such as Fed Funds rate, Libor, Euribor and Eonia play a key role in the monetary transmission of major economies, because they are frequently employed by central banks as operational targets while serving as the benchmarks for the interest rates of loans and other credit instruments. Although the major benchmark rates in the CNY interbank money market, such as the SHIBOR and interbank repo rate, are not explicitly targeted by the PBOC, they are found to be significantly reactive to the PBOC's monetary policy instruments (See Porter and Xu, 2009; He and

Wang, 2012). In comparison, the CNH interbank money market is a freely-traded money market beyond the jurisdiction of the PBOC and is directly exposed to the impact of monetary policy actions by foreign central banks. Suppose we consider the CNY interbank interest rate as a receptor for the monetary policy shocks from PBOC and the CNH interbank interest rate as a receptor for foreign monetary shocks. We can then assess the status of China's monetary policy autonomy by examining the interaction between the two interest rates. For a given period, if the CNH interbank interest rate is found to be driving the CNY interbank interest rate but not the other way around, it is a strong evidence that China does not maintain monetary autonomy during that period. Lastly, the interaction between the CNH-CNY interest rate spread and the exchange rate volatility of CNH can reflect if the PBOC uses capital controls to stabilize the exchange rate of renminbi. Unlike the fluctuation of the CNY exchange rate which is constrained by the PBOC, the fluctuation of the CNH exchange rate is dictated by market forces. One way for the PBOC to stabilize the exchange rate of the renminbi in the international market is by instituting capital controls. As mentioned earlier, the tightness of the capital controls on renminbi can be signaled by the CNH-CNY interest rate spread. If we find that the exchange rate volatility drives the CNH-CNY interest rate spread for a given period, it is a strong evidence that the PBOC sacrifices financial market openness in favor of exchange rate stability.

Based on the assessment above, we develop an empirical approach in this paper to unveil the statuses of the three components of the monetary policy trilemma in China and explore how the PBOC alters its handling of the trilemma overtime. Before getting into the details of our analysis, we first provide a background on the CNY and CNH interbank money markets in Section 4.2. We then present our methodology, our data and the theoretical basis for our empirical analysis in Section 4.3, and discuss our empirical results in Section 4.4. In the end, we summarize our major findings and their policy implications in Section 4.5.

4.2 Background

The CNY interbank money market was established in the 1990s when China's monetary authority started reforming the country's financial system and allowing banks and other financial institutions to lend to each other in a public marketplace. The CNY interbank market is the first market in China where the interest rates are determined by market transactions instead of being specified by the government. Currently, there are two major types of reference interest rates for CNY interbank market transactions: the SHIBOR and the interbank repo fixing rate. The SHIBOR is a type of unsecured interbank interest rates with maturities ranging from overnight to a year. The daily published SHIBOR rates with different maturities are determined by averaging the quotes from a board of domestic banks and domestic branches of foreign banks in a similar manner like the Libor. The interbank repo fixing rate is a type of secured interbank interest rates determined by averaging the rates of actual repo transactions during a specific time window in each trading day with additional adjustments for trading days without significant number of actual transactions. Although interbank repo transactions come in different maturities, the fixing rates are published only for three maturities: overnight, 7-

day, and 14-day. With the exception of the tightly regulated deposit and loan interest rates, the interest rates in China are now largely determined by market forces after two decades of gradual interest rate liberalization. Most of the newly issued bonds in China are priced using either the SHIBOR or interbank repo fixing rate as benchmarks.

Compared to the CNY interbank money market, the wholesale money market for the CNH has a much shorter history and is still in its early stage of development. The renminbi traditionally did not have a significant presence outside of China until recent years when the policymakers in China started opening up the country's financial market and promoting the international use of the renminbi with the help of China's booming economy and growing external linkages. Since the early 2010s, the trading of the renminbi has increasingly taken place in the foreign exchange (FX) markets at offshore locations, with Hong Kong, London, Singapore and New York being the top centers (Funke et al., 2015). In merely six years since April 2010, the renminbi has risen from the eighteenth most traded currencies in the world to the current eighth spot (Bank for International Settlements, 2010, 2016). During the same period, the renminbi has also become a major payment currency for international transactions. It was only the seventeenth most used international payment currency in November 2011, but now it is the sixth (SWIFT, 2011, 2016). As the quantity of the renminbi at offshore locations grew along with the rapid expanding CNH FX trading and payment activities, it was inevitable that more and more CNH lending and borrowing activities would take place and a formal money market and benchmark interest for the CNH would be needed. On June 24, 2013, the CNH Hong Kong Interbank Offered Rate (HIBOR) was formally introduced by the Hong Kong TMA, marking the establishment of a formal CNH interbank money market in Hong Kong, the leading hub for CNH trading and deposits.

The relationship between the CNY and the CNH interbank money markets is conceptually similar to the relationship between the Fed Funds market and the Eurodollar market. The CNY interbank money market, like the Fed Funds market, lies within the border of its issuing country and are subjected to the financial regulations and monetary policy actions of the country, while the CNH interbank money market, like the Eurodollar market, hosts the currency circulating outside of its issuing country and is largely beyond the control of the country's financial regulators and monetary authority. The onshore interbank market often occupies a key position in a country's financial system, because it is not only the venue where financial institutions borrow short-term funds from each other in order to maintain liquid operation and fulfill their government-mandated capital/reserve requirements, but also a platform where the country's central bank intervenes market interest rates. For example, the U.S. Federal Reserve manages the U.S. interest rates by targeting the Fed Funds rate, the shortest end of the yield curve, and using OMOs to maintain the Fed Funds effective rate around the target level. The PBOC also conduct OMOs via the CNY interbank money market and use various policy instruments to influence the SHIBOR and the interbank repo fixing rates, despite not targeting the interbank interest rates explicitly. Unlike the onshore interbank markets that exist in many countries, active offshore money markets only exist for currencies that have substantial presence outside of their countries of origin, such as the USD. The offshore USD, including the USD outside of Europe, is collectively referred to as Eurodollar due to historical reasons. The most important hub for Eurodollar is the London interbank money market, where the benchmark interest rate for Eurodollar, Libor, is determined. Given the fact that Hong Kong hosts the first formal CNH interbank money market, the Hong Kong interbank market for the CNH can be considered having a similar role as the London interbank market for the Eurodollar. Under this assumption, the CNH HIBOR can be viewed as the Libor equivalent for the renminbi.

Despite the analogy between the CNY/CNH interbank money markets for the renminbi and the Fed Funds/Eurodollar money markets for the USD, the interaction between the benchmark interest rates for CNY (i.e. the SHIBOR and the interbank repo fixing rates) and the benchmark interest rate for CNH, the CNH HIBOR, does not at all resemble the interaction between the Fed Funds rate and the USD Libor. Historically, the USD Libor almost always closely tracks the Fed Funds effective rate. From Figure 4.1, we can see that USD Libor rates with short maturities have been consistently moving in close proximity with the Fed Funds rate over the last 15 years, except during the 2007 U.S. subprime crisis. In comparison, throughout the entire history of the CNH HIBOR, its relationship with the CNY SHIBOR or repo rates seems to have gone through several major shifts (see Figures 4.2 and 4.3). There were times when the CNH HIBOR roughly fluctuated around the CNY interbank interest rates (e.g. between mid-2014 to mid-2015 and during the second quarter of 2016). There were also times when the interest rates of CNH and CNY seemed completely irrelevant and differed by astronomical amounts (e.g. during January 2016 and during January 2017). The massive gaps up to a few thousand basis points (bps) between the interest rates of CNH and CNY during those periods dwarf the maximum difference between Libor and Fed Funds rate during the subprime crisis, even though there has not been any major financial crises in either Hong Kong or Mainland China since the introduction of the CNH HIBOR. This puzzling observation is difficult to be explained by market forces alone.

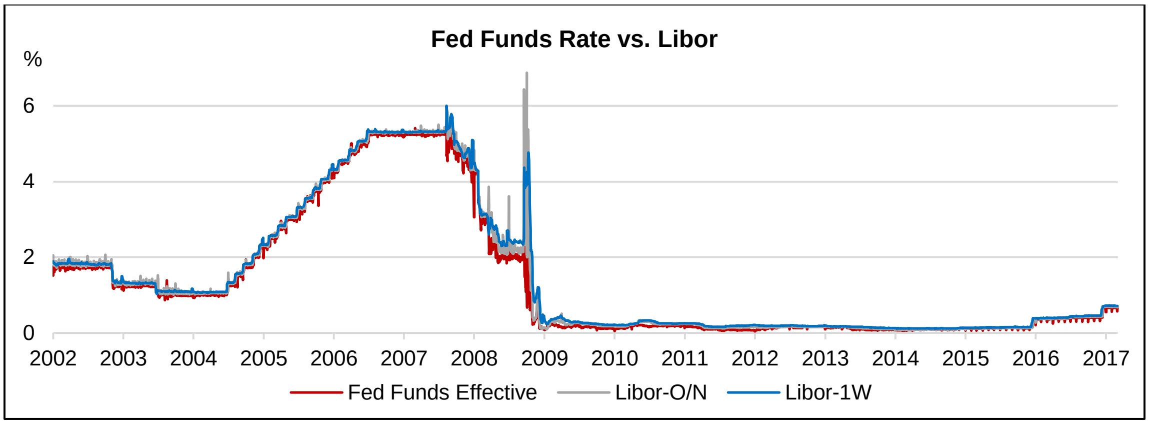

Figure 4.1. Fed funds effective rate vs. the USD Libor rates with overnight and 1-week maturities (Source: FRED)

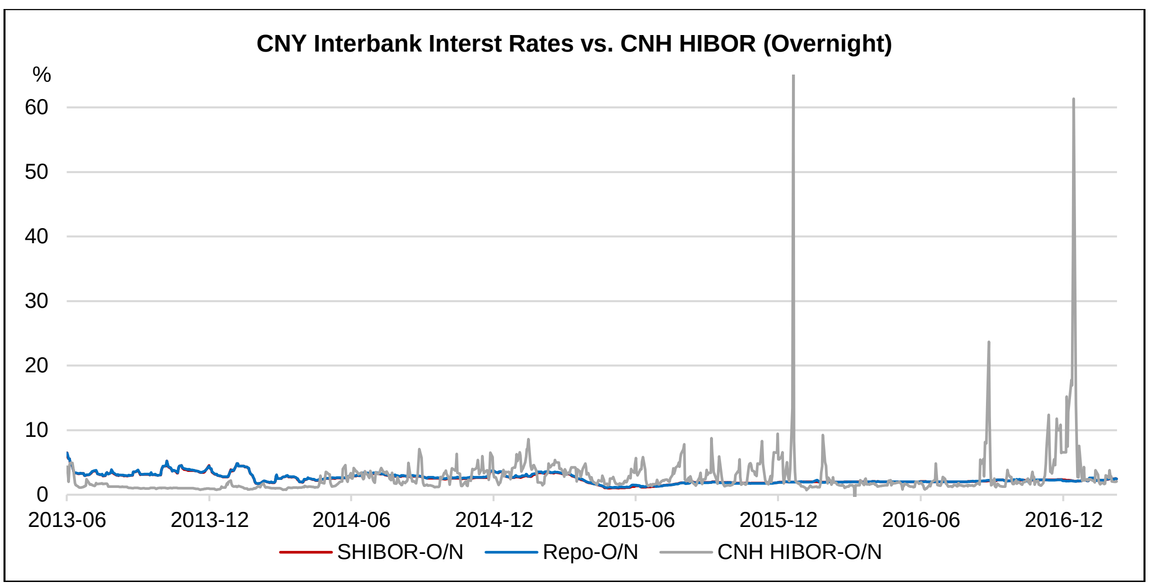

Figure 4.2. CNY SHIBOR and repo fixing rates vs. CNH HIBOR of overnight maturity (Source: CEIC)

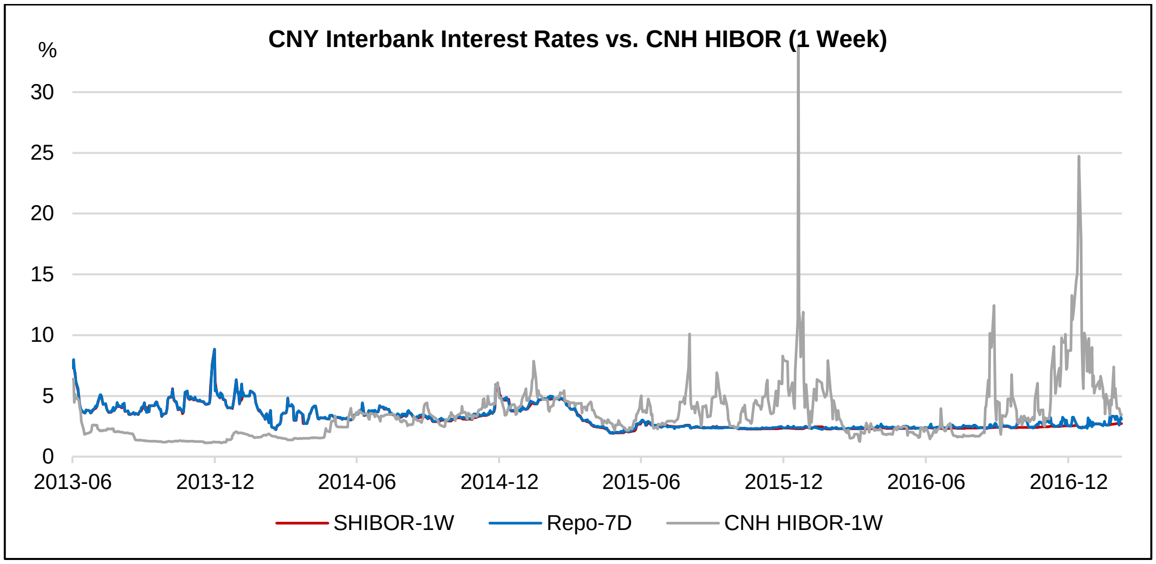

Figure 4.3. CNY SHIBOR and repo fixing rates vs. CNH HIBOR of 1-week maturity (Source: CEIC)

The stark contrast between the onshore-offshore interest rate interactions of the renminbi and the USD is a strong reminder for the fundamental differences between the renminbi and the USD money markets, despite their superficial similarities. These differences are directly tied to the trilemma mentioned in Section 4.1. The USD is a fully convertible currency with unrestricted cross-border mobility between the U.S. market and the offshore markets. It means that any significant exchange rate and interest rate divergence for the USD at onshore and offshore locations can be easily offset by arbitrage, unless there are major financial crises making the financial institutions unable or unwilling to take advantage of such arbitrage opportunities. In comparison, the renminbi is only a partially convertible currency, and the flow of renminbi between the onshore and offshore markets are tightly regulated by China's monetary authority. The CNY is subjected to both exchange rate controls and capital controls. The current exchange rate scheme for the CNY is a managed floating system in reference to a basket of currencies. The PBOC specifies the daily central parity exchange rates for the CNY based on the basket and enforces a daily trading band for the CNY/USD exchange rate in regards to its central parity rate, which was set to +/- 1% in 2010 and widened to +/- 2% since March, 2014 (Funke et al., 2015). Besides the exchange rate controls, there is also a daily limit for the CNY holders on how much they can convert their CNY into foreign currencies as well as a limit on how much renminbi cash they can bring out of Mainland China and turn into the CNH. Unlike the CNY, the CNH is fully convertible at offshore locations with market-determined exchange rates. But once the CNY becomes the CNH, it will be difficult for it to be turned back into the CNY, because there are only a few restrictive channels for the CNH holders to bring their renminbi back to the domestic financial markets in China. The obvious segmentation between the onshore and offshore markets of the renminbi implies that the discrepancies between the exchange rates or interest rates of the CNY and the CNH do not always mean arbitrage opportunities. It all depends how the PBOC enforces the capital controls and prioritize its policy objectives. For example, if the PBOC prioritize the objective of renminbi internationalization, it may opt for less capital controls while maintaining a relatively stable renminbi exchange rate in order to make the renminbi more attractive in the international market, which in turn means that it has to compromise on monetary policy autonomy. If instead the PBOC intends to focus on the domestic monetary objectives while limiting the interference from the international market, it may have to enforce more capital controls in order to avoid excess fluctuation of the renminbi exchange rates. As mentioned in Section 4.1, by empirically examining the interactions between the short-term interbank interest rates of the CNY and the CNH, we can learn about how the PBOC prioritizes its policy objectives amid the trilemma.

4.3 Methodology

In this section, we extend on the framework we establish in Section 4.1 and present the details of the empirical methods and model settings being used to assess each of the three components of the monetary trilemma in China based on the interaction of the CNY and CNH interbank interest rates. We then describe the data we use to conduct our analysis after specifying our empirical approach in Sections 4.3.1-4.3.3.

4.3.1 Assessing the strength of capital controls based on the two interest rates

Capital control is a major monetary measure that has adverse impact on a country's financial market openness. The efficacy of capital controls in China was previously examined by Ma and McCauley (2008) based on the yield gap between the onshore and offshore renminbi and a few other measures. At the time of their study, the offshore renminbi was yet to be assigned its formal abbreviation CNH, the formal offshore renminbi money market was yet to be formed, and the interest rate benchmark for the offshore renminbi was nonexistent. In order to measure the difference between the onshore and offshore renminbi interest rates, Ma and McCauley (2008) calculated the covered-interest-parity-(CIP)-implied offshore renminbi interest rate using the offshore renminbi non-deliverable forward (NDF) exchange rate and the USD Libor. They found that the capital controls in China was able to consistently maintain an economically significant yield gap between the onshore and offshore renminbi. They also found that the yield gap might have been shifted multiple times by the PBOC's policy changes.

Following Ma and McCauley's (2008) approach, we use the interest rate spread between the CNY and the CNH as the main indicator for China's capital controls in this study. Instead of having to estimate the offshore renminbi interest rate based on the CIP, we now enjoy the convenience of having the market-determined benchmark interest rates for both the CNY and the CNH interbank money markets, allowing us to explore the gap between them directly. As shown in Section 4.2, a persistent CNH-CNY interest rate spread still exist as of early 2017, suggesting that impact of capital controls in China still remains. Meanwhile, the strength of capital controls in China as indicated by the CNH-CNY interest rate spread seems to have gone through several major shifts over the last 3-4 years. The first part of our empirical analysis is dedicated to pinpointing the timing of these shifts and identifying the policy factors that may have contributed to these shifts. Our approach here is to first calculate the CNH-CNY interest rate spread based on a pair of onshore/offshore interest rates with comparable risk characteristics and maturity, then conduct a structural break test on the interest rate spread to determine the number and the timing of significant shifts in its mean. Our approach relies on the following three assumptions: the CNH-CNY interest rate spread fluctuates around a zero mean with finite variances if capital controls are nonexistent or nonbinding; binding capital controls move the mean interest rate spread away from zero and may also alter the variance of the interest rate spread at the same time; and policy change related to capital control may result in a sudden shift in the mean of the interest rate spread. Based on these assumptions, we can then examine the shifts in the mean of the CNH-CNY interest rate spread using the structural break testing and dating procedures specified in Bai and Perron (2003). The reason why we choose Bai and Perron's (2003) method is because it is capable of simultaneously detecting and dating multiple break points in a linear model under fairly loose assumptions. Their procedure does not require the error variance of the linear model to be constant, provided the breaks in the variance occur at the same dates as the breaks in the parameters of the model, in our case, the mean of the interest rate spread. The model to be tested for structural breaks is specified as the following:

$$S_t = C_i + u_{it} \qquad i = 1, 2, \dots, \mathrm{N} + 1; t = 1, 2, \dots, \mathrm{T} \tag{4.1}$$

where i is the number of the periods separated by the N structural breaks, $S_t = r_{CNH,t} - r_{CNY,t}$ is the CNH-CNY interest rate spread, C_i is the mean of the interest rate spread for period i, and u_{it} is the random disturbance for period i and time t with mean zero and finite variance.

Using the methods provided by Bai and Perron (2003), we can first test for the existence of multiple structural breaks against the hypothesis of no structural breaks in the above model, then simultaneously determine the optimal number of break points and the break dates. Since the mean of the interest rate spread C_i is the only parameter in the model, each structural break in the model represents a shift in the mean of the interest rate spread. Based on the break dates, we can divide our data into subsamples and examine if the mean CNH-CNY interest rate spread is significantly different from zero in each subsample. In the meantime, we can examine if there were policy changes related to capital controls that took place around the break dates and verify if the directions of the shifts in the mean interest rate spread at the structural breaks were consistent with the policy changes.

4.3.2 Assessing the status of monetary policy autonomy based on the two interest rates

Suppose the analysis specified in Section 4.3.1 reveals that the strength of the capital controls in China has experienced major shifts in the recent history and the shifts were evidently related to certain policy changes by the PBOC. We want next to find out is whether or not the monetary policy autonomy in China was better maintained during the periods with tighter capital controls than the periods with looser capital controls. As mentioned in Section 4.1, we consider the CNY interbank interest rate as the receptor for domestic monetary policy shocks and the CNH interbank interest rate as the receptor for foreign monetary policy shocks. Although maintaining a difference between the CNY and the CNH interest rates is already an indication for monetary autonomy, we want to take a step further to explore if one of the two interests is the driver for the other in the different periods separated by structural breaks. Specifically, we want to examine the causal relationship between the two interest rates based on the Granger causality concept first proposed by Granger (1969). This concept has been employed by numerous studies, such as Karfakis and Moschos (1990), Katsimbris and Miller (1993), Hassapis, Pittis and Prodromidis (1999) and Wang, Yang and Li (2007), to examine the interest rate linkages across international money markets. Most of these studies examine the pairwise Granger causal relationships among the interest rates of European Monetary System (EMS) members, as well as between the interest rates of EMS members and the other major economies in the world. They inspire us to conduct a similar study between the CNY and the CNH interest rates.

In this study, we largely follow the framework provided by Granger, Huang and Yang (2000) to assess the Granger causality between the CNY and the CNH interest rates. Although their study focuses on the bivariate causality between the stock prices and the exchange rates instead of between two interest rates, they specifically address the issue of applying Granger causality tests to the time series that are prone to the issues of unit root, cointegration, and structural breaks, which are exactly the potential issues we may encounter in our data. We adopt the formulation of the Granger causality tests directly from Granger, Huang and Yang (2000), but we handle structural break, unit root and cointegration differently from their approach. Instead of dealing with the structural breaks in the Granger causality tests, we adopt the break dates directly from the results of the analysis specified in Section 4.3.1. We intend to perform a Granger causality test for each of periods separated by the structural breaks. But before doing so, we need to verify if unit roots and cointegration exist in our data, because the formulation of the interest rate models being tested for Granger causality depends on the presence of unit root and cointegration. The Granger causality test for each period is based on a bivariate vector autoregression (VAR) model. As shown by Granger (1988), the existence of cointegration substantially affects the results of Granger causality tests. To address this issue, we first perform unit root tests on the two interest rate series for each period. In the periods when the interest rates are stationary, we do not need to worry about cointegration and can conduct a Granger causality test to a VAR model based on the levels of the interest rates.

If unit root presents in a specific period, the data in that period is then further tested for cointegration using the Johansen procedure developed by Johansen (1991). In the case that both interest rates are I(1) but not cointegrated, the VAR model for that period is specified based on the first-difference series. In the case that cointegration exists between the two interest rates, an error correction term is then added to the VAR model according to Granger, Huang and Yang (2000). The three variants of bivariate VAR models being used in our Granger causality tests[19] are specified as the following:

(a) If the two interest rates are both stationary in period i:

$$r_{CNY,t} = \alpha_{0,i} + \sum_{j=1}^{k} \alpha_{1,i,j} r_{CNY,t-j} + \sum_{j=1}^{k} \alpha_{2,i,j} r_{CNH,t-j} + \varepsilon_{CNY,t} \tag{4.2}$$

$$r_{CNH,t} = \beta_{0,i} + \sum_{j=1}^{k} \beta_{1,i,j} r_{CNY,t-j} + \sum_{j=1}^{k} \beta_{2,i,j} r_{CNH,t-j} + \varepsilon_{CNH,t} \tag{4.3}$$

(b) If the two interest rates are I(1) but not cointegrated in period i:

$$\Delta r_{CNY,t} = \alpha_{0,i} + \sum_{j=1}^{k} \alpha_{1,i,j} \Delta r_{CNY,t-j} + \sum_{j=1}^{k} \alpha_{2,i,j} \Delta r_{CNH,t-j} + \varepsilon_{CNY,t} \tag{4.4}$$

$$\Delta r_{CNH,t} = \beta_{0,i} + \sum_{j=1}^{k} \beta_{1,i,j} \Delta r_{CNY,t-j} + \sum_{j=1}^{k} \beta_{2,i,j} \Delta r_{CNH,t-j} + \varepsilon_{CNH,t} \tag{4.5}$$

(c) If the two interest rates are I(1) and cointegrated in period i:

$$\Delta r_{CNY,t} = \alpha_{0,i} + \delta_{1,i}\left(r_{CNY,t-1} - \gamma r_{CNH,t-1}\right) + \sum_{j=1}^{k} \alpha_{1,i,j} \Delta r_{CNY,t-j} + \sum_{j=1}^{k} \alpha_{2,i,j} \Delta r_{CNH,t-j} + \varepsilon_{CNY,t} \tag{4.6}$$

$$\Delta r_{CNH,t} = \beta_{0,i} + \delta_{2,i}\left(r_{CNY,t-1} - \gamma r_{CNH,t-1}\right) + \sum_{j=1}^{k} \beta_{1,i,j} \Delta r_{CNY,t-j} + \sum_{j=1}^{k} \beta_{2,i,j} \Delta r_{CNH,t-j} + \varepsilon_{CNH,t} \tag{4.7}$$

The optimal number of lags k for the interest rate model in each period i is determined by the Bayesian Information Criterion (BIC). For the periods that match Scenarios (a) or (b), failing to reject the $H_0: \alpha_{2,i,1} = \alpha_{2,i,2} = \cdots = \alpha_{2,i,k} = 0$ implies the CNH interbank interest rate does not Granger cause the CNY interbank interest rate in period i; and failing

[19] The testing procedure in this study follows the standard type of Granger causality test. Alternative testing procedures involving out of sample forecasting have been proposed but are no often used (See Granger, 1980).

to reject the $H_0: \beta_{1,i,1} = \beta_{1,i,2} = \cdots = \beta_{1,i,k} = 0$ implies that the CNY interbank interest rate does not Granger cause the CNH interbank interest rate. For the periods that match Scenario (c), failing to reject the $H_0: \alpha_{2,i,1} = \alpha_{2,i,2} = \cdots = \alpha_{2,i,k} = 0 \; and \; \delta_{1,i} = 0$ implies the CNH interbank interest rate does not Granger cause the CNY interbank interest rate in period i; and failing to reject the $H_0: \beta_{1,i,1} = \beta_{1,i,2} = \cdots = \beta_{1,i,k} = 0 \; and \; \delta_{2,\mathrm{i}} = 0$ implies that the CNY interbank interest rate does not Granger cause the CNH interbank interest rate.

Given the results from the Granger causality tests, we can then assess the status of monetary policy autonomy in China throughout the different periods. If the CNH interest rate does not Granger cause the CNY interest rate in a specific period, we consider monetary policy autonomy being well-maintained in that period. If for the same period, we also find that CNY interest rate Granger causes the CNH interest rate, it is an evidence that China's monetary authority has the ability to influence the renminbi interest rates abroad even with the segmentation between the domestic and international markets. We are particularly interested in the status of monetary policy autonomy during the periods when the capital controls are loose. The trilemma implies that in order to maintain a higher degree of financial market openness, the monetary authority needs to compromise either monetary policy autonomy or exchange rate stability. By examining the status of monetary policy autonomy during the periods when capital controls are loose, we are able to infer if China's monetary authority gives up some degrees monetary policy autonomy in exchange for more financial market openness. If this is not the case according to the Granger test results, then we suspect that it is exchange rate stability that is being compromised among the three aspects of the trilemma. The methods we employ to examine the connection between the exchange rate stability and capital controls are specified in Section 4.3.3.

4.3.3 Assessing the PBOC's policy stance on exchange rate stability based on the two interest rates

In Section 4.3.1, we have already established the connection between the CNH-CNY interest rate spread and the capital controls on the renminbi in China. Suppose we use the CNH-CNY interest rate spread as a proxy for the strength of capital controls on the renminbi. By examining the interaction between the CNH-CNY interest rate spread and the exchange rate volatility of the renminbi, we can verify if tightening capital controls has been used by the PBOC as a countermeasure against increasing fluctuation in the renminbi exchange rate. The method we use to perform this examination is again based on the concept of Granger causality, and the testing strategies are directly borrowed from Section 4.3.2. If the exchange rate volatility is found to Granger cause the interest rate spread, and the causality is positive, i.e. higher exchange rate volatility leads to wider interest rate spread, it is an indication that capital controls maybe have been strengthened in response to excess exchange rate volatility. If instead the exchange rate volatility does not Granger cause the interest rate spread, but the interest rate spread Granger cause the exchange rate volatility, it could imply two different scenarios depending on the sign of the Granger causality from the interest rate spread to the exchange rate volatility. Positive causality implies that stronger capital controls may have been the reason for higher exchange rate volatility rather than the policymakers' response to it. Negative causality implies that imposing more capital controls may have been effective in curbing the exchange rate volatility.

Before conducting the Granger causality tests, we need to specify an empirical measure for the exchange rate volatility of the renminbi to pair with the CNH-CNY interest rate spread. As mentioned earlier, there are two types of renminbi exchange rates, the onshore rates and the offshore rates. In this study, the volatility of the offshore CNH/USD exchange rate is chosen instead of the onshore CNY/USD exchange rate, because the volatility of the offshore exchange rate is more representative of the varying supply and demand of the renminbi in the international FX market, compared to the volatility of the onshore exchange rate that is artificially limited by the daily trading band set by the PBOC (see Section 4.2). Inspired by the fact that the PBOC enforces a percentage-based daily trading band to cap the daily fluctuation of the CNY exchange rates, we define our daily volatility measure of the CNH/USD exchange rate as the absolute value of the daily percentage change of the CNH/USD exchange rate. Suppose E_t is the nominal CNH/USD exchange rate at the end of trading day t. Our volatility measure is calculated as $v_t = |100 * (E_t/E_{t-1} - 1)|$. The policy objective of maintaining exchange rate stability can then be quantified as to minimize v_t. To assess the Granger causal relationships between the interest rate spread and the exchange rate volatility, we replace the $r_{CNY,t}$ (or its first-difference $\Delta r_{CNY,t}$) and $r_{CNH,t}$ (or its first-difference $\Delta r_{CNH,t}$) in Equations (4.2)-(4.7) with the interest rate spread S_t (or its first-difference ΔS_t) and the exchange rate volatility v_t (or its first-difference Δv_t) , and then follow the same procedures as specified in Section 4.3.2.

4.3.4 The data

The data required to conduct the analyses specified in Section 4.3.1 includes the daily CNY and CNH interbank interest rates as well as the daily CNH/USD exchange rate. As mentioned earlier, there are two major types of CNY interbank interest rate benchmarks, the SHIBOR and the interbank repo fixing rates. There are limitations with using either of the two in the current study, because neither of them is fully comparable to the CNH HIBOR, our only choice available for the CNH interbank interest rate. By definition, the SHIBOR is the closest counterpart to the CNH HIBOR in the CNY money market, because they are both determined by averaging the quotes from a board of selected contributing banks in a fixed daily quotation window rather than the rates from actual transactions. However, between the August 1, 2014 and December 30, 2016, the SHIBOR had been published daily at 9:30am, which was close to two hours ahead of the daily publication time of CNH HIBOR at 11:15am. Therefore, the SHIBOR and the CNH HIBOR on the same date do not necessarily reflect the same set of market information. Meanwhile, the SHIBOR and the CNY HIBOR have different day-count conventions. The SHIBOR is annualized based on the day-count convention of 360 days per year, while the CNH HIBOR is annualized based on the day-count convention of 365 days per year. Compared to the SHIBOR, the CNY interbank repo fixing rate has two major advantages. First, the CNY interbank repo fixing rate has been published daily at 11:30am throughout the entire history of the CNH HIBOR, which is only 15 minutes apart from the daily publication time of the CNH HIBOR. Therefore, the spread between the two rates is less susceptible to market shocks that take place during the period between the publication times of the two interest rates. Secondly, the CNY interbank repo fixing rate has the same day-count convention as the CNH HIBOR, thus can be directly compared to the CNH HIBOR without conversion. However, there is a potential issue with choosing the CNY interbank repo fixing rate as the CNY interest rate to be used in our study. As mentioned earlier, the repo interest rate is a type of collateralized interest rate while the SHIBOR and the CNH HIBOR are both credit-based unsecured rates. Even in absence of capital controls, the credit risk premium in the CNH HIBOR alone could lead to a difference between the CNY repo fixing rate and the CNH HIBOR. Yet, given the fact that there has not been a major bank solvency issue in Mainland China or Hong Kong since the time when the CNH HIBOR was introduced, the credit risk premium in the CNH HIBOR is likely very small, especially in short maturities. Meanwhile, switching to the SHIBOR will not make much difference, because the gap between the SHIBOR and the interbank repo fixing rate is trivial compared to the gap between the interbank repo fixing rate and the CNH HIBOR (See Figures 4.2 and 4.3). Based on the above assessment, we select the CNY interbank repo fixing rate instead of the SHIBOR as the CNY interest rate to be paired with the CNH HIBOR in this study. We specifically choose the 7-day (or 1-week) variants of the two types of interest rates to conduct our analysis, because the 7-day (or 1-week) maturity is one of the two most frequently traded maturities in the CNY and the CNH money markets along with the overnight maturity, and it is much less volatile compared to the overnight rates. The data of the 7-day CNY interbank repo fixing rate and the 1-week CNH HIBOR are obtained from CEIC. In addition to the interest rate data, we obtain the daily data of the CNH/USD exchange rate from Thomson Reuters Datastream. The sample period of our data is between June 24, 2013, when the CNH HIBOR was introduced and March 2, 2017 when the databases were last accessed. It is worth nothing that the holiday schedules in the two markets are different. For the dates when only one of the two markets was open for business, we fill in the market rate from the previous business day for the market that was closed. The interest rate data, the calculated CNH-CNY interest rate spread and the exchange rate data are visualized in Figures 4.4, 4.5 and 4.6, respectively.

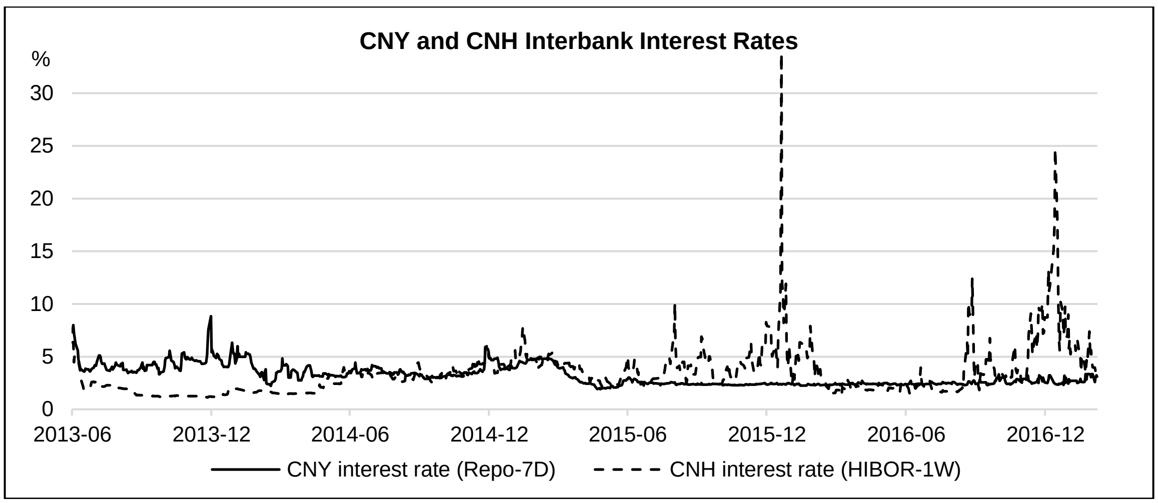

Figure 4.4. Interest rate data (Source: CEIC, Datastream)

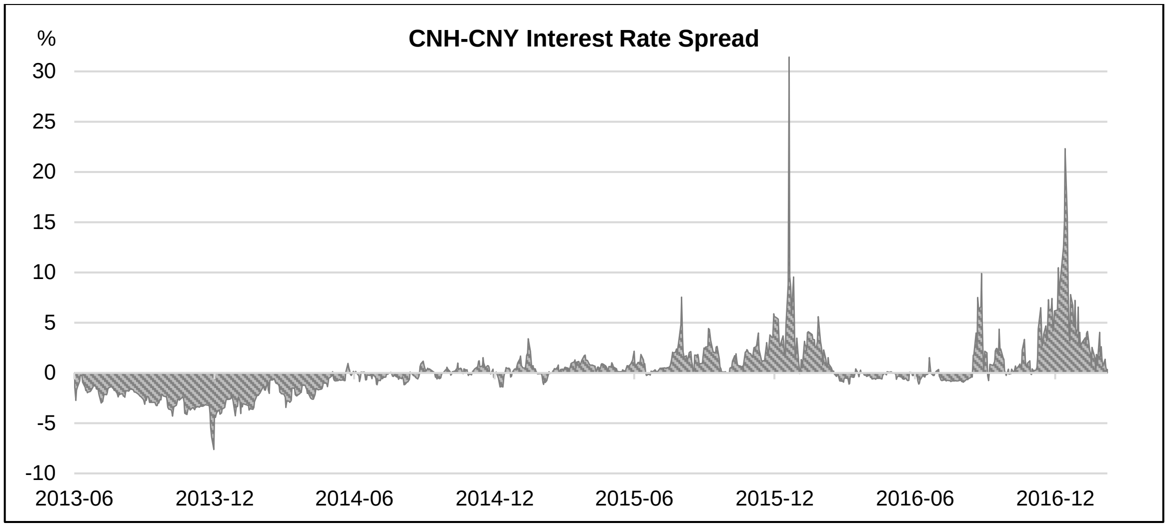

Figure 4.5. CNH-CNY interest rate spread (Source: authors)

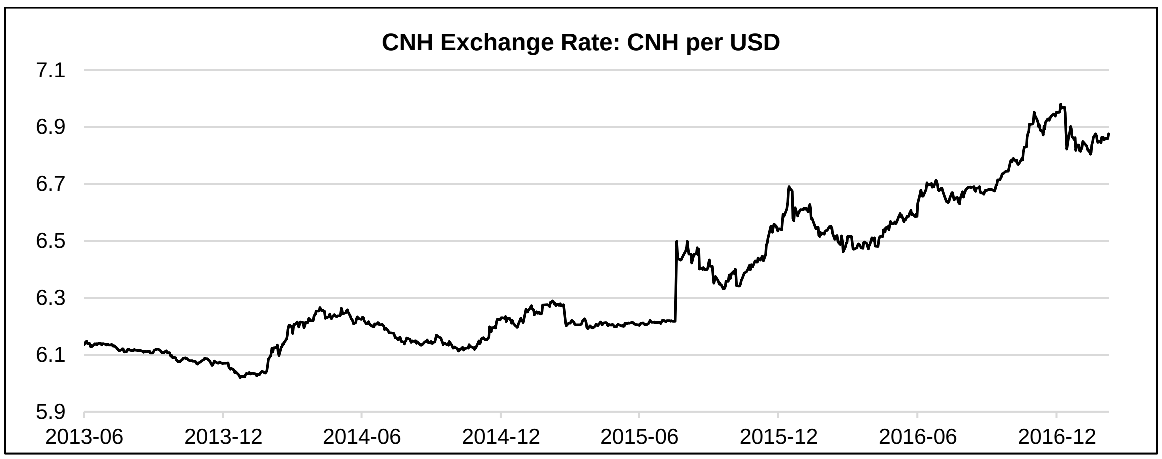

Figure 4.6. CNH exchange rate (Source: Datastream)

4.4 Empirical Results

In the next three subsections, we present the results of the analyses specified in Sections 4.3.1, 4.3.2 and 4.3.3, and discuss the likely contributing factors for our findings.

4.4.1 The structural breaks in the CNH-CNY interest rate spread

We employ the algorithm specified by Bai and Perron (2003) to estimate the optimal number of break points and the break dates in the CNH-CNY interest rate spread series based on the model setting described in Section 4.3.1. We set the minimum interval between break points as 10% of all the observations, and select the best break point number and date combination based on BIC. We identify four break points in the interest rate spread series, which took place on May 14, 2014, August 12, 2015, February 29, 2016 and September 7, 2016, respectively. Based the break dates, we divide our sample into five periods and calculate the mean interest rate spread for each period. The mean interest rate spreads in the five periods are -248bps, 19bps, 260bps, -34bps and 323bps, respectively. These means are all statistically different from zero at 5% level but their differences from zero vary greatly in magnitude. The five periods separated by the break dates and the fitted mean for each period are visualized in Figure 4.7.

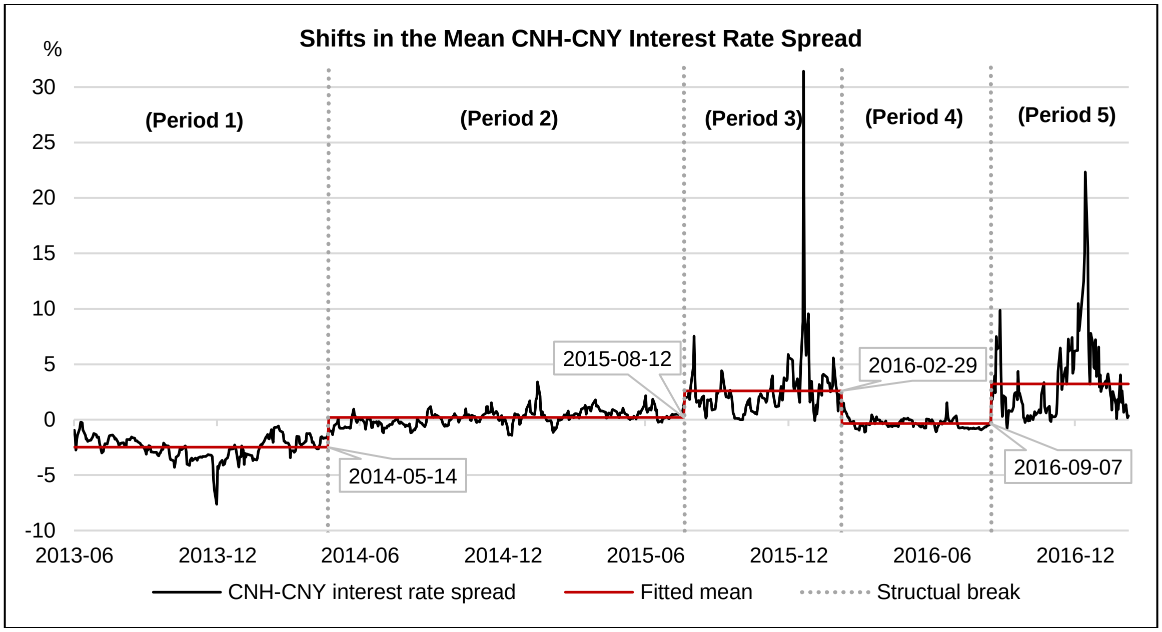

Figure 4.7. Structural breaks and the shifts in the mean CNH-CNY interest rate spread. (Source: authors)

From Figure 4.7, we can see obvious indications for alternations between tight and loose capital controls. In Periods 1, 3 and 5, the interest rate spread fluctuated around a mean vastly different from zero, signaling tight capital controls and the inability for traders to conduct cross-market arbitrage during those periods. In comparison, the interest rate spread in Periods 2 and 4 fluctuated around a mean much closer to zero, implying that the capital controls may have been loosened during the two periods. Meanwhile, the fluctuation of the interest rate spread was more volatile in Periods 1, 3 and 5 than in Periods 2 and 4. Referring back to Figure 4.4, we can see that the high volatility of the interest rate spread in Period 1, 3, and 5 was related to one of the two interest rates being much more volatile than the other during those periods. The CNY interest rate was the more volatile one in Period 1 while the CNH interest rate was the more volatile one in

Periods 2 and 3. According to Brunnermeier and Pederson (2009), less liquidity of an asset leads to its higher price volatility in a financial market. Based on this property, we conjecture that the CNY money market was less liquid than the CNH money market in Period 1, but more liquid than the CNH money market in Periods 3 and 5. The enforcement of tight capital controls in Period 1, 3, and 5 may have prevented the renminbi from being brought from the more liquid market to the less liquid market, subsequently allowing a substantial gap between the borrowing costs in the CNY and CNH money markets to persist during the these period. This conjecture also explains why the CNY interest rate was mostly higher than the CNH interest rate in Period 1 but lower than the CNH interest rate in Periods 3 and 5.

In order to uncover the policy related factors that led to the structural breaks and to infer the motivations behind the shifting capital controls, we further explore the policy decisions by the PBOC and its affiliated agencies as well as the major market events surrounding the break dates. However, it is often difficult to make a clear-cut assessment on the intentions of China's monetary policymakers, because they have the power to intervene the renminbi money markets without resorting to explicit policy changes and their actions are not always publicized. For example, since the Hong Kong branches of China's large state-owned banks are among the major participants in the CNH money market, the PBOC has the power to tighten up the supply of renminbi in the CNH market by privately addressing these banks via "window guidance"[20] without making public

[20] Windows guidance refers to a persuasion tactic used by the central banks of China and Japan to pressure banks and other financial institutions into adhering to policy guidelines. This tactic is known as "moral suasion" or "jawboning" in other countries, and is non-mandatory in nature.

announcements or policy changes. Therefore, we have no choice but rely heavily on informative conjectures to interpret our results.

The first structural break that took place in May, 2014 was likely a gradual process rather than an abrupt market reaction to a particular policy change. The narrowing CNH-CNY interest rate spread in April and May, 2014 may have been contributed by both the increasing flexibility of the Renminbi Qualified Foreign Institutional Investor (RQFII) program and the rapid expansion of the so-called "dim sum" bond market[21] in early 2014. Launched in 2011, the RQFII program allows qualified financial institutions to invest their CNH holdings back to the financial markets in Mainland China, including the interbank market and the stock market, making it a major channel for CNH holders to take advantage of the higher interest rate in the CNY market and the investment opportunities otherwise unavailable to CNH holders. However, the RQFII program is rather restrictive. Institutions need to obtain prior approval to take part in the program. Once approved, they are subjective to a series of regulatory restrictions, such as the quotas on how much they can invest in total and how much they can invest in a specific security. Some of these restrictions were relaxed in early 2014. In March and April 2014, the maximum proportion of outstanding stocks of a single company that can be invested by foreign investors via the RQFII program was raised from 20% to 30% by the Shanghai Stock Exchange (SSE) and the Shenzhen Stock Exchange (SZSE), respectively (SSE, 2014; SZSE, 2014). In late May 2014, the State Administration of Foreign Exchange (SAFE), China's foreign exchange

[21] Dim sum bond refers to the renminbi-denominated bonds issued outside of Mainland China (usually in Hong Kong). They are named after dim sum, a popular type of cuisine in Hong Kong.

regulator, further relaxed rules on how financial institutions could utilize their quotas to invest in open-ended mutual funds (Reuters, 2014). Both of these new rules increased the flexibility of the RQFII program, making the repatriation of renminbi funds from offshore locations more convenient. Meanwhile, the rapidly expanding dim sum bond market in Hong Kong may have encouraged a growing number of Mainland-based enterprises based in Mainland China to obtain renminbi financing from CNH holders, thereby allowing them to take advantage of the lower interest rate in the offshore market. The rising popularity of CNH financing by Mainland entities in early 2014 was evident by the 80% year-over-year growth of dim sum bond issuances during the period between January 1, 2014 and May 5, 2014, and the fact that the Mainland-based financial institutions had already used up 85% of annual quota of dim sum bond issuances as of May 5, 2014 (Ministry of Commerce, 2014). Although there were still restrictions for Mainland-based entities to bring the renminbi funds raised from the offshore market back to the onshore market, the financing opportunities in the dim sum bond market nonetheless allowed a proportion of the liquidity needs in the onshore market to be shifted offshore. In summary, the relaxation of the RQFII program and the expansion of the dim sum market during Period 1 were both capable of improving the interactivity between the CNY and the CNH money markets, making them the most likely contributors to the structural break in May 2014 and the seemingly loosened capital controls in Period 2.

The second structural break that took place around August 12, 2015 was unambiguously related to the surprising devaluation of the renminbi on August 11, 2015. On this date, the PBOC set its official central parity CNY/USD exchange rate down nearly

2% to 6.2298 CNY per USD in what it said was a change in methodology to make the currency more responsive to market forces (Reuters, 2015a; PBOC, 2016a). Following its biggest one-day fall since 1994, the CNY/USD exchange rate was allowed to slide even further on August 12, 2015, amounting to a 3.5% drop in two days (Reuters, 2015b). The offshore CNH/USD exchange rate fell even more, losing over 4% in two days since August 11, 2015, as shown in Figure 4.6. The PBOC did not provide any justification for the devaluation beyond the methodology change. But the media speculated that the devaluation was intended to boost Chinese exports amid the slowing economic growth in the China (Reuters, 2015a and 2015b). The potential explanation for why the sudden devaluation led to a structural break in the CNH-CNY interest rate spread and the seemingly tightened capital controls in Period 3 is two-fold. First, the capital controls on the renminbi may have been inherently more restrictive on the outflows to the offshore market than the inflows to the onshore market in order to encourage the repatriation of the renminbi while limiting capital outflows. In Period 2, the cross-border flows of the renminbi were likely dominated by the inflows from the CNH-market-based investors driven by the heated stock market in Mainland China[22]. In this case, the capital controls would appear to be relatively loose and the CNH-CNY interest rate spread would be small. However, the direction of the renminbi net cross-border flows may have been quickly reversed after the stock market crash in June, 2015 and the renminbi devaluation in August, 2015. The combined impact of these events would drive foreign investors back to the CNH

[22] As a reference, the SSE Composite Index, which gauges the performance of the stocks listed in the Shanghai Stock Exchange, was originally at around 2000 points in early May 2014, but more than doubled in less than a year and eventually crossed the 5000-point mark in June 2015.

market where they could freely exchange their renminbi for other currencies to avoid further loss. In this case, the capital controls would appear to be much stronger and the CNH-CNY interest rate spread would be much larger compared to Period 2. Secondly, the capital controls may have been further tightened by the PBOC during Period 3 in order to stabilize the renminbi exchange rate in the international market after the one-off devaluation and deter the renminbi short-sellers. Following the shocking devaluation of the renminbi, the panicking CNH depositors in Hong Kong may have rushed to withdraw their renminbi funds from the banks and converted the funds into other currencies, putting pressure on both the liquidity condition in the CNH interbank money market and the CNH exchange rate. Meanwhile, the renminbi short-sellers may have taken advantage of the falling CNH exchange rate by borrowing funds from the CNH interbank money market and selling them in the FX market, further reducing the liquidity in the CNH interbank money market and driving down the CNH exchange rate. To counter these market activities, the PBOC may have resorted to new capital control measures to dry up the supply of the renminbi liquidity in the CNH money market and push up the CNH interest rate, thereby making it much more costly for short-sellers to borrow and more attractive for the CNH depositors to hold on to their positions. In this case, we would also see a sustaining positive CNH-CNY interest rate spread in Period 3. There were indeed indications that the PBOC had implemented new policy measures to tighten the outflows of the renminbi during Period 3. In November, 2015, the PBOC reportedly used window guidance to instruct the CNH clearing banks to suspend their bond repurchase transactions with onshore banks in the CNY money market, making it difficult for the CNH clearing banks to finance in the CNY money market (Reuters, 2015c). On January 12, 2016, the overnight CNH HIBOR soared to a record high of 66.82% (See Figure 4.2), which was said to be caused by the PBOC deliberately holding back the supply of its currency offshore to squeeze the CNH short positions, according to traders in Hong Kong (Reuters, 2016a). On January 20, 2016, the PBOC published a new regulation stating that the CNH deposits that the offshore institutions kept at onshore bank accounts would be subjected to the same reserve requirement as the regular onshore bank accounts (PBOC, 2016b), reversing a previous exemption on reserve requirement for such deposits and further reducing the liquidity in the CNH money market. In Section 4.4.3, we will specifically emphasize on how the capital controls on the renminbi have interacted with the fluctuation of the CNH exchange rate.

The third structural break that took place at the end of February, 2016 was likely due to some of the capital control measures implemented in Period 3 being partially relaxed at the end of February and at the beginning of March in 2016. On February 24, 2016, the PBOC announced a new rule intended to expand the participation of qualified foreign institutional investors in the CNY interbank bond market, which removed their investment quotas in the market and simplified the administrative procedures for them to take part in the market (PBOC, 2016b). This new rule meant that more offshore traders would gain access to onshore bond investment opportunities as well as onshore repo financing opportunities. The offshore traders could utilize the latter as a new source for renminbi liquidity. Meanwhile, on March 1, 2016, the PBOC reduced the reserve requirement for all banks in China by 0.5%, meaning that 0.5% of all the CNH deposits that were kept at onshore bank accounts could be freed up from the mandatory reserve. Both of these two policy adjustments would help easing the supply of renminbi in the CNH money market. In comparison, it is difficult to determine the policy factors that may have contributed to the fourth structural break that took place around September 7, 2016, because there were no capital-control-related policy adjustments announced by China's monetary authority immediately before or after the break date. However, the timing of the structural break leads us to speculate its connection to the G20 meeting that took place in Hangzhou, China on September 4-5, 2016 and the inclusion of the renminbi as the fifth currency in the IMF SDR basket on October 1, 2016. The exchange rate issue was an important discussion topic during the G20. The G20 leaders affirmed that they would refrain from competitive devaluations of their currencies (G20, 2016). The monetary authority in China may have purposely tightened the capital controls following the G20 meeting to stabilize the renminbi exchange rate in the international market and send a gesture of good will to the other major economies. Meanwhile, some traders in the FX market suggested that the upcoming SDR inclusion could be another reason why the PBOC wanted to stabilize the exchange rate, although there was no confirmation of that (Reuters, 2016b). The fact that the CNH exchange rate remained steady at just below 6.7 CNH per USD during the entire September, 2016, but resumed its decline after October 1, 2016 seems to support the above speculations (see Figure 4.6). As previously mentioned, we will discuss more about how the capital controls on the renminbi had interacted with the CNH exchange rate during Period 5 in Section 4.4.3.

4.4.2 The Granger causal relationships between the two interest rates

In Section 4.4.1, we unveil the periodic shifts in the capital controls on the renminbi by China's monetary authority based on the structural break analysis of the CNH-CNY interest rate spread. In this subsection, we aim to find out whether or not the monetary policy autonomy in China was better maintained during the periods with tight capital controls (i.e. Periods 1, 3 and 5) and was compromised during the periods with loose capital controls (i.e. Periods 2 and 4) based on the Granger causality tests specified in Section 4.3.2. Before we conduct the Granger causality tests, we first determine which one among the three model variants (a), (b) and (c) in Section 4.3.2 is applicable to each of the five periods. In the first step, we apply the augmented Dickey-Fuller test at 10% level on both the levels and the first differences of the two interest rates to determine their orders of integration in each of the five periods. The results are shown in Table 4.1.

	Period 1 (6/24/2013 - 5/14/2014)	**Period 2** (5/15/2014 - 8/12/2015)	**Period 3** (8/13/2015 - 2/29/2016)	**Period 4** (3/1/2016 - 9/7/2016)	**Period 5** (9/8/2016 - 3/2/2017)
$r_{CNY,t}$	I(0)	I(1)	I(0)	I(0)	I(0)
$r_{CNH,t}$	I(0)	I(1)	I(0)	I(0)	I(1)

Table 4.1. Orders of integration

We can see that unit roots only presented in the two interest rates in Period 2 and the CNH interest rate in Period 5, and only the interest rates in Period 2 were possible to be cointegrated. Therefore, we conduct the Granger causality tests based on the VAR model variant (a) for Periods 1, 3 and 4, and based on the VAR model variant (b) for Period 5. Meanwihle, we need to further test for the cointegration of the two interest rates in Period

2 to determine whether model variant (b) or (c) is applicable for Period 2. In the next step, we choose the optimal number of lags for the VAR models in Period 1, 3, 4 and 5 as well as the lag order for the Johansen cointegration test in Period 2 based on BIC. The results are shown in Table 4.2.

	Period 1	**Period 2**	**Period 3**	**Period 4**	**Period 5**
Endogenous variables	$(r_{CNY,t}, r_{CNH,t})$	$(r_{CNY,t}, r_{CNH,t})$	$(r_{CNY,t}, r_{CNH,t})$	$(r_{CNY,t}, r_{CNH,t})$	$(\Delta r_{CNY,t}, \Delta r_{CNH,t})$
Optimal VAR model	VAR(2)	VAR(2)	VAR(1)	VAR(1)	VAR(1)

Table 4.2. Optimal lag orders for the VAR models in each period

Before performing the Granger tests, we assess the cointegration relationship between the two interest rates in Period 2 using the trace test version of the Johansen procedure. The test rejects the null hypothesis of zero cointegration relationship at 1% level. Therefore, the two interest rates were cointegrated in Period 2, and we use the VAR model variant (c) to conduct the Granger causality test for Period 2. Meanwhile, the Johansen procedure estimates the long-run relationship between the two interest rate to be $d_t = r_{CNY,t} - 1.2567\ r_{CNH,t}$, where d_t is a stationary series. Hence, we set $\gamma = 1.2567$ in the Equations (4.6) and (4.7) of the VAR model variant (c). The p-values from the Granger causality tests based on the VAR model in each period are shown in Table 4.3.

H_0	Period 1	Period 2	Period 3	Period 4	Period 5
$r_{CNY} \nrightarrow r_{CNH}$	0.2272	0.0561*	0.3807	0.1473	0.5128
$r_{CNH} \nrightarrow r_{CNY}$	0.2062	0.1383	0.6550	0.1734	0.7751

Table 4.3. The results of the Granger causality tests in each period. "$\nrightarrow$" represents "does not Granger cause". The numbers in the table are p-values based on F-tests. *: significant at 10% level

The results from the Granger causality tests suggest that China's monetary policy autonomy has been well-maintained throughout the five periods regardless of tight or loose capital controls, because the CNH interbank interest rate with direct exposure to foreign monetary shocks has not been found to Granger cause the CNY interbank interest rate in any of the five periods. It appears that the monetary policy autonomy of the PBOC was not compromised when capital controls were loosened, which leads us to suspect that it was the exchange rate stability being compromised among the three aspects of the trilemma. In Section 4.4.3, we will verify if this was indeed the case in reality. Meanwhile, the ability for the PBOC to directly intervene the CNH money market, as discussed in Section 4.4.1, may have also contributed to the sustaining monetary policy autonomy over the five periods, because it allowed the PBOC to respond to foreign monetary shocks directly in the international market without interfering its policymaking in the domestic market.

Besides the implications on monetary policy autonomy, the Granger causality analysis highlights the uniqueness of Period 2 among the five periods. The signs of the segmentation between the CNY and CNH interbank money markets were the least pronounced during Period 2. In Section 4.4.1, we have already shown that the benchmark interest rates in the two markets during Period 2 were the closest to each other among the five periods, differing by only 19bps in average. In this section, we further show that the offshore interest rate was not only cointegrated with the onshore interest rate, but was also driven by the onshore interest rate as suggested by the significant Granger causality from the CNY interbank interest rate to the CNH interbank interest rate. Based on these findings and the fact the most dramatic rise and fall in China's stock market during the last five years took place in Period 2, we suspect there was a strong connection between the loosened capital controls and the violent stock market movements during Period 2, but we are uncertain about which one was the cause and which one was the outcome. A future study can be conducted to explore whether it was the loosened capital controls and the subsequent expansion in foreign capital inflows that caused the rapid rise in China's stock market during Period 2, or it was the sustaining inflows of foreign capitals driven by China's heated stock market that allowed China's monetary authority to maintain relatively loose capital capitals during Period 2.

4.4.3 The interaction between the interest rate spread and the CNH exchange rate volatility

As discussed in Sections 4.4.1 and 4.4.2, we do not find any indications that the shifting capital controls over the five periods have significantly affected the monetary policy autonomy in China. In this subsection, we attempt to verify if the shifting capital controls were related to the need to stabilize the renminbi exchange rate in the international market by exploring the interactions between the CNH-CNY interest rate spread and the volatility of the CNH/USD exchange rate. The calculated volatility measure v_t is shown in Figure 4.8.

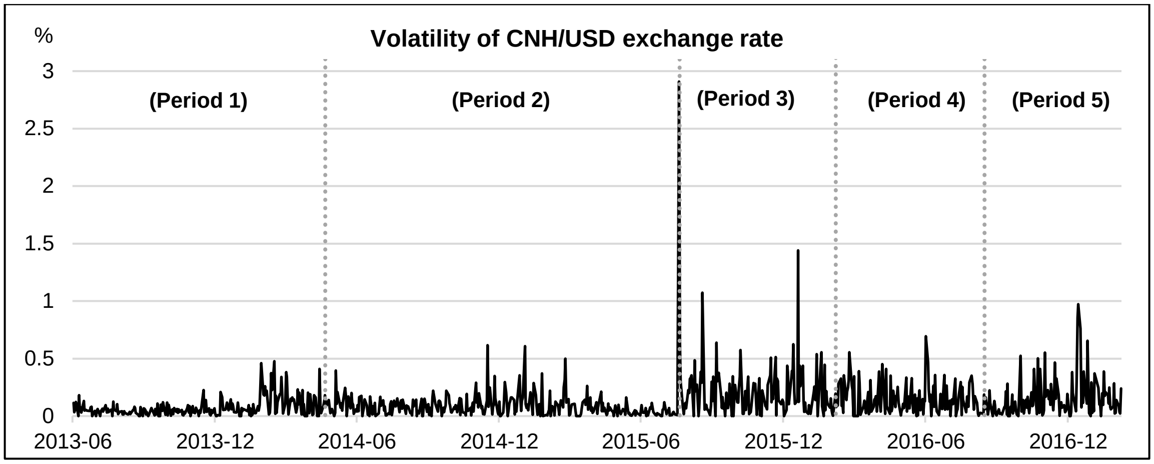

Figure 4.8. The calculated volatility measure of the CNH/USD exchange rate (Source: authors)

The average daily fluctuation of the CNH/USD exchange rate in the five periods are 0.076%, 0.098%, 0.196%, 0.147%, and 0.152%, respectively. From Figure 4.8, we can obviously see that the fluctuation of the CNH/USD exchange has become substantially more volatile since the second structural break that took place around August 12, 2015. Meanwhile, we find that the two periods with the highest average volatility are actually the two periods with the tightest capital controls instead of the two periods with loose capital controls.

As specified in Section 4.3.3, we use Granger causality tests between the CNH-CNY interest rate spread and the volatility measure of the CNH/USD exchange rate to verify the relationship between the strength of capital controls and the exchange rate stability. The Granger causality tests for all the five periods are conducted on the first-differences of the interest rate spread and the exchange rate volatility measure in order to circumvent the apparent asymmetry in the distribution of our volatility measure. The optimal lag orders for the VAR models used for the Granger tests are selected based on BIC and listed in Table 4.4. The results of the Granger causality test in each period are tabulated in Table 4.5. Additionally, because the signs of the Granger causal relationships are also important for the analysis in this subsection, we report the parameter estimates of VAR models for the two periods with significant Granger causality test results in Table 4.6.

	Period 1	**Period 2**	**Period 3**	**Period 4**	**Period 5**
Endogenous variables	$(\Delta S_t, \Delta v_t)$	$(\Delta S_t, \Delta v_t)$	$(\Delta S_t, \Delta v_t)$	$(\Delta S_t, \Delta v_t)$	$(\Delta S_t, \Delta v_t)$
Optimal VAR model	VAR(1)	VAR(1)	VAR(1)	VAR(2)	VAR(2)

Table 4.4. Optimal lag orders for the VAR models in each period

$\boldsymbol{H_0}$	**Period 1**	**Period 2**	**Period 3**	**Period 4**	**Period 5**
$S_t \nrightarrow v_t$	0.4546	0.4633	0.0839*	0.8489	0.0596*
$v_t \nrightarrow S_t$	0.9580	0.5973	0.3013	0.8576	0.0801*

Table 4.5. The results of the Granger causality tests in each period. "$\nrightarrow$" represents "does not Granger cause". The numbers in the table are p-values based on F-tests. *: significant at 10% level

	Period 3: VAR(1)		Period 5: VAR(2)	
	ΔS_t	Δv_t	ΔS_t	Δv_t
ΔS_{t-1}	-0.2856*** (0.0900)	-0.0147* (0.0084)	-0.0888 (0.0941)	0.0202** (0.0087)
Δv_{t-1}	-0.7955 (0.7681)	-0.2884*** (0.0713)	2.0256** (0.9790)	-0.5738*** (0.0907)
ΔS_{t-2}			-0.1720* (0.0904)	-0.0026 (0.0084)
Δv_{t-2}			0.1709 (0.9935)	-0.3351*** (0.0920)
Constant	-0.0200 (0.2353)	-0.0090 (0.0218)	-0.0106 (0.1740)	0.0003 (0.0003)

Table 4.6. The parameter estimates for the VAR models in Periods 3 and 5. Standard errors in parenthesis. *: significant at 10% level; **: significant at 5% level; *: significant at 1% level**

The main implications from the results above are two-fold. First, the strength of capital controls in Periods 2 and 4, the two periods with relatively loose capital controls, is not significantly related to the exchange rate stability in these two periods, because we do not find any significant Granger causal relationships between the interest rate spread and the exchange rate volatility measure. There is no indication that the loosened capital controls in Periods 2 and 4 have negatively affected the exchange rate stability during these periods. Secondly, there are strong evidences that tightening capital controls may have been used by the PBOC as a countermeasure to the destabilizing CNH exchange rate during Periods 3 and 5, the two periods with the strongest capital controls. But the evidences are incomplete. As discussed in Section 4.3.3, if the tightened capital controls were triggered by increasing CNH exchange rate volatility, we should see a significant and positive Granger causal relationship from the exchange rate volatility measure to the capital control measure, i.e. the interest rate spread. According to the Granger test results in Table 4.5 and the VAR parameter estimates in Table 4.6, such a causal relationship had indeed existed in Period 5, but not in Period 3. Meanwhile, if imposing tighter capital controls had been effective in curbing the exchange rate volatility during these period, we should see a significant and negative Granger causal relationship from the interest rate spread to the exchange rate volatility in these period. We are able to find such a causal relationship in Period 3, but not in Period 5. Despite the significant Granger causal relationship from the interest rate spread to the exchange rate volatility in Period 5, the partial impact from the interest rate spread to the exchange rate was positive instead of negative, as suggested by the parameter estimates of the VAR model in Period 5. As such, although the rising CNH exchange rate volatility appears to have led to the tighter capital controls in Period 5, the capital controls may have further increase the CNH exchange rate volatility rather than reducing it. In comparison, even though the tightened capital controls in Period 3 were probably not triggered by the increasing CNH exchange rate in this period, the capital controls appears to have helped curb the CNH exchange rate volatility in this period. In summary, the financial market openness in China may have been compromised in Period 3 and 5 in favor of exchange rate stability, but such comprise seems to have limited success in supporting the exchange rate stability of the renminbi in the international market.

4.5 Conclusion and Policy Implications

Combining the empirical results from Section 4.4, we are able to draw a big picture on how the three components of the monetary policy trilemma have evolved in China over the five periods. In Table 4.7, we summarize our findings in each of the five periods using qualitative terms.

Components of the trilemma	**Period 1** (6/24/2013 - 5/14/2014)	**Period 2** (5/15/2014 - 8/12/2015)	**Period 3** (8/13/2015 - 2/29/2016)	**Period 4** (3/1/2016 - 9/7/2016)	**Period 5** (9/8/2016 - 3/2/2017)
The level of financial market openness	relatively low	relatively high	relatively low	relatively high	relatively low
The status of monetary policy autonomy	maintained	maintained	maintained	maintained	maintained
The level of exchange rate stability	relatively high	relatively high	relatively low; affected by capital controls	relatively low	relatively low; affected by capital controls

Table 4.7. The attainment of the three components of the monetary policy trilemma. The level of financial market openness in each period is assessed based on the strength of capital controls in each period

Our findings suggest that the trilemma may have been a binding constraint for the PBOC in Periods 1, 3, 4 and 5, because at least one of the three components of the trilemma was compromised during each of these four periods. However, the trilemma seems to have been temporarily overcome in Period 2. Although strictly speaking, the financial market in Mainland China was far from being completely open in Period 2 due to the various policy restrictions on cross-border capital movements. Yet, it is still surprising to see that China's policymakers were able to maintain the highest level of financial market openness among the five periods in Period 2 without sacrificing much on the monetary policy autonomy and the exchange rate stability of the renminbi.

Besides revealing the status of the trilemma as a binding policy constraint in China, our findings also shed lights on the shifting policy priorities of the PBOC over the last few years. It seems that, for the PBOC, the top priority among the three components of the trilemma has always been monetary policy autonomy, because this property has been well-maintained throughout our sample period regardless of the statuses of financial market openness and exchange rate stability, as indicated by our results. The PBOC's second policy priority appears to be alternating between financial market openness and exchange rate stability. As discussed earlier, promoting the internationalization of the renminbi has been a major policy objective for China's policymakers in recent years. This objective demands the PBOC to increase the openness of China's financial market while maintaining a relatively stable renminbi exchange rate, which could be difficult to achieve if monetary policy autonomy is viewed as a prerequisite by China's policymakers. In Period 2, the PBOC may have been helped by the heated stock market in Mainland China, so that it could open up more of China's domestic financial market without worrying much about capital outflows and destabilizing renminbi exchange rate. However, since the collapse of China's stock market in June, 2015 and the shocking devaluation of the renminbi by the PBOC in August, 2015, the PBOC no longer had the favorable market environment needed to advance the renminbi internationalization. Therefore, in the three periods following the structural break in August, 2015, the PBOC could only elect to focus on one of the two objectives: maintaining exchange rate stability and maintaining financial market openness.

In conclusion, our empirical examination on the interaction between the onshore and offshore renminbi interbank interest rates, enabled by the recent introduction of the CNH HIBOR, allows us to take a rare glimpse into the thinking of China's monetary policymakers and conjecture how they have handled the well-known monetary policy trilemma over the last few years. Our results single out the period between May 15, 2014 and August 12, 2015 as a unique period when a relatively high degree of financial market openness, well-maintained monetary policy autonomy, and a relatively stable exchange rate had coexisted with each other in China. Such a period represents the best case scenario that has been achieved by China's monetary policymakers in recent years when facing the challenge of the monetary policy trilemma. A further study can be conducted to identify the key market and policy factors that have contributed to the favorable situation in this period, and to explore the potential practices that can be adopted by China's monetary policymakers to achieve a favorable policy outcome in the future.

CHAPTER V

SUMMARY

The empirical findings in Chapters II, III and IV provide partial answers to the policy questions raised in Chapter I. The results presented in Chapter II suggest that the interbank interest rates in China are still responsive to some of the PBOC's traditional policy instruments such as the deposit benchmark rate and the reserve requirement ratio, but the magnitude of their responses to the policy instruments has been significantly altered by the structural changes related to the 2007-08 global financial crisis and the PBOC's two major operational changes in 2011 and 2013, respectively. Meanwhile, despite the fact that the PBOC has been frequently conducting open market operations in the interbank money market, it is still incapable of managing interest rates with open market operations alone, because the interbank interest rates are yet to become significantly responsive to open market operations. Additionally, there were significant discrepancies between the SHIBOR and the interbank repo rate's responses to policy instruments after the structural changes, hinting a potential complication for the PBOC to control interest rates via the interbank money market.

The results presented in Chapter III suggests that transactions in the interbank money market and the exchange-based money market in China had allowed liquidity shocks to circumvent the regulatory restrictions and market segmentation that set apart the banking sector and China's volatile stock market during the rollercoaster ride of China's stock market between late-2014 and mid-2015 and the "SHIBOR shock" in mid-2013.

This finding can serve as a reminder for China's policymakers and financial regulators regarding the risk of a widespread illiquidity contagion associated the rapid expansion of the two money markets. In order to prevent a system-wide liquidity crisis that could endanger the solvency of China's banking sector, the policymakers in China should closely monitor the flows of funds through the two money markets in China and create new policy measures to alleviate liquidity shocks transmitted through money market transactions.

The results presented in Chapter IV suggest that, as the PBOC opens up China's domestic financial markets and promotes the internationalization of the renminbi currency in recent years, its policymaking has been largely bounded by the monetary policy trilemma like the central banks in the other major economies, with the exception of a 15-month period since May 2014. During this period, a relatively high degree of financial market openness, well-maintained monetary policy autonomy, and a relatively stable renminbi exchange rate had coexisted in China, as indicated by the onshore and offshore renminbi interbank interest rates as well as the renminbi exchange rate. However, this period did not last beyond August 2015. As implied by the results in Chapter IV, the PBOC may have switched their policy priorities among the three components of the trilemma several times in responses to changing market environments. These findings highlight the difficulty for the PBOC to achieve certain policy objectives without compromising on the others.

In summary, this dissertation provides important monetary policy insights related to China's interbank money market that are yet to be uncovered by the previous economics and finance literature. These insights can be valuable for the monetary policymakers in China as they move forward in the further liberalization of China’s financial system.

REFERENCES

Andrews, Donald W.K. 1991. "Heteroskedasticity and Autocorrelation Consistent Covariance Matrix Estimation." *Econometrica* 59 (3): 817-858. doi:10.2307/2938229

Arouri, Mohamed El Hedi, Jamel Jouini, and Duc Khuong Nguyen. 2011. "Volatility Spillovers between Oil Prices and Stock Sector Returns: Implications for Portfolio Management." *Journal of International Money and Finance* 30 (7): 1387-1405. doi:10.1016/j.jimonfin.2011.07.008

Bai, Jushan and Pierre Perron. 2003. "Computation and Analysis of Multiple Structural Change Models." *Journal of Applied Econometrics* 18 (1): 1-22. doi:10.1002/jae.659.

Bank for International Settlements. 2010. "Triennial Central Bank Survey-Report on Global Foreign Exchange Market Activity in 2010." Bank for International Settlements, December.

— — —. 2016. "Triennial Central Bank Survey-Foreign Exchange Turnover in April 2016." Bank for International Settlements, September.

Bartolini, Leonardo, Giuseppe Bertola, and Alessandro Prati. 2002. "Day-to-Day Monetary Policy and the Volatility of the Federal Funds Rate." *Journal of Money, Credit, and Banking* 34 (1): 137-159. doi:10.1353/mcb.2002.0025.

Bernanke, Ben S. and Alan S. Blinder. 1992. "The Federal Funds Rate and the Channels of Monetary Transmission." *The American Economic Review* 82 (4): 901-921.

Bloomberg News, 2015. "China Brokers Tighten Margin Loan Rules Amid Bubble Concerns." Bloomberg News., last modified May 27, accessed November 7, 2016, http://www.bloomberg.com/news/articles/2015-05-28/china-brokers-tighten-margin-lending-rules-to-limit-rising-risks.

Brunnermeier, Markus K. 2009. "Deciphering the Liquidity and Credit Crunch 2007-2008." *The Journal of Economic Perspectives* 23 (1): 77-100. doi:10.1257/jep.23.1.77.

Brunnermeier, Markus K. and Lasse Heje Pedersen. 2009. "Market Liquidity and Funding Liquidity." *The Review of Financial Studies* 22 (6): 2201-2238. doi:10.1093/rfs/hhn098.

Cassola, Nuno and Nathan Porter. 2013. "Systemic Liquidity, Monetary Operations, and Financial Stability in China." In *China's Road to Greater Financial Stability: Some Policy Perspectives*, edited by Udaibir S. Das, Jonathan Fiechter and Tao Sun, 193-241: International Monetary Fund.

Chen, Hongyi, Qianying Chen, and Stefan Gerlach. 2011. "The Implementation of Monetary Policy in China: The Interbank Market and Bank Lending." *Hong Kong Institute of Monetary Research Working Paper* No.26.

Chiang, Thomas C., Bang Nam Jeon, and Huimin Li. 2007. "Dynamic Correlation Analysis of Financial Contagion: Evidence from Asian Markets." *Journal of International Money and Finance* 26 (7): 1206-1228. doi:10.1016/j.jimonfin.2007.06.005.

China Banking Regulatory Commission (CBRC), 2013. *Notice of the China Banking Regulatory Commission on Relevant Issues Concerning Regulating the Investment Operation of Wealth Management Business of Commercial Banks.* China Banking Regulatory Commission Document No. 8 [2013]. [in Chinese].

Chu, Charlene, Chunling Wen, and Hiddy He. 2011. "Chinese Banks: Cash Cushions Thinning as Liquidity Erodes and Forbearance Burdens Rise." *China: Special Report.* December 2. Fitch Ratings, Hong Kong SAR.

Engle, Robert. 2002. "Dynamic Conditional Correlation: A Simple Class of Multivariate Generalized Autoregressive Conditional Heteroskedasticity Models." *Journal of Business & Economic Statistics* 20 (3): 339-350. doi:10.1198/073500102288618487.

Fan, Longzhen and Chu Zhang. 2007. "Beyond Segmentation: The Case of China's Repo Markets." *Journal of Banking and Finance* 31 (3): 939-954. doi:10.1016/j.jbankfin.2006.06.014.

Frank, Nathaniel, Brenda González-Hermosillo and Heiko Hesse. 2008. "Transmission of Liquidity Shocks: Evidence from the 2007 Subprime Crisis." *IMF Working Paper* No. 08/200. doi:10.5089/9781451870589.001.

Frank, Nathaniel and Heiko Hesse. 2009. "The Effectiveness of Central Bank Interventions during the First Phase of the Subprime Crisis." *International Monetary Fund Working Paper* No. 09/206.

Freixas, Xavier and Jean-Charles Rochet. 2008. *Microeconomics of Banking*. 2nd ed. MIT Press.

Funke, Michael, Chang Shu, Xiaoqiang Cheng, and Sercan Eraslan. 2015. "Assessing the CNH-CNY Pricing Differential: Role of Fundamentals, Contagion and Policy." *Journal of International Money and Finance* 59: 245-262. doi:10.1016/j.jimonfin.2015.07.008.

G20. 2016. "G20 Leaders' Communique Hangzhou Summit.", last modified September 6, accessed April 7, 2017, https://www.g20.org/Content/DE/_Anlagen/G7_G20/2016-09-04-g20-kommunique-en.pdf?__blob=publicationFile&v=6.

Gorton, Gary and Andrew Metrick. 2012. "Securitized Banking and the Run on Repo." *Journal of Financial Economics* 104 (3): 425-451. doi:10.1016/j.jfineco.2011.03.016.

Granger, C.W.J. 1980. "Testing for Causality: A Personal Viewpoint." *Journal of Economic Dynamics and Control* 2 (4): 329-352. doi:10.1016/0165-1889(80)90069-X

Granger, C.W.J. 1988. "Some Recent Development in a Concept of Causality." *Journal of Econometrics* 39 (1): 199-211. doi:10.1016/0304-4076(88)90045-0.

Granger, C.W.J., Bwo-Nung Huang, and Chin-Wei Yang. 2000. "A Bivariate Causality between Stock Prices and Exchange Rates: Evidence from Recent Asian Flu." *Quarterly Review of Economics and Finance* 40 (3): 337-354. doi:10.1016/S1062-9769(00)00042-9.

Hamilton, James D. 1996. "The Daily Market for Federal Funds." *Journal of Political Economy* 104 (1): 26-56. doi:10.1086/262016.

Hassapis, Christis, Nikitas Pittis, and Kyprianos Prodromidis. 1999. "Unit Roots and Granger Causality in the EMS Interest Rates: The German Dominance Hypothesis Revisited." *Journal of International Money and Finance* 18 (1): 47-73. doi:10.1016/S0261-5606(98)00044-8.

He, Dong and Honglin Wang. 2012. "Dual-Track Interest Rates and the Conduct of Monetary Policy in China." *China Economic Review* 23 (4): 928-947. doi:10.1016/j.chieco.2012.04.013.

Johansen, Søren. 1991. "Estimation and Hypothesis Testing of Cointegration Vectors in Gaussian Vector Autoregressive Models." *Econometrica* 59 (6): 1551-1580. doi:10.2307/2938278.

Karfakis, Costas J. and Demetrios M. Moschos. 1990. "Interest Rate Linkages within the European Monetary System: A Time Series Analysis: Note." *Journal of Money, Credit and Banking* 22 (3): 388-394. doi:10.2307/1992567.

Kawai, Masahiro and Li-Gang Liu. 2015. "Trilemma Challenges for the People's Republic of China." *Asian Development Review* 32 (1): 49-89. doi:10.1162/ADEV_a_00047.

Krishnamurthy, Arvind, Jennie Bai, and Charles-Henri Weymuller. 2016. "Measuring Liquidity Mismatch in the Banking Sector." *NBER Working Paper Series* No. 22729. doi:10.3386/w22729.

Ma, Guonan and Robert N. McCauley. 2008. "Efficacy of China's Capital Controls: Evidence from Price and Flow Data." *Pacific Economic Review* 13 (1): 104-123. doi:10.1111/j.1468-0106.2007.00392.x.

Ma, Guonan, Xiandong Yan, and Xi Liu. 2011. "China's Evolving Reserve Requirement." *BIS Working Papers* No. 360.

Ministry of Commerce. 2017. "Overseas Usage of RMB Increases, and the Dim Sum Bond Issuance Will Reach New Height this Year.", last modified May 10, accessed April 3, 2017 http://www.mofcom.gov.cn/article/i/dxfw/gzzd/201405/20140500580867.shtml. [in Chinese].

Moschitz, Julius. 2004. "The Determinants of the Overnight Interest Rate in the Euro Area." *European Central Bank Working Paper Series* No. 393.

Mundell, Robert A. 1963. "Capital Mobility and Stabilization Policy Under Fixed and Flexible Exchange Rates." *Canadian Journal of Economics and Political Science/Revue Canadienne De Economiques Et Science Politique* 29 (04): 475-485. doi:10.2307/139336.

Nelson, Daniel B. 1991. "Conditional Heteroskedasticity in Asset Returns: A New Approach." *Econometrica* 59 (2): 347-370. doi:10.2307/2938260.

People's Bank of China. 2005. *The Chronicle of Major Monetary Policy Events in China, 2004*. People's Bank of China. March 25. [in Chinese].

———. 2009. *The Chronicle of Major Monetary Policy Events in China, 2009*. People's Bank of China, February 24. [in Chinese].

———. 2010. *The People's Bank of China Annual Report*. People's Bank of China. [in Chinese].

———. 2011. *The Chronicle of Major Monetary Policy Events in China, 2010*. People's Bank of China, February 1. [in Chinese].

———. 2012. *The Chronicle of Major Monetary Policy Events in China, 2011*. People's Bank of China, February 28. [in Chinese].

———. 2013. *The Chronicle of Major Monetary Policy Events in China, 2012*. People's Bank of China, February 22. [in Chinese].

———. 2014. *The Chronicle of Major Monetary Policy Events in China, 2013*. People's Bank of China, February 28. [in Chinese].

———. 2015a. *Report of China's Monetary Policy Implementation, 1st Quarter 2015*. People's Bank of China, May 9. [in Chinese].

———. 2015b. *The Chronicle of Major Monetary Policy Events in China, 2014*. People's Bank of China, February 26. [in Chinese].

———. 2015c. *The Chronicle of Major Monetary Policy Events in China, 1st Quarter 2015*. People's Bank of China, May 18. [in Chinese].

———. 2015d. *The Executive Report of China's Monetary Policy, 1st Quarter 2015*. People's Bank of China. [in Chinese].

———. 2016a. *The Chronicle of Major Monetary Policy Events in China, 1st Quarter 2016*. People's Bank of China, May 17. [in Chinese].

———. 2016b. *The Chronicle of Major Monetary Policy Events in China, 2015*. People's Bank of China, February 23. [in Chinese].

Porter, Nathan and TengTeng Xu. 2009. "What Drives China's Interbank Market?" *IMF Working Paper* No. 09/189.

Prati, Alessandro, Leonardo Bartolini, and Giuseppe Bertola. 2003. "The Overnight Interbank Market: Evidence from the G-7 and the Euro Zone." *Journal of Banking and Finance* 27 (10): 2045-2083. doi:10.1016/S0378-4266(02)00320-5.

Reuters. 2013. "China Cash Squeeze Eases, but Bank Shares Take Big Hit." last modified June 24, accessed December 3, 2015. http://www.reuters.com/article/2013/06/24/us-markets-china-bonds-idUSBRE95N08420130624.

———. 2014. "China Relaxes Rules for Asset Managers on using RQFII Quotas- State Circular.", last modified June 6, accessed April 3, 2017, http://www.reuters.com/article/china-markets-rqfii-idUSL3N0ON1UM20140606.

———. 2015a. "China Devaluation Sparks Fear of Currency War, Angers U.S. Lawmakers.", last modified August 11, accessed April 3, 2017, http://www.reuters.com/article/us-china-markets-yuan-idUSKCN0QG04U20150811.

———. 2015b. "China Lets Yuan Fall further, Fuels Fears of 'Currency War'.", last modified August 12, accessed April 3, 2017, http://www.reuters.com/article/us-china-markets-yuan-idUSKCN0QG04U20150812.

———. 2015c. "REFILE-UPDATE 2-China Tightens Offshore Yuan Market to Slow Outflows, Rates Rise.", last modified November 18, accessed April 3, 2017, http://www.reuters.com/article/china-yuan-clearing-idUSL3N13D25O20151118.

———. 2016a. "UPDATE 2-China Aims at Speculators with Offshore Yuan Rates of 94 Pct.", last modified January 12, accessed April 3, 2017, http://www.reuters.com/article/china-offshore-yuan-idUSL3N14W1JW20160112.

———. 2016b. "UPDATE 2-Hong Kong Yuan Borrowing Rate at 7-Mth High as China Steadies Currency.", last modified September 14, accessed April 7, 2017, http://www.reuters.com/article/china-offshore-yuan-idUSL3N1BQ1Y2.

Shanghai Stock Exchange. 2014. *Notice of the Shanghai Stock Exchange on Issuing the Detailed Implementation Rules of the Shanghai Stock Exchange for the Securities Trading of Qualified Foreign Institutional Investors and RMB Qualified Foreign Institutional Investors.* Shanghai Stock Exchange Document No. 12 [2014]. [in Chinese].

Shao, Ling. 2006. "A Comparative Analysis of China's Interbank Bond Market and Exchange Bond Market." Master Thesis. Xiamen University. [in Chinese].

Shenzhen Stock Exchange. 2014. *Notice of the Shenzhen Stock Exchange on Issuing the Detailed Implementation Rules of the Shenzhen Stock Exchange for the Securities Trading of Qualified Foreign Institutional Investors and RMB Qualified Foreign Institutional Investors.* Shenzhen Stock Exchange Document No. 36 [2014]. [in Chinese].

Smith, Josephine. 2012. "The Term Structure of Money Market Spreads during the Financial Crisis." Unpublished Working Paper. New York University.

SWIFT. 2011. *SWIFT RMB Tracker, November 2011*. November 25. SWIFT. Brussels, Belgium.

———. 2016. *SWIFT RMB Tracker, November 2016*. November 23. SWIFT. Brussels, Belgium.

The Economist. 2013a. "The Shibor Shock; China's Banks." *The Economist*, Jun 22, 72.

———. 2013b. "Ten Days in June; China's Banks." *The Economist*, Jul 6, 65.

Wan, Xiaoxi. 2006. "The Pricing Model for the Interest Rate Spread between Treasury Bond and Policy Financial Bond and its Tests." *China Money* (4): 44-47. [in Chinese].

Wang, Zijun, Jian Yang, and Qi Li. 2007. "Interest Rate Linkages in the Eurocurrency Market: Contemporaneous and Out-of-Sample Granger Causality Tests." *Journal of International Money and Finance* 26 (1): 86-103. doi:10.1016/j.jimonfin.2006.10.005.

Yang, Jian, Yinggang Zhou, and Zijun Wang. 2009. "The Stock–bond Correlation and Macroeconomic Conditions: One and a Half Centuries of Evidence." *Journal of Banking and Finance* 33 (4): 670-680. doi:10.1016/j.jbankfin.2008.11.010.

Zeileis, Achim. 2006. "Implementing a Class of Structural Change Tests: An Econometric Computing Approach." *Computational Statistics and Data Analysis* 50 (11): 2987-3008. doi:10.1016/j.csda.2005.07.001.

———. 2005. "A Unified Approach to Structural Change Tests Based on ML Scores, F Statistics, and OLS Residuals." *Econometric Reviews* 24 (4): 445-466. doi:10.1080/07474930500406053.

Zeileis, Achim and Kurt Hornik. 2003. "Generalized M-Fluctuation Tests for Parameter Instability." *Report Series* No. 80. SFB “Adaptive Information Systems and Modelling in Economics and Management Science”. August 2-6, Vienna, Austria.

Zhao, Luyuan. 2015. "An Analysis of the Interest Rate Spread between Treasury Bond and Policy Financial Bond." *China Bond* (4): 31-40. [in Chinese].

Zhou, Wenyuan, Zhao Li, and Zheng Sun. 2013. "The Choice of Benchmark Interest Rate and the Pricing of Floating Rate Notes." *China Bond*, July, 73-80. [in Chinese].