学籍番号:CD142008

The Renminbi Exchange Rate Regime after the Reform in 2005

2005 年為替改革後の人民元為替制度に関する実証研究

大学院商学研究科

博士後期課程　会計・金融専攻

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Acknowledgement

First and foremost, I am deeply grateful to Prof. Eiji Ogawa (the main Ph.D. supervisor) and Prof. Masaharu Hanazaki (the Ph.D. co-supervisor). Words are not enough to express my gratitude for their excellent guidance, outstanding advises and never-ending encouragement during the past four years.

I also would like to thank Prof. Takashi Misumi, Prof. Hisashi Nakamura, Prof. Kentaro Kawasaki (Toyo University), Prof. Sanae Ohno (Musashi University), Prof. Takuji Kinkyo (Kobe University), and two anonymous referees of *Japanese Journal of Monetary and Financial Economics* (JJMFE) for their helpful comments on this study. Furthermore, I thank the participants at the Japan Society of Monetary Economics (JSME) Annual Meetings (Spring 2015, Autumn 2016 and Autumn 2017) and the participants at the Hitotsubashi University Center for Financial Research (HCFR) workshops for their helpful comments.

I would like to thank Hitotsubashi University, the Nomura Foundation, and the Kaneko Foundation for International Cultural Communication (KFICC) for their financial support.

Finally, I would like to express my heartfelt gratitude to my great parents for their love, supports and constant encouragements over these years. I undoubtedly could not have done this without you.

Contents

Chapter 1. Introductions

During the last decade when the Chinese economy rapidly developed, China has implemented multiple reforms on the renminbi exchange rate regime to make it more market-based and more suitable to the domestic economic development. The beginning of China's exchange rate reforms is 21 July 2005 when People's Bank of China announced to implement a reform of the exchange rate regime switching from the dollar-peg regime to a managed floating regime with reference to a currency basket and the supply-demand conditions. Since 2010, China has implemented the Renminbi Internationalization to make the renminbi become a global currency, including many reforms such as the renminbi-denominated trade settlements and the setup of offshore renminbi markets. Since the renminbi offshore exchange rate market was established in 2011, the offshore renminbi markets have rapidly developed in many global financial centers, mainly in Hong Kong. The global use of renminbi has increased to the 5th largest, following with the US dollar, Euro, British pound and Japanese yen until the end of 2015. Accomplished with China's large economic size and the increasing renminbi global use, the renminbi was included into the Special Drawing Right (SDR) basket of International Monetary Fund (IMF) in 2016. Many scholars believed that the Chinese renminbi will play an important role in adjusting the global trade imbalance and diversifying global reserve currencies in the international monetary system in future. Due to the renminbi exchange rate regime during 2005–2016 mentioned above, this study has three research objects as follows.

First, this study tried to clarify whether the well-known "*de facto vs. de jure*" problem existed in the renminbi regime during 2005–2016. Some scholars proposed the "*de facto vs. de jure*" problem, which is defined as that the monetary authorities always implement different foreign exchange policies from what they officially claim to follow, particularly in emerging countries such as China. In the early period of the renminbi managed floating regime, many scholars revealed that the renminbi exchange rate was very similar to a dollar-peg rather than a free-floating, due to the high cointegration between the renminbi and the US dollar. The renminbi reforms in recent years again raised the question of what is the *de facto* exchange rate regime of the renminbi, especially considering the recent renminbi depreciation and reforms in August 2015 which was designed to make the currency more market-based. Although China did not publish the components of the official reference currency basket, the China Foreign Exchange Trade System (CFETS) renminbi index published in 2016 provided new evidence about the possible components of the official reference currency basket. This study clarified the "*de facto vs. de jure*" from two perspectives: first, the components of the implicit currency basket was examined by employing the well-known Frankel-Wei model (see Frankel and Wei, 1994, 2008), basing on daily exchange rate data during 2005–2016. Possible structural changes were put into consideration. Second, the renminbi regime was evaluated through the exchange rate flexibility, which provides another perspective to observe the regime switches beside the implicit currency basket, as supposed by Calvo and Reinhart (2002) and Levy-Yeyati and Sturzenegger (2005). Moreover, Dixon, Zhang, and Dai (2016) developed an autoregressive model with Markov switching process to identify the exchange rate regime switches, and this model was employed in this study.

The empirical results of the Frankel-Wei model show that in the implicit currency basket of the renminbi, the US Dollar had a dominant weight (more than 0.9), especially during the Global Financial crisis (GFC) when China actually pegged the renminbi to the US dollar again to lower down the crisis shock. However, the weight of the US dollar decreased significantly after the renminbi reform in 2015. On the other hand, the weights of the other possible components, e.g. Euro, British pound and Japanese yen, varied in different periods and increased after the 2015 reform in general. Moreover, due to the results of the exchange rate flexibility model with a Markov Switching process, it is obvious that the renminbi exchange rate flexibility sharply decreased after 2014, when the monetary authority used a large amount of official foreign reserves to cope with the big renminbi depreciation pressure. Combining with the implicit currency basket and the flexibility of renminbi, the existence of the "*de facto vs. de jure*" problem in the renminbi exchange regime during 2005–2016 has been confirmed.

Second, the linkage between the onshore and the offshore renminbi exchange rates was intensively focused on by policymakers and scholars, because the setup of the offshore renminbi markets could provide valuable experience for the regulatory reforms in Mainland China. Different with the heavily regulated onshore renminbi market, the offshore renminbi exchange rates could float freely and sensitively reflect the supply-demand conditions of the market participants. Deregulations in the cross-border capital flows lead to a tighter interaction between the onshore and the offshore renminbi rates. Previous literature proposed that the cross-market spillover effect between the onshore and offshore rates was very large in the early period since the offshore market established, and these two renminbi exchange rates had a very similar trend.

This study focused on the effect of the renminbi reform in 2005 on the onshore-offshore linkage, because the reform shocks on the two renminbi seemed very large, and the pricing differential between the two RMB rates sharply increased, showing a possible structural change. Therefore, this study examined the onshore-offshore linkage from two perspectives: first, the cross-market spillover effect was analyzed by employing a DCC-GARCH model; second, this study also analyzed the different adjustment mechanisms of the onshore-offshore pricing differential by employing a self-excited threshold autoregressive (SETAR) model.

The empirical results are as follows. Referring to the estimated results of the DCC-GARCH model, the mean spillover effect from offshore to onshore was much larger than the vice versa in the total period, revealing that the onshore renminbi market had a stronger power in pricing determination than the offshore market. This is very different from the early stage when the offshore market was just built. Moreover, the official renminbi exchange rate (or the so-called central parity rate) was the most determinant factor for both two renminbi rates, showing the strong policy power for the renminbi. The dynamic conditional correlations (DCC) between the forecast errors of the two renminbi rates decreased and became more volatile in the post-reform sub-period. Furthermore, the results of the SETAR model show that the onshore-offshore pricing differential became larger and less convergent after the reform. These results reveal that the reform shock in 2015 weakened the onshore-offshore linkage.

Third, China's trade imbalance (surplus) sharply deteriorated in the 2000s and returned to an acceptable level in recent years. The classical theories of the international finance, e.g. Friedman (1953) and Obstfeld and Rogoff (1996), proposed that a more flexible exchange rate is key to one country's trade rebalance. However, the recent literature, e.g. Chinn and Wei (2013), revealed that more exchange rate flexibility may not lead to the reversion of the trade imbalance, due to that the nominal exchange rate needs time to affect the real exchange rate, which matters for the trade rebalance. This study tried to solve whether the renminbi exchange rate effectively helped to rebalance China's large trade imbalance since 2005 when China switched renminbi regime from dollar-peg to the managed floating regime. By employing structural vector autoregressive (SVAR) model including five variables (foreign GDP, real interest rate, domestic GDP, trade and real effective exchange rate) proposed by Ogawa and Iwatsubo (2009), this study examined the period during 1998–2016 basing on quarterly data. Also, to examine the time-varying effect of the trade rebalance, this study employed a time-varying parameter vector autoregressive (TVP-VAR) model proposed by Primiceri (2005) and Nakajima (2011). Moreover, referring to the widely-known exchange rate pass-through argument, exchange rate affects one country's trade through adjusting the domestic price level. Hence, this study used the SVAR model including four variables (nominal effective exchange rate, import price index, producer price index and export price index) proposed by Ito and Sato (2008) to examine China's exchange rate pass-through. A TVP-VAR model was also employed to examine the time-varying effect.

The results show that the impulse response of trade to REER was negative in the total period by the SVAR model, showing that the appreciation of REER could generally help reduce China's large trade surplus in the total period. Moreover, the time-varying impulse response of trade to REER by the TVP-VAR model shows that the trade rebalance effect of exchange rate was less effective in the 2000s when the "saving glut" dominated the rapid increase of China's trade imbalance; but it is more effective during 2010–2016 when China's trade surplus returned to a normal level. Furthermore, it is revealed that the increased exchange rate pass-through effectively explained the increased trade rebalance effect after the global financial crisis, but it is less effective for the 2000s. Last, this study found the time-lag of both the trade rebalance effect and the pass-through effect, which take nearly one year to reflect the exchange rate change.

This paper is organized as follows. Chapter 1 provided an outline of the paper as a whole. Chapter 2 identifies the *de facto* renminbi exchange rate regime during 2005–2016 for two perspectives: the implicit currency basket model proposed by Frankel and Wei (2008) and the exchange rate flexibility model with a Markov switching process proposed by Dixon *et al.* (2016). This study proved the existence of the well-known "*de facto vs. de jure*" in the renminbi exchange rate regime. Chapter 3 examined the linkage between the onshore and offshore renminbi exchange rates from two perspectives: the cross-market spillover effect by using a DCC-GARCH model and the adjustment dynamics of the onshore-offshore pricing differential by using a SETAR model. This study proved that the reform shock in 2015 weakened the onshore-offshore linkage. Chapter 4 examined the effect of the exchange rate on rebalancing China's trade imbalance and the exchange rate pass-through effect during 2008–2015. Chapter 5 concludes.

Chapter 2. Diversifying reference currency basket and decreasing degree of flexibility in exchange policy of China

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2.1 Introduction

Clarifying the implemented renminbi exchange rate regime is crucial because of the widespread "*de facto* vs. *de jure*" problem (see Calvo and Reinhart, 2002; Frankel and Wei, 1994; Levy-Yeyati and Sturzenegger, 2005; Obstfeld and Rogoff, 1995), which is characterized by monetary authorities implementing different foreign exchange policies from what they officially claim to follow, particularly in emerging countries. In July 2005, China announced that it was shifting the renminbi exchange rate regime from a dollar-peg to managed floating with reference to a currency basket, without publishing the details of the basket components. Since 2009, when China promoted its renminbi internationalization program, renminbi has been widely considered to be a potential way of diversifying global reserve currencies in the international monetary system (see Ito, 2017; Kawai and Pontines, 2016), especially after renminbi was included in the special drawing right (SDR) basket of the International Monetary Fund (IMF) in October 2016. The increased importance of renminbi again raised the question of what is the *de facto* exchange rate regime of the renminbi, especially considering recent renminbi depreciation and the renminbi

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※This Chapter is based on the journal paper with peer-reviewed, as Luo, Pengfei (forthcoming), "Diversifying reference currency basket and decreasing degree of flexibility in exchange policy of China", *Japanese Journal of Monetary and Financial Economic*, which was accepted in October 2017. The earlier version of this chapter was presented at the annual meeting of Japan Society of Monetary Economics, Kansai University (Osaka), on 15 October 2016.

reforms on 11 August 2015 designed to make the currency more market-based.

Table 2.1 provides the details of the renminbi regime reforms in recent years. Some main points of these reforms are needed to be considered. Firstly, the renminbi exchange rate has been largely dominated by the official rate, or the so-called "central parity rate". In every trading days of the domestic exchange market, the China Foreign Exchange Trade System (the official interbank exchange platform) publishes the daily official rate. The day's transaction prices are limited to a certain range (or the so-called limited bands). During 2015–2016 when the managed floating regime was at a very early stage, the limited band was ±0.3% of the official rates. Although it has been enlarged for several times in recent years and is up to ±2% in March 2014, the trading band of the domestic exchange rate is still being largely controlled by the monetary authority through the official rates and the limited pricing bands. Secondly, though the pricing mechanism of the official rate was published by Governor Zhou Xiaochuan of People's Bank of China as "a currency basket including the main trade partners' currencies" in 2006, the detailed weights of each currency has not been published. Thirdly, China is widely considered to heavily intervene in the domestic exchange market to suppress fluctuations by the large foreign reserves. The details of exchange rate intervention are not published. In summary, accompanying with the development of renminbi exchange market, lack of transparency in renminbi exchange rate interventions has been fiercely criticized by some countries like the United States as "exchange rate manipulator". Therefore, it is extremely important to examine the *de jure* exchange rate regime of the renminbi, due to the possible existence of the so-called "*de facto vs. de jure*" problem lead by the intervention of the monetary authority.

<insert **Table 2.1** here>

The present study evaluated the *de facto* exchange rate regime of China from two perspectives. Firstly, the implicit currency basket model, or the widely-known Frankel-Wei model proposed by Frankel and Wei (2008), has been widely used to reveal the components of one country's currency basket. Furthermore, China has published the official renminbi exchange rate index with component currencies, which will be helpful to reveal the weights of these target currencies in renminbi's implicit currency basket by employing the Frankel-Wei model. Secondly, another method to evaluate one country's *de facto* exchange rate regime is by the exchange rate flexibility, as proposed by scholars, e.g. Calvo and Reinhart (2002) and Levy-Yeyati and Sturzenegger (2005). Moreover, Dixon *et al.* (2016) supposed to implement a Markov switching method to identify different exchange rate regimes through the varying flexibilities. These two main methods were employed in this study to clarify the *de facto* renminbi exchange rate regime during 2005–2016.

The main findings of the present study show that the "*de facto* vs. *de jure*" problem existed from 2005 to 2016. During this period, the *de jure* renminbi exchange rate regime was managed floating with reference to a currency basket. On the contrary, the *de facto* regime was a dollar-peg during the Global Financial Crisis (GFC) in 2008–2010. In addition, during 2005–2008 and 2010–2015, the US dollar's weight in the implicit renminbi currency basket was near to unity, meaning that the renminbi exchange rate regime was a crawling-peg with the US dollar as the only anchor rather than a currency basket. Furthermore, after the renminbi reforms in August 2015, the US dollar's weight decreased to about 0.86, showing that the renminbi exchange rate regime is more likely to be a currency basket because of its more diversified components compared with before 2015. Finally, the results of the foreign exchange flexibility model show that China has adjusted its regulation on exchange rate flexibility according to different external environments. The empirical results reveal that under unstable situations such as the GFC and European debt crisis, renminbi flexibility was heavily regulated, especially after the renminbi reforms in August 2015.

The rest of this Chapter is organized as follows. Section 2.2 states the previous literature. Section 2.3 explains two methodologies employed in this study to identify the de facto exchange rate regimes: the Frankel-Wei model (implicit currency basket model) proposed by Frankel and Wei (2008), and the exchange rate flexibility model with a Markov switching process which was proposed by Dixon *et al.* (2016). Section 2.4 reports the empirical results. Section 2.5 contains the conclusions and implications of the study.

2.2 Previous literature

Previous studies have often discussed the *de facto* renminbi exchange rate regime. For example, the Frankel–Wei model (see Frankel and Wei, 1994, 2008) is widely used to estimate the components of the implicit currency basket. The early debate on the renminbi exchange rate regime focused on whether the US dollar-peg was to be retained for the implementation of the managed floating regime with a reference currency basket. Many scholars have argued that the

US dollar was still the single anchor of renminbi before the global financial crisis (GFC) in 2008–2009, meaning that the so-called managed floating regime is similar to a crawling-peg regime with a US dollar anchor (see Eichengreen, 2007; Frankel and Wei, 2008; Ito and Orii, 2006; Moosa, Naughton, and Li, 2009; Ogawa and Sakane, 2006; Zeileis, Shah, and Patnaik, 2010). For example, Ogawa and Sakane (2006) analyzed the very early period since China implemented the managed floating regime during 2015–January 2016 by employing the Frankel-Wei model, and revealed the dominatingly high weight of the US dollar in renminbi's reference currency basket. Also, Zeileis *et al.* (2010) analyzed the period during 2005–2008 (the global financial crisis) and investigated the US dollar's dominant role in renminbi's basket.

In addition, the IMF's Annual Report on Exchange Arrangements and Exchange Restrictions (AREAER) classifies renminbi as a crawling-like arrangement, in that "*a currency appreciates or depreciates in a sufficiently monotonic and continuous manner with a narrow margin of 2% for at least six months*," rather than as a "floating" currency. Because the official China Foreign Exchange Trade System (CFETS) renminbi index published in 2015 provides new evidence of the components of renminbi's reference basket, it is employed in this study to analyze the implicit basket of the renminbi and possible regime-switching points.

Moreover, many researchers have also argued that the degree of exchange rate flexibility is a good measure for capturing the evolution of a country's exchange rate regime because of the "fear of floating"; in other words, monetary authorities do not always let their currencies flexibly float as they claim (see Calvo and Reinhart, 2002; Dixon *et al.*, 2016; Levy-Yeyati and Sturzenegger, 2005). Furthermore, Dixon *et al.* (2016) proposed defining an exchange rate regime in terms of the degree of exchange rate flexibility under a Markov-switching process, thereby providing a method other than the Frankel–Wei model to identify the regime-switching points of the renminbi. This method is also used herein to reveal the *de facto* exchange rate regime of the renminbi.

2.3 The implicit currency basket of renminbi

2.3.1 Methodology

The People's Bank of China (PBOC), the Chinese central bank, announced a regime switch from a dollar-peg to a managed floating regime in July 2005. Since then, the renminbi exchange rate has been managed by referring to a currency basket; however, the details of the basket have not been published. Frankel and Wei (1994) proposed their implicit currency basket model based on monthly exchange rate data to reveal the "*de facto* vs. *de jure*" problem in East Asian currencies. This model has been widely used by other researchers to analyze renminbi's exchange rate regime. Both Frankel and Wei (2008) and Frankel and Xie (2010) revised this model to a daily data-based model. Moreover, the selection criteria for the numeraire currency and structural change test (see also Zeileis *et al.* (2010)) were mentioned in the revised model. In this study, the implicit currency basket model proposed by Frankel and Wei (2008) is employed to estimate the components and weights of renminbi's implicit currency basket, written as

$$RMB_t = \sum_{i=1}^{n} \omega_t \cdot X_{i,t} \tag{2.1}$$

where RMB_t is the exchange rate of renminbi against one numeraire currency at time t; $X_{i,t}$ is the exchange rate of reference currency i against the numeraire; n kinds of currencies are included in the basket; and ω_i represents the weight of currency i. The exchange rate of renminbi against one numeraire currency is considered to be a weighted sum of the exchange rates of the components in the basket against the numeraire. Moreover, there are no constant or error terms on the right-hand side of the equation if the currency basket is perfect. To avoid the non-stationarity problem, the logarithm returns of the exchange rate were used. Furthermore, Frankel and Wei (2008) suggested using logarithm returns rather than nominal returns to avoid the non-stationarity problem, written as

$$\Delta \ln RMB_t = c + \sum_{i=1}^{n} \left[\omega_t \cdot \Delta \ln(X_{i,t}) \right] + u_t \tag{2.2}$$

where the constant c represents the gradual crawling trend (either appreciation or depreciation) of renminbi against the entire currency basket. u_t is the error term, showing the differential from the rate decided by the basket.

The selection criterion for the numeraire proposed by Frankel and Wei (1994) are as follows: the numeraire currency is not included within the right-hand side of the Frankel-Wei model, and satisfies the "*floating*" and "*remote*" selection criterion. In addition, it is a "*tradable*" currency in the domestic interbank market. In the previous literature, the Swiss franc (see Eichengreen, 2007; Frankel and Wei, 1994) and the Canadian dollar (see Yamazaki, 2006) have also been feasible selections. In addition, Ogawa and Shimizu (2006) used the trade-weighted average of the US dollar and euro as the numeraire of the Asian Monetary Unit. Additionally, the SDR was employed as the numeraire (see Fang, Huang, and Niu, 2012; Frankel and Wei, 2008; Frankel and Xie, 2010). However, referring to the composition of the SDR basket, there should be multicollinearity when the SDR is used as the numeraire of renminbi's reference currency basket. In this study, the Mexican peso was chosen as the numeraire, as it is "*floating*", "*remote*" and "*tradable*" in China's interbank exchange market.

Regarding data frequency, although many studies have used monthly exchange rates to estimate implicit currency baskets, this study employed daily exchange rates, because the effects of intervention may be eliminated during the month (see Frankel and Xie, 2010; Zeileis *et al.*, 2010). An ordinary least squares regression was employed for the estimation. Additionally, the weights in the Frankel–Wei model are not necessarily positive because they are proxied for by the estimated co-movement between the renminbi and one component currency. Hence, a negative weight for a certain foreign currency in the basket realistically reflects its negative correlation with renminbi in a certain period (see Branson and Katseli, 1982; Edison and Vårdal, 1990; Zhang, Shi, and Zhang, 2011).

Furthermore, structural changes in renminbi's reference basket may have occurred within the analysis period owing to the inconsistency of the basket components. Given that the details of the PBOC's interventions are also unpublished, the structural change test proposed by Bai and Perron (2003) was employed to verify the multiple structural breakpoints in a linear regression, based on the residual sum of squares (see Frankel and Xie, 2010; Zeileis *et al.*, 2010).

2.3.2 Empirical results

The data for the daily foreign exchange rates were collected from DataStream. The study period, which runs from 21 July 2005 to 29 July 2016, is divided into three sub-periods: the pre-crisis period from 21 July 2005 to 15 July 2008 when a managed floating regime was implemented; the in-crisis period from 16 July 2008 to 18 June 2010 when the renminbi/USD exchange rate was the *de facto* dollar-peg during the GFC; and the post-crisis period from 21 June 2010 to 29 July 2016. The models for each sub-period are then compared.

Thirteen currencies are included in the renminbi index: the US dollar (USD), euro (EUR), Japanese yen (JPY), British pound (GBP), Australian dollar (AUD), Canadian dollar

(CAD), Swiss franc (CHF), Hong Kong dollar (HKD), Malaysian ringgit (MYR), New Zealand dollar (NZD), Russian ruble (RUB), Singapore dollar (SGD), and Thai baht (THB). As the US dollar is renminbi's single anchor and dominates the weight in the basket, filtering on these 13 currencies is essential for restraining multicollinearity. First, the Singapore dollar, Thai baht, and Hong Kong dollar were excluded from the model because of their extremely high correlations with the US dollar (see **Table 2.2**). The Malaysia ringgit was also excluded thanks to the high similarity between its reference basket and that of renminbi (see Rajan, 2012). Meanwhile, the Russian ruble was excluded owing to its violent fluctuations against other currencies since 2014 when the oil price dropped sharply. Therefore, eight currencies were chosen from the CFETS renminbi index as the components on the right-hand side of Eq. (2.2).

<insert **Table 2.2** here>

Table 2.3 displays the estimated results of the Frankel–Wei models. The results of the pre-crisis period in Column (1) and in-crisis period in Column (2) show that the weight of the US dollar is near unity (0.952 and 0.984, respectively), confirming that it was the single anchor of renminbi before 2010. Although the coefficients of some of the currencies are significant in the pre-crisis and in-crisis periods, the weights of all the currencies except the US dollar are lower than 0.05.The constant in the pre-crisis period is -0.022 (daily, or -5% yearly), showing the steady appreciation trend of the renminbi against the whole basket before the GFC. In the in-crisis period, the renminbi exchange rate is shown to be an anchor only for the US dollar, without a significant trend. These results show that before the GFC, Chinese monetary authorities implemented a crawling-peg with a steady appreciation trend, in which the US dollar was the only anchor. Later, in the in-crisis period, fixing renminbi to the US dollar led to a higher weight for the US dollar and an extremely high R2 of the Frankel–Wei model. Referring to previous studies using the Frankel–Wei model to estimate the renminbi currency basket, Frankel and Wei (2008) proposed that the US dollar's weight in the renminbi currency basket was 1.07 from 2005 to 2008, with the SDR as the numeraire currency. Further, according to Zeileis *et al.* (2010), the US dollar's weight was 0.969 from March 2006 to August 2008, with the Swiss franc as the numeraire. In summary, the above results for the pre-crisis and in-crisis periods are similar to those in the literature, confirming that the US dollar had a dominantly high weight in the renminbi reference basket despite different numeraire selections.

<insert **Table 2.3** here>

I now concentrate on the renminbi regime since 2010 when it switched from a dollar-peg to managed floating. Column (3) shows the estimated results for the post-crisis period from 21 June 2010 to 29 July 2016, while Columns (4) and (5) show the estimated results in the sub-periods separated by the structural change (see Bai and Perron, 2003). The only one breakpoint at a 5% significance level is 8 August 2015, which is the same as the adjustment of renminbi's official rate, and this divides the post-crisis period into two sub-periods: Sub-period 1 and Sub-period 2.

Referring to the estimated coefficients, the US dollar had the highest weight in the basket (0.93, significant at 1% level). The weights of the other currencies were far lower, and not all the results were significant. The constant term shows an average daily appreciation trend of the renminbi against the whole basket, although this is not significant. Comparing the results for Sub-period 1 (in Column (4)) with those for Sub-period 2 (in Column (5)), the weight of the US dollar significantly decreases from 0.95 to 0.86, while the weights of the other main reserve currencies (yen and pound) increase and become significant; however, the weights of the Australian dollar, New Zealand dollar, Canadian dollar, and Swiss franc remain almost constant. The constant terms are -0.007% and 0.023% daily (or -1.87% and 5.83% yearly) in the two sub-periods, showing a significant change in the crawling policy of the PBOC since the reforms in 2015.

In regards to euro, its weight in the pre-crisis and the post-crisis sub-periods are negative and insignificant (-0.03 and -0.014, respectively), even if the European Union is the largest trading partner of China. This study explained the results as follows: in the pre-crisis period, the managed floating regime was at the very early stage and was very similar to the dollar-peg regime. Hence, it is possible that the Chinese monetary authority did not put euro into the reference currency basket, which was also proposed by the previous literature (see also Moosa *et al*., 2009; Ogawa and Sakane, 2006; Zeileis *et al*., 2010). Furthermore, the post-crisis sub-period in the empirical analysis includes the period of the European sovereign debt crisis when the eurozone economy was in recession and the euro exchange rate depreciated. On the other hand, at the same time, the renminbi exchange rate appreciated, leading to the negative co-movement between euro and renminbi. The insignificance of the euro's weights calculated by the Frankel-Wei model reflects euro's lack of importance in the renminbi reference currency basket, showing that the Chinese monetary authority protected the renminbi from the shock of the European debt crisis.

This study used *t*-tests on the difference between the coefficients in Sub-periods 1 and 2 for a robustness check. The null hypothesis was (5)-(4) = 0, meaning that there was no structural change in either of the sub-periods. The results show that the null hypotheses on the constant term and the US dollar, euro, yen, and pound were rejected, demonstrating that the changes in the crawling trend and weights of the main reserve currencies led to the structural change in renminbi's reference basket. In addition, as the weights of the Australian dollar, New Zealand dollar, Canadian dollar, and Swiss franc did not structurally change to a significant degree, the constraint that the weights of these four currencies were stable and unchanged was added into the Frankel–Wei model with a structural change. Columns (7) and (8) display the results, while Column (9) shows the *t*-test results for the null hypothesis that (8)-(7) = 0. There was one structural change on 8 August 2015, which matches the results in Columns (4) and (5). These results support the robustness of the Frankel–Wei model with a structural change.

2.4 The exchange rate flexibility of renminbi

2.4.1 Methodology

Following Levy-Yeyati and Sturzenegger (2005), the differential of the exchange rate flexibilities between multiple currencies was used to distinguish between exchange rate regimes. Because renminbi is different from the domestic exchange market, it could be traded in global financial markets such as Hong Kong and New York without the PBOC's interventions. If the US dollar is the single anchor of the renminbi, the renminbi/USD rate in the domestic market is presumed to be the PBOC's initial interventional target. Hence, Dixon *et al.* (2016) built a flexibility index Fle_index_t, represented by the differential of renminbi/USD rate flexibilities between the domestic and global markets, to evaluate the PBOC's regulatory effect on the domestic market, written as

$$Fle\_index_t = 100 \times \frac{Reletive\ Volatility\ Ratio_t}{Reference\ Base} = 100 \times \frac{sd(D)_{t-20,t}/sd(G)_{t-20,t}}{Reference\ Base} \tag{2.3}$$

The steps of this process are as follows. First, $Relative\ Volatility\ Ratio_t$ is built to evaluate the relative degree of volatility in the domestic market ($sd(D)_{t-20,t}$) against that in the global market ($sd(G)_{t-20,t}$), represented by the standard deviations of daily renminbi/USD logarithm returns within 21 days (one trading month) both domestically and globally. Then, $Reletive\ Volatility\ Ratio_t$ is divided by $Reference\ Base$, the ratio on a specific date as the base, to create an index. As cross-border capital flows are restricted in Mainland China, heavy regulations (such as interventions) on the renminbi/USD rate in the domestic market lower Fle_index_t during a specific period. Meanwhile, deregulations in the domestic market raise Fle_index_t.

Furthermore, because Fle_index_t proxies for the flexibility of the regulated renminbi rate compared with the unregulated renminbi rate, it is assumed to have different adjustment processes when monetary authorities heavily or lightly regulate the renminbi exchange rate. Hence, (see Dixon *et al.*, 2016) applied an Markov switching framework to reveal the regime changes in the renminbi exchange market evaluated by Fle_index_t, written as

$$Fle\_index_t = \alpha(s_t) + \beta[Fle_{index_{t-1}} - \alpha(s_{t-1})] + \varepsilon_t$$

$$\text{Regime variable: } s_t = \begin{cases} 1 & \text{high} - \text{flexibility regime} \\ 2 & \text{low} - \text{flexibility regime} \end{cases} \text{ when } \alpha(s_t = 1) > \alpha(s_t = 2) \tag{2.4}$$

where two flexibility regimes (or two states), namely a high-flexibility regime and low-flexibility regime, are included in the Markov switching framework, which is identified by an unobservable regime variable s_t. $s_t = 1$ shows the high-flexibility regime with light regulations and $s_t = 2$ shows the low-flexibility regime with heavy regulations. The mean (constant) term coefficient $\alpha(s_t)$ depends on s_t, while the autoregressive coefficient β is unconditional on s_t. The error term ε_t follows a usual i.i.d assumption. Because flexibility is larger on average in the high-flexibility regime than in the low-flexibility regime, the mean coefficient $\alpha(s_t)$ should fulfill $\alpha(s_t = 1) > \alpha(s_t = 2)$, which is employed as the criterion to identify the two possible regimes. Under the Markov switching framework, the regime variable s_t at each time point *t* can be estimated Hamilton (1994). Hence, Dixon *et al.* (2016) suggested that the regime-switching points can be adopted to identify different exchange rate regimes from the perspective of their exchange rate flexibility. Moreover, they proposed an extended Markov switching process by adding some of the possible driving factors of the flexibility index into the standard Markov switching process in Eq. (2.4) as a robustness check, written as

$$Fle\_index_t = \alpha(s_t) + \beta[Fle\_index_{t-1} - \alpha(s_{t-1})] + \sum \gamma_i \cdot Z_{i,t} + \varepsilon_t$$

$$\text{Regime variable: } s_t = \begin{cases} 1 & \text{high} - \text{flexibility regime} \\ 2 & \text{low} - \text{flexibility regime} \end{cases} \text{ when } \alpha(s_t = 1) > \alpha(s_t = 2) \tag{2.5}$$

where $Z_{i,t}$ and γ_i represent the additional driving factors and their coefficients, while γ_i was hypothesized to be unconditional on the regime variable s_t. Eq. (2.5) uses the same criterion to identify the two possible regimes as before.

Dixon *et al.* (2016) suggested two possible driving factors. The first one, CDS_DIF, represents the spread of credit default swaps between China and the United States. This is employed to proxy for the sovereign risk differential. The differential between domestic and global sovereign risk drives capital to flow to low-risk nations owing to risk aversion, leading to renminbi appreciation in the domestic market and thus a higher flexibility index, although capital restrictions do suppress this effect. Hence, the sign is hypothesized to be negative.

The second one is the exchange market pressure (EMP), a variable adopted to evaluate the intervention effect by using official foreign reserves. Emerging countries are assumed to directly intervene in foreign exchange markets by using official foreign reserves to lower exchange rate volatility (see Frankel and Wei, 1994, 2008; Levy-Yeyati and Sturzenegger, 2005). In this study, the form of daily-based EMP supposed by Frankel and Xie (2010) is employed, which is written as

$$EMP_t = \Delta \ln X_t + \Delta \ln(FR_t / MB_t) \tag{2.6}$$

where X_t, FR_t, and MB_t represent the renminbi/USD rate in the domestic market, official Chinese foreign reserves, and Chinese monetary base (M2), respectively. Additionally, daily-based FR_t and MB_t are converted from the published monthly data by using a cubic spline interpolation. Hence, the sign of EMP is hypothesized to be negative.

Moreover, this study adds another possible driving factor to extend the Markov switching model, namely the interest rate differential between the domestic and global markets (INT_DIF). In reference to interest rate parity theory, higher domestic interest rates lead to a higher renminbi rate in the domestic market and thus a higher flexibility index, although capital controls do minimize this effect. Therefore, the sign of INT_DIF's coefficient is hypothesized to be positive.

2.4.2 Empirical results

Here, the daily renminbi rate in New York markets[1] provided by Federal Reserve Economic Data was employed to proxy for the market-driven renminbi rate. Although Dixon *et al.* (2016) employed the Bank of China bid rate as the regulated renminbi rate, this study chose the daily exchange rates in the Shanghai Interbank market to represent the entire Mainland China market regulated by the intervention of the monetary authorities. The relative volatility ratio on 31 December 2006 was set as the reference base.

Fig 2.1 displays the flexibility index as calculated by Eq. (2.2). Shortly after the renminbi reforms in 2005, Fle_index surged from a low level (6.9 on 19 August 2005) to a high level (88.3 on 1 September 2005), showing a sharp increase in the exchange rate flexibility of Mainland China in the initial stage of the implementation of managed floating. After that, the index fluctuated within the range of 50 to 150 until the monetary authority re-pegged renminbi to the US dollar in 2008. From 2008 to 2010, the flexibility index experienced a two-year low (below 60 most of the time). After the renminbi exchange rate regime switched from a dollar-peg to managed floating in June 2010, the flexibility index gradually returned to the level before the GFC. Moreover, at the end of 2013 when the PBOC dominated unilateral appreciation by raising the official rate to strengthen the renminbi internationalization program, the flexibility index surged sharply and even exceeded 300. The above results for 2005–2013 are similar to those of Dixon *et al.* (2016), even though they chose the BOC bid rate as the regulated renminbi rate. Moreover, the flexibility index supports the idea that central banks tend to lower exchange rate volatility in the domestic market to stabilize their domestic currencies under uncertain financial circumstances globally (see D. He and McCauley, 2010).

<insert **Fig 2.1** here>

Let us now concentrate on the period from 2014 to 2016, which was not included in Dixon *et al.* (2016). The flexibility index gradually increased from 24 on 24 March 2014 when the daily limit band expanded from ±1% to ±2%. However, it plunged in December 2014 and

[1] Although Hong Kong is the largest offshore renminbi market globally, the Hong Kong renminbi to US dollar spot exchange rates market began in March 2011. Therefore, the daily spot renminbi to US dollar exchange rate in New York published by the Federal Reserve is selected as the proxy for the offshore renminbi exchange rate.

stayed at a low level until May 2015 when negotiations about renminbi's inclusion in the SDR basket began. The flexibility index rose to about 200 following the renminbi regime reforms in August 2015 and fell to about 30 in December 2015. In 2016, it first increased to about 150 and then began to fall in June. Overall, given that the degree of flexibility switched multiple times during the study period from 2005 to 2016, the Markov switching framework is helpful to identify the possible regimes and regime-switching points for the PBOC's regulation of the renminbi exchange rate.

The estimated results of the Markov switching model in **Table 2.4** provide evidence that the degree of flexibility varies markedly between the two regimes. As shown in Panel A of Column (1), in the high-flexibility regime, the constant coefficient $\alpha(s_t = 1)$ is 101.39; in the low-flexibility, the constant coefficient $\alpha(s_t = 2)$ is 39.38 (significant), thereby fulfilling the criterion that $\alpha(s_t = 1) > \alpha(s_t = 2)$. Therefore, Regime 1 and Regime 2 correspond to the situations when $s_t = 1$ and $s_t = 2$. The coefficient β is 0.98 (significant), showing the high persistence of the autoregressive effect. Moreover, Panel B shows the high regime dependence in both regimes: the probability of staying in the same regime is 99.14% and 99% for the high-flexibility $(s_t = 1)$ and low-flexibility regimes $(s_t = 2)$, respectively. Panel C shows the constant expected duration of the two regimes: 117 days in the high-flexibility regime and 100 days in the low-flexibility regime.

<insert **Table 2.4** here>

The estimated smooth regime probabilities shown in **Fig 2.2** allow us to identify the regime-switching points. The highlighted parts in Panels A and B show the smooth regime probability of the high-flexibility and low-flexibility regimes, respectively. The high-flexibility probability from 2005 to 2008 supports that the domestic foreign exchange market enjoyed a flexible period with light regulation when China implemented managed floating. However, the re-pegging of the renminbi to the US dollar during the GFC caused a low-flexibility period from 2008 to 2010. After 2010, when China re-implemented managed floating, the low-flexibility regime continued until the end of 2012 despite the heavy regulation implemented in Q2 2012 to reduce the shock of the European debt crisis. From the end of 2012 to the end of 2014, the low-flexibility regime continued.

<insert **Fig 2.2** here>

A high-flexibility regime arose in the first half of 2015. Figure 3 shows that the renminbi exchange rates both in domestic and in global markets were stable during this period, leading to a higher degree of flexibility compared with 2012–Q4 2014 when the global renminbi rate was more flexible than the domestic renminbi rate. From mid-2016, the degree of flexibility of renminbi switched to a low-flexibility regime because renminbi depreciated more markedly in the global market than in the domestic market.

Furthermore, the estimated result of the extended Markov switching model shows that different market conditions between domestic and global markets (CDS_DIF and INT_DIF) and the scale of interventions calculated through official foreign reserves (EMP) can explain the exchange rate flexibility in the domestic market compared with the global market. Although these factors have the hypothesized signs, not all of them are significant, possibly because of the restrictions placed on cross-border capital flows in China. Moreover, the similar and significant estimated coefficients and transition matrix in the extended Markov switching model prove the robustness of the Markov switching framework for explaining the different adjustment processes of the degree of flexibility under the two regimes.

In summary, by employing the exchange rate flexibility model proposed by Dixon *et al.* (2016), the main findings are threefold. First, the degree of flexibility shows distinct adjustment processes under high-flexibility and low-flexibility regimes. Second, the Chinese monetary authorities reduced renminbi exchange rate flexibility during the GFC (e.g., 2008–2010 and 2012) to eliminate shocks on the renminbi exchange rate. Third, during the renminbi depreciation from Q1 2014 (except in the first half of 2015), the monetary authorities restricted renminbi flexibility to prevent sharp depreciation.

2.5 Conclusion

As stated by Levy-Yeyati and Sturzenegger (2005), identifying the *de facto* exchange rate regime demands the combination of exchange rate volatility and the volatility of exchange rate changes. In this study, I tried to reveal the *de facto* renminbi foreign exchange rate regime during 2005–2016 from two perspectives: the implicit currency basket proposed by Frankel and Wei (2008) and the degree of flexibility with a Markov switching process proposed by Dixon *et al.* (2016).

Table 2.5 compares the estimated *de facto* renminbi regimes with the *de jure* regimes that were officially announced.

<insert **Table 2.5** here>

The first finding of this study is that the so-called "*de facto* vs. *de jure*" problem existed in renminbi exchange rate regimes. The *de facto* regime during the GFC was a dollar-peg rather than a *de jure*-managed floating regime with reference to a currency basket. Furthermore, the components of the implicit currency basket show that China implemented a crawling-peg regime rather than managed floating with reference to a currency basket in 2005–2008 and 2010–August 2015, as the US dollar's weight in the implicit currency basket is significantly near to unity (see the estimated results of the Frankel–Wei models in **Table 2.2**). This result supports the IMF's AREAER, which classifies renminbi as a crawling-like currency. On the contrary, since August 2016, when renminbi was reformed to be more market-based, the basket components are shown to be more diversified because of the clear decline in the US dollar's weight from 0.95 to 0.86, supporting the official announcement on 11 August 2016 that re-emphasized the reference to a currency basket.

Moreover, it is revealed that the monetary authorities adjusted their regulation on exchange rate flexibility according to real-world situations. For example, in the pre-crisis period from 2005 to 2008, the high-flexibility regime helped the development of the renminbi exchange rate market, while the low-flexibility regime during the GFC from 2008 to 2010 helped reduce global shocks. In addition, the official announcement in 2010 concerning the implementation of a more flexible regime is supported by the high-flexibility regime from June 2010 to Q4 2012, although this regime only lasted for two years. Indeed, during the period of strong depreciation from Q4 2014 to Q3 2015, a high-flexibility regime arose for two possible reasons. First, the heavy interventional cost under strong depreciation restrained the monetary authorities' interventions, supported by the sharp decline in China's official foreign reserves. Second, political considerations meant that the PBOC retained a relatively flexible renminbi to meet the IMF's requirements for renminbi inclusion in the SDR. Since the regime reforms of August 2015, the low-flexibility regime has been implemented to relieve the sharp depreciation.

These findings suggest some implications for future renminbi regime reforms. Although the renminbi exchange market has been deregulated (e.g., daily trading bands have been expanded), the dominant weight of the US dollar in the implicit currency basket of renminbi shows that the renminbi rate still heavily depends on the US dollar, which would slow the process of renminbi becoming a widely used global currency. Hence, a more diversified reference currency basket is needed if China wishes to continue to promote renminbi internationalization in the future. Furthermore, it is appropriate for China to continue to prioritize renminbi rate stability rather than structural reforms under uncertain external conditions such as the GFC and renminbi depreciation. Hence, the deregulation of renminbi flexibility in the renminbi internationalization policy should be promoted under more stable circumstances in the future.

Chapter 3. The linkage between the onshore and offshore renminbi exchange rates

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3.1 Introduction

Since the offshore renminbi market established in Hong Kong in 2011, it has attracted much attention from scholars and policymakers. As an important experimental field of the renminbi internationalization, the offshore renminbi market could provide a meaningful experience for the future deregulations on the onshore renminbi market. **Table 3.1** shows the different market conditions between the onshore and the offshore renminbi markets, which are considered to lead to different renminbi exchange rates: the onshore rate (named as the CNY rate) is heavily regulated by the official renminbi rate (or the so-called central parity rate), daily limited pricing bands, and direct intervention by the Chinese monetary authority, since China announced to switch from a dollar-peg regime to a managed floating regime in 2005, while the offshore rate (named as the CNH rate) is free floating without restrictions. Moreover, regulations on the cross-border capital flows in Mainland China limit the cross-market arbitrage between the two renminbi markets.

<insert **Table 3.1** here>

※ The earlier version of this chapter was presented at the annual meeting of Japan Society of Monetary Economics on 30 September 2017 (Kagoshima University), as Luo, Pengfei (2017), "*the Effect of the 2015 Renminbi Reform on the Relationship between Onshore and Offshore Exchange Markets*".

Fig 3.1 shows that the renminbi deposit and bond volumes in Hong Kong experienced a large increase during 2011–2014. The renminbi deposit volume had grown 2.5 times from 1200 billion yuan in 2011 to about 10000 billion yuan in 2015, while the bond volume of renminbi had grown nearly 10 times from 40 billion yuan in 2011 to nearly 400 billion yuan in the same period. The increased market size of the Hong Kong offshore renminbi market and the deregulations on cross-border capital flows in the onshore market brought about a tighter linkage between the onshore and the offshore renminbi exchange rates, as proposed by some scholars, e.g. (see D. He and McCauley, 2010) and Maziad and Kang (2012). However, under the background of the renminbi depreciation since 2014, the People's Bank of China, the Chinese central bank, surprisingly announced to reform the quotation mechanism of the official policy rate to become more market-based and launched a 1.86% renminbi depreciation on 11 August 2016. **Fig 3.2** shows that the renminbi reform in August 2015 led to sharp depreciation both in the onshore and the offshore markets. Moreover, although the trends of the two renminbi exchange rates seemed very similar before the reform in 2015, they became to largely vary in the very early period after the reform, and there was larger renminbi depreciation in the offshore market. However, the large pricing differential between the two renminbi rates became to fade out in the first quarter of 2016 (after a half year of the reform in 2005). Hence, this renminbi reform in 2015 raised a question: was the linkage between the onshore and offshore renminbi exchange rates strengthened or weakened after the reform?

<insert **Fig 3.1** here>

<insert **Fig 3.2** here>

Most of the previous studies analyzed the onshore-offshore linkage from two perspectives: firstly, the cross-market spillover effects between the onshore and the offshore rates are employed for evaluating the cross-market interactions (see Cheung and Rime, 2014; Maziad and Kang, 2012; Yan and Ba, 2010). Furthermore, the pricing differential between the CNY and CNH rates is employed for evaluating the onshore-offshore market integration, considering the different market conditions and limited arbitrage channels (see Cheung, Hui, and Tsang, 2017; Craig, Hua, Ng, and Yuen, 2013; Funke, Shu, Cheng, and Eraslan, 2015). (see Craig *et al.*, 2013) also proposed that the different adjustment processes of the pricing differential could provide information about the intervention policy of the monetary authorities. Therefore, this study analyzed the linkage between the two renminbi rates during 19 March 2014–30 December 2016 from the two perspectives proposed in the previous literature: firstly, the cross-market spillover effect was analyzed by employing a DCC-GARCH model. Second, the adjustment dynamics of the pricing differentials between the onshore and the offshore renminbi exchange rates were analyzed by employing a self-exciting threshold autoregressive (SETAR) model. Moreover, the large reform effect on the two renminbi rate in August 2015 was also put in consideration by dividing the total sample period into two sub-periods: the pre-reform period from 19 March 2014 to 7 August 2015, and the post-reform period from 17 August 2015 to 30 December 2016

The main findings are as follows: firstly, by employing a DCC-GARCH model basing on the daily exchange rate data, I found that the offshore renminbi rate had a larger spillover effect on the onshore rate than the vice versa, and both the onshore and the offshore rate were largely determined by the official rate, showing a high policy control power in renminbi exchange rate pricing. The conditional correlations between the two renminbi exchange rates sharply decreased after the reform and gradually recovered, showing a significant reform effect on the onshore-offshore linkage. Furthermore, by employing a SETAR model basing on the daily onshore-offshore pricing differential data, I found that the pricing differential became larger and less convergent after the reform, showing the increased onshore-offshore segregation. Therefore, due to the results above, it is obviously the onshore market in Mainland China has a larger pricing determinant power and the renminbi reform in August 2015 significantly harmed the onshore-offshore linkage.

The rest of this chapter is organized as follows. Section 3.2 states the previous literature. Section 3.3 discusses the cross-market spillover effect between onshore and offshore by using a DCC-GARCH model. Section 3.4 discusses the variant adjusting mechanisms of the onshore-offshore pricing differential before and after the reform by using a SETAR model. Section 3.5 provides the conclusions and implications.

3.2 Previous literature

Due to the heavy cross-market capital flow restrictions in Mainland China, scholars such as Fung and Yau (2012) and Gagnon (2016) suggested that the spillover effect between the two renminbi rates could function through expectations: the onshore rate (CNY) affects the offshore rate (CNH) as a policy signal, while the offshore rate (CNH) affects the onshore rate (CNY) as a market signal basing on market transitions. Reseraches about the onshore-offshore linkage in the very early stage revealed that in the early stage when the offshore market established, the spillover effect from the offshore rate (CNH) to the onshore rate (CNY) is much larger than the vice versa, due to the pricing advantage of the offshore market when the onshore market is heavily regulated. For example, Maziad and Kang (2012) a revealed that the spillover effect from offshore to onshore is larger than vice versa in 2010, showing the pricing advantage of the offshore renminbi market by using a BEKK-GARCH model. Yan and Ba (2010) proposed a similar result with Maziad and Kang (2012), by using a DCC-GARCH model. Furthermore, Leung and Fu (2014) suggested the cross-market spillovers become two-way in 2013, but were less significant, by using VAR and GARCH models. After several deregulations after 2013, e.g. widening the daily limited band and admitting foreign financial institutions into the onshore interbank market, Gagnon (2016) suggested that the cross-market spillover effect between the two renminbi markets would be larger, due a more important role played by the market power in the pricing mechanism of the renminbi.

Moreover, some scholars suggested that the onshore-offshore pricing differentials could provide evidence of the interactions between the two renminbi rates, and proposed some characteristics of the onshore-offshore pricing differentials. For example, Craig *et al.* (2013) suggested that the onshore-offshore pricing differential could reflect the onshore-offshore market integrations and the effect of restrictions on the cross-border capital flows. Also,(see D. He and McCauley, 2010) suggested that the offshore rate always had larger volatilities than the onshore rate when strong shocks happened, and the daily limited bands and the interventions in the onshore market widened the pricing differential. Furthermore, Yu (2012) and Gagnon (2016)argued that a larger pricing differential between onshore and offshore will spark stronger cross-market capital flows (though limited), and then attract monetary authority's intervention for stabilization, leading to different dynamics of the pricing differential. Lastly, Funke *et al.* (2015) proposed that the participants in the two markets have different reactions to some influence factors such as global risk and the policy signals. They also indicated that a regime switching with a threshold is necessary for identifying different adjustment mechanism and different driving factors of the pricing differential in future research. They also pointed out that some exogenous driving factors should be used to explain the onshore-offshore pricing differential, for instance, the policy rate.

3.3 The cross-market spillover effect between the onshore and offshore exchange rates

The total cross-market spillover effect between the two renminbi rates is contradictive for: on one side, referring to China's announcement to make the onshore rate more market-based in the reform in 2015, deregulations on the onshore market will lead to larger cross-market spillover effects, due to the tight economic connections between the Mainland China and Hong Kong. On the other side, the rapid decrease of China's foreign reserves implies large interventions and stronger regulations on the onshore rate, which will weaken the cross-market spillover effects. Therefore, some relative questions are as follows: did the magnitudes of the cross-market spillover effects between the onshore rate and the offshore rate change after the reform? If so, which had a leading role in the pricing determination? In this paper, I applied a DCC-GARCH framework to solve this problem.

3.3.1 Methodology

A generalized autoregressive conditional heteroscedasticity (GARCH) framework proposed by Bollerslev (1986), is well-known for analyzing interlinkages between financial markets. In this paper, a dynamic conditional correlation GARCH (DCC-GARCH, henceforth) model proposed by Engle and Sheppard (2001) and Engle (2002) is employed to measure the time-varying conditional correlation between onshore and offshore markets. With reference to Maziad and Kang (2012), the mean equation consisting a determining process is specified as:

$$Y_t = C + AY_{t-1} + u_t \text{ or } \begin{pmatrix} y_{1,t} \\ y_{2,t} \end{pmatrix} = \begin{pmatrix} c_1 \\ c_2 \end{pmatrix} + \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix} \begin{pmatrix} y_{1,t-1} \\ y_{2,t-1} \end{pmatrix} + \begin{pmatrix} u_{1,t} \\ u_{2,t} \end{pmatrix} \quad (3.1)$$

where Y_t is a 2×1 vector including $y_{1,t}$ and $y_{2,t}$, the daily logarithm returns of onshore CNY and offshore CNH rates against the US dollar between time $t-1$ and t, respectively. C is a 2×1 vector of constant terms capturing daily appreciation or depression trends. In the coefficient matrix A, parameters a_{11} and a_{22} capture the lagged impacts from the market itself; a_{12} and a_{21} capture the cross-market spillover effects, showing how the exchange rate return in one market at time $t-1$ spillover to the rate in the other market at time t. $u_{1,t}$ and $u_{2,t}$ are defined as forecast errors by Maziad and Kang (2012), which are estimated by regression process.

Furthermore, the forecast errors are assumed to follow a multivariate DCC-GARCH framework suggested by Engle (2002), shown in Equation (3.2). There are two steps for estimating the parameters in the DCC-GARCH: the first step is the estimation of the univariate GARCH, and the second step is the estimation of the time-varying conditional correlations for forecast errors $u_{1,t}$ and $u_{2,t}$ in the mean equation. The multivariate DCC-GARCH model is defined as:

$$\begin{cases} u_t = H_t^{1/2}\varepsilon_t \\ H_t = D_t R_t D_t \\ D_t = \mathrm{diag}(\sqrt{h_{11,t}}, \sqrt{h_{22,t}}) \\ R_t = (\mathrm{diag}(Q_t))^{-1/2} Q_t (\mathrm{diag}(Q_t))^{-1/2} \\ Q_t = (1-\lambda_1-\lambda_2)\bar{Q} + \lambda_1 \tilde{u}_{i,t-1}\tilde{u}_{j,t-1} + \lambda_2 Q_{t-1} \end{cases} \tag{3.2}$$

where H_t is a matrix of time-varying conditional variance h_t; the variances $h_{11,t}$ and $h_{22,t}$ are obtained with univariate GARCH (1,1) process as

$$h_t = b_0 + b_1 u_{t-1}^2 + b_2 h_{t-1} \tag{3.3}$$

ε_t is an 2×1 vector of normal, independent, and identically distributed innovations. R_t is a 2×2 symmetric dynamic correlations matrix and D_t is a 2×2 diagonal matrix of conditional standard deviations for forecast residuals. Q_t is a 2×2 time-varying covariance matrix of standardized residuals $\tilde{u}_{i,t} = u_{i,t}/h_{i,t}$, and $\bar{Q}$ is the unconditional correlations of $\tilde{u}_{i,t-1}\tilde{u}_{j,t-1}$. Constraints that both λ_1 and λ_2 are non-zero are set. If they are zero, the dynamic conditional correlation turns into a constant one (or called constant conditional correlation GARCH model, or CCC-GARCH).The parameters in DCC-GARCH are estimated using quasi-maximum likelihood method (QMLE). Under the Gaussian assumption, the log-likelihood function is

$$\mathrm{LL} = -\frac{1}{2}\sum_{1}^{2}[2\log(2\pi) + \log|D_t|^2 + u_t' D_t^{-1} D_t^{-1} u_t] + (\log|R_t| + \tilde{u}_t' R_t^{-1}\tilde{u}_t - \tilde{u}_t'\tilde{u}_t) \tag{3.4}$$

Furthermore, some exogenous factors impacting both of the onshore and offshore rates are added to the mean equation for controlling, specified as

$$Y_t = C + AY_{t-1} + BF_{t-1} + u_t \tag{3.5}$$

where F_{t-1} and B represent vectors of exogenous factors and their coefficients, respectively. They are as follows.

First, the daily return of the official policy rate of renminbi against the US dollar, written as fix_t, measures the policy effect from the monetary authorities. Regarding to previous literature, e.g. D. He and McCauley (2010) and Craig *et al.* (2013), the daily official policy rate locks the range of transaction prices in the onshore market, and provides effective information about the official attitude to the future renminbi exchange rate. Hence, the signs of the coefficients on the two renminbi rates are hypothesized to be positive. Moreover, some other forms proposed by Cheung *et al.* (2017), which capture the effect by the official policy rate, are also employed for robustness check: the differential between the policy rate at time *t* and the onshore (offshore) market rates at *t*-1, represented as $fix1_t$ and $fix2_t$ respectively, basing on the thought that the policy rate is a policy tool for correcting the market rate.

Secondly, indicators for market conditions are also controlled in the model: the bid-ask spreads of the exchange rates represented as CNY_BA_t and CNH_BA_t, show the market liquidity conditions. Meanwhile, the interest differential between renminbi and the US dollar could affect the renminbi exchange rate through cross-border capital flows, basing on the Interest Rate Parity theory. CNY_INT_t and CNH_INT_t represent the interest differentials between renminbi and the US dollar in the Mainland and Hong Kong. What is more, the logarithm return of volatility index, represented as VIX_t, is employed to gauge the market's fear about the emerging countries' currencies, e.g. Liang, Shi, Wang, and Xu (2016). In this paper, the volatility index is employed as a global factor. By adding these exogenous factors, the standard DCC-GARCH model in Equation (3.1) is transformed into an extended form as Equation (3.5).

3.3.2 Empirical result

Table 3.2 shows the data descriptions, and all the data are gathered from Thomas Reuters Datastream database. **Table 3.3** reports the summary statistics in two sub-periods: the pre-reform sub-period from 19 March 2014 to 7 August 2015, and the post-reform sub-period from 17 August 2015 to 30 December 2016, respectively. The starting date of the pre-reform samples is set to be 17 March 2014 to control the deregulatory effect when China widened the daily limited band from

±1% to ±2% of the official policy rate. Furthermore, regarding that the renminbi has depreciated against the US Dollar since February 2014 when it reached a record high after the Global Financial Crisis in 2008, the effect of appreciation/depreciation trend switch is controlled in the selected samples. Additionally, samples in the following week of the reform are excluded, due to abnormally values of CNY and CNH[2] caused by the reform shock. By comparing the summary statistics in the two sub-periods, the findings are: the larger means and standard deviations of CNY_t and CNH_t in the post-reform sub-period show larger depreciation trends and more volatile market conditions both in the onshore and offshore markets. Furthermore, the means of the official policy rate fix_t show that China permitted larger devaluations in the post-reform sub-period as announced in the reform.

<insert **Table 3.2** here>

<insert **Table 3.3** here>

Panels in **Table 3.4** report the estimation results of the DCC-GARCH model for the pre-reform and post-reform sub-periods, respectively. Both the benchmark and extended DCC-GARCH models satisfy the constraint that both of λ_1 and λ_2 are non-zero, which is used to identify whether a DCC-GARCH or a CCC-GARCH model satisfies.

<insert **Table 3.4** here>

Regarding to the estimated parameters in the mean equations, the main findings are: first, the spillover effect from CNH to CNY (pre-reform: 0.26; post-reform: 0.15) was much larger than the vice versa (pre-reform: 0.05; post-reform: 0.06), showing the pricing advantage of the offshore market, despite that this advantage declined after the reform. On the other hand, the policy rate played a more important role in the pricing determinations both of the onshore and the offshore rates, and this policy effect was much larger than the two-way spillover effects, showing that both of the onshore and offshore rates were heavily policy driven either before or after the reform. Moreover, the coefficients of the other form of the policy rate became significant through the reform ($fix1_t$: 0.02 to 0.29; $fix2_t$: 0.005 to 0.42), showing that the policy rate functioned as a market correction tool more after the reform, which could support the reform announcement to become more market-based. Additionally, most of the other controlled exogenous factors were

[2] The official policy rate depreciated by 1.86% and 1.62% on August 11 and 12, 2015, leading to violent market conditions both in CNH and CNY.

not significant in either sub-period, and their coefficients were much less than the cross-market spillovers and the policy effect.

Referring to the dynamic conditional correlation between forecast errors in Figure.3, it mainly ranged from 0.55 to 0.8 before the reform, and a sharp decline from 0.8 to 0.6 was observed in Q2 2015 when China fixed the policy rate and expanded the intervention scale by foreign reserves to slow down the onshore rate depreciation. After the reform, the correlation was steady until the end of 2015 and declined sharply in Q1 2016 when the depreciation was much larger in the offshore market rather than the onshore market in this period. The correlation then returned to about 0.8 rapidly[3] and oscillated upward to 0.9 in Q3. The correlation declined to 0.6 and then fluctuated ranging around 0.6 in Q4 2016 when the renminbi depreciated largely in both markets, and the magnitude of depreciation in offshore was much larger than onshore. That is to say, due to that the offshore rate always depreciated more sharply than the onshore rate after the reform in August 2015, the correlation between the forecast errors was much more volatile in the post-reform period. In order to compare the magnitude of the time-varying correlations in two sub-periods, a t-test for the means and a Wilcoxon z-test for the medians are employed. The results were reported in Table.5. The null hypothesis that the means and medians of correlations equal in two sub-periods were rejected, showing a significant structural change. The magnitude of the correlation is proved to significantly decline by -4.137% in the mean.

In summary, regarding the two-way spillover effects and the correlation between forecast errors which are estimated by the DCC-GARCH models, it is worth noting that the onshore-offshore linkage was weaker after the reform.

3.4 The onshore-offshore pricing differential

3.4.1 Methodology

[3] Some researchers such as Shen and Luk (2017) attributed the sharp fluctuation of the CNH rate in Q1 2016 to monetary authorities' intervention by squeezing RMB liquidity to defend RMB. However, no details about the interventions have been officially published.

The threshold autoregressive model (TAR) is widely-used for analyzing asset prices, which rely on one or more threshold variables for identifying regime switches. Tong and Lim (1980) proposed the self-excited TAR (SETAR) model which is a special case of the TAR model, that the lagged term of the dependent variable is treated as the threshold variable. The SETAR model could help to identify the different adjustment process (or regimes) of the financial assets under different pricing levels. This study employs a SETAR model specified as:

$$D_t = c^s + \beta^s D_{t-1} + \sum \gamma_i^s F_{i,t} + u_t$$

$$\text{with state } s = \begin{cases} 1 & D_{t-1} \leq \lambda \\ 2 & D_{t-1} > \lambda \end{cases} \tag{3.6}$$

where D_t is the onshore-offshore pricing differential. It is calculated by $D_t = \log(CNH_t/CNY_t)$, where CNH_t and CNY_t are the offshore and onshore renminbi exchange rates against the US dollar, respectively. A positive D_t represents a discount of CNH against CNY. $F_{i,t}$ is possible exogenous driving factor, including the return of the policy rate (fix_t), the bid-ask spreads (CNY_BA_t, CNH_BA_t), the onshore-offshore interest differential (INT_t), the volatility index (VIX_t), and the dollar index (DXY_t). c^s, β^s and γ_i^s represent the coefficients which rely on the regime s. Two regimes are identified by the lagged term D_{t-1} and a threshold λ. We note regime s=1 if $D_{t-1} \leq \lambda$, showing an integrational state when the pricing differential is smaller than threshold λ; and we note regime s=2 if $D_{t-1} > \lambda$, showing a segregational state when the pricing differential is larger than threshold λ. The parameter β^s shows the rate of convergence of the pricing differential. The coefficients and threshold of the SETAR model are estimated by the minimization of the sum of square errors (SSR) proposed by Bai and Perron (2003).

3.4.2 Empirical results

Table 3.5 reports the summary statistics of the two sub-periods: the pre-reform sub-period is from 19 March 2014 to 7 August 2015, while the post-reform sub-period is from 17 August 2015 to 30 December 2016. Both the means and the standard deviations of the pricing differentials increased, showing that the CNH rate depreciated more than the CNY rate through the reform in 2015. **Fig 3.4** plots the pricing differential during the total period from March 2014 to December 2016. It is obvious that the onshore-offshore pricing differential became larger and more volatile after the reform, supporting that the pricing differential has different dynamics (or adjustment mechanisms) in the pre-reform and post-reform periods.

<insert **Table 3.5** here>

<insert **Fig 3.4** here>

Panels of **Table 3.6** report the estimated coefficients of the SETAR models in the pre-reform and the post-reform periods, respectively. Comparing the results in two sub-periods, the main findings are as follows:

<insert **Table 3.6** here>

Firstly, regarding the reform effect on the onshore-offshore pricing differential, the post-reform model had a much larger explanatory power, due to that the adjusted R-square largely increases from 0.48 in pre-reform to 0.8 in post-reform. The estimated threshold values increased from 12.57 in pre-reform to 50.19 in post-reform, showing the border for separating two regimes became larger in the post-reform. The constant became larger after the reform in both regimes, showing the faster depreciation in offshore than in onshore.

Second, referring to the coefficients of lagged term, the pricing differential tends to be less convergent (or more stable) both in the state 1 (from 0.62 to 0.68 through reform) and state 2 (from 0.49 to 0.84 through reform), showing that the two renminbi rates became more segregational after the reform.

Furthermore, referring to the estimated coefficients of the exogenous driving factors, some global factors such as VIX_t and DXY_t are significant in both sub-periods, showing the different reactions to the global shocks in the two markets. Other factors such as the bid-ask spread and the interest differential have weak robustness, referring to the coefficient significance.

In summary, the results of the SETAR models show that the onshore-offshore pricing differential became larger and less convergent after the reform, showing the increased onshore-offshore segregation. The possible reason is that China's efforts to stabilize the onshore rate after the reform, such as official interventions and strengthening regulations on capital flows, made the cross-market arbitrage more difficult. Though China permitted renminbi depreciation in the official rate after the reform, the offshore rate tended to depreciate more largely than the onshore market rate, and interventions and capital controls made the pricing differential more steady. Therefore, from the perspective of the pricing differential adjustment mechanisms, the onshore-offshore linkage obviously became weaker after the reform.

3.5 Conclusion

Since the offshore renminbi market was set up in Hong Kong in 2011, it has rapidly developed and has become a renminbi hub for the renminbi-denominated trade settlements and financial investments, due to increasing market size and out of restrictions relative to the onshore market. The linkage between the onshore and the offshore rates has been widely concerned during the past years, because it could provide valuable experience for deregulations on the onshore exchange market in future. Be different with the early literature, this study focused on the onshore-offshore linkage under a different circumstance that during 2014–2016 the renminbi faced a large depreciation pressure and experienced a big reform shock in August 2015. This study analyzed the linkage between the onshore and the offshore rates from two perspectives: firstly, I examined the cross-market spillover effect by using a DCC-GARCH model. Second, I examined the adjustment mechanism of the onshore-offshore pricing differential by employing a SETAR model. The reform effect was put into consideration by dividing the total period from March 2014 to December 2016 by the 2015 renminbi reform, and comparing results in the two sub-periods. The empirical results of both models revealed that the onshore-offshore linkage was weaker after the reform, due to the weaker cross-market spillover effect and the less convergent pricing differential in the post-reform period comparing to the pre-reform period.

Since the renminbi internationalization was officially launched in 2009, China has affirmed its long-term target to make the renminbi become a global currency by deregulating on the onshore exchange regimes and building an offshore renminbi market in Hong Kong and other financial centers. The large depreciation pressure of renminbi after 2014 forced the monetary authority to slow down the steps of deregulations and stabilize the renminbi exchange rate firstly. This paper revealed that the onshore-offshore linkage was weaker after the reform in 2015, though China announced to make the onshore rate more market-based. If China chooses to promote the renminbi internationalization by launching more deregulations on the onshore exchange market and the cross-border capital flows, the onshore-offshore linkage is expected to be more tightened in future.

Chapter 4. The trade rebalance effect of exchange rate and the exchange rate pass-through

4.1 Introduction

China's reforms on the renminbi exchange rate regime raised a question: did the renminbi exchange rate effectively helped to rebalance China's large current account surplus since 2005 when China switched renminbi regime from dollar-peg to the managed floating regime? During the last fifteen years, policymakers and scholars have strongly concerned China as the key to improving the global imbalance, which is mainly characterized as the large current account deficit for the United States and the large current account surpluses for most East Asian countries and the oil exporting nations. Among these countries, China has been widely considered as the key factor to rebalance the global trade, due to its large trading volume and large trade surplus. It is widely believed that the exchange rate appreciation should lead to a decrease in trade surplus.

Fig.4.1 shows China's trade (goods: net) and the exchange rate during 1998–2016. In the 2000s the trade imbalance (trade surplus in the percentage of GDP) has rapidly increased from 2% in 2001 to 9% in 2008. In the other hand, the renminbi (real effective exchange rate, 2010=100) firstly depreciated by about 16% from 2001 to 2005, and generally kept appreciating since 2005 when China implemented the managed floating regime, despite some short period of depreciation, e.g. 2008 (the global financial crisis) and 2016 (the renminbi reform in 2015). Generally speaking, it seems like a negative relation between the renminbi exchange rate and the trade surplus in a long run, but it is not consistent during the total period.

This paper examined the trade rebalance effect of China's exchange rate during 1998–2016. The main findings are as follows. By employing a structural VAR (SVAR) model proposed by Ogawa and Iwatsubo (2009) basing on the neo-classical IS framework, it is revealed that generally in the total period, the appreciation of China's real effective exchange rate could help reduce the large trade surplus. But this effect varied over time and is more effective during the 2010–2016 when China's trade surplus returned to a normal level relative to the economic size, referring to a time-varying parameter VAR (TVP-VAR) model proposed by Nakajima (2011). Basing on that, this paper further examined whether the exchange rate pass-through affected the trade rebalance effect of the exchange rate, by employing the SVAR model proposed by Ito and Sato (2008) and a TVP-VAR model to identify the time-variance. It is revealed that the increased exchange rate pass-through effectively could well explain the increased trade rebalance effect after the global financial crisis, but it is less effective for the 2000s.

The rest of this chapter is organized as follows: in section 4.2, the previous literature is reviewed. In section 4.3, the trade rebalance effect of China's exchange rate is examined. In section 4.4, the exchange rate pass-through effect is examined. Section 4.5 concludes.

4.2 Previous literature

Conceptually, one country's exchange rate should be negatively correlated with its current account (see Friedman, 1953; Obstfeld and Rogoff, 1996). That is to say, the higher exchange rate will lead to more import and less export, reducing the trade imbalance. Furthermore, it points to the effective exchange rate (REER) which is the weighted average of a country's currency relative to a basket of its trade partners' currencies, rather than the nominal exchange rate. However, the exchange rate's effect on rebalancing the trade imbalance depends on some things.

First, it depends on one country's economic structure. The widely-known "global saving glut" hypothesis proposed by Bernanke (2005) describes a situation in which one country's desired domestic savings exceeds desired domestic investment leads to a trade surplus, due to the countries highly excess domestic savings, especially the East Asian countries such as China. Most previous literature investigated China's large trade surplus during the 2000s, and indicated that the largest dominant of China's large trade surplus is the Chinese GDP, or aggregate domestic demand, rather than the exchange rate (see Cline, 2012; Felipe, Kintanar, and Lim, 2006; Fratzscher, Juvenal, and Sarno, 2010; L. He, 2008; Ma, McCauley, and Lam, 2013; Thorbecke and Smith, 2010). For example, against to the criticism of China's exchange rate manipulation by the US government, Ogawa and Iwatsubo (2009) revealed that the renminbi revaluation should contribute less to the reduction of China's large trade surplus in the 2000s by employing structural employed vector autoregressive (SVAR) approach. They argued that the "global saving glut" argument relies on neo-classical economics, in which it is not the exchange rate but rather the saving-investment balance that determines the current account in the 2000s.

Another factor which refers to the exchange rate's effect on the trade rebalancing is the exchange rate regime. Scholars such as Obstfeld and Rogoff (1996) and Hoffmann (2013), supposed that a flexible exchange rate regime could help to reduce the global imbalance. Most of the literature about China's trade surplus in the 2000s used data during 1990s to around 2006, when China mainly implemented dollar-peg. On the other hand, scholars such as Thorbecke and Smith (2010), Chinn and Wei (2013) and Li, Ma, and Xu (2015) supposed that switching to a more flexible nominal exchange rate may not immediately facilitate the current account adjustment, because reflections in the effective exchange rate need time. Referring to Dixon *et al.* (2016) and Luo (forthcoming), the flexibility of renminbi exchange rate has increased during 2005–2016, because China implemented many reforms on the renminbi. Therefore, exchange rate's effect on rebalancing trade could be expected to increase during this period.

Furthermore, exchange rate affects one country's trade through import price, export price, and domestic price. Referring to the exchange rate pass-through (ERPT) theory, the incompleteness of the exchange rate pass-through will worsen the trade imbalance adjustment. Cheng and Liu (2007), Cui, Shu, and Chang (2009) and Sheng and Tao (2013) revealed the incompleteness of China's ERPT before the GFC in 2008. Auer (2015) suggested that the revaluation of renminbi during 2005–2008 has increased the pass-through effect on domestic price and spread to the United States through export. In general, the ERPT effect could help to explain the exchange rate's effect on rebalancing trade.

Additionally, Primiceri (2005) and Nakajima (2011) introduced a time-varying parameter VAR (TVP-VAR) model, which allows time variation of stochastic volatility as well as covariance across innovations in different variables. The TVP-VAR model is becoming modern in analyzing the determinant of the trade imbalance or the ERPT effect, e.g. Nakajima and Watanabe (2012) and Shioji (2015). Considering that the several reforms on the renminbi exchange rate should affect the trade rebalancing and the exchange rate pass-through, analyzing by using the TVP-VAR model could provide some evidence of the possible structural changes.

4.3 The renminbi's rebalance effect on China's trade

4.3.1 Methodology

(1) SVAR model

In this part, I analyze the renminbi exchange rate's effect on rebalancing China's large trade surplus. Ogawa and Iwatsubo (2009) employed a standard IS balance model of the neo-classical framework. The current account of one country equals to the domestic savings-investment gap as

$$S(\bar{Y}, \bar{r}) - I(\bar{r}) = CA(e, \bar{Y}, \bar{Y}^*) \tag{4.1}$$

where *S* is the domestic savings, I is the domestic investments, *CA* is the current account, *Y* is the domestic real GDP, Y^* is the foreign real GDP, *r* is the domestic real interest rate, *e* is the real effective exchange rate, respectively. The assumption of flexible prices in the neo-classical framework requires that the domestic real GDP (*Y*) is determined to fully employed factors of the production. Both the foreign real GDP (Y^*) and the real interest rate are assumed to be exogenous for the home country. Both of the real domestic GDP (*Y*) and the real interest rate (*r*) determines the domestic savings-investment gap, or the current account (*CA*). The real exchange rate (*e*) is assumed to adjust to match the current account (*CA*).

Therefore, follows the neo-classical framework, a five variables Structural VAR (SVAR) model with five endogenous variables could be employed, written as

$$\begin{gathered} \mathrm{B(L)}y_t = u_t \\ \mathrm{E}(u_t \; u_t') = \mathrm{D} \\ \mathrm{E}(u_t \; u_{t+i}') = 0, \mathrm{s} \neq 0 \\ \mathrm{B(L)} = B_0 - B_1 L - B_2 L^2 - \cdots - B_s L^s \end{gathered} \tag{4.2}$$

where y_t is a $\mathrm{k} \times 1$ vector of endogenous variables, u_t is a $\mathrm{k} \times 1$ vector of mean zero structural innovations, B(L) is a *s*th order matrix polynomial in the lag operater L, B_0 specify the simultaneous relations of the structural shock by recursive identification, and is assumed that A is lower-triangular, which is the standard recursive constraint.

(2) TVP-VAR model

Moreover, I employ the TVP-VAR model proposed by Primiceri (2005) and Nakajima (2011) for examining the time-varying effect, written as

$$Ay_t = F_1 y_{t-1} + \cdots + F_s y_{t-s} + u_t, t = \mathrm{s} + 1, \ldots, \mathrm{n} \tag{4.3}$$

where y_t a $\mathrm{k} \times 1$ vector of endogenous variables. A_t and F_t are $\mathrm{k} \times \mathrm{k}$ matrices of time-invariant coefficients. The disturbance is u_t a $\mathrm{k} \times 1$ structural shock and we assumed that $u_t \sim N(0, \Sigma\Sigma)$ where

$$\Sigma = \begin{pmatrix} \sigma_1 & 0 & \cdots & 0 \\ 0 & \sigma_2 & & 0 \\ \vdots & & \ddots & \vdots \\ 0 & & \cdots & \sigma_k \end{pmatrix} \tag{4.4}$$

We specify the simultaneous relations of the structural shock by recursive identification, assuming that A is lower-triangular,

$$A = \begin{pmatrix} 1 & 0 & \cdots & 0 \\ a_{21} & 1 & & 0 \\ \vdots & & \ddots & \vdots \\ a_{k1} & & \cdots & 1 \end{pmatrix}. \tag{4.5}$$

The representation of the reduced form of the structural model is defined as follows:

$$y_t = B_1 y_{t-1} + \cdots + B_s y_{t-s} + \mathrm{A}^{-1} \Sigma \quad \varepsilon_t \tag{4.6}$$

where $B_i = A^{-1} F_i$, for i=1,…,s. Stacking the elements in the rows of B_i to form β $(k^2 s \times 1\ vector)$, and defining $X_t = I_k \otimes (y'_{t-1}, \ldots, y'_{t-i})$, where $\otimes$ denotes the Kronecker product, the model can be rewritten as

$$y_t = X_t \beta \quad + \mathrm{A}^{-1} \Sigma \quad \varepsilon_t \tag{4.7}$$

where all the parameters are time-invariant. We extend it to the TVP-VAR model by allowing the parameters to change over time, written as

$$y_t = X_t\beta_t + A_t^{-1}\sum_t \varepsilon_t\, , t = s+1, \dots, n \tag{4.8}$$

where the coefficients β_t and the parameters A_t are time-variant. Following Primiceri (2005), let $a_t = (a_{21}, a_{31}, a_{32} \dots, a_{k,k-1})'$ be a stacked vector of the lower-triangular elements in A_t and $h_t = (h_{1t}, \dots, h_{kt})'$ with $h_{jt} = \log \sigma_{jt}^2$, for $j = 1, \dots, k,\ t = s+1, \dots, n$. We assume the time-variant parameters follow a random walk process as follows.

$$\beta_{t+1} = \beta_t + u_{\beta t} \tag{4.9}$$

$$\alpha_{t+1} = \alpha_t + u_{\alpha t} \tag{4.10}$$

$$h_{t+1} = h_t + u_{ht} \tag{4.11}$$

$$\begin{pmatrix} \varepsilon_t \\ \beta_t \\ \alpha_t \\ h_t \end{pmatrix} = N\left(0,\ \begin{pmatrix} I & O & O & O \\ O & \Sigma_\beta & O & O \\ O & O & \Sigma_\alpha & O \\ O & O & O & \Sigma_h \end{pmatrix}\right) \tag{4.12}$$

for $t = s+1, \dots, n$, where $\beta_{s+1} \sim \mathrm{N}(\mu_{\beta_0}, \Sigma_{\beta_0})$, $\alpha_{s+1} \sim \mathrm{N}(\mu_{\alpha_0}, \Sigma_{\alpha_0})$, and $h_{s+1} \sim \mathrm{N}(\mu_{h_0}, \Sigma_{h_0})$.

The estimation procedure for the TVP-VAR model os illustrated by extending several parts of the algorithm for the TVP regression model. Let $\mathrm{y} = \{y_t\}_{t=1}^n$, and $\omega = (\Sigma_\beta, \Sigma_\alpha, \Sigma_h)$. We set the prior probability density as $\pi(\omega)$ for ω. Given that data y, we draw samples from the posterior distribution, $\pi(\beta, \alpha, \mathrm{h}, \omega |\ \mathrm{y})$, by the following MCMC algorithm:

(1) Initialize $\beta, \alpha, \mathrm{h}$ and ω,

(2) Sample $\beta \mid \alpha, \mathrm{h}, \Sigma_\beta$ and y,

(3) Sample $\Sigma_\beta \mid \beta$,

(4) Sample $\alpha \mid \beta, \mathrm{h}, \Sigma_\alpha$ and y,

(5) Sample $\Sigma_\alpha \mid \alpha$,
(6) Sample $\mathrm{h} \mid \alpha, \beta, \Sigma_\mathrm{h}$ and y,

(7) Sample $\Sigma_\mathrm{h} \mid \mathrm{h}$,

(8) Go to (2).

To obtain the posterior distribution, 10000 iterations of the Gibbs sampler are used and the first iterations for convergence are dropped.

4.3.2 Empirical results

I estimated the SVAR model and the TVP-VAR model by using the quarterly data as follows. The sample period covers from 1998Q1 to 2016Q4. Date on Chinese nominal and real gross domestic production (base year: 2010), and Chinese consumer price index (CPI) are available from National Bureau of Statistics of China (http://www.stats.gov.cn/). Data on the detailed balance of payment and China's one-year domestic bank lending rates are available on the People's Bank of China (PBOC) website (http://www.pbc.gov.cn/). Be noticed that, the current account term in the balance of payments statistics (IMF, BPM6) includes four terms: goods trade, services trade, primary income and secondary income. Referring to China's current account, the primary and secondary incomes are very small. The services trade includes payments of overseas travels, which has extremely affected by travel policies. Therefore, the term "current account: goods, net" is used in this study. The net trade balance is converted into the percentage of Chinese nominal GDP (goods trade/GDP*100, unit:%). The real interest rates were calculated by $real\ interest\ rate = bank\ lending\ rate - CPI$. Moreover, I used the real GDP data of the total Organisation for Economic Co-operation and Development countries as the foreign real GDP (base year: 2010), which are available from the OECD data website (https://data.oecd.org/). Data on China's real effective exchange rates (REER) are available from Bank of International Settlements website. The original data on real GDP have been seasonal adjusted. Chinese real GDP (Y), OECD real GDP (Y*) and real effective exchange rate are transferred into logarithm. **Table.4.1** gives the details of the variables.

<insert **Table 4.1** here>

Table.4.2 reports the descriptive statistics and the unit root test results (Augmented Dicky-fuller test and Phillips-Perron test) on data, showing that not all the variables are stationary at level. It is puzzling whether to difference or not to difference the variables before building the VAR framework. Hamilton (1994) suggest not to differencing the variables, because it may lead to a large loss of data. Therefore, be similar with Ogawa and Iwatsubo (2009), this paper estimates the VAR in levels. The lag length of VAR is set to 4, basing on the Schwarz information criterions

(BIC).

<insert **Table 4.2** here>

The panels in **Fig 4.2** report the accumulated responses of trade to one Cholesky standard error innovations of the variables. *trade* has a negative impulse response to *reer*, showing that appreciation of renminbi leads to a decrease in the trade surplus, or the trade rebalance. Moreover, in the first four periods (or one year), the response of *trade* is near to zero, showing that the trade surplus does not begin to decrease after the appreciation of exchange rate. On the other hand, the impulse responses of trade to both Y^* and Y are positive, showing that both the domestic and foreign economic growths lead to an increase in the trade surplus. This result shows that in the total period during 1998–2016, the appreciation of renminbi leads to the decrease of the trade surplus, while the domestic economic growth leads to the increase of the trade surplus. Referring to the saving glut argument, China's high domestic savings rate leads to the high saving-investment gap, which then leads to the net increase of trade surplus when the domestic economy keeps growing.

<insert **Fig 4.2** here>

Fig 4.3 reports the variance decomposition of *trade* in the SVAR model. During the first 12-ahead periods (three years), the foreign real GDP and the real interest rate are very large. However, in the long-run (after 12-ahead periods), the exchange rate and the domestic GDP becomes the largest two variables which lead to the variance of *trade*, except *trade* itself. Specifically, in the long-run, 40% of the variance of *trade* can be explained by itself, 20% can be explained by *reer,* 12% can be explained by Y^*, 14% can be explained by Y, and 14% can be explained by r. In summary, the impulse response functions and the variance decompositions in the structural VAR model suggest that the appreciation of real effective exchange rate could help improve the trade imbalance of China, but this rebalance effect becomes effective after some time, rather than immediately.

<insert **Fig 4.3** here>

Although the results of the structural VAR model shows a negative relationship between the exchange rate and the trade surplus in the total period, it seems to vary over time. Hence, it is necessary to identify the time-varying features by employing the time-varying parameter VAR model. This paper utilized an ox package developed by Jouchi Nakajima[4]. A drawback of this methodology has to do with the curse of dimensionality. Similar with Shioji (2015), as the model becomes large, I quickly faced a limitation of the PC's computing ability. For this reason, I set the lag length at 2 (two quarters). All the variables and the VAR ordering were set as the same with the structural VAR model, which have been mentioned above.

Fig 4.4 reports the time-varying accumulated impulse responses of *trade* to one standard error shock of *reer* during the total period from 1998Q1 to 2016Q4. In the short-run (4-period ahead, or one year), the impulse response is very stable, valuing between -0.06 to -0.08, while in the mid-run and long-run (two, three, and four years intervals), the time-varying features of the impulse response become very significant. The accumulated impulse response of *trade* to *reer* fluctuated between -0.035 and -0.05 during 1998 to 2003, and kept decreasing during from 2004 to 2008. After the financial crisis in 2008, it kept a gradual increase during from 2009 to 2014. Then, the impulse response became stable at -0.34. In summary, the rebalance effect of the exchange rate on trade imbalance became smaller before the financial crisis in 2008, and then gradually recovered.

<insert **Fig 4.4** here>

Furthermore, as suggested by Chinn and Wei (2013), a more flexible nominal exchange rate regime does not always facilitate the current account (or trade) adjustment, because it is the real effective exchange rate, rather the nominal exchange rate, which has a rebalancing effect on trade. And the reflection of the real effective exchange rate (REER) to the nominal exchange rate needs time. Therefore, this paper also aims to reveal whether regime changes of the nominal renminbi exchange rate effectively affect the exchange rate's rebalance effect on trade. Referring to Luo (forthcoming), four time points of the nominal renminbi regime switches during 1998–2016 are selected: (1) 2005Q3 when China announced to switch renminbi regime from dollar-peg regime to the managed floating regime; (2) 2008Q3 when China repegged renminbi to the US dollar without announcement; (3) 2010Q2 when China recovered the managed floating from dollar-peg regime; (4) 2015Q3 when China devaluated the exchange rate of renminbi against the US dollar and announced to revise the pricing mechanism of the official rate. Referring to Figure. 4, rather than an increase, I observed a decrease of the impulse magnitude in 2005Q3 when exchange rate flexibility increased. During 2010–2015, the impulse magnitude became larger

[4] The ox TVP-VAR package developed by Jouchi Nakajima are available at https://sites.google.com/site/jnakajimaweb/program/.

when the nominal exchange rate flexibility increased. Moreover, at 2015Q3 the impulse response became stable and did not increase. In summary, the results of the TVP-VAR model support the viewpoint that a nominal exchange rate regime switch may not immediately facilitate the trade rebalancing, because reflections in the effective exchange rate need time, as supposed by previous literature (see Chinn and Wei, 2013; Cline, 2012; Li *et al.*, 2015; Thorbecke and Smith, 2010).

4.4 The renminbi's exchange rate pass-through

In section 4.3, the rebalance effect of exchange rate on trade imbalance has been analyzed. Referring to the results of the structural VAR model, in the total period during 1998–2016 the appreciation of real effective exchange rate had a negative effect on trade, which could help rebalance China's large trade surplus. Furthermore, the results of the TVP-VAR model show that, although the real effective exchange rate gradually appreciated during the sample period, the trade rebalancing effect of exchange rate did not significantly increase as expected. A possible reason is the weak exchange rate pass-through. Therefore, in this section, I examined the exchange rate pass-through by employing the structural VAR model and the time-varying parameter VAR (TVP-VAR) model which have been stated in section 4.3.

Ito and Sato (2008) suggested a structural VAR model basing on the variable ordering which is decided by the domestic production chain as follows. The exchange rate shock affects the import price first, then the domestic producer price, and at last, the export price. Different from the SVAR model in section 4.2, the nominal effective exchange rate (NEER) is used here, rather than the real effective exchange rate (REER). Therefore, the ordering in the structural VAR model is set as follows: $y_t = (NEER_t, IPI_t, PPI_t, CPI_t)'$. Moreover, the simultaneous relations of the structural shock by recursive identification is assumed as lower-triangular, which is the standard recursive constraint.

<insert **Fig 4.5** here>

The sample period covers from 1998M1 to 2016M12. Data on nominal effective exchange rate are available from Bank of International Settlements. **Fig 4.5** shows the monthly average data of the renminbi's nominal effective exchange rate during January 1998–December 2016 (2010=100).The nominal effective exchange rate (NEER) for the renminbi was stable during

2005–2008 when China implemented the managed floating regime. In the period of the Global Financial Crisis during 2008–2010, the NEER firstly surged and then declined, due to China implementing dollar-peg again. Moreover, the NEER had gradually appreciated by 26% during 2011–2015. Lastly, we can find a trend switch from appreciation to depreciation from the end 2015 when China devaluated the renminbi officially. Data on China's import price index (IPI), producer price index (PPI) and export price index (EPI) are available from National Bureau of China. All the four variables are I(1) and stationary at first difference. Hence, I take all the variables (logarithm) into the first difference. The statistics and the unit root test results are reported in **Table 4.3**. Basing on Schwarz information criterion (BIC), the lag structure is set as lag=1.

<insert **Table 4.3** here>

Panels in **Fig 4.6** reports the accumulated impulse responses of the price indexes to the one standard error shock of NEER, which are estimated by the SVAR model. All the three price variables take about ten periods to fully respond to the NEER shock. To the one standard error shock of NEER appreciation, the response of NEER itself is 0.02, the response of IPI is -0.028, the response of PPI is -0.012, and the response of EPI is -0.005, respectively. That is to say, the exchange rate pass-through to import price is bigger than that of producer price, then bigger than that export price. Referring to Kang and Liao (2016), the processed goods has a large weight in China's total export. Besides the imported raw materials whose prices are sensitively affected by the exchange rate, the export prices are also decided by the domestic production process which is not sensitive to the exchange rate. This reason could explain why the import price response is larger than that of the producer price and export price.

<insert **Fig 4.6** here>

Panels of **Fig 4.7** report the time-varying accumulated responses of price indexes to NEER shock at the 1, 3, 6, 12-ahead response length. All of *IPI*, *PPI* and *EPI* impulse responses to NEER shock become steady after the first six months (6-ahead period). Totally, the exchange rate pass-through of import price index (*IPI*) is the largest, producer price index (*PPI*) is the second, and export price index (*EPI*) is the least. This is consistent with the result in structural VAR model which is time-invariant. Furthermore, it is obvious that the pass-through of *IPI*, *PPI,* and *EPI* have a similar time-varying trend. During 1998–2005 when the dollar-peg regime was implemented, the pass-through effects kept fluctuating at a relatively low level. Since 2005 when the managed floating regime was implemented, the pass-through effects became sharply increasing, and reached to peak in early 2008. However, they had sharply decreased to the level in 2006 until early 2010, due to the recovery of the dollar-peg regime in the global financial crisis. After China ended the dollar-peg and implemented the managed floating regime again, the pass-through effects sharply increased in the period of 2010–2012, then decreased to the level in 2007. Since 2014, the pass-through effects kept steady. However, significant changes of the pass-through effects are not observed in 2015 when China announced the renminbi devaluation.

<insert **Fig 4.7** here>

Combined with the time-varying trade rebalance effect of the exchange rate in section 4.3, I found that: first, the decrease of pass-through effect could well explain the low level of the trade rebalance effect in 2008 when China implemented the dollar-peg regime. Second, during 2005–2008 the pass-through effect could not explain the decreasing trade rebalance effect. While the pass-through effects became stronger, the trade rebalance effect gradually decreased. This result is consistent with the idea that in the 2000s it was the saving glut, rather than the exchange rate, that dominated the rapid increase in China's export (see Chinn and Wei, 2013; Cline, 2012; Ma *et al.*, 2013; Ogawa and Iwatsubo, 2009). During 2010–2016, the pass-through effect could explain the trend of the trade rebalance effect in general, though the trade rebalancing effect did not fluctuate so sharply as the pass-through effect in the European sovereign crisis.

4.5 Conclusions

Since the Chinese renminbi exchange rate regime switched from the dollar-peg regime to the managed floating regime in 2005, many exchange rate reforms have been implemented to increase the exchange flexibility in recent years, which are widely considered to increase the effect of exchange rate on adjusting China's large trade imbalance in the 2000s. This paper examined the trade rebalance effect of China's exchange rate during 1998–2016. By employing a structural VAR (SVAR) model proposed by Ogawa and Iwatsubo (2009) basing on the neo-classical IS framework, this paper suggested that generally in the total period, the appreciation of China's real effective exchange rate could help reduce the large trade surplus.

Furthermore, the time-varying parameter VAR (TVP-VAR) model revealed that: on one hand, accompanied with the large decline in the trade rebalance effect before the global financial crisis, China's trade surplus has rapidly increased in the 2000s. The implementation of the managed floating regime did not improve the trade rebalance effect. On the other hand, after the global financial crisis, the renminbi's real effective exchange rate (REER) kept appreciated. The improvement of the trade rebalance effect in this period effectively helped rebalance the large trade imbalance to the normal level. In summary, it is obvious that the improvement of the renminbi's trade rebalance effect after the global financial crisis led to the rebalancing of China's trade.

Lastly, this paper examined whether the exchange rate pass-through affected the trade rebalance effect of the exchange rate, by employing the SVAR model proposed by Ito and Sato (2008) which based on the domestic production process and a TVP-VAR model to identify time-variance. It is revealed that the increased exchange rate pass-through effectively explained the increased trade rebalance effect after the global financial crisis, but it is less effective for the 2000s. Last, this study found the time-lag effect of both the trade rebalance effect and the pass-through effect, which take nearly one year to reflect the exchange rate change.

Chapter 5. Conclusions

Since the 2000s when the Chinese economy boosted rapidly, the renminbi exchange rate has been focused on by policymakers and scholars. Over the last decade, China has implemented the managed floating regime with reference to a currency basket and the market supply-demand conditions to replace the dollar-peg regime which was implemented before 2005. Different with a single free floating regime or a single dollar-peg regime, the managed floating was proved to be more like a limited floating regime under the strong regulations by the monetary authority, though the lack of transparency in this regime was widely known due to the examples of some developing economies such as China. Over the managed floating regime of the Chinese renminbi during 2005–2016, some interesting findings were detected in this study.

First, I found the existence of the well-known "*de facto vs. de jure*" problem, which is defined as that the monetary authorities always implement different foreign exchange policies from what they officially claim to follow, in China's managed floating regime. This study showed that the weight of the US dollar was kept at an extremely high level in renminbi's reference currency basket, referring to the results of the implicit currency basket model (or the so-called Frankel-Wei model) proposed by Frankel and Wei (2008), though it decreased after the renminbi reform on 11 August 2015. Especially, China actually recovered the dollar-peg regime to cope with the shock of the global financial crisis during 2008–2010 by fixing the official rate. Furthermore, not only the level of the renminbi exchange rate, but also the flexibility was proved to be largely controlled, especially during 2014-2016 when China faced a large renminbi depreciation pressure. Therefore, China's managed floating regime should be looked as a crawling peg regime to the US dollar with strict regulations on both the level and the flexibility by the monetary authority during 2005–2016, despite the relaxation after the renminbi reform in 2015. In future works, it is necessary to keep track with the implicit currency basket of the renminbi and the renewed quotation mechanism of the policy rate when published by the monetary authority.

Second, after the financial crisis in 2008, China implemented a couple of policies to boost the global use of the renminbi, e.g. the setup of offshore renminbi markets and the applications of the renminbi trade settlements. The offshore renminbi rate could provide some valuable experience for the reforms on the onshore market in future, because it is free floating and out of heavy interventions by the monetary authority. This study focused on the linkage between the onshore and the offshore renminbi rates during March 2014–December 2016 when renminbi faced a large depreciation pressure. By employing a DCC-GARCH model, this study proved that the cross-market spillover effect was very different with the early stage of the offshore market during 2011–2014. The offshore market was proved to have the pricing determinant power, due to a larger spillover from offshore to onshore than the vice versa, and the high determinant power of the onshore policy rate to both market renminbi rates. Furthermore, this study found that the renminbi reform on 11 August 2015 significantly decreased the onshore-offshore linkage, due to the lowered dynamic conditional correlation by the DCC-GARCH model, and the larger and less convergent onshore-offshore pricing differential by the SETAR model. In future works, a microstructure analysis on the onshore-offshore linkages basing on high-frequency data will be necessary to better understand the common shock effect to each market and their linkage, though this paper did not do so, due to lack of data.

Third, this study examined the trade rebalance effect of the renminbi and the exchange rate pass-through during 1998–2016. This study reveal the real effective exchange rate (REER) of renminbi could help improve the large trade imbalance in the total period by employing a structural VAR model, and revealed that the trade rebalance effect became larger after the global financial crisis by employing a TVP-VAR model which could provide the time-variant characteristics of the impulse response to shocks. Furthermore, by using a structural VAR model and a TVP-VAR model, this study also found that the increased exchange rate pass-through could effectively explain the increased trade rebalance effect after the global financial crisis, but it is less effective for the 2000s when the saving glut argument dominated the rapid increase of China's trade surplus, as proposed by much previous literature. Lastly, this study almost did not find significant changes of the trade rebalance effect of exchange rate and the exchange rate pass-through when renminbi regime reforms were implemented, supporting the absence of robust association between the de facto nominal exchange rate regime and the adjustment of trade proposed by previous literature, e.g. Chinn and Wei (2013).

Referring to the empirical results of this study, some policy implications are provided at last. China should enhance the reform on renminbi pricing determination process to become more market-based, and some regional cooperation, e.g. the "Belt and Road" programs with the ASEAN and the European countries, will be good chances to boost the global use of renminbi both in official and private sectors. Also, due to the trilemma argument in international economics, to make renminbi become a global trade settlement currency and a global reserve currency, free capital flow should be a more smart selection than the fixed exchange rate for China in the long term, though the pace of opening capital account is based on the stability of China's domestic economy and the domestic financial system. Pegging or crawling to the US dollar its high weight in the renminbi reference basket should be a responding to an unstable circumstance at some certain periods, but in the long run, it should be gradually lowered if China aims to achieve the long-run target to make renminbi free floating as officially announced.

Bibliography

[1] Auer, R. A. (2015). "Exchange Rate Pass-Through, Domestic Competition, and Inflation: Evidence from the 2005–08 Revaluation of the Renminbi". *Journal of Money, Credit and Banking, 47*(8), 1617-1650.

[2] Bai, J., & Perron, P. (2003). "Computation and analysis of multiple structural change models". *Journal of applied econometrics, 18*(1), 1-22.

[3] Bernanke, B. S. (2005). "The global saving glut and the U.S. current account deficit". Board of Governors of the Federal Reserve System (U.S.). Retrieved from: https://www.federalreserve.gov/boarddocs/speeches/2005/200503102/

[4] Bollerslev, T. (1986). "Generalized autoregressive conditional heteroskedasticity". *Journal of econometrics, 31*(3), 307-327.

[5] Branson, W. H., & Katseli, L. T. (1982). "Currency Baskets and Real Effective Exchange Rates". In M. Gersovitz, C. F. Diaz-Alejandro, G. Ranis & M. R. Rosenzweig (Eds.), *The Theory and Experience of Economic Development: Essay in Honour of Sir Arthur Lewis* (pp. 194-214). London: George Allen and Unwin.

[6] Calvo, G. A., & Reinhart, C. M. (2002). "Fear of floating". *The Quarterly Journal of Economics, 117*(2), 379-408.

[7] Cheng, H., & Liu, L. (2007). "The Effect of RMB Exchange Rate Pass-through: An Empirical Analysis Based on VAR [J]". *Journal of Financial Research, 4*(7), 002.

[8] Cheung, Y.-W., Hui, C.-H., & Tsang, A. (2017). "The RMB Central Parity Formation Mechanism after August 2015: A Statistical Analysis". *HKIMR Working Paper*, *No. 2017-6*: Hong Kong Institute for Monetary Research (HKIMR). Retrieved from: https://ssrn.com/abstract=2938311

[9] Cheung, Y.-W., & Rime, D. (2014). "The offshore renminbi exchange rate: Microstructure and links to the onshore market". *Journal of International Money and Finance, 49*, 170-189.

[10] Chinn, M., & Wei, S.-J. (2013). "A Faith-Based Initiative Meets the Evidence: Does a Flexible Exchange Rate Regime Really Facilitate Current Account Adjustment?". *The Review of Economics and Statistics, 95*(1), 168-184.

[11] Cline, W. R. (2012). "Projecting China's current account surplus". *Policy Briefs in International Economics*, *No. 12-7*: Peterson Institute for International Economics. Retrieved from: https://piie.com/sites/default/files/publications/pb/pb12-7.pdf

[12] Craig, R., Hua, C., Ng, P. K., & Yuen, R. (2013). "Development of the Renminbi Market in Hong Kong SAR: Assessing Onshore-Offshore Market Integration". *IMF Working Paper*,

No. 13-268: International Monetary Fund (IMF).

[13] Cui, L., Shu, C., & Chang, J. (2009). "Exchange rate pass-through and currency invoicing in China's exports". *China Economic Issues, 2*(09), 1-27.

[14] Dixon, R., Zhang, Z., & Dai, Y. (2016). "Exchange Rate Flexibility in China: Measurement, Regime Shifts and Driving Forces of Change". *Review of International Economics, 24*(5), 875-892.

[15] Edison, H. J., & Vårdal, E. (1990). "Optimal currency baskets for small, developed economies". *The Scandinavian Journal of Economics, 92*(4), 559-571.

[16] Eichengreen, B. (2007). "China's exchange rate regime: the long and short of it". In C. Calomiris (Ed.), *China's Financial Transition at a Crossroads* (pp. 314-342). New York: Columbia University Press.

[17] Engle, R. F. (2002). "Dynamic conditional correlation: A simple class of multivariate generalized autoregressive conditional heteroskedasticity models". *Journal of Business & Economic Statistics, 20*(3), 339-350.

[18] Engle, R. F., & Sheppard, K. (2001). "Theoretical and empirical properties of dynamic conditional correlation multivariate GARCH". *NBER Woking Paper*, *No. 8554*: National Bureau of Economic Research (NBER).

[19] Fang, Y., Huang, S., & Niu, L. (2012). "De facto currency baskets of China and East Asian economies: The rising weights". *BOFIT Discussion Paper*, *No. 2012-2*: Bank of Finland, Institute for Economies in Transition (BOFIT).

[20] Felipe, J., Kintanar, K., & Lim, J. A. (2006). "Asia's Current Account Surplus: Savings Glut or Investment Drought?". *Asian Development Review, 23*(1), 16.

[21] Frankel, J. A., & Wei, S.-J. (1994). "Yen bloc or dollar bloc? Exchange rate policies of the East Asian economies" *Macroeconomic Linkage: Savings, Exchange Rates, and Capital Flows, NBER-EASE Volume 3* (pp. 295-333): University of Chicago Press.

[22] Frankel, J. A., & Wei, S.-J. (2008). "Estimation of de facto exchange rate regimes: Synthesis of the techniques for inferring flexibility and basket weights". *NBER Working Paper*, *No. 14016*: The National Bureau of Economic Research (NBER).

[23] Frankel, J. A., & Xie, D. (2010). "Estimation of De Facto Flexibility Parameter and Basket Weights in Evolving Exchange Rate Regimes". *The American Economic Review, 100*(2), 568-572.

[24] Fratzscher, M., Juvenal, L., & Sarno, L. (2010). "Asset prices, exchange rates and the current account". *European economic review, 54*(5), 643-658.

[25] Friedman, M. (1953). "The Case for Flexible Exchange Rates". In M. Friedman (Ed.), *Essays in Positive Economics* (pp. 157-203). Chicago: University of Chicago Press.

[26] Fung, H. G., & Yau, J. (2012). "Chinese offshore RMB currency and bond markets: The role

of Hong Kong". *China & World Economy, 20*(3), 107-122.

[27] Funke, M., Shu, C., Cheng, X., & Eraslan, S. (2015). "Assessing the CNH–CNY pricing differential: Role of fundamentals, contagion and policy". *Journal of International Money and Finance, 59*, 245-262.

[28] Gagnon, J. E. (2016). "A new development in offshore renminbi". *Renminbi Series*, *No. 3*: Peterson Institute for International Economics.

[29] Hamilton, J. D. (1994). "Time series analysis" (Vol. 2, pp. 690-696). Princeton: Princeton university press.

[30] He, D., & McCauley, R. N. (2010). "Offshore markets for the domestic currency: monetary and financial stability issues". *BIS Working Paper*, *No. 320*: Bank of International Settlements (BIS).

[31] He, L. (2008). "RMB Exchange Rate and China's Current Account Balance". *Journal of Financial Research, 333*, 13-27.

[32] Hoffmann, M. (2013). "What drives China's current account?". *Journal of International Money and Finance, 32*, 856-883.

[33] Ito, T. (2017). "A new financial order in Asia: Will a RMB bloc emerge?". *Journal of International Money and Finance, 74*, 232-257.

[34] Ito, T., & Orii, K. (2006). "On Determinants of the Yen Weight in the Implicit Basket System in East Asia". *RIETI Discussion Paper*, *No. 06020*: Research Institute of Economy, Trade and Industry (RIETI).

[35] Ito, T., & Sato, K. (2008). "Exchange Rate Changes and Inflation in Post-Crisis Asian Economies: Vector Autoregression Analysis of the Exchange Rate Pass-Through". *Journal of Money, Credit and Banking, 40*(7), 1407-1438.

[36] Kang, J. S., & Liao, W. (2016). "Chinese imports: What's behind the slowdown?". *IMF Working Paper, 16*(106).

[37] Kawai, M., & Pontines, V. (2016). "Is there really a renminbi bloc in Asia?: A modified Frankel–Wei approach". *Journal of International Money and Finance, 62*, 72-97.

[38] Leung, D. W., & Fu, J. (2014). "Interactions between CNY and CNH Money and Forward Exchange Markets". *HKIMR Working Paper, 2014*(13).

[39] Levy-Yeyati, E., & Sturzenegger, F. (2005). "Classifying exchange rate regimes: Deeds vs. words". *European economic review, 49*(6), 1603-1635.

[40] Li, H., Ma, H., & Xu, Y. (2015). "How do exchange rate movements affect Chinese exports?—A firm-level investigation". *Journal of International Economics, 97*(1), 148-161.

[41] Liang, Y., Shi, K., Wang, L., & Xu, J. J. (2016). "Fluctuation and Intervention: A Tale of Two RMB Markets". Retrieved from: https://ssrn.com/abstract=2826482

[42] Luo, P. (forthcoming). "Diversifying reference currency basket and decreasing degree of flexibility in exchange rate policy of China". *Japanese Journal of Monetary and Financial Economic, forthcoming*.

[43] Ma, G., McCauley, R., & Lam, L. (2013). "The roles of saving, investment and the renminbi in rebalancing the Chinese economy". *Review of International Economics, 21*(1), 72-84.

[44] Maziad, S., & Kang, J. S. (2012). "RMB internationalization: onshore/offshore links". *IMF Working Paper*, *No. 12-133*: International Monetary Fund (IMF).

[45] Moosa, I., Naughton, T., & Li, L. (2009). "Exchange rate regime verification: Has China actually moved from a dollar peg to a basket peg?". *International Economics, 62*(1), 41-67.

[46] Nakajima, J. (2011). "Time-varying parameter VAR model with stochastic volatility: An overview of methodology and empirical applications". *Monetary and Economic Studies, 29*, 107-142.

[47] Nakajima, J., & Watanabe, T. (2012). "Time-Varying Vector Autoregressive Model-A Survey with the Application to the Japanese Macroeconomic Data". *Economic Review, 63*(3), 193-208.

[48] Obstfeld, M., & Rogoff, K. (1995). "Exchange rate dynamics redux". *Journal of political economy, 103*(3), 624-660.

[49] Obstfeld, M., & Rogoff, K. S. (1996). "Foundations of international macroeconomics" (Vol. 30): MIT press Cambridge, MA.

[50] Ogawa, E., & Iwatsubo, K. (2009). "External adjustments and coordinated exchange rate policy in Asia". *Journal of Asian Economics, 20*(3), 225-239.

[51] Ogawa, E., & Sakane, M. (2006). "Chinese Yuan after Chinese exchange rate system reform". *China & World Economy, 14*(6), 39-57.

[52] Ogawa, E., & Shimizu, J. (2006). "Stabilization of effective exchange rates under common currency basket systems". *Journal of the Japanese and international economies, 20*(4), 590-611.

[53] Primiceri, G. E. (2005). "Time varying structural vector autoregressions and monetary policy". *The Review of Economic Studies, 72*(3), 821-852.

[54] Rajan, R. S. (2012). "Management of exchange rate regimes in emerging Asia". *Review of Development Finance, 2*(2), 53-68.

[55] Shen, J., & Luk, M. (2017). "Comparing two episodes of CNH liquidity squeeze to defend RMB". *Economics Research*: Mizuho Securities Asian Ltd.

[56] Sheng, W., & Tao, T. (2013). "The Incomplete Pass-Through of the RMB Exchange Rate Fluctuation——Based on the Perspective of Asymmetry [J]". *Shanghai Finance, 9*, 010.

[57] Shioji, E. (2015). "Time varying pass-through: Will the yen depreciation help Japan hit the

inflation target?". *Journal of the Japanese and international economies, 37*, 43-58.

[58] Thorbecke, W., & Smith, G. (2010). "How would an appreciation of the Renminbi and other East Asian currencies affect China's exports?". *Review of International Economics, 18*(1), 95-108.

[59] Tong, H., & Lim, K. S. (1980). "Threshold autoregression, limit cycles and cyclical data". *Journal of the Royal Statistical Society. Series B (Methodological)*, 245-292.

[60] Yamazaki, K. (2006). "Inside the currency basket". Columbia University and Mitsubishi UFJ Trust and Banking Corp.

[61] Yan, M., & Ba, S. (2010). "The dynamic relationship among RMB spot exchange rate, onshore forward exchange rate and offshore forward exchange rate after the implementation of NDF regulation policy". *Journal of Finance and Economics, 36*(2).

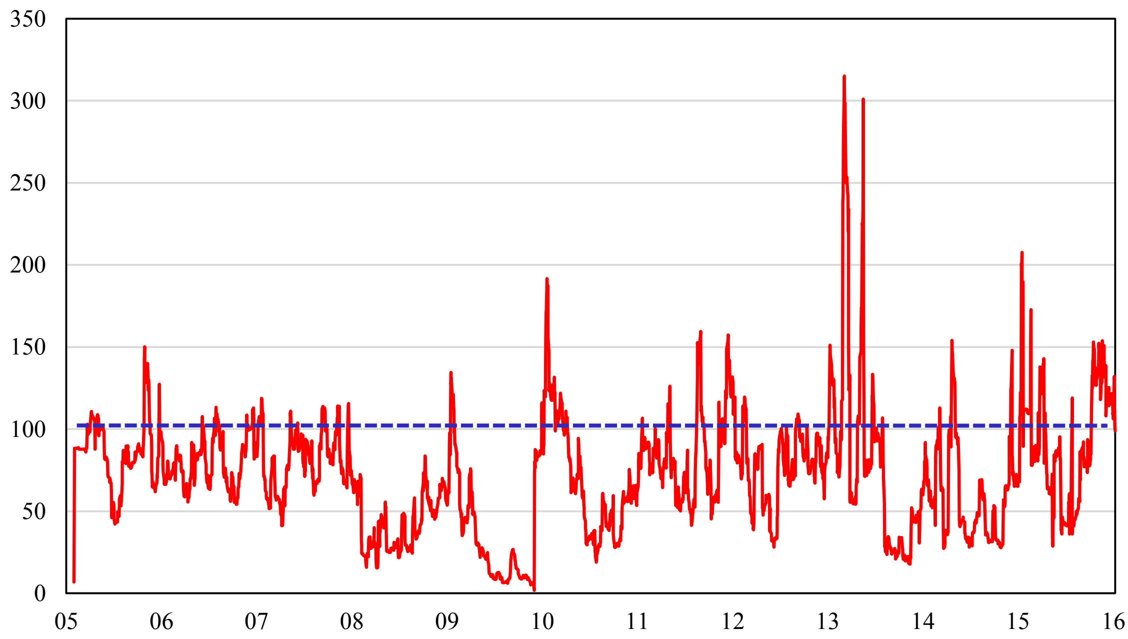
[62] Yu, Y. (2012). "The Current RMB Exchange Rate Volatility and RMB Internationalization". *International Economic Review, 1*, 18-26.

[63] Zeileis, A., Shah, A., & Patnaik, I. (2010). "Testing, monitoring, and dating structural changes in exchange rate regimes". *Computational Statistics & Data Analysis, 54*(6), 1696-1706.

[64] Zhang, Z., Shi, N., & Zhang, X. (2011). "China’s new exchange rate regime, optimal basket currency and currency diversification". *BOFIT Working Paper*, *No. 2011-19*: Bank of Finland, Institute for Economies in Transition (BOFIT).

Appendix

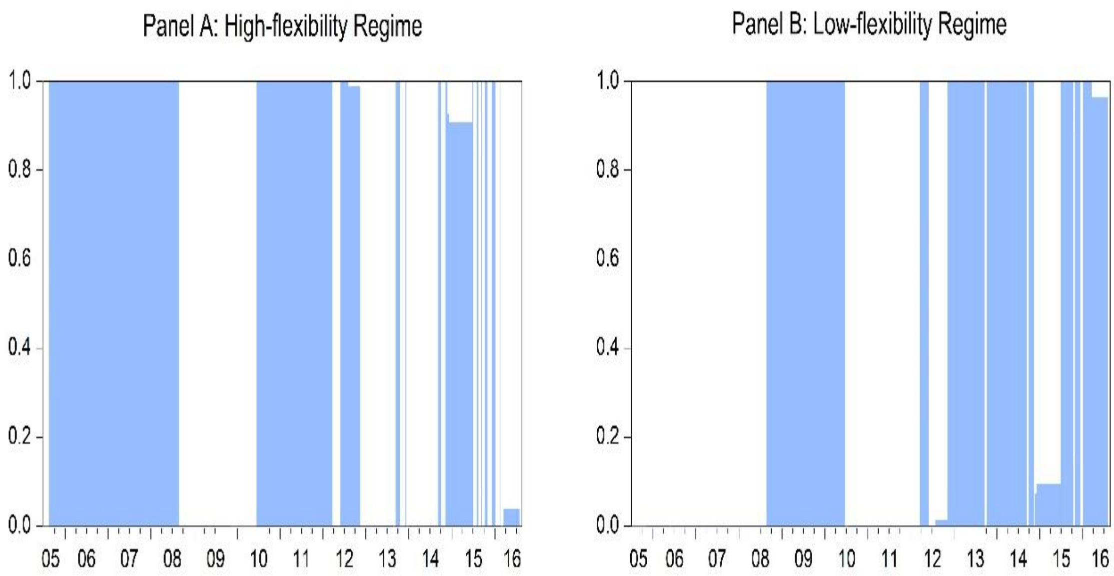
Figure 2.1 Exchange rate flexibility index for renminbi



Author's calculation.

Note: This figure displays the flexibility index (in red line) calculated according to Equation (2.3), which is an exchange rate flexibility model basing on an autoregressive model with Markov switching process, proposed by Dixion, Zhang and Dai (2016). The index=100 means the equality of RMB to the US dollar exchange rate flexibility between the Shanghai and New York markets.

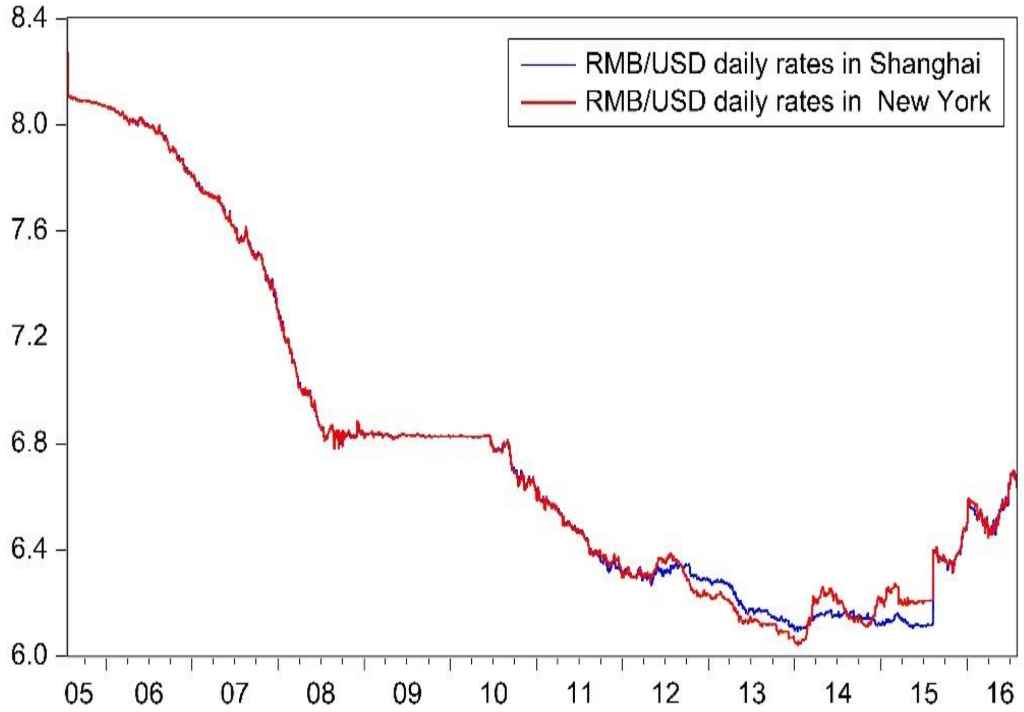
Figure 2.2 Smooth regime probabilities of exchange rate flexibilities



Author's calculation.

Note: The highlighted parts show the smooth probabilities of the high-flexibility regime in Panel A and of the low-flexibility regime in Panel B. These are estimated by using the standard Markov switching model in Equation (2.4).

Figure 2.3 the RMB/USD exchange rates



Source: Datastream

Note: This figure shows the daily renminbi/US dollar closing rates in the Shanghai Interbank market (in blue line) which represent regulated renminbi/US dollar rates, and the daily renminbi/US dollar rates in New York (in red line) which represent unregulated rates. All data were collected from Reuters DataStream.

Table 2.1 China's reforms of the RMB exchange rate since 2005

1994–2005	Official dollar-peg regime.
2005, July	China revalued RMB against the US dollar by 2.1% and announced a switch from a dollar-peg regime to a managed floating regime based on market supply and demand, with reference to a currency basket. A ±0.3% daily RMB/USD trading band around the central rate, published by the PBOC as the official rate, is implemented in the interbank market.
2005, Aug	Governor Zhou revealed the components of the reference basket: the US dollar, yen, euro, pound sterling, Korean won, Singapore dollar, Malaysian ringgit, Russian ruble, Australian dollar, Thai baht, and Canadian dollar. Weights are secret.
2006, Dec	The method of deciding the central rate was reformed.
2007, May	China widened the daily trading band from ±0.3% to ±0.5%.
2008, Jul	China effectively re-pegged RMB to the US dollar by fixing the central parity rate.
2009, Jul	China launched its RMB internationalization program to allow RMB to become a global currency. It also began to permit domestic firms to settle in RMB in global trading.
2010, Jun	China announced the resumption of its exchange rate reforms of RMB and increased currency flexibility, heralding the end of the US dollar-peg in the GFC.
2012, Mar	China allowed all domestic firms to settle in RMB.
2012, Apr	China widened the daily trading band from ±0.5% to ±1%.
2014, Jan	RMB hit a record high of 6.04883 against the US dollar since the reform in 2005.
2014, Mar	China widened the daily trading band from ±1% to ±2%.
2015, Aug	China revalued RMB against the US dollar by -1.8% and announced a reform of the way in which the central rate is decided (mainly dominated by market makers' bid prices); it also re-emphasized the reference to a basket of currencies.
2015, Dec	It was decided that RMB would join the basket of the IMF's SDR with a 10.92% weight from October 2016.
2015, Dec	The CFETS Renminbi Index was launched with reference to a basket of currencies and details of the calculation method were published.

Source: People's Bank of China (PBOC)

Table 2.2 Correlations among the exchange rates

	AUD	CAD	CHF	CNY	EUR	GBP	HKD	JPY	MYR	NZD	RUB	SGD	THB	USD
AUD	1.00													
CAD	0.78	1.00												
CHF	0.20	0.45	1.00											
CNY	0.08	0.44	0.91	1.00										
EUR	0.28	0.54	0.83	0.72	1.00									
GBP	0.05	0.40	0.91	0.94	0.79	1.00								
HKD	0.10	0.50	0.89	0.97	0.75	0.95	1.00							
JPY	0.79	0.79	0.10	-0.03	0.28	0.02	0.11	1.00						
MYR	0.69	0.81	0.47	0.49	0.48	0.42	0.50	0.55	1.00					
NZD	0.32	0.45	0.83	0.84	0.69	0.78	0.76	0.01	0.60	1.00				
RUB	0.25	-0.06	-0.75	-0.83	-0.50	-0.81	-0.84	0.27	-0.13	-0.58	1.00			
SGD	0.28	0.59	0.94	0.96	0.80	0.93	0.95	0.16	0.61	0.88	-0.75	1.00		
THB	0.29	0.62	0.85	0.90	0.70	0.84	0.94	0.25	0.63	0.73	-0.75	0.93	1.00	
USD	0.10	0.50	0.89	0.97	0.75	0.94	1.00	0.11	0.50	0.75	-0.84	0.95	0.95	1.00

Author's calculation.
Note: the abbreviations in this table represent the US dollar (USD), euro (EUR), Japanese yen (JPY), British pound (GBP), Australian dollar (AUD), Canadian dollar (CAD), Swiss franc (CHF), Hong Kong dollar (HKD), Malaysian ringgit (MYR), New Zealand dollar (NZD), Russian ruble (RUB), Singapore dollar (SGD), and Thai baht (THB). All variables are the daily exchange rates of one currency against the Mexican peso. The time period is from July 21 July 2005 to 30 December 2016.

Table 2.3 Results of the Frankel–Wei model

	Pre-crisis 2005–2008	In-crisis 2008–2010	Post-crisis 2010–2016	Sub-period 1	Sub-period 2	Difference (5)-(4)	Sub-period 1’	Sub-period 2’	Difference (8)-(7)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
C	-0.022%***	-0.002%	-0.002%	-0.007%**	0.023%***	0.031%***	-0.007%**	0.024%***	0.031%***
	(0.004%)	(0.004%)	0.003%	(0.004%)	(0.009%)	(0.009%)	(0.004%)	(0.009%)	(0.009%)
USD	0.952***	0.984***	0.93***	0.951***	0.857***	-0.094***	0.952***	0.86***	-0.092***
	(0.013)	(0.008)	(0.009)	(0.01)	(0.02)	(0.022)	(0.01)	(0.019)	(0.021)
EUR	-0.03	0.031***	-0.014	0.004	-0.068**	-0.071**	0.003	-0.037*	-0.04**
	(0.021)	(0.012)	(0.008)	(0.009)	(0.03)	(0.031)	(0.009)	(0.019)	(0.02)
JPY	0.015*	-0.002	0.009	0.006	0.035**	0.029*	0.005	0.04***	0.035**
	(0.009)	(0.006)	(0.006)	(0.007)	(0.014)	(0.016)	(0.007)	(0.014)	(0.015)
GBP	-0.005	0.01*	0.029***	0.011	0.045***	0.034*	0.01	0.044***	0.033**
	(0.01)	(0.006)	(0.008)	(0.01)	(0.014)	(0.017)	(0.01)	(0.014)	(0.017)
AUD	0.003	-0.004	0.017*	0.018*	0.025	0.006	0.02**		-
	(0.01)	(0.006)	(0.009)	(0.01)	(0.02)	(0.022)	(0.009)		-
NZD	0.01	0.003	0.005	0.005	0.007	0.002	0.005		-
	(0.008)	(0.007)	(0.008)	(0.009)	(0.016)	(0.018)	(0.008)		-
CAD	-0.007	-0.007	0.007	0.006	-0.006	-0.012	0.004		-
	(0.008)	(0.006)	(0.01)	(0.011)	(0.021)	(0.024)	(0.01)		-
CHF	0.044**	-0.016	0.002	0.001	0.042	0.041	0.003		-
	(0.018)	(0.01)	(0.006)	(0.006)	(0.03)	(0.03)	(0.006)		-
Obs.	777	503	1595	1338	257	-	1338	257	-
R2	0.941	0.994	0.957	0.959		-	0.959		-

Author’s calculation.

Note: This table displays the estimated weights of the reference currencies by using the daily-based implicit currency basket model in Eq. (2.2). Variables include US dollar (USD), euro (EUR), Japanese yen (JPY), British pound (GBP), Australian dollar (AUD), Canadian dollar (CAD), Swiss franc (CHF).Standard errors are in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Columns (1), (2), and (3) show the results for the pre-crisis period (July 21, 2005 to July 15, 2008), in-crisis period (July 16, 2008 to June 18, 2010), and post-crisis period (June 21, 2010 to July 29, 2016), respectively. Sub-periods 1 and 2 of the post-crisis period in Columns (4) and (5), respectively are separated by a structural breakpoint, August 8, 2015, which is estimated by following Bai and Perron (2003). Moreover, a restriction that AUD, NZD, CAD, and CHF are not conditional on the regime is added into the model for a robustness check, and the results are shown in Columns (7) and (8). The *t*-tests on the difference term (6) and (9) are taken, and the null hypotheses are (5)-(4) = 0 and (8)-(7) = 0, respectively.

Table 2.4 Markov-switching results for the flexibility index

	(1)		(2)	
Panel A: Regime varying coefficients				
	Regime 1	Regime 2	Regime 1	Regime 2
α	101.39***	39.38***	99.5***	37.96***
AR(1)	0.98***		0.98***	
LOG(SIGMA)	1.98***		1.98***	
EMP	-		-107.7***	
CDS_DIF	-		-0.01	
INT_DIF	-		0.91***	
Log Likelihood	-9858.83		-9848.69	
Panel B: Constant transition probabilities P(i, k) = P(s(t) = k | s(t-1) = i)				
P(1,1)	99.14%		99.13%	
P(1,2)	0.86%		0.87%	
P(2,1)	1.00%		0.99%	
P(2,2)	99.00%		99.01%	
Panel C: Constant expected duration (days)				
Regime 1	117		115	
Regime 2	100		101	
Panel D: Transition matrix parameters				
P11-C	4.75***		4.73***	
P21-C	-4.6***		-4.6***	

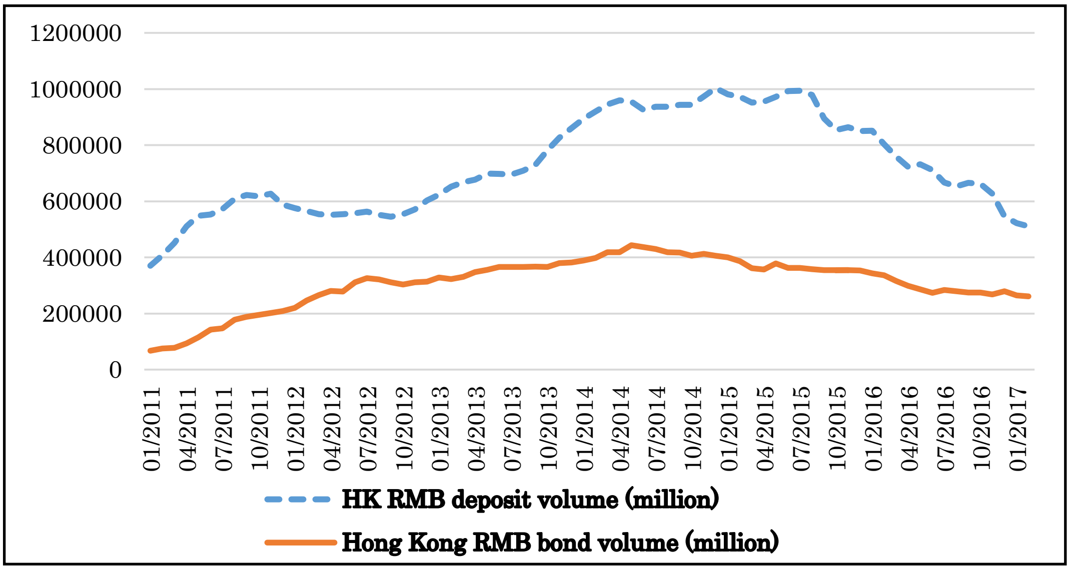
Author's calculation.
Note: This table displays the estimated coefficients of a Markov switching model of the flexibility index. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Columns (1) and (2) show the estimated results of the two possible forms of MS models, which are represented in Eq. (3.4) and Eq. (3.6), respectively.

Table 2.5 The RMB foreign exchange rate regimes: *de facto* vs. *de jure*

Period	Date	***de jure***	***de facto***	
			Implicit currency basket (Frankel–Wei models)	Degree of flexibility (Markov-switching models)
Pre-crisis	June 21, 2005–July 15, 2008	Managed floating with reference to a currency basket. (1) central parity rate (2) daily trading band	Crawling-peg (1) appreciation (2) US dollar anchor	High
In-crisis	July 16, 2008–June 18, 2010		Dollar-peg	Low
Post-crisis	June 19, 2010–August 10, 2015		Crawling-peg (1) appreciation (2) US dollar anchor	High in 2010–Q4 2012; low in Q4 2012–Q4 2014; high in Q4 2014–Q3 2015
	August 11, 2015–July 29, 2016		Currency basket (1) depreciation	Low

Note: This table compares the *de facto* RMB foreign exchange rate regime announced by the monetary authorities with the *de jure* RMB foreign exchange rate regime evaluated from two perspectives: the implicit currency basket using Frankel–Wei models and flexibility regimes using MS models.

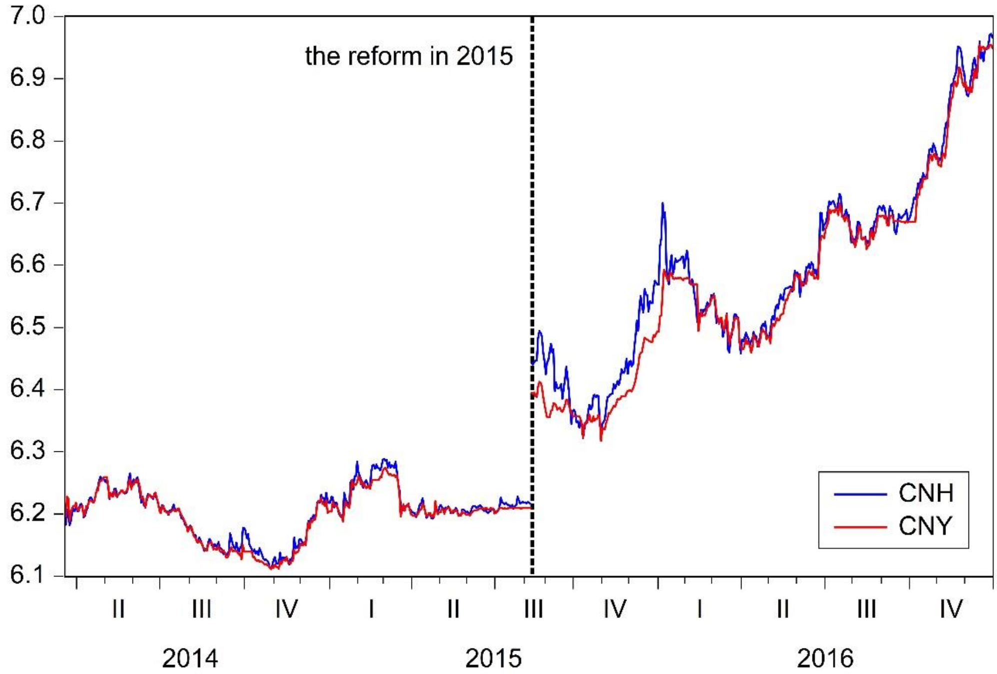
Figure 3.1 The offshore CNH exchange market size



Source: Hong Kong Monetary Authority (HKMA); Datastream

Note: this figure shows the volumes of the renminbi deposit and the remaining volume of the renminbi bonds issued in Hong Kong during 2011 when the Hong Kong offshore renminbi market was officially established in 2016. The unit is 1 million yuan renminbi.

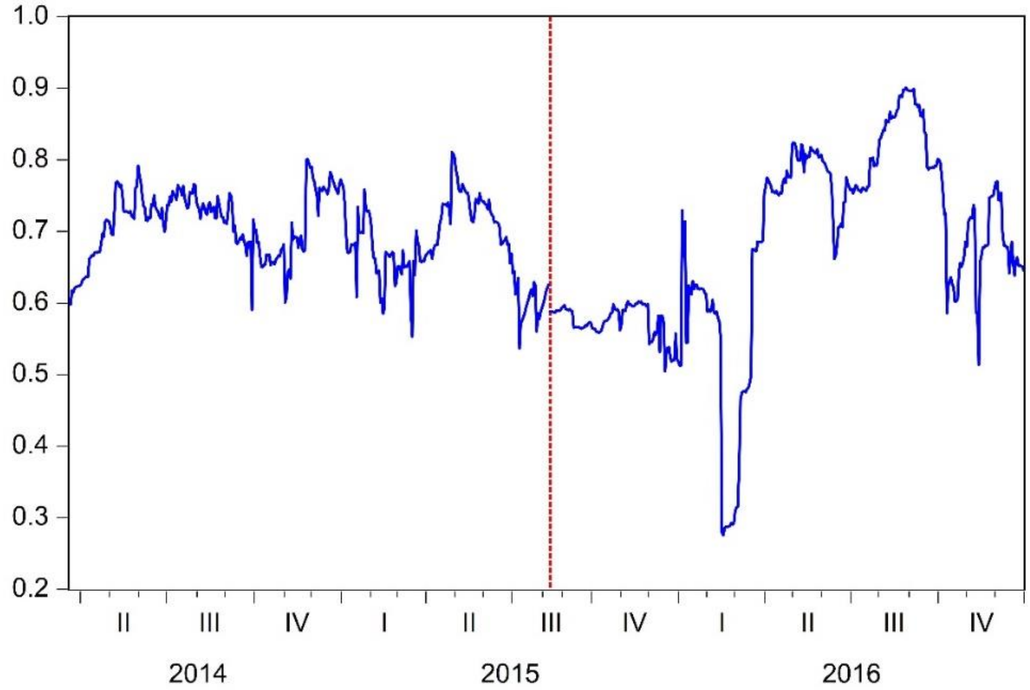
Figure 3.2 The onshore and offshore RMB exchange rates



Source: Datastream

Note: this figure shows the onshore rate (CNY, in red line) and the offshore rate (CNH, in blue line), respectively, ranging from 19 March 2014 to 30 December 2016. The vertical dash line shows the RMB reform on 11 August 2015. A large differential between the two renminbi rates was significantly observed after the renminbi reform on 11 August 2015.

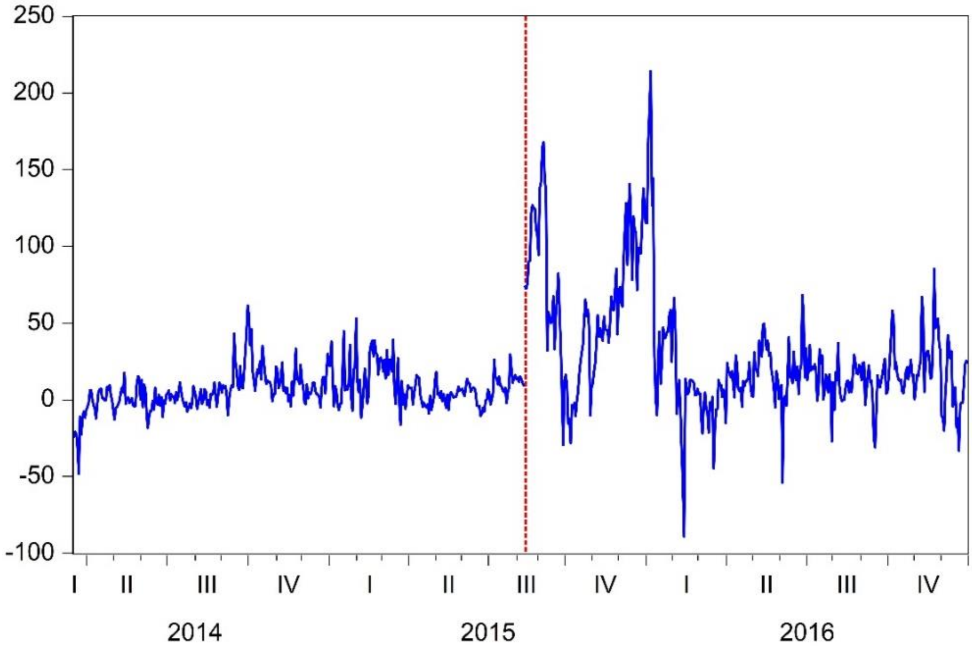
Figure 3.3 The time-varying conditional correlations



Author's calculation

Note: this figure reports the estimated dynamic conditional correlation between CNY and CNH by using a DCC-GARCH model, ranging from 19 March 2014 to 30 December 2016. The vertical dash line shows the RMB reform on 11 August 2015.

Figure 3.4 The onshore-offshore pricing differential



Author's calculation

Note: this figure shows the onshore-offshore pricing differential calculated by $\log(CNH_t/CNY_t)$, ranging from 19 March 2014 to 30 December 2016. The vertical dash line shows the RMB reform on 11 August 2015. A larger value of the pricing differential shows a depreciation in the CNH rate relative to the CNY rate.

Table 3.1 The market conditions of CNY and CNH exchange rates

	CNY	CNH
exchange rate regime	Managed floating	Free floating
capital restrictions	yes	no
the policy rate	Central parity rate	no
daily price band	2% of the policy rate (from April 2014)	no
intervention	yes	no
forward	yes	yes

Source: Bank of International Settlement (2016), *BIS Triennial Central Bank Survey 2016*

Table 3.2 Descriptions of variables

Variables	Descriptions
CNY	daily logarithm return of onshore CNY/USD spot rate
CNH	daily logarithm return of offshore CNH/USD spot rate
fix	daily logarithm return of policy CNY/USD spot rates
fix1	logarithm pricing differentials between the official rate at t and offshore CNH/USD spot rate at t-1
fix2	logarithm pricing differentials between the official rate at t and onshore CNY spot rate at t-1
CNH_BA	bid-ask spread of the offshore spot rate
CNY_BA	bid-ask spread of the onshore spot rate
CNY_INT	3-month interest differential between onshore renminbi and US. Dollars in the global market: $\text{SHIBOR 3M}_t - \text{LIBOR USD 3M}_t$
CNH_INT	3-month interest differential between offshore renminbi and US. Dollars in the global market: $\text{HIBOR CNH 3M}_t - \text{LIBOR USD 3M}_t$
VIX	daily logarithm return of VIX index

Table 3.3 Summary Statistics of variables

Panel A: Pre-reform

	CNH	CNY	FIX	H_BA	Y_BA	H_INT	Y_INT	VIX
Mean	0.17	0.08	-0.08	17.95	10.15	4.25	3.12	-0.68
Median	-1.53	0	0.65	19	10	4.48	2.95	-31.3
Max	56.31	49.9	17.75	38	45	5.27	5.03	1797.93
Min	-39.44	-58.32	-36.59	3	1	2.57	2.07	-1299.84
Std. Dev.	13.48	11.27	5.74	5.05	6.95	0.75	0.72	386.65
Skewness	0.82	-0.05	-1.49	0.01	2.05	-0.93	0.46	0.66
Kurtosis	5.47	8.29	10.01	5.69	8.62	2.91	2.26	5.1
JB	132.53***	422.98***	877.98***	109.55***	730.44***	52.64***	21.09***	92.69***
Obs.	363	363	363	363	363	363	363	363

Panel B: Post-reform

	CNH	CNY	FIX	H_BA	Y_BA	H_INT	Y_INT	VIX
Mean	2.13	2.31	2.25	15.78	35.81	2.32	3.55	0.46
Median	2.51	0.22	0.3	17	31	2.27	3.29	-30.86
Max	92.73	67.51	90.65	29	136	2.87	9.8	3065.49
Min	-126.99	-118.98	-56.35	4	1	1.92	1.68	-2252.6
Std. Dev.	24.34	18.48	20.04	4.33	22.7	0.28	1.52	508.82
Skewness	-0.56	-0.63	0.22	-0.38	0.26	0.4	1.17	0.86
Kurtosis	6.9	9.87	4.22	2.96	2.57	2.07	4.37	8.72
JB	247.56***	732.38***	25.39***	8.55**	6.75**	22.76***	110.03***	534.97***
Obs.	360	360	360	360	360	360	360	360

Note: ***, p<0.01; **, P<0.05; *, P<0.1. Panel A shows the pre-reform basic statistics of variables, includes data from 19 March 2014 to 7 August 2015. Panel B shows the post-reform basic statistics of variables, includes data from 17 August 2015 to 30 December 2016.

Table 3.4 Estimated coefficients of DCC GARCH model

Panel A: pre-reform period

	(1)		(2)		(3)		(4)		(5)		(6)		(7)	
	CNH_t	CNY_t	CNH_t	CNY_t	CNH_t	CNY_t	CNH_t	CNY_t	CNH_t	CNY_t	CNH_t	CNY_t	CNH_t	CNY_t
Mean equations														
constant	0.27	0.12	0.24	0.02	1.87	0.70	-1.11	-0.74	0.38	1.03	0.20	-0.05	-0.54	0.25
	(0.59)	(0.41)	(0.59)	(0.42)	(1.20)	(0.72)	(1.66)	(0.54)	(2.12)	(1.34)	(0.59)	(0.40)	(2.33)	(1.32)
CNH_{t-1}	-0.01	0.26***	-0.06	0.21***	-0.01	0.26***	-0.09	0.20***	-0.05	0.21***	-0.05	0.21***	-0.08	0.20***
	(0.07)	(0.05)	(0.08)	(0.05)	(0.07)	(0.05)	(0.08)	(0.05)	(0.08)	(0.05)	(0.07)	(0.05)	(0.08)	(0.05)
CNY_{t-1}	0.05	-0.18**	0.09	-0.13*	0.06	-0.17**	0.09	-0.14**	0.08	-0.12*	0.09	-0.12*	0.12	-0.13*
	(0.08)	(0.07)	(0.08)	(0.07)	(0.08)	(0.07)	(0.08)	(0.07)	(0.08)	(0.07)	(0.08)	(0.07)	(0.08)	(0.07)
FIX_t			0.32**	0.31***			0.34***	0.31***	0.29**	0.32***	0.26**	0.31***	0.30**	0.31***
			(0.13)	(0.08)			(0.12)	(0.08)	(0.12)	(0.08)	(0.13)	(0.08)	(0.13)	(0.08)
$FIX1_t$					0.02									
					(0.01)									
$FIX2_t$						0.005								
						(0.006)								
H_BA_t							0.09						0.10	
							(0.09)						(0.10)	
Y_BA_t								0.09**						0.09**
								(0.04)						(0.04)
H_INT_{t-1}									-0.09				-0.35	
									(0.69)				(0.71)	
Y_INT_{t-1}										-0.29				-0.28
										(0.34)				(0.33)
VIX_t											0.003**	0.0003	0.003*	0.0003
											(0.002)	(0.001)	(0.002)	(0.001)
Variance-covariance equations														
constant	7.43**	9.83**	6.50**	7.81*	6.71**	10.20**	0.05	0.05	6.23**	7.70*	5.94**	8.38*	6.16**	6.37
	(3.33)	(4.75)	(2.98)	(4.32)	(3.07)	(5.14)	(0.04)	(0.04)	(2.70)	(4.06)	(2.49)	(4.42)	(2.73)	(3.90)
ARCH	0.07***	0.29***	0.07***	0.27***	0.07***	0.29***	0.90***	0.90***	0.06***	0.26***	0.06***	0.25***	0.07***	0.30***
	(0.02)	(0.06)	(0.02)	(0.06)	(0.02)	(0.06)	(0.04)	(0.04)	(0.02)	(0.05)	(0.02)	(0.05)	(0.02)	(0.07)
GARCH	0.88***	0.67***	0.89***	0.70***	0.89***	0.66***	0.71***	0.71***	0.90***	0.70***	0.90***	0.69***	0.89***	0.70***
	(0.03)	(0.07)	(0.03)	(0.06)	(0.03)	(0.070)	(0.06)	(0.06)	(0.03)	(0.06)	(0.03)	(0.06)	(0.03)	(0.06)
λ_1	0.04		0.03		0.04		0.05		0.01		0.01		0.04	
	(0.03)		(0.04)		(0.03)		(0.04)		(0.02)		(0.01)		(0.04)	
λ_2	0.90***		0.92***		0.91***		0.90***		0.96***		0.96***		0.90***	
	(0.04)		(0.06)		(0.04)		(0.04)		(0.03)		(0.03)		(0.06)	
correlation	0.72***		0.70***		0.72***		0.71***		0.67***		0.68***		0.71***	
	(0.05)		(0.06)		(0.05)		(0.06)		(0.05)		(0.04)		(0.06)	
LL	-2642		-2635		-2641		-2632		-2635		-2632		-2629	

Note: t-value in parentheses; *, p-value<0.1; **, p-value<0.05; ***, p-value<0.01

Table 3.4 Estimated coefficients of DCC GARCH model (continued)

Panel B: post-reform period

	(1)		(2)		(3)		(4)		(5)		(6)		(7)		(8)	
	CNH_t	CNY_t	CNH_t	CNY_t	CNH_t	CNY_t	CNH_t	CNY_t	CNH_t	CNY_t	CNH_t	CNY_t	CNH_t	CNY_t	CNH_t	CNY_t
Mean equations																
constant	1.69	1.88**	0.94	1.00	6.51***	2.42**	5.11*	-0.87	1.20	3.94	0.95	1.03	5.23	-1.18	13.44***	9.87*
	(1.13)	(0.95)	(1.10)	(0.91)	(1.30)	(0.98)	(3.04)	(1.34)	(2.19)	(5.46)	(1.08)	(0.90)	(3.92)	(6.72)	(3.58)	(5.37)
CNH_{t-1}	0.04	0.15***	-0.03	0.11**	0.15**	0.09**	-0.02	0.09*	-0.03	0.09*	-0.03	0.10**	-0.02	0.09*	0.19***	0.09**
	(0.08)	(0.05)	(0.07)	(0.05)	(0.07)	(0.04)	(0.07)	(0.05)	(0.07)	(0.05)	(0.07)	(0.05)	(0.07)	(0.05)	(0.07)	(0.04)
CNY_{t-1}	0.06	-0.11	-0.13	-0.32***	-0.01	-0.09	-0.13	-0.33***	-0.13	-0.32***	-0.13	-0.31***	-0.13	-0.33***	-0.04	-0.10
	(0.09)	(0.07)	(0.09)	(0.08)	(0.08)	(0.06)	(0.09)	(0.08)	(0.09)	(0.08)	(0.09)	(0.08)	(0.09)	(0.08)	(0.08)	(0.06)
FIX_t			0.44***	0.44***			0.40***	0.41***	0.41***	0.41***	0.43***	0.43***	0.40***	0.41***		
			(0.08)	(0.07)			(0.07)	(0.06)	(0.07)	(0.06)	(0.07)	(0.06)	(0.07)	(0.06)		
$FIX1_t$					0.29***										0.33***	
					(0.05)										(0.04)	
$FIX2_t$						0.42***										0.44***
						(0.048)										(0.04)
H_BA_t							-0.25						-0.25		-0.23	
							(0.18)						(0.19)		(0.17)	
Y_BA_t								0.06**						0.06**		0.06**
								(0.03)						(0.03)		(0.03)
H_INT_{t-1}									-0.02				-0.05		-0.85	
									(0.60)				(0.60)		(0.570)	
Y_INT_{t-1}										-1.15				0.12		-4.29**
										(2.34)				(2.67)		(2.11)
VIX_t											0.005**	0.004*	0.005**	0.003*		
											(0.002)	(0.002)	(0.002)	(0.002)		
Variance-covariance equations																
constant	102.89*	7.48	45.50	143.15**	56.80***	45.81**	75.10	186.89**	62.90	176.40**	60.90	154.87**	76.26*	191.75*	48.11***	37.16**
	(58.65)	(4.69)	(34.88)	(66.01)	(21.66)	(19.88)	(55.54)	(92.83)	(48.68)	(87.24)	(44.94)	(74.77)	(45.93)	(101.70)	(17.58)	(14.70)
ARCH	0.09***	0.006	0.08**	0.01	0.24***	0.20***	0.11**	0.06	0.09**	0.06	0.09**	0.09	0.11**	0.05	0.24***	0.22***
	(0.03)	(0.007)	(0.04)	(0.07)	(0.07)	(0.06)	(0.05)	(0.04)	(0.04)	(0.04)	(0.04)	(0.06)	(0.04)	(0.04)	(0.06)	(0.06)
GARCH	0.76***	0.98***	0.84***	0.47**	0.72***	0.70***	0.77***	0.35	0.80***	0.39	0.80***	0.441	0.77***	0.33	0.73***	0.71***
	(0.11)	(0.02)	(0.09)	(0.21)	(0.06)	(0.08)	(0.13)	(0.31)	(0.11)	(0.28)	(0.11)	(0.24)	(0.11)	(0.34)	(0.06)	(0.07)
λ_1	0.05***		0.08		0.16***		0.04**		0.05***		0.08**		0.05***		0.190***	
	(0.01)		(0.05)		(0.05)		(0.02)		(0.01)		(0.03)		(0.02)		(0.05)	
λ_2	0.95***		0.90***		0.68***		0.95***		0.95***		0.90***		0.95***		0.59***	
	(0.01)		(0.08)		(0.12)		(0.01)		(0.01)		(0.05)		(0.01)		(0.08)	
correlation	1.18		0.70***		0.81***		0.84***		0.74**		0.71***		0.80**		0.82***	
	(0.88)		(0.14)		(0.04)		(0.29)		(0.35)		(0.11)		(0.34)		(0.03)	
LL	-3068		-3045		-3013		-3041		-3044		-3043		-3039		-3003	

Note: t-value in parentheses; *, p-value<0.1; **, p-value<0.05; ***, p-value<0.01

Table 3.5 Tests of equality on the estimated dynamic conditional correlations (DCC)

	Observations	Mean	Median	Std. Dev.	Mean Increase(%)	t test p-value	z test p-value
pre-reform DCC	362	0.698	0.702	0.054	-4.137%	0.000	0.005
post-reform DCC	359	0.669	0.666	0.132			

Note: this table reports the results of the equality tests on the dynamic conditional correlations between the forecast errors basing on equation (3.1). The breakpoint for two sub-periods is 11 August 2015, when PBoC announced a reform of the quotation mechanism of the policy fixing rate and a renminbi devaluation. The p-value of the t-test shows the statistical significance of the mean differences. The p-value of Wilcoxon z-test represents the statistical significance of the median difference.

Table 3.6 Estimated coefficients of the SETAR model

Panel A. pre-reform

	(1)		(2)		(3)		(4)		(5)		(6)		(7)	
	I	II	I	II	I	II	I	II	I	II	I	II	I	II
Threshold λ	12.57		12.57		12.57		12.57		77.99		12.57		12.74	
Obs	272	90	272	90	272	90	272	90	271	91	271	91	272	90
C	2***	8.52***	1.95***	8.39***	2.1	3.44	3.62***	8.85***	1.98***	8.53***	1.67***	7.08***	4.69**	7.21
	(3.5)	(3.65)	(3.4)	(3.58)	(1.03)	(0.67)	(3.93)	(3.52)	(3.5)	(3.68)	(3.1)	(3.24)	(2.08)	(1.36)
D_{t-1}	0.66***	0.46***	0.67***	0.47***	0.66***	0.43***	0.61***	0.47***	0.67***	0.46***	0.66***	0.51***	0.62***	0.49***
	(8.77)	(5.1)	(8.8)	(5.18)	(8.76)	(4.52)	(7.72)	(5.14)	(8.94)	(5.16)	(9.35)	(6.07)	(8.42)	(5.56)
FIX			-0.09	-0.14									-0.06	-0.1
			(-0.85)	(-0.91)									(-0.63)	(-0.63)
H_BA					0.02	0.37*							-0.09	0.18
					(0.02)	(1.39)							(-0.88)	(0.7)
Y_BA					-0.04	-0.1							0.002	-0.24*
					(0.15)	(-0.7)							(0.03)	(-1.84)
HY_INT							-1.21**	-0.55					-1.16**	-0.36
							(-2.23)	(-0.35)					(-2.18)	(-0.23)
VIX									0.003**	0.004*			0***	0**
									(1.97)	(1.89)			(2.67)	(2.35)
DXY											0.05***	0.11***	0.06***	0.12***
											(4.29)	(6.29)	(4.7)	(6.37)
R2	0.471		0.473		0.475		0.479		0.481		0.545		0.495	
Adj.R2	0.467		0.466		0.464		0.471		0.474		0.539		0.476	

Note: t-value in parentheses; *, p-value<0.1; **, p-value<0.05; ***, p-value<0.01. Regime 1 shows an integrational state when $D_{t-1} < \lambda$, and regime 2 shows a segregational state when $D_{t-1} > \lambda$, as mentioned in Equation (6). Panel A shows the pre-reform basic statistics of variables, includes data from 19 March 2014 to 7 August 2015. Panel B shows the post-reform basic statistics of variables, includes data from 17 August 2015 to 30 December 2016.

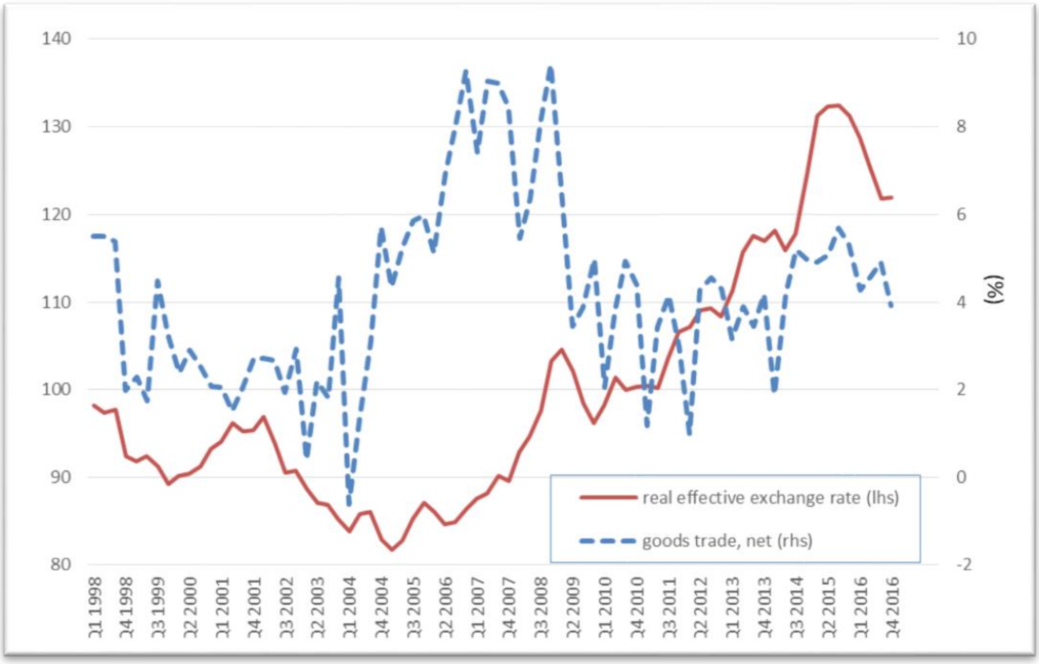
Table 3.6 Estimated coefficients of the SETAR model (continued)

Panel B. post-reform

	(1)		(2)		(3)		(4)		(5)		(6)		(7)	
regime	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Threshold λ	10.41		10.41		10.41		10.41		58.68		58.68		50.19	
Obs	113	246	113	246	113	246	113	246	298	61	298	61	279	80
C	1.37	2.4	1.02	3.03	6.33	8.25	3.86	1.96	5.32***	18.96**	5.2***	20.71***	10.56**	13.43
	(0.71)	(1.24)	(0.51)	(1.53)	(0.73)	(1.41)	(1.63)	(0.96)	(3.77)	(2.4)	(3.82)	(2.7)	(2.02)	(1.09)
D_{t-1}	0.33***	0.9***	0.34***	0.9***	0.33	0.89	0.28***	0.9***	0.7***	0.77***	0.69***	0.76***	0.68***	0.84***
	(2.69)	(28.45)	(2.77)	(28.49)	(2.61)	(26.83)	(2.26)	(27.02)	(13)	(10.71)	(13.09)	(10.99)	(10.91)	(13.31)
FIX			-0.06	-0.1									-0.09	-0.24
			(-0.65)	(-1.51)									(-1.64)	(-1.54)
H_BA					-0.35	-0.14							-0.14	-0.28
					(-0.78)	(-0.47)							(-0.55)	(-0.44)
Y_BA					0.01	-0.09							-0.06	-0.15
					(0.15)	(-1.56)							(-1.27)	(-1.19)
HY_INT							2.07***	-0.61					0.65	-3.27
							(1.79)	(-0.62)					(0.89)	(-1.19)
VIX									0.001	0.01***			0	0.01***
									(0.44)	(2.84)			(0.27)	(4.12)
DXY											0.13***	0.06	0.16***	0.09**
											(5.53)	(1.59)	(6.31)	(2.45)
R2	0.774		0.775		0.776		0.776		0.777		0.791		0.806	
Adj.R2	0.772		0.772		0.771		0.773		0.774		0.788		0.797	

Note: t-value in parentheses; *, p-value<0.1; **, p-value<0.05; ***, p-value<0.01. Regime 1 shows an integrational state when $D_{t-1} < \lambda$, and regime 2 shows a segregational state when $D_{t-1} > \lambda$, as mentioned in Equation (6). Panel A shows the pre-reform basic statistics of variables, includes data from 19 March 2014 to 7 August 2015. Panel B shows the post-reform basic statistics of variables, includes data from 17 August 2015 to 30 December 2016.

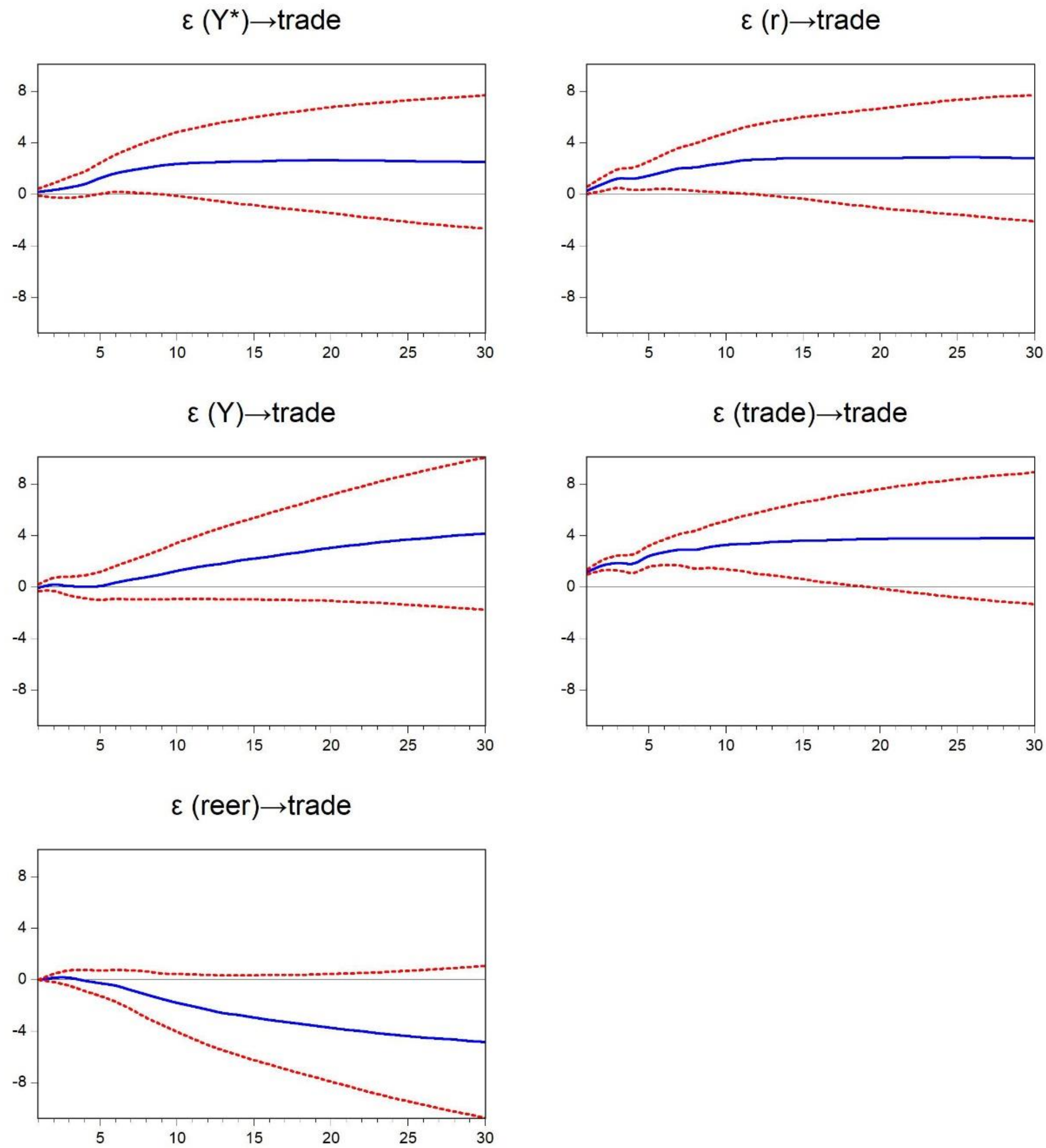
Figure 4.1 China's goods trade and exchange rate during 1998–2016



Source: People's Bank of China (PBoC); Bank of International Settlements (BIS); author's calculation.

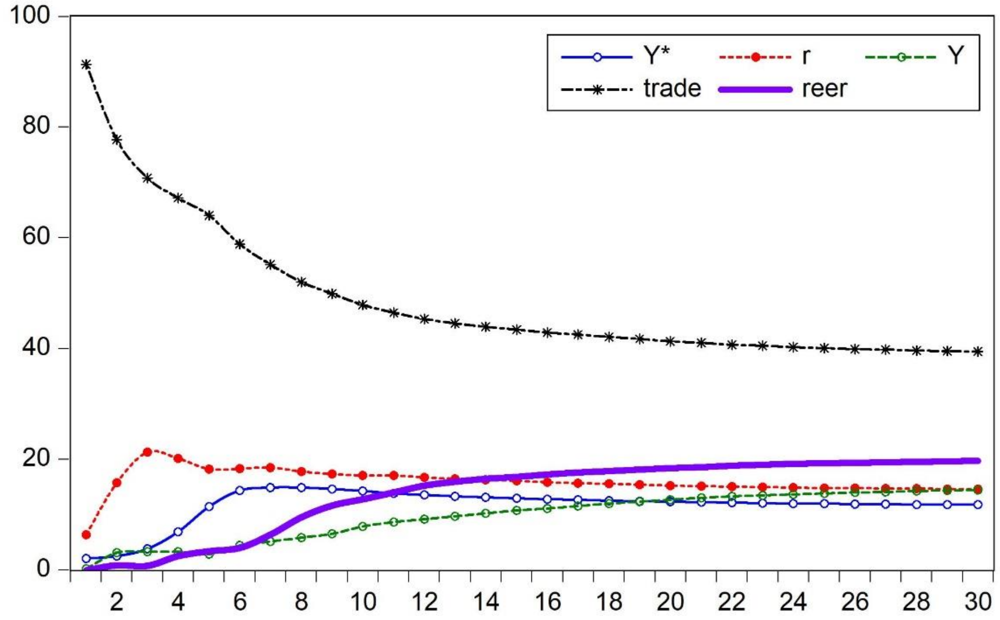
Note: it is the real effective exchange rate (REER) basing on the price level in 2010, rather than the nominal renminbi exchange rate. The "goods trade (net)" is based on the Sixth Edition of the Balance of Payments Manual (BPM6) by International Monetary Fund (IMF), and has been converted to the ratio of the nominal GDP (% of GDP), which could be used to evaluate the trade rebalance level relative to the domestic economic size.

Figure 4.2 The accumulated impulse responses of *trade* to shocks



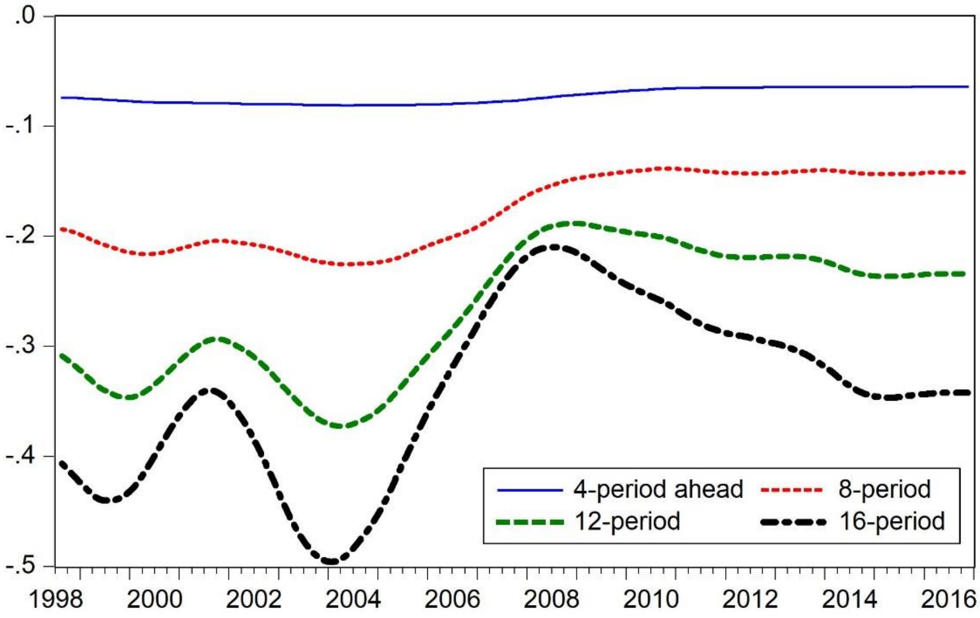
Note: the blue lines show the accumulated responses of *trade* to Cholesky One standard error of *Y*, r, Y, trade* and *reer*, basing on a five-variable structural VAR (SVAR) model proposed by Ogawa and Iwatsubo (2009). The red dotted lines show the 95% confidence intervals.

Figure 4.3 Variance decomposition of *trade*



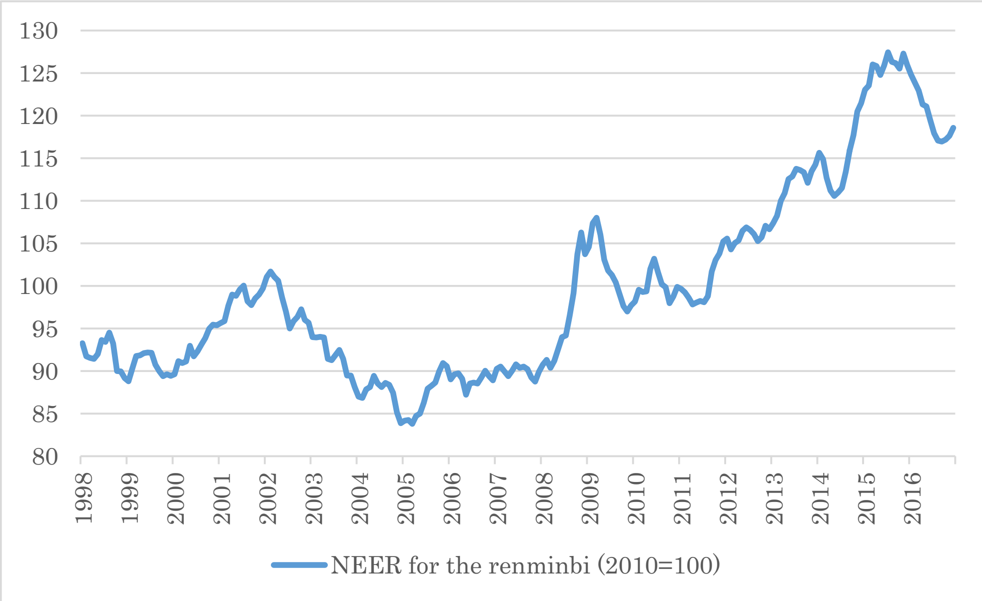
Note: this figure shows the variance decomposition of variable "*trade"* to shocks, basing on a five-variable structural VAR (SVAR) model proposed by Ogawa and Iwatsubo (2009). The variables in the figure mean as follows: *Y**, the real GDP of total OECD countries (logarithm); *Y*, China's real interest rate; *r*, China's real interest rate; *trade*, the net goods trade (in % of GDP); *reer*, real effective exchange rate, respectively.

Figure 4.4 Time-varying accumulated impulse responses of trade to REER shock



Note: this figure reports the time-varying accumulated impulse responses of *trade* to one standard error shock of *reer* at 4, 8, 12, 16-ahead period. Calculations are based on the TVP-VAR model proposed by Nakajima (2011). Due to the limitation of PC's computation power, the lag structure of the TVP-VAR model is set as 2, which is different with the structural VAR model.

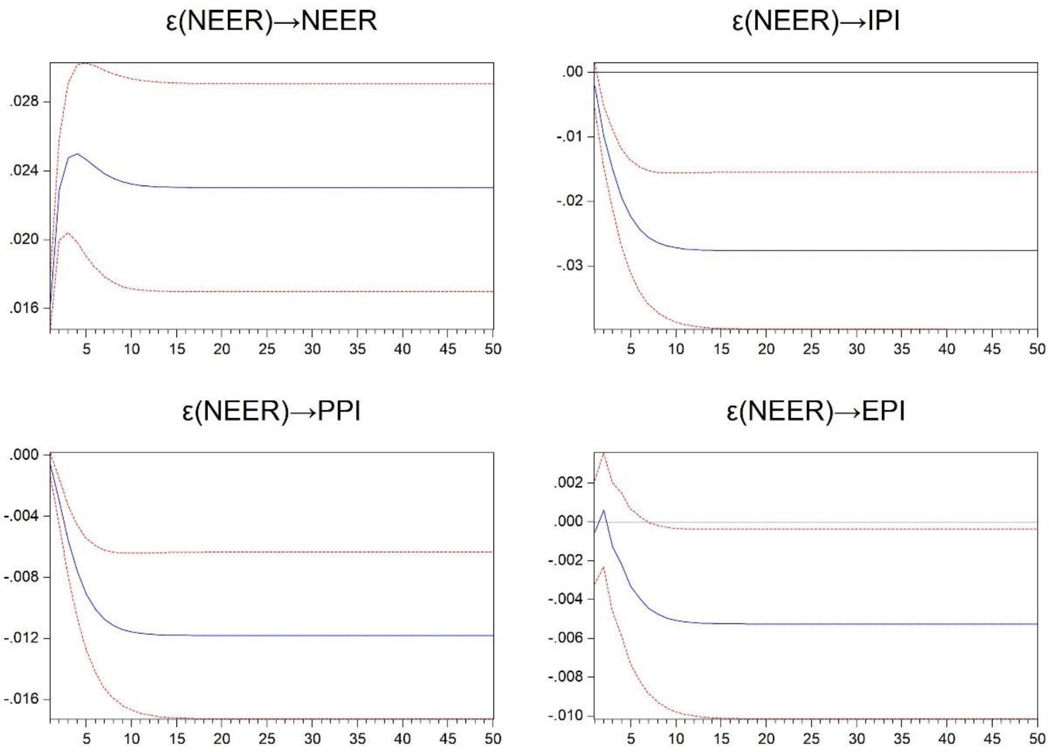
Figure 4.5 The nominal effective exchange rate for the renminbi (2010=100)



Source: Bank for International Settlements (BIS)

Note: The nominal effective exchange rate (NEER) for the renminbi is calculated as the geometric weighted average of bilateral exchange rates. The weights are based on trade in the 2011–2013, with 2010 as the base year (2010=100).

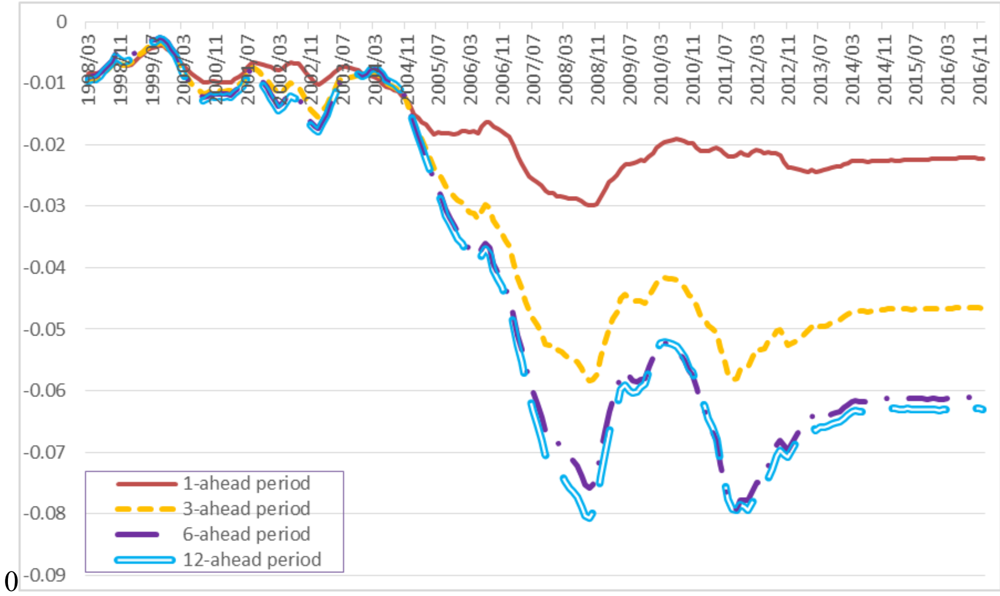
Figure 4.6 Accumulated impulse responses of price indexes to NEER shock



Note: the panels in this figure shows the impulse response results of a three-variable structural VAR (SVAR) model proposed by Ito and Sato (2008). The blue lines show the accumulated responses of *NEER* (nominal effective exchange rate), *IPI* (import price index), *PPI* (producer price index) and *EPI* (export price index) to Cholesky one standard error of *NEER*. The red dotted lines show the 95% confidence intervals.

Figure 4.7 Time-varying accumulated impulse responses to NEER shock

(A) impulse responses of import price index (IPI)



(B) impulse responses of producer price index (PPI)

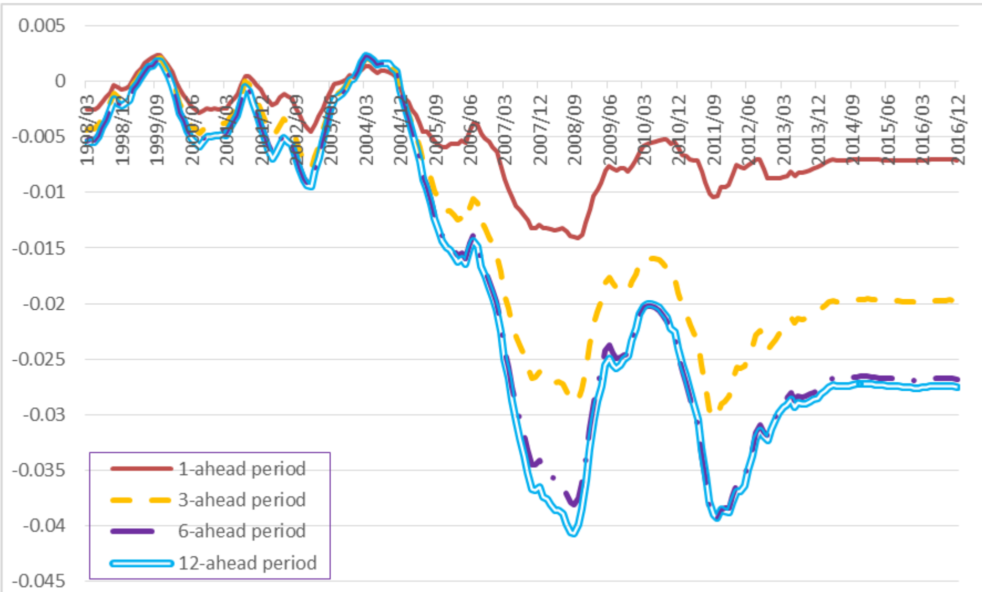
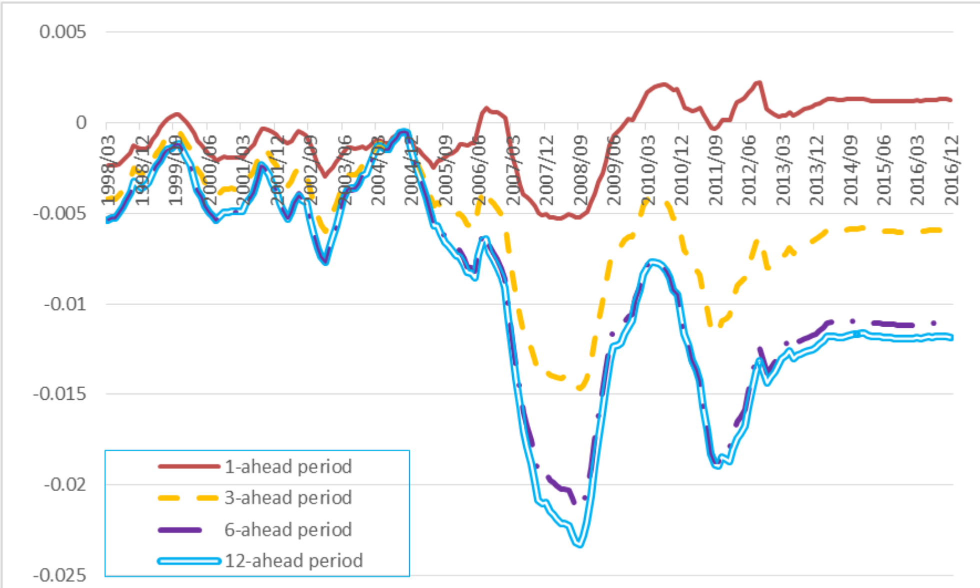


Figure 4.7 Time-varying accumulated impulse responses to NEER shock (continued)

(C) impulse response of export price index (EPI)



Note: the panels in this figure report the time-varying accumulated impulse responses of *IPI* (import price index), *PPI* (producer price index) and *EPI* (export price index) to one standard error shock of *NEER* (nominal effective exchange rate) at 4, 8, 12, 16-ahead period. Calculations are based on the TVP-VAR model proposed by Nakajima (2011). The lag structure is set to 1.

Table 4.1 Variable definitions

variables	definitions
Y*	real GDP of total OECD countries (logarithm)
r	China's real interest rate
Y	China's real GDP (logarithm)
trade	China's net trade (% of GDP)
reer	BIS real effective exchange rate of China (logarithm)

Source: People's Bank of China; OECD database; BIS; author's calculation.

Table 4.2 Descriptive statistics and unit root test

Descriptive statistics					
	*Y**	*r*	*Y*	*trade*	*reer*
Observations	76	76	76	76	76
Mean	17.552	3.941	6.999	4.214	4.595
Median	17.574	3.890	7.048	4.223	4.567
Maximum	17.715	8.820	7.798	9.401	4.886
Minimum	17.348	-0.530	6.136	-0.594	4.403
Std. Dev.	0.099	2.163	0.521	2.150	0.133
Skewness	-0.359	0.166	-0.084	0.481	0.706
Kurtosis	2.116	2.676	1.641	3.037	2.471
Unit root test					
Augmented Dicky-Fuller test statistics	-3.062	0.077**	0.071	-1.994	-2.318
Phillips-Perron test statistics	0.478	-2.599*	-0.064	-3.754***	-2.095

Note: in the unit root test, the null hypothesis is that the unit root exists. *and** mean the null hypothesis is rejected at 90% and 95% confidence intervals, respectively.

Table 4.3 Descriptive statistics and the unit root test

Descriptive statistics				
	NEER	*IPI*	*PPI*	*EPI*
Observations	227	227	227	227
Mean	-9E-04	0.0002	0.0003	9.20E-05
Median	0.0004	-0.003	0	0
Maximum	0.0488	0.1193	0.0385	0.0705
Minimum	-0.056	-0.1242	-0.044	-0.0628
Std. Dev.	0.018	0.0315	0.009	0.0227
Skewness	-0.165	-0.0134	-0.06	0.3376
Kurtosis	3.1177	4.7318	8.0552	3.3524
unit root test				
Augmented Dicky-Fuller test statistics	9.084***	-6.332***	-5.81***	-22.755***
Phillips-Perron test statistics	-10.003***	-14.861***	-5.975***	-21.786***

Note: in the unit root test, the null hypothesis is that the unit root exists. *and** mean the null hypothesis is rejected at 90% and 95%, respectively.