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Managing the Managed Float in China

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To My Parents

Managing the Managed Float in China

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Abstract

Despite the promising reform objectives announced on 21 July 2005, there remain much uncertainty and controversy surrounding China's managed floating regime and its future. Hence, this research aims to provide a comprehensive analysis of the key issues raised over the course of the post-reform era.

We begin by investigating whether the flexibility of RMB has increased following the reform announcement. A daily-based flexibility indicator is developed to more accurately detect the extent to which the Chinese currency is market-driven. This indicator is then utilized in a Markov switching model. The subsequent results suggest that the RMB flexibility has switched between two distinctive regimes, confirming that RMB flexibility did increase after the 2005 reform, while the so-called Fear of Floating was also apparent. Additionally, we discuss possible driving factors underlying the evolution of the RMB flexibility.

Next, we consider another crucial aspect of the current managed floating regime, the equilibrium exchange rate level for RMB. The NATREX approach is selected, as we argue that it represents the most suitable solution for the purpose of our research. The empirical findings reveal not only the exogenous fundamental factors that have impacted the real exchange rate of RMB in the manner predicted by the NATREX model, but also evidence that the presumed portfolio channel did not work effectively for China in the sample period, which is contrary to the findings of previous studies.

Looking ahead, we argue that the Reference Rate system could be a promising option for China. From the managerial aspect, we propose an optimal exchange rate management for China, which takes the presence of heterogeneous agents into consideration. We demonstrate that this strategy, once adopted, offers the optimal trade-off between the cost of intervention and the cost of no intervention.

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Declaration

The content of this thesis is based on research carried out at Durham University Business School. No part of this thesis has been submitted elsewhere for any other degree or qualification in this or any other university.

Statement of Copyright

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Table of Contents

List of Tables

List of Figures

Chapter 1

Introduction

1.1Background and Motivation

The remarkable growth of China's economy in recent decades, attributable largely to China's outstanding performance in global trade, has become an important factor shaping the world economic and political order. Thanks to the radical economic reform embarked upon in 1978, in 2013 China surpassed the US to become the world's largest trading nation (Anderlini and Hornby, 2014). While China has been enjoying its rising global influence, researchers and policy-makers worldwide have turned their attention to its exchange rate policy, i.e. the fixed nominal exchange rate against the US dollar, particularly since the start of 1994. From the early 2000s, one popular idea in international circles was that China's currency, the RMB, had been severely undervalued, an argument supported by the evidently huge surplus of both current and capital account. It was widely reported at that time that the US Congress had repeatedly pressured the US Treasury to declare that China was intentionally manipulating its currency in order to achieve a competitive advantage in trading (Goldstein, 2003; and Coundert and Couharde, 2007).

The then top leaders in China continued to insist that the RMB was at an appropriate level and that it was crucial to maintain that level, thus giving little positive response

to the international pressures. However, as the pressure intensified it was reported that China's leadership started to rethink their position on holding a fixed RMB. The final news of reform emerged when the Chinese leaders and market participants achieved a consensus on having a more flexible exchange rate. On 21 July 2005 the Chinese central bank (People's Bank of China, PBOC hereinafter) announced the lifting of the dollar peg and the overall aim to '*build a managed, floating exchange rate mechanism based on market supply and demand and to maintain the yuan's basic stability at a reasonable equilibrium level*' *(People's Daily, 22 July 2005)*. With immediate effect, a flexible mechanism was phased in with the RMB being allowed to move in a narrow band around a central parity rate determined with reference to market makers' opinions and movements of a basket of world currencies.

In essence, the overall aim of exchange rate reform can be broken down into two relating objectives: 1) to increase the flexibility in the process of setting the daily spot RMB price and 2) to maintain the RMB in a reasonably stable level as determined by policy makers. In our research, these two objectives are investigated in detail in Chapter 2 and Chapter 3, respectively.

If history has taught us anything, it is that it is deeds, rather than words, that matter. Hence, we are interested to explore to what extent the reform has accomplished its objectives in the 10 years since its announcement in July 2005. It is interesting to note that in the early post-reform era, the Chinese authority repeatedly tried to promote the idea that substantial progress had been made, citing the clear

appreciation of both the nominal and effective exchange rate against the major trading currencies. However, a large body of literature, for example Eichengreen (2007) and Frankel (2009), argued that the RMB was still firmly pegged to the US dollar, as the variation in nominal exchange rate of the RMB could be attributed almost exclusively to the movements of the US dollar, while the other presumed basket-currencies exerted little influence. To make matters worse, the exchange rate reform was noticeably disrupted by the fallout from the global financial crisis, and in late 2008 the Chinese authority reinstituted a fixed nominal exchange rate of RMB against the US dollar. This continued until 2010, when the PBOC announced on 19 June that it would 'proceed further with reform of the RMB exchange rate regime and enhance the RMB exchange rate flexibility'.[1]

Since the 2005 reform, the PBOC has also endeavoured to launch two further policy changes, namely capital account liberalization and internationalization of the RMB. With regard to the former, while the PBOC has declared publicly that China has made substantial progress in liberalizing its capital account against the criteria set by the IMF, scholars have been much more conservative on this issue. On one hand, studies such as Ma and McCauley (2008) argue that China has maintained strong control over capital flows, especially short-run speculative ones. On the other hand, scholars are still debating the necessity and potential schedule for China to fully liberalize its capital account. Nevertheless, the Chinese authority has already

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[1]PBOC News Archive. [Online] Available at:

http://www.pbc.gov.cn/english/130721/2845862/index.html. Accessed on 1 September 2016.

undertaken several meaningful experiments, including the establishment of the Shanghai Pilot Free Trade Zone.

On the issue of RMB internationalization, here again opinions are divided. Although Chinese officials have not publicly endorsed promotion of the RMB as an international currency, it has actively promoted the RMB as a future option for international settlement. Evidence for the implementation of this policy can be found in the fact that China has signed currency swap agreements with more than 20 monetary authorities, ranging from the emerging markets in Asia to developed countries, with a total amount of more than 2 trillion yuan. The determination of the Chinese authority in pushing forward RMB internationalization is further exemplified by the fact that the RMB has joined the US dollar, euro, pound and yen in the IMF's Special Drawing Rights (SDR) from Oct. 1, 2016 with a weight of 10.92 percent.[2]

In contrast to the eye-catching speed of economic growth, China is widely known for being slow to complete its reform measures, something that has attracted wide concern and criticism. The exchange rate regime reform is no exception. It seems plausible to contend that there is still much uncertainty among market participants as regards the ongoing exchange rate reform, especially among foreign investors. To take the most recent incident as an example, on 11 August 2015 the global financial market was shocked by the sudden devaluation of the RMB, the largest

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[2] IMF Press Release. N0. 15/543. [Online] Available at:
https://www.imf.org/en/News/Articles/2015/09/14/01/49/pr15543. Accessed on 1 September 2016.

one-day drop observed in two decades. To make matters worse, the market was not fully convinced by the PBOC's explanation that the devaluation was merely the result of a policy change on how the central parity rate of the RMB is derived. As a result, the PBOC was forced to intervene to stop the RMB from depreciating too rapidly, and a significant loss of foreign reserves was incurred in a short time. Meanwhile, in a notable break from usual practice, top officials at the PBOC had to make frequent public appearances to defend such a policy move. We contend that one major reason for this incident is that the market did not believe the market exchange rate was close to its equilibrium level as the government claimed, and it is then not surprising that there were panic reactions from investors.

1.2 Research Questions

To address the current controversies pertaining to the reform progress and the concerns over its future, we are highly motivated to offer a thorough investigation of the exchange rate reform. In Chapter 2, we focus on the key objective of the reform, to increase the flexibility of the RMB. When investigating whether or not the RMB flexibility has increased, an appropriate measurement for exchange rate flexibility is of vital importance. Using popular methods, such as proposed by Levy-Yeyati and Sturzenegger (2003, 2005), the mainstream finding is that the RMB flexibility is still very limited, and consequently China is still classified by the IMF as a soft peg in 2014. However, we argue that these methods may not be sufficient to detect changes of the RMB flexibility as they all suffer from some methodological limitations, especially the dependence on monthly data. Hence, we seek to address the following two research questions:

- Can the existing approaches produce satisfying exchange rate flexibility results in the case of China's RMB? If not, how should the measurement be constructed?

- Has the RMB flexibility changed in the manner officially claimed? If so when did the changes happen and what were the underlying driving factors?

In Chapter 3, we investigate whether the RMB has reached its equilibrium level during the 10-year post-reform period. This question warrants close examination, because the equilibrium exchange rate plays an irreplaceable role in the exchange rate regime. China is a great example in point. Between 1994 and July 2005, China fixed its exchange rate against the US dollar at 8.275, while the international community argued that it was severely undervalued compared to its equilibrium exchange rate. As a result, the Chinese authority finally gave the green light to the reform. However, even though the RMB has since seen consistent appreciation, the question is still very much relevant in the current managed floating regime. Given the experience of previous intermediate exchange rate regimes, like the Adjustable Peg, the maintenance would be extremely costly, if not impossible, when the market has little confidence in the (implied) equilibrium exchange rate that the central bank upholds. We also note in Chapter 3 that researchers have developed various ways to conceptualize and calculate the equilibrium exchange rate. Specifically, we examine the following research questions:

- Why is the NATREX approach proposed by Stein (1994) suitable for China?
- From an empirical perspective, which exogenous fundamental factors have

impacted the real exchange rate of RMB in the manner prescribed by the NATREX approach? Moreover, does the real exchange rate converge to the moving NATREX?

In Chapter 4, in light of the issues raised above, we seek to offer an optimal management strategy for the Chinese exchange rate regime. Compared to the questions explored in Chapter 2 and Chapter 3, a much smaller number of studies have focused on the managerial aspect of exchange rate regime. To fill this gap, we turn for help to the stochastic optimal control theory, because it is more realistic to consider the management of exchange rates in an evolving system such that new information (or shocks) arrives in an unpredictable fashion and it is up to the policy-maker to act accordingly to achieve the best outcome. We note that in this strand of literature there is a key assumption that agents are not capable of obtaining parameters of the response function of the central bank; this rules out the potential impact from agents' response to the government intervention on the exchange rate, and thus ensures that the solution is tractable (Cadenillas and Zapatero, 1999).

However, this assumption seems to be somewhat unrealistic, especially in light of recent findings on the presence of heterogeneous agents in the foreign exchange market and the impact of central bank intervention on those agents. In fact, the existence of heterogeneous agents, aka the heterogeneity found in traders' investment strategies, is well-established in various financial markets. In the context of the foreign exchange market, a number of empirical anomalies, such as the 'Disconnect' puzzle (Frankel and Froot, 1986), the 'Forward Discount Bias' (Froot

and Frankel, 1989) and the 'Excess Volatility' puzzle (LeBaron, 2006), have all been argued to be related to the heterogeneous agents. Recently there has arisen ample empirical evidence that heterogeneity does exist and those heterogeneous agents may switch their trading strategies over time. As a result, those studies provide a convincing argument for the necessity of central bank intervention. For example, from a theoretical standpoint, De Grauwe and Grimaldi (2006) explain that in a free-floating regime, central bank intervention helps to prevent the development of an exchange rate bubble. There is also strong empirical evidence, such as Beine et al. (2009) and Maatoug et al. (2011), to indicate that central bank intervention is effective such that it can help increase the proportion of fundamentalists and/or decrease the impact of chartists, which in turn helps the market exchange rate to return to the equilibrium level.

Hence, we need to take the presence of heterogeneous agents into consideration when constructing an optimal exchange rate management strategy. This is particularly relevant in the context of the Chinese foreign exchange market, as we know that the market participants can only quote the price of RMB against foreign currencies within pre-determined trading limits around the central parity rate, and the PBOC can directly intervene in the market by placing orders. Moreover, we note that major players in the Chinese foreign exchange market are more or less owned by the government. Hence, it seems plausible to assume that traders would follow the PBOC's intentions rather than the other way around. Therefore, we consider the following research questions:

- Do heterogeneous agents exist in the Chinese foreign exchange market?

- To what extent does the PBOC intervention impact the market, which is modelled as consisting of fundamentalists and Moving-Average traders?

- What is the optimal exchange rate management strategy for China?

In light of the results obtained, in Chapter 5 we aim to identify the issues that should be addressed in China's ongoing exchange rate regime and explain why the Reference Rate system might be a desirable choice for China to adopt as its form of managed floating.

Despite the promising reform announcement, there is still much doubt over the true nature of the reformed exchange rate regime. Some empirical studies suggest that China has in fact maintained a peg to the US dollar. In the 2014 Annual Report on Exchange Arrangements and Exchange Restrictions, the IMF identified the Chinese exchange rate regime as a crawling-like arrangement, noting that it maintains a *de facto* peg to the US dollar. Hence, we argue that if the Chinese government genuinely wants to fulfil its commitment to allow more market forces in the price formation process of the RMB, it must state explicitly what the 'managed floating regime' represents, including its objectives, the means to uphold the regime, and the boundaries of government intervention such as the specific situations when central bank intervention can be considered. Failure to do so will damage investor confidence, which will in turn make the survival (or success) of the regime highly costly, if not impossible. To summarize, in this chapter we consider the following research question:

- Why is the Reference Rate regime a desirable choice for China to adopt as

its form of managed floating? Moreover, how should it be implemented?

1.3 Main Findings and Contribution

The choice of exchange rate regime is of vital importance to the country concerned, especially for an economy in transition, such as China. Therefore, the main contribution of our research is to offer a comprehensive valuation of China's ongoing exchange rate regime, aiming to provide clearer answers to some widely debated key issues. In a nutshell, we contribute to the literature first by providing strong empirical evidence that, since the July 2005 reform, the flexibility of RMB has indeed increased, and the real exchange rate of RMB has markedly appreciated to a level close to its equilibrium value. Secondly, this research sheds light on the future of this ongoing reform. In particular, we explain why the Reference Rate regime represents a promising future for China, and present an optimal management strategy that falls in line with China's so-called managed floating.

To explain the contribution in more detail, here we list the findings in sequence. In Chapter 2, the first contribution is that we build a new daily-based flexibility indicator specifically for China. This overcomes the deficiencies found in the conventional models, such as their over-reliance on the monthly data. Because government intervention is usually conducted at a higher frequency, monthly average data may camouflage the frequency and effects of government intervention. The results confirm that this newly built index tracks the evolution of the essence of China's exchange rate regime well and reveals richer information, which may otherwise remain hidden in the conventional models. The second major finding of

Chapter 2 is the evidence of Fear of Floating in China, in light of the nonlinearity found in the newly built index. Using the Markov switching model, we find evidence that the RMB flexibility has switched between two regimes, where the parameters in the high- and low-flexibility states differ noticeably. As a follow-up, the third finding of Chapter 2 is our identification of a few determinants underlying the movements of RMB flexibility. The interest rate differential between China and the US seems to have a positive effect on the RMB flexibility in both regimes, although the coefficients are not statistically significant. Even though EMP[3] has a negative effect on the RMB flexibility in both regimes, the magnitude of the effect decreases drastically from the low-flexibility regime to the high-flexibility regime. We also find that the CDS index, which indicates the risk China is exposed to, may serve as an early warning signal for regime shifts of RMB flexibility, since a higher risk spread lowers the probability of the RMB staying in the high-flexibility state.

In Chapter 3, the first potential contribution is that we provide reasons why the NATREX model is appropriate for estimating the equilibrium exchange rate for China. In comparison with other models, the NATREX stands out as it not only offers a quite general yet straightforward framework, but also represents a 'positive' rather than a 'normative' concept. The latter is quite important for policy-makers, as they could test what impacts one policy might have on the real exchange rate of the RMB. Despite the fact that the NATREX has been successfully applied to a number of currencies, our research is one of very few studies that strive to employ this approach for the RMB. In terms of empirical findings, we not only identify the

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[3] It stands for Exchange Market Pressure, which will be discussed in detail in Chapter 2.

exogenous fundamental factors that have impacted the real exchange rate of RMB in the manner predicted by the NATREX model, but also find that the presumed portfolio channel did not work effectively for China in the period studied, which is in contrast to the findings of previous studies. We argue that this is largely due to the state of China's economic development and accordingly its choice of policy mix, including but not limited to capital control measures.

The major contribution of Chapter 4 is that we construct an optimal exchange rate management strategy for China, something not previously attempted in the literature. First, using a Markov switching model, we offer empirical evidence that heterogeneous agents, represented by fundamentalists and chartists (Moving-Average traders), do exist in the Chinese foreign exchange market. Conventionally, the Moving-Average traders, as an example of chartists, are often criticized for destabilizing the market. However, in the case of China, we find that MA traders actually helped the market exchange rate move closer to the equilibrium level, as the RMB was considered to be severely undervalued. Secondly, unlike previous studies, which implicitly impose the assumption that at any time there is only one trading strategy in operation, we include both fundamentalists and chartists in the model at all times. In terms of the impacts central bank intervention might have upon the heterogeneous agents, we find that the estimation results should be interpreted carefully. On one hand, if the government intervention objective was to decrease the exchange rate volatility, the PBOC intervention can be considered very successful, as the volatility is more than 7 times larger in the 'active' state than in the 'calm' state, and both fundamentalists and MA traders play an insignificant role. On the other hand, if the government intervention objective was to close the gap

between nominal exchange rate and the underlying equilibrium exchange rate, the PBOC intervention should be considered as a failure. When the intervention intensity drops, which is proxied by an increase in the flexibility index, we could expect the probability of staying in an 'active' regime, or of transiting out of the 'calm' regime, to increase, whereby both fundamentalist and MA traders play a significant role in pushing the real exchange rate of the RMB back to its equilibrium value.

Based on the empirical findings, we extend the stochastic impulse control model by characterizing a 'reaction period' as introduced in Kercheval and Moreno (2009) and Bensoussan et al. (2012). Then the optimal exchange rate management strategy aims to achieve the optimal trade-off between cost of intervention and no intervention. The subsequent solution solved propose there exists an intervention-free zone within which the exchange rate can float freely as in a pure floating regime. However, when the exchange rate reaches the upper or lower edge of this zone, the optimal strategy would determine what is the best intervention size. It is demonstrated that this strategy offers valuable insights for the central bank from an operational perspective as, once adopted, it effectively solves the problems inherent in a market populated by heterogeneous agents, such as excessive exchange rate volatility and large misalignment, thereby lowering the chances of official intervention.

Despite recent reforms, China still faces significant challenges to formulate sensible arrangements for a managed floating exchange rate regime. Drawing on the findings

from previous chapters, in Chapter 5, we contribute to the literature by arguing why a Reference Rate system could be a promising option for China. Such a regime presents a simple yet solid framework for regulating the level and movement of the exchange rate. Its primary appeal is its ability to provide ample room for the exchange rate to fluctuate on the basis of market demand and supply, while acknowledging the necessity and desirability of central bank intervention. Moreover, the Reference Rate regime explicitly lays out the objective and boundaries of the intervention, which helps to avoid the pitfalls of both a pegged rate and a freely floating rate.

1.4 Organization of the Thesis

Following this introductory chapter, the thesis comprises four main chapters and a sixth, concluding chapter. Chapter 2 aims to answer the question of whether the flexibility of the RMB has increased following the July 2005 reform. In accordance with the idea that currency flexibility should be defined as to truly reflect the degree to which the monetary authority allows market forces to influence the price formation process, Chapter 2 presents a nuanced investigation of the degree and dynamics of flexibility in China's exchange rate regime. A high-frequency data model is developed to more accurately detect the extent to which the Chinese currency is market-driven. This indicator is then utilized in a Markov switching model to examine whether there has been any shift in RMB flexibility. Additionally, this chapter strives to identify possible factors that have driven the evolution of RMB flexibility.

Chapter 3 looks at another central pillar of the managed floating regime, the equilibrium exchange rate level for RMB. It starts with an overview of the most influential theories and methodologies that have been developed in this line of research. Then, we list reasons for the selection of the NATREX approach in this study. The chapter then offers a thorough empirical investigation of the real exchange rate of RMB in the NATREX framework, which is decomposed into three parts: the long-run analysis, the medium-run analysis and the misalignment between the real exchange rate and the NATREX value.

Chapter 4 focuses on the managerial perspective of the ongoing exchange rate regime. To address the lack of transparency in the current so-called managed floating regime, we argue that the optimal stochastic control theory can be of great help. In addition, this chapter recognizes the heterogeneous agent literature, which provides another strong argument why central bank intervention is needed. Based on the empirical evidence from the Chinese foreign exchange market, this chapter presents a rule-based official intervention strategy for the Chinese authority and offers numerical simulation to explain how it could be implemented.

Chapter 5 notes that to fulfil its commitment to establish a managed floating regime and solve the issues raised in previous chapters, China needs to come up with a sensible and executable management framework. To this end, we follow John Williamson and provide reasons why a Reference Rate system could be a promising option for China. This thesis argues that the Reference Rate system is appealing because it not only falls into line with the objective of China's reform, which is to

allow market forces to play a larger role in the exchange rate system, but also leaves room for the authority to exert its influence in accordance with the pre-determined rules. The chapter also discusses the rules and policy coordination of the system and how the regime may be operationalized.

Chapter 6 offers concluding remarks in light of the previous chapters. The limitations of the research are outlined, and future improvements are proposed.

Chapter 2

Exchange Rate Flexibility in China: Measurement, Regime Shifts and Driving Forces of Change

2.1 Introduction

China's exchange rate policy has been the subject of much debate during the past decade. The early debate focused on whether the Renminbi (RMB) was undervalued and the possible consequences thereof. More recently, however, discussions of the appropriate institutional arrangements for the Chinese currency have become prominent. A major aspect of the debate concerns the degree of flexibility of the Chinese exchange rate regime, which is the essential feature of exchange rate regime classification.

China maintained an exchange rate pegged to the US dollar from 1994 to 2005. Despite problems with an enduring, rigid dollar peg, some scholars maintain that China should continue the dollar peg because increased flexibility might result in deflation as it had in Japan (e.g., McKinnon, 2006, 2007; McKinnon and Schnabl, 2009, 2012). Arguing against continuation of the dollar peg, Roberts and Tyers (2003) demonstrate that in the face of external shocks, a flexible exchange rate regime would help China avoid the harmful consequences of a fixed exchange rate policy. For instance, it helps to reduce currency market speculation (Eichengreen,

2004, 2007). Both Obstfeld (2007) and Roubini (2007) contend that the large, modernized, diverse Chinese economy and eventual convertibility with open capital markets require exchange rate flexibility. Support for greater flexibility in China is also voiced by Bernanke (2005), Frankel (2006), Roubini and Setser (2005), Prasad et al. (2005), Goldstein and Lardy (2006), and Morrison and Labonte (2013), among others.

In response to international calls for change, the People's Bank of China, the Chinese central bank, announced in July 2005 the end of the dollar peg and a shift to a market-based, managed floating exchange rate regime. A flexible mechanism is to be phased in by allowing the RMB to move within a narrow band around a central parity rate that is determined with reference to market makers' opinions, movements of a basket of world currencies, and macroeconomic conditions. Although this experiment was disrupted in mid-2008 with the onset of the global financial crisis, in June 2010, the PBOC announced that it would 'proceed further with reform of the RMB exchange rate regime and increase the RMB exchange rate flexibility'.

China's move to a more flexible exchange rate system, if completed, is significant because, as the second largest economy in the world, China has become increasingly important in international financial markets. While enhanced flexibility in China's exchange rate regime may mitigate the effects of exchange rate misalignment, it might also indicate greater market orientation, which could be helpful in attaining a sound exchange rate policy over the long run. Furthermore, the market orientation

of Chinese exchange rate policy also increases the likelihood that the RMB will become an international currency (Eichengreen, 2011). However, China is internationally noted for intervening in the foreign exchange market, which causes the exchange rates to fail to reflect resource scarcity. The ensuing distortionary effects on international trade and capital movements are grave and are often cited as major contributing factors to global imbalances.

Moreover, it is also well known that the reforms have been largely government administered when they do not always act on their public pronouncements. In foreign exchange policy, this discrepancy is best known as fear of floating (Calvo and Reinhart, 2002), that is, countries who claim a floating exchange rate regime do not actually allow their currencies to fluctuate with changing economic conditions. Hence, a country's *de jure* exchange rate regime could be quite different from the *de facto* regime, a phenomenon that is widespread, particularly in the emerging markets. In this light, China's high profile reform announcements warrant careful examination (Eichengreen, 2007; Frankel, 2009). To detect the discrepancy between policy words and deeds, it is necessary and desirable to design a proper measure of exchange rate flexibility to gauge the *de facto* Chinese exchange rate regime and, hence, help us detect if fear of floating exists in China.

A good measure of exchange rate flexibility is also instrumental for capturing the evolution of a country's exchange rate regime because the selection of an exchange rate regime is a continuous process. Given that the degree of flexibility is the essential feature of an exchange rate arrangement, the regime that China operates

during different periods may be defined in terms of the degree of flexibility, thus the flexibility index is also instrumental to improve our understanding of China's exchange rate regime selection process.

Earlier studies generally examine exchange rate flexibility in terms of the statistical property of nominal exchange rates (Lanyi and Suss, 1982; Barr, 1984). Recent research however puts an increasing emphasis on the indications of economic forces behind exchange rate changes, e.g. Girton and Roper (1977), Calvo and Reinhart (2002) and Levy-Yeyati and Sturzenegger (2005), with one common feature as they are all monthly based. However, this may prevent them from producing more accurate results as the effects of intervention may be offset during the month. Thus, a higher frequency based method is very much needed. To this end, we marry the merits of the existing studies to construct a new flexibility index for RMB featuring the post-reform period. A market-oriented principle was closely followed in the sense that the flexibility index is designed to provide a plausible estimate of the extent to which the Chinese government allows the RMB to be driven by market forces.

To build the daily flexibility index, we utilize exchange rate data from the largest Chinese commercial bank dealing in the foreign exchange market, i.e. Bank of China, and the New York Federal Reserve. The results suggest that there were sizable increases in flexibility immediately after the reform announcement; however, this process was disrupted when the adverse effects of the global financial crisis emerged in mid-2008. The PBOC quietly re-pegged the RMB to the US dollar, and

the flexibility index consequently dropped dramatically, indicating that Chinese intervention thwarted the market forces driving the exchange rate. This low-flexibility policy was enforced until June 2010, when the central bank announced the re-institution of exchange rate reform.

We then examine China's exchange rate policy by investigating changes in the flexibility of the RMB exchange rate in a regime-switching setting. This newly constructed daily flexibility indicator is applied in a Markov switching model to examine whether and when there are regime breaks in the RMB exchange rate flexibility. The results obtained through the Markov switching model suggest that the dynamics of RMB flexibility have passed through two distinct switching states wherein the parameters of the high- and low-flexibility states differ noticeably. The timing of these regime shifts provides evidence of fear of floating in China. For the sample period as a whole, the degree of RMB flexibility in China is relatively low despite the reforms, reflecting the gradual pace of China's transition to a floating exchange rate system. Overall, the Chinese government still exerts considerable control over the foreign exchange market, whereas China is edging towards greater exchange rate flexibility, especially in the wake of the global financial crisis.

The remainder of this chapter is organized as follows. The next section reviews the related literature by way of examining the main exchange rate flexibility models. Section 3 is devoted to the construction and analysis of the new exchange rate flexibility index. Section 4 examines structural changes in the Chinese exchange

rate regime through a Markov switching model and possible driving factors. Section 5 provides summary and concluding remarks.

2.2 Literature Review of Exchange Rate Flexibility

2.2.1 Exchange Rate Flexibility and Swoboda Thesis

The concept of exchange rate flexibility was originally introduced in the classic theories as the criterion to categorize the different exchange rate arrangements observed in the real world. In operational terms, the degree of exchange rate flexibility is usually proxied by the variability of the exchange rate (e.g. Barr, 1984). Thus, 'exchange rate flexibility' has generally been considered identical to 'exchange rate variability' in the early literature.

Researchers seemed to have neglected the importance of having a well-defined measurement of the criterion before they can build theories based on that. Perhaps the best example in point is the 'Swoboda Thesis', more popularly known as the 'bipolar view' in the literature, stating that when economies are confronted with high international capital mobility, they are forced to abandon the intermediate exchange-rate regimes and to choose between the 'corner solutions', the freely floating regime or a fixed regime.

There are two main approaches to testing the 'Swoboda Thesis': one is to look at the distribution of each exchange rate type over time and the other is to investigate

the performance of different exchange rate regimes in periods of crisis. Nevertheless, the results found so far are mixed (Fischer, 2001; Bubula and Ötker-Robe, 2002; Calvo and Reinhart, 2002; Eichengreen, 2008 and Angkinand et al., 2009).

Advances in finding a better measurement of exchange rate flexibility were made since 2000s. Exceptional work in line include Bulula and Ötker-Robe (2002), Calvo and Reinhart (2002), Reinhart and Rogoff (2004) and Levy-Yeyati and Sturzenegger (2003, 2005). However, Willett et al. (2012) points out that each of these studies still has its own limitations. Therefore, we in this study define 'exchange rate flexibility' as the measurement of the extent to which the monetary authority allows the market to freely determine the price of one currency in the foreign exchange market. This definition has two clear conceptual differences to its predecessors: firstly, it emphasizes on the important role played by central banks in setting the price of their currency; secondly, because it seems almost impossible to derive the absolute value of the degree of exchange rate flexibility, this definition proposes that the measurement could be done on a relative basis.

2.2.2 Why China Needs More Exchange Rate Flexibility

Despite the fact that previous empirical findings of 'Swoboda Thesis' are somewhat ambiguous, it did sheds some lights on why China chose to reform its exchange rate regime. Specifically, we have identified four main factors in this study.

Political Pressure

Since 2002, the evidently huge surplus of both current and capital account has pushed China's major trading partners such as Japan and the US to complain that the RMB is severely undervalued (e.g. Goldstein, 2003 and Coundert and Couharde, 2007). However, at that time, top leaders of China still hold the view that the RMB is at an appropriate level and it is crucial to maintain that level, thus giving little positive response to international pressures. Nevertheless, things started to turn around when this pressure intensified and it is well reported that China's top leadership start to rethink their position in holding a fixed RMB. The final news of reform came out at a time when a consensus of having a more flexible exchange rate emerged among the Chinese political leaders and market participants.

Risk of Maintaining the Peg

Many studies have argued that by maintain the peg, the Chinese monetary authority essentially forfeited some flexibility in conducting its own policy, which has brought in instability to the Chinese economy in recent years (He, 2007). For example, in a hope to slow down the foreign capital inflows, PBOC has been resistant to raise domestic lending rates (which were presumed to be already at a high level at that time) even in the face of domestic inflation. Consequently, this in turn has created excessive demand for loans and has exacerbated inflation (Goldstein and Lardy, 2006).

Cost of Maintaining the Peg

Maintaining the peg not only carries unpredictable risk, it also generates real cost. It is widely acknowledged that the PBOC has frequently intervened in the foreign exchange market and conducted sterilization subsequently. Estimates of the amount of intervention the PBOC has been able to sterilize range from approximately 70% (He, 2007) to 90% (Ouyang et al., 2010). However, the efficacy of the sterilization is reported to decay over time, while the cost is increasing. For instance, PBOC has to pay a higher interest rate for central bank bills it issued than what it can receive from the US government bonds. Therefore, the more intervention is put to use, the higher the loss will be.

In addition to the sterilization cost, Prasad et al. (2005) discuss other potential costs of not having a more flexible exchange rate. For instance, the depreciation of the US dollar since 2003 have effectively deteriorated the terms of trade (TOT) for China, which suggests significant welfare losses for the Chinese economy. Moreover, their study points out that the persistent pressure for an appreciation of RMB created by the increase of domestic productivity has to be relieved either by changes in the nominal exchange rate or inflation, while the former is typically presumed as the more preferable option.

Capital Account Liberalization and RMB Internationalization

Despite the scare incidence that Chinese officials are willing to talk about one particular policy, we notice that academics are debating heavily on two hot related topics in recent years: the capital account liberalization and RMB internationalization. There is a growing body of researches focusing on these two issues and we only intend to briefly present some major findings here.

In terms of the issue of capital account liberalization, the first thing to note is that China is still assumed to be capable of maintaining strong control over the capital flows. For instance, Ma and McCauley (2008) offer both price and flow evidence. Second, while the academics are debating the necessity and potential schedule for China to fully liberalise its capital account, the Chinese authority has already undertaken several meaningful experiments, including the newly set up of the China (Shanghai) Pilot Free Trade Zone.

With regards to the issue of RMB internationalization, opinions are divided as well. Though the Chinese officials disclose no public endorsement for promoting the RMB as an international currency, it did push forward the RMB as a future option for international settlement. The implementation of this policy is reflected by the fact that China has signed currency swap agreements with 20 monetary authorities, with a total amount of more than 2 trillion yuan, ranging from the emerging markets in Asia to western countries such as UK. It has been well acknowledged in the literature that this objective cannot be easily done unless we have a clear increase of the degree of RMB flexibility.

In summary, each of the factors raised above have played an important role in shaping China's future exchange rate regime. The July 2005 reform reflected the Chinese leadership's perceptions that having a more flexible RMB does not only help build a new and responsible image in the international system, it also has significant economic benefits domestically. While to enhance the RMB flexibility seems like a long-time job, the problem resulted from of a lack of flexibility from yesterday reminds us the work to do today.

2.2.3 Review of Measurements of Exchange Rate Flexibility

Calvo and Reinhart Model

Conditional on each of the four exchange rate arrangements[4], Calvo and Reinhart (2002) estimate the probability of the changes of the exchange rate, as well as the foreign exchange reserves and the interest rate, that falls within some pre-specified bounds. Subsequently, they propose a multivariate index to capture the extent of exchange rate variability relative to the variability of the instruments employed for stabilizing the exchange rates.

Levy-Yeyati and Sturzenegger Model

Previous studies have well documented that changes in foreign exchange reserves or the interest rate may in fact contain ineffective information. Ghosh et al. (2002) note that interest rates in most developing countries are not determined solely by

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[4] They are the peg, limited flexibility, managed floating and freely floating.

the market, but are administrated by monetary authorities to cope with other policy objectives. Similar arguments could be found in other studies such as Willett et al. (2012). Moreover, Ghosh et al. (2002) argue that changes of foreign reserves could reflect more than just government intervention. For example, the interests incurred on foreign currency denominated assets clearly jeopardize the usefulness of employing foreign reserve changes as the proxy for government intervention. Nevertheless, it is widely assumed that in countries such as China, those transactions account for only a very small proportion of the total reserve changes. Therefore, reserve changes are generally assumed as a sufficient yet imperfect proxy.

Given these facts, Levy-Yeyati and Sturzenegger (2003, 2005) utilize the behaviour of exchange rates and foreign reserves as an indicator of exchange rate flexibility. More specifically, based on the three classifying variables they have grouped exchange rate regimes into four types: fixed, crawling peg, dirty floating and flexible.

Modelling Flexibility Based on Exchange Market Pressure

It is widely held that in any market, the existence of excess demand would generate changes in the endogenous variables that could help restore equilibrium. Thus, the observed changes in those variables could be used for assessing the degree of the unobservable excess demand.

In the context of foreign exchange market, Girton and Roper (1977) first introduced the concept of 'Exchange Market Pressure' (EMP hereinafter) as a measure of the difference between quantities demanded and supplied in the foreign exchange market at a particular exchange rate. They constructed an EMP index that is the sum of international reserve changes and exchange rate changes. Since then, a large number of investigations have been conducted employing this terminology and we have seen huge developments in this strand of literature (Roper and Turnovsky, 1980; Eichengreen et al., 1995; Weymark, 1997 and Klaassen and Jager, 2011).

In terms of modelling exchange rate flexibility based on EMP, the main strand is to assess the proportion of exchange market pressure that is reflected in movements in the exchange rates relative to the proportion that is mitigated by policy instruments such as official intervention. The greater the former, the more flexible is the regime, regardless of how the exchange market pressure is represented. However, there are some limitations to this approach. It is not only because changes of foreign reserves represent transactions other than government intervention, it could run into trouble as well when official intervention is conducted as 'leaning with the wind' (Willett et al., 2012). In addition, their study points out that the traditional EMP may also generate incorrect results when there are trends in reserves or exchange rates. Therefore, they propose a new methodology that uses two parameters: one for the trend and another for deviations around the trend.

The alternative strand of the literature of modelling exchange rate flexibility with EMP follows the pioneering work of Frankel and Wei (2008) and Frankel and Xie (2010). The flexibility parameter β is estimated by the following equation:

$$\Delta H_t = c + \sum_{i=1}^{N} w_i * \Delta X(i)_t + \beta * \Delta EMP_t + \mu_t \qquad (2.1)$$

where H is the log value of the home currency, and X is the value of the N potential currencies in the basket; ΔEMP is the percentage change of the EMP index, which represents shocks in demand for the currency.

Under this setting, Frankel and Wei (2008) contend that the more flexible the exchange rate regime of a country, the higher β (and the error variance), but the lower R^2 will be. However, as the authors note, this model would be perfect if authorities were to use foreign reserves as the only intervention tool. Another major limitation of this approach is that it could not produce accurate estimations when the regime in operation switches frequently. Therefore, Frankel and Xie (2010) recommend dividing the whole sample period into several sub-sample periods for further estimation by applying the Bai and Perron (2003) approach first.

2.3 A Daily-based Flexibility Index

The models discussed above can generate a time series of flexibility index, which provides a useful summary of the evolving nature of a country's exchange rate system. They also enable a look into indications of the economic influences including government policy that underlie exchange rate movements, or the lack

thereof. Unfortunately, these models suffer from a common drawback, that is, the reliance on monthly data to compute the flexibility indexes. Such dependency is problematic because government intervention is usually conducted in a higher frequency (Beine et al., 2009; Reitz et al., 2010). Accordingly, monthly average data may camouflage the frequency and effects of government intervention. To overcome this problem, we develop a high-frequency approach based on daily data to measure exchange rate flexibility.

2.3.1 Construction

In China, foreign exchange transactions are administered via the Chinese Foreign Exchange Trading System (CFETS), which is a computerized national network that publishes the central parity rate (CPR) of the RMB against the US dollar at 9:15 AM (Beijing time) each business day. The CPR rate, which is set by the Chinese central bank, considers three influences: the individual rates offered by official market makers, international currency movements and macroeconomic conditions. Because this rate-setting process is led by the Chinese central bank, the CPR is considered as the official exchange rate, which then provides a benchmark rate for the Chinese foreign exchange system. This rate-setting process also reveals the fact that exchange rate rigidity in China is often the result of government control which shadows the influence of market forces and therefore, it is necessary and appropriate to define the flexibility of exchange rate in terms of the extent to which a monetary authority allows the market to influence the price of the country's currency in the foreign exchange market.

In this research, by comparing the variability of this official rate with the market rate, a gap could be revealed, which may serve as a measure indicating government intervention in the currency movements.[5] Through this, one may gauge the extent to which the RMB is allowed to move in line with supply and demand forces. After searching for a proxy that reflects the market, we selected a market rate series for the RMB/USD that is published by the Federal Reserve Bank of New York (Federal Reserve or FED hereinafter), which uses data from a sample of market participants. These data are the noon buying rates of the RMB against the US dollar in New York on business days for cable transfers payable in foreign currencies. This series can provide useful information for our research because it is highly unlikely that the Chinese government can control the exchange rate in New York. Though we acknowledge that the usefulness of FED rates is limited by its transaction volume, it does cover the whole sample period which maybe not be possible in other markets.

However, by its nature the official central parity rate tends to be of low variability, which limits the indicative accuracy of the changeability differential between this rate and the market rate as a flexibility index. This prompts us to search for a domestic exchange rate whose variability can be meaningfully compared to that of the RMB exchange rates in New York. We then choose the exchange rate quoted

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[5] It would be straightforward to deploy official intervention data to calculate the flexibility index. However, no publication of such data in China and some proxies have to be chosen. The usual proxy for intervention, i.e. changes in foreign reserves is not directly feasible in the Chinese context since reserve changes are usually reported in China at monthly frequency and their changes are often caused by a variety of reasons, not necessarily by intervention. Empirically, given the property of time series of reserves data, no reliable method can be applied to derive sound daily interpolation. In this light, we choose to rely on the information revealed by the exchange rates.

by the Bank of China (BOC) because it is the earliest and of the largest player in the foreign exchange market in China and its rate series is representative of the rates offered by commercial banks in China. [6] It is important to note that Chinese trading rules require commercial banks to conduct their market transactions based on the CPR, and the quoted rates must be within a government-specified band, which was initially +/- 3‰ and has recently expanded to +/- 2% around the central parity rate.[7] So the BOC exchange rates are in fact semi-controlled. However, with the development of China's financial reforms, the BOC increasingly has its own commercial interests and its rates become gradually more driven by market influences. As such, comparing the variability of this semi-government influenced rate to that of the Federal Reserve rate may provide useful information on the extent of RMB flexibility.

Use of the ratio may have another advantage over the other competing methods. It is well known that currency prices are influenced by common international factors or events despite its own characteristics. In this light, the volatility ratio helps to analyse the relative strength of market forces that is transmitted to the movements of the RMB exchange rates, which directly reflects the essence of our definition of the currency flexibility measure. Based on these comparisons, we then estimate the high-frequency model to produce flexibility indicators for the RMB. The procedure

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[6] The BOC rate is from Bank of China, available in DataStream by 16:15 (GMT) on each business day.

[7] The fluctuation band was officially announced on July 21, 2005 to be +/- 0.03% around the central parity. This was raised to +/- 0.05% from May 21, 2007. From April 16, 2012, the band was expanded to +/- 1% and on March 17, 2014 it became +/- 2%.

involves the following steps. First, we calculate the standard deviation of returns of the RMB/USD rates from the BOC in the last 21 business days (including the current business day)[8] to proxy exchange rate volatility of the current business day. Next, the daily relative volatility ratio is obtained by dividing the volatility of the BOC exchange rates by that of the market-based exchange rates.

Finally, to index these ratios, we take the base as of January 4, 2006 when the aforementioned central parity rate pricing rule was officially installed. This means that the value of the flexibility ratio on that day is made to be 100, and this reference base is then applied to every daily flexibility ratio in the series:

$$\text{Flexibility Index}=100*\frac{\text{Relative Volatility Ratio}}{\text{Reference Base}} \qquad (2.2)$$

Because the pegged RMB/USD exchange rate is upheld before July 21, 2005, the rolling calculation of the daily flexibility index begins on July 22, 2005, the first business day after the reform was announced, and ends on March 29, 2013, the latest day in our sample period. We denote the computed daily index of RMB flexibility as BOC_FED and plot the series in the following figure, while the black line represents the mean flexibility value as 115.3.

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[8] We have chosen 21 days because there are approximately 21 working days in a calendar month. We have also tried 10 days and 60 days, and the results show no significant difference.
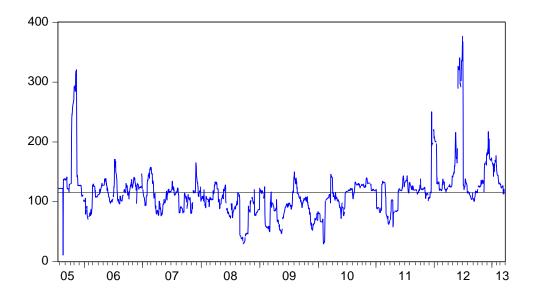
Figure 2.1 Exchange Rate Flexibility of the RMB

It is clearly seen from the figure that the index has its ups and downs during the sample period, which confirms previous findings that the RMB flexibility was enhanced after the 2005 reform before it was later disrupted by the outbreak of two crises. For instance, starting from mid-2008 until the second reform announcement, the flexibility index was hardly seen beating its mean value, suggesting the Chinese authority tightened exchange rate control when it feared that the global financial crisis posed a threat to the export sector. A similar decrease was also captured when the European sovereign debt crisis emerged. However, this time the low flexibility phase did not last long.

In addition to confirming the commonly held market perceptions, our high-frequency data model offers richer information about currency flexibility in China. For example, since the 2005 reform China's exchange rate management has been subject to several changes. Under the regime aforementioned, the Chinese monetary

authorities mainly deploy two tools to prevent or restrict undesirable fluctuations in the exchange rate: one is the government controlled central parity rate and the other is the band in which the RMB rate is allowed to fluctuate in the marketplace. Initially, the central parity rate was based on the previous day's closing price. This practice would continue the momentum of previous exchange rate changes such that cumulative exchange rate variation and level changes could be quite sizable. Fearing rapid appreciation of the exchange rate and increasing variation, the government changed this pricing rule on January 4, 2006 and reset the central parity rate on the opening of every business day rather than simply using previous day's closing rate.[9] As a result, though the BOC_FED index exhibits a surge after the reform[10], it sharply decreased in January 2006. These developments are well captured by the proposed flexibility index.

The fact that the two exchange rates are drawn from different markets may trigger some doubts on the role played by capital control policies, as it is widely held that Chinese authority has adopted tight control on the capital flows, which largely disrupted the link between onshore and offshore markets. Therefore, some may argue that the volatility difference in the two exchange rate series should be

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[9] This policy was changed again on 11 August 2015 as the PBOC latest effort to improve the central parity rate-setting process.

[10] Our results show that the first dramatic increase of the flexibility index occurred around October 2005, not immediately after the reform announcement date. However, it simply suggests that the Chinese authorities has proceeded the reform cautiously, which reinforces the fact that our index could offer more information.

considered as a measure of capital control intensity rather than an exchange rate flexibility as we discussed above. [11]

While we do acknowledge that there is some effect of capital control on the exchange rates from a theoretical perspective, the *de facto* intensity of this impact is however much in question empirically. Aizenman and Sengupta (2013) find that capital account openness plays no significant role in China's trilemma configurations[12], which confirms a widely held view that the effects of China's capital controls are not omniscient, but are decaying off over time. In fact, arbitrage between China and rest of the world is not entirely impossible and may be prevailing at some point (Galati et al., 2007 and Ma and McCauley, 2008). Yu (2008) notes that a large portion of China's large trade surplus, as well as the FDI inflows, is essentially hot money which is processed under the radar. Moreover, compared to the changing volatility ratio index, it is worthy to point out that the Chinese authority does not change its stance on the capital control very often for the time period in

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[11] While it seems not appropriate to use our volatility difference to proxy the intensity of capital controls, it is important to note that exchange rates is one of the many economic factors that are impacted by the capital control policies, which in turn makes it possible to build alternative measure of the intensity of capital controls. In fact, there have been a few well known models in the literature, such as Edison and Warnock (2003), Chinn and Ito (2008).

[12] The 'Trilemma' theory states that an open economy at any time may only simultaneously choose two out of three potentially desirable objectives: namely the autonomy in conducting monetary policy, stable exchange rates and internationally free capital movements. Though it was first proposed in the 1960s, the existence of the 'trade-off' has gone through arduous verification, including some recent studies such as Aizenman et al. (2008), Aizenman and Glick (2009), and Aizenman et al. (2011).

consideration, the fact of which is clearly evident from the annual IMF report on Exchange Arrangements and Exchange (AREAER).

Though we cannot fully rule out the impact of capital controls on our index, it is important to note that exchange rate flexibility is defined here as the extent to which the authority allows the market forces to impact the price of RMB, treating all forms of control policies equal, which include but are not limited to the direct sell (or purchase) in the FX market, 'window guidance', and the capital control policies as well. Put in other words, we are more interested in the end-product of the 'managed' floating rate system that China adopts without differentiating the specific 'intervention' form at the other end.

2.3.2 The Companioning EMP

In light of the recent exchange rate flexibility models, it seems plausible to double-check the usefulness of our flexibility index by looking at the companying EMP. To this end, we follow Klaasen and Jager's (2011) method in calculating a daily-based measurement of EMP. Compared to the other popular approaches, Klaasen and Jager's (2011) method stands out as this measure is consistent with the very definition of EMP and does not rely on any exchange rate model. Another crucial feature of their method is that the measure is consistent across frequencies. Thus, it is straightforward to aggregate the daily EMPs to obtain a monthly measure.

In Klaasen and Jager's (2011) study, the specific form of EMP is written as follows,

$$EMP_t = \Delta S_t + w_i(i_t - i_t^d) + w_c c_t \tag{2.3}$$

where ΔS_t is the nominal exchange rate change at time t, defined as the domestic currency price (RMB) of one unit of foreign currency (USD); i_t is the domestic interest rate; i_t^d stands for the interest rate level if exchange rate objective is not a determinant. As shown in Klaasen and Jager (2011), i_t^d can be reasonably simplified by using the foreign interest rate level as the proxy; w_i is the weight of relative interest rate level $(i_t - i_t^d)$ and w_c is the weight of the scaled intervention.

We use the overnight interest rate from PBOC and Federal Reserve to represent the interest rate level in China and the US respectively. The weights of w_i and w_c are set equal to the standard deviation of the nominal exchange rate changes to that of the interest rate and the scaled intervention component respectively.

As discussed above, the change of foreign reserve might not serve as a perfect proxy for exchange rate intervention. Hence, to better proxy the unobservable central bank intervention, we make use of one unique statistic from the PBOC, called 'funds outstanding for foreign exchange'. It can be considered as the result of intervention as it mirrors the purchase/sell of foreign assets. To make it more comparable, the level of 'funds outstanding for foreign exchange' is scaled down by the preceding domestic M1. The data for M1 and 'funds outstanding for foreign reserve' is collected from PBOC. However, as they are only available in monthly frequency,

we apply the cubic interpolation method to transform them into a daily–based series[13].

Similar to the flexibility index, the EMP series is calculated from July 22, 2005 to March 29, 2013, and the result is plotted in the following figure. It is that there was a negative EMP, i.e. an appreciation pressure, on the RMB during most of the sample period. In contrast to policy-makers' intentions, following the 2005 reform, the appreciation pressure exaggerated sharply rather than being alleviated, which reflects the prevailing market perception that a consistent appreciation of RMB was on its way. A negative EMP was maintained until December 2007 when the market panicked about the looming crisis. However, the market quickly reversed its course by recognizing that the outlook for China's growth was strong and the RMB was still undervalued. Nevertheless, it is observed that from mid-2008 to mid-2010, the EMP was close to zero, indicating relatively low appreciation pressure on the RMB during that period. Following the second reform announcement, the EMP quickly decreased. Since then it has several brief reversals as a result of prevailing market conditions.

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[13] To check the robustness of our daily-based EMP, we have calculated the monthly EMP for RMB for the sample period using other popular methods, including Weymark (1997), Stavarek (2007). We find the results have a high positive correlation with the monthly aggregated EMP using the Klaassen and Jager's (2011) method. We have scaled up the results 100 times to make it more compatible to other variables in the following estimation.
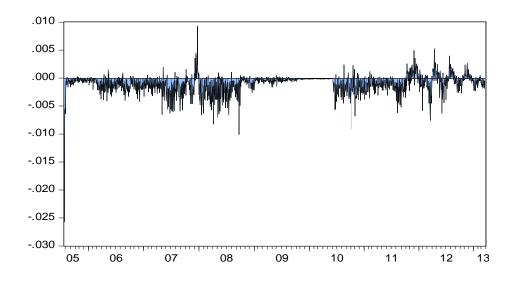
Figure 2.2 Exchange Market Pressure of RMB

As discussed above, existing studies have emphasized that high volatility, or a relatively high volatility ratio, does not necessarily mean the currency is truly flexible. It is imperative to take into account the prevailing pressures. The degree of flexibility of one currency is only warranted when there is a considerable level of exchange market pressure overhang. Hence, we may visually compare the patterns observed in the two figures to check if our flexibility index makes sense.

On one hand, during the crisis period, even though there was little pressure on the RMB, the flexibility index was in a 'low' phase, which supports the claim that reform was halted by the Chinese authority and the RMB was not flexible. On the other hand, in non-crisis periods, the striking difference in the flexibility index may help to locate 'high' flexibility phases. Notwithstanding the considerable pressure at the time, the several surges of the flexibility index clearly indicate that RMB was actually flexible, though those periods seem to be rather short-lived. In summary, it seems safe to say that the effectiveness of our flexibility index is warranted and

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RMB has undergone several different flexibility phases, revealing more 'hidden' dynamics than those suggested by existing studies.

2.4 De Facto Regime Switches and Fear of Floating in China

Sudden changes in government policy may induce drastic breaks in the behaviour of economic variables (Hamilton, 1989; Sims and Zha, 2006). Such breaks often mean the typical behaviour of a variable switches to a very different one, and China's exchange rate policy is a case in point. During the sample period, the Chinese authorities have initiated two rounds of reforms of the exchange rate system, allowing greater room for market forces to influence the RMB price, focusing primarily on that against the US dollar. This implies that, during the period under examination the RMB rate switched from a pegged to a managed flexible rate regime, and back and forward twice. As a result, the behaviour of the RMB rate and the property of China's exchange rate system had both exhibited distinct patterns.

Given the importance of regime switches, researchers logically would like to detect the regime changes as they happen so that they may find out the implications of the regime break and to design suitable responses accordingly. However, it is unrealistic to expect a single, linear model to characterize all the distinct behaviours of the variables in different regimes. In contrast, the Markov regime-switching (MRS) models prove appropriate in capturing more complex dynamic patterns of the variables in question.

The Markov regime-switching models have found wide applications in economics and finance (Ang and Timmermann, 2012). Among the pioneering studies, Hamilton (1989) applies the MRS model to research into the US business cycle. Many papers applying the methodology then follow suit. Recent studies have also deployed the MRS models to explain exchange rate behaviour, e.g. Engle and Hamilton (1990), Engle (1994), Bollen et al. (2000), Bergman and Hansson (2005), Ichiue and Koyama (2011).

For our research interests, in addition to capture regime changes in the Chinese exchange rate policy, the Markov switching model has another helpful property; it allows the detection of the timing of regime shifts, which would help to resolve the problem noted by Frankel and Xie (2010) and identify proper 'break-points' to differentiate sub-periods. Furthermore, analysis of the regime shifts can help us achieve a better understanding of a critical attribute of the Chinese exchange rate regime. Exemplified by fear of floating, studies have pointed out that countries do not always conform to their public announcements, i.e. there is considerable differences between policy announcement and its implementation. As one key objective of this chapter is to find out exactly when the policy shift starts to impact the behaviour of the RMB/USD exchange rate, we cannot solely rely on the *de jure* dates. By detecting the timing of RMB's regime shift, the Markov model would help capture the critical features of China's exchange rate policy in a time of economic transition.

2.4.1 Estimation

Given the findings in the previous section, we assume that there have been two flexibility regimes, i.e. a high-flexibility regime and a low-flexibility regime. As the flexibility is built on the standard deviation of exchange rates, we only need to use the mean (constant) coefficient to differentiate these two regimes while the variance parameter is assumed to be non-switching. In addition, to take account the common dependence of the second moments of the exchange rates, we include an AR (1) term in our model. Accordingly, the Markov switching model could be written as follows and we report the estimation results in Table 2.1.[14]

$$Fle\_Index_t = \mu(s_t) + \phi_i(Fle\_Index_{t-1} - \mu(s_{t-1})) + \varepsilon_t \qquad (2.4)$$

where Fle_Index_t is the BOC_FED flexibility index at time t. It is conditional on an unobservable variable s_t, which has two possible values: $s_t = 1$ (Low-flexibility) and $s_t = 2$ (High-flexibility); μ denotes the mean parameter depending on the regime at time t which is assumed to be changeable in those two states; ε_t is the error term, following the usual iid assumption.

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[14] A common estimation procedure is followed in this study and hence the detailed technical description was left out. Interested readers can find such information easily in all the aforementioned studies. Hamilton (2010) gives excellent review for the MRS model.

Table 2.1 Markov Regime Switching Results of Flexibility Index

Panel A	Regime Varying Coefficients	
	Regime 1	**Regime2**
Constant	85 (5.53***)	155 (10.09***)

	Regime Invariant Coefficients
AR(1)	0.99 (267.88***)
Log (SIGMA)	2.06 (123.20***)
Log Likelihood	-6354.92

Panel B	Constant Transition Probabilities
	P(i,k)=P(s(t)=k|s(t-1)=i
P(1,1)=99.1%	P(2,1)=0.8%
P(1,2)=0.9%	P(2,2)=99.2%
Constant Expected Durations (Days)	
Regime 1	125.9
Regime 2	114.4
Transition Matrix Parameters	
P11-C	4.83 (13.36 ***)
P21-C	-4.73 (-13.05***)

Notes: This table presents the results of the two-state Markov switching model of the BOC_FED flexibility index. In Panel A, we report the estimated coefficients for the regime-varying and regime-invariant variables, with the corresponding z-statistics in parentheses. Panel B reports the constant transition probabilities between the two regimes, the expected duration for each regime, and the transition matrix parameters. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

Several interesting results emerge from the estimation of the MRS model. Firstly, it helps us to formally test regime switches in the flexibility index that we construct. We make use of a likelihood ratio (LR) test proposed by Garcia and Perron (1996). The null hypothesis is there is no regime shifts (the flexibility index is better

represented by a linear AR) against the alternative of the presence of regime switches (the flexibility index is better accounted by the MRS model). The LR is calculated as follows:

$$LR = 2*|\ln L_{MRS} - \ln L_{AR}| \qquad (2.5)$$

where $\ln L_{MRS}$ and $\ln L_{AR}$ denote the log likelihood of the MRS and the linear autoregressive model, respectively. As shown in Table 2.2, the LR test statistic is highly significant at the 1% significance level. Based on Davies (1987) critical values, we reject the null and confirm the regime shifts in RMB flexibility.

Table 2.2 LR Test Results

$\ln L_{MRS}$	$\ln L_{AR}$	LR
-6354.92	-6721.50	736.16***

Notes: Similar to the estimated MRS model, the linear model has an order of one autoregressive term. *** indicates significance at the 1% levels.

Secondly, we provide evidence that the exchange rate flexibility index varies markedly between the two regimes. In the low-flexibility state, the coefficient on the constant reads 85 and in the high-flexibility state it is shown to be 155. The adoption of a managed floating rate regime has helped the RMB achieve an increase in flexibility. Of 1805 observation days, 855 days (approximately 47.4%) are in the high-flexibility state though mostly in the period before the 2008 global financial crisis.

In contrast to the sharp difference in the mean coefficient, both regimes show high regime dependence: it almost has a probability of one to stay in the same regime. Moreover, there is little difference in the length of the expected duration of each regime. The low-flexibility state reports an expected duration of 125.9 days while the expected duration of the high-flexibility is only 11 days shorter.

Thirdly, we plot the estimated smooth regime probabilities to see when the regime switches take place. Though Figure 2.3 is quite self-explanatory, we report the estimated 'starting' and 'ending' dates of the 'high-flexibility' regime in the Table 2.3. The first thing worthy to note is that generally speaking it confirms the switches that were presumed by the market and lends a direct support to the usefulness of the flexibility index as depicted in Figure 2.1. For instance, in the face of the worst financial crisis since the Great Depression of the 1930s, China took a cautious stance towards policy responses, including exchange rate arrangements. The RMB exchange rate was kept inflexible, as the flexibility index was hardly seen beating its mean value, during the global financial crisis period. It is also seen from Figure 2.1 that the flexibility index reached a record high in early July 2012 but dropped rapidly afterwards. However, our MRS model well captured this short-lived flexible period in Figure 2.3, which corresponds to the last 'High-flexibility' regime in Table 2.3. Nevertheless, it is worthy to note that Figure 2.3 does not reconcile perfectly with Figure 2.1, which is based on the MRS approach. For example, not all the 'peaks' of the flexibility index dates fall within the 'High-flexibility' regime.

Secondly, the MRS model report different starting and ending dates for the 'crisis period'. According to Table 2.3, the 'high-flexibility' regime was ended on 25 August 2008 and resumed on 23 March 2010, while the official resumption of the reform was announced on 19 June, 2010, suggesting the *de facto* regime switch did occur a little earlier.[15]

Lastly, the MRS model reveals more shifts of the RMB flexibility which may otherwise remain 'hidden'. In the case where monetary authorities do not publicly announce its intervention operations, we follow studies such as Beine et al. (2009), Gnabo et al. (2009), and Dewachter et al. (2014) to make use of Factiva to double-check the results from the MRS model. Through search we obtain daily Reuters reports on information of the spot foreign exchange market including media analysis of the Chinese RMB/ US dollar and other related news. It proves particularly useful as some traders' comments are connotative of possible intervention by the Chinese monetary authorities. These international reports are usually reliable and often helpful for one to identify the 'surprising' points relating to the shift of China's policy regime. For all those 'break points' that we identified as the dates when the RMB shifted out of the 'high flexibility' regime, we could find corresponding reports made by traders indicating that there was a high chance that the PBOC had intervened on the dates. For instance, the first shift to the 'low flexibility' regime is estimated to occur on 13 September, 2005. On that day, the Reuters reported that

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[15] Through Factiva, we find that on 7 April 2010, the headline news was that in the meeting soon to be held between the presidents of China and the USA, and the RMB exchange rate would be a major issue to be discussed. On the following day, 8 April 2010, there was news that China would soon announce a change to its then exchange rate regime.

one trader explicitly commented that the PBOC was very likely to have intervened as no one else would buy the US dollars under the prevailing market conditions. On the other hand, while traders also reported occasions of possible Chinese intervention in the 'high flexibility' period, the frequency of such occasions is much less than in the 'low flexibility' period. This reinforces our argument that while we cannot rule out the possibility that central bank intervention may have taken place on the same day when we observe a high value of the flexibility index, the frequency of such occurrence is reasonably low and the flexibility index represents an improvement on the previous models.

In summary, the estimated switch dates give sound evidence of fear of floating in China. This also suggests that China's move to greater RMB flexibility is not a one-off event. Rather, it is a process where the *de facto* regime switching occurs in a gradual manner.

Low-flexiblity Regime

High-flexibility Regime
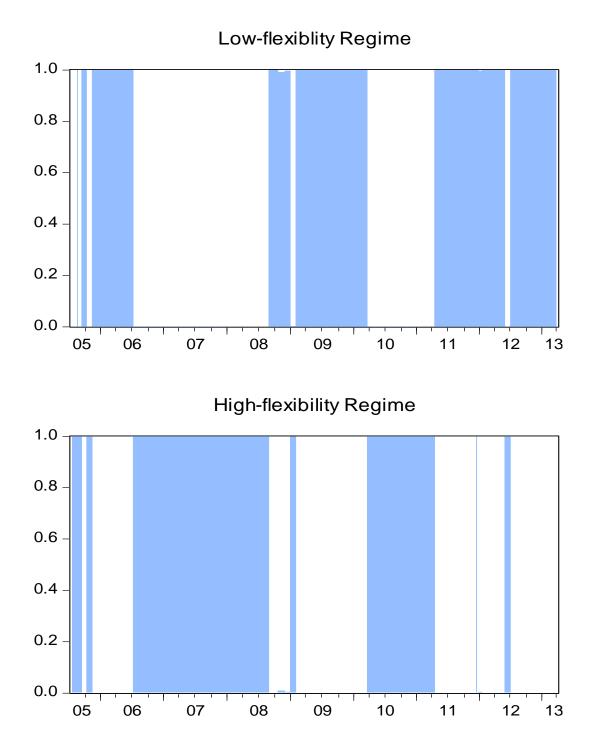
Figure 2.3 Smooth Probabilities of Regimes

Table 2.3 Starting and Ending Dates of the 'High-flexibility' Regime

	Starting Date	Ending Dates
1	25 July 2005	12 September 2005
2	17 October 2005	15 November 2005
3	13 July 2006	25 August 2008
4	31 December 2008	9 February 2009
5	23 March 2010	20 April 2011
6	5 June 2012	5 July 2012

Notes: The reported dates are based on the smoothed regime probabilities, estimated from a two-state Markov switching model of the BOC_FED flexibility index.

2.4.2 Possible Driving Forces

For possible drivers of the regime switching of exchange rate flexibility, there is currently no consensus in the literature. Here we choose to look into three variables that may plausibly affect the dynamics of the exchange rate regime switching. The first candidate is the interest rate differential between China and the US, which has been persistent and largely in China's favour over the sample period. It is noticed that there is much coverage in both literature and news that the interest rate differential has induced arbitrage from international investors, which is further fuelled by a one-way betting on RMB appreciation. Jongen et al. (2012) and Spronk et al. (2013) have shown that the level of interest rate differential plays an important role in determining trading strategies in the foreign exchange market, which

ultimately contributes to higher volatility. Hence, given a higher interest rate differential we would expect to see higher exchange rate volatility, which implies a positive relation between the interest rate differential and the flexibility index. However, this impact may be dampened by the interventionist policy as it pushes the authorities to respond more aggressively when there is a higher interest rate differential. Therefore, we only hypothesize that the coefficient of interest rate differential displays a regime-switching behaviour, without specifying the sign of the relation.

The second candidate is the EMP, which is included here for two reasons. On one hand, recent studies, such as Frankel and Xie (2010), have used EMP as an explanatory variable in econometric estimation to investigate to what extent exchange rate flexibility is affected by currency pressures. On the other hand, EMP provides a summary indicator of various underlying factors. Aizenman et al. (2012), Aizenman and Pasricha (2012) and Feldkircher et al. (2014) have all proposed possible determinants of the exchange market pressure. However, those variables are only measured at a relatively lower frequency, such as monthly, quarterly or even annually. Intuitively, the interventionist policy predicts a negative relation between EMP and the flexibility index as the surge of currency pressure would motivate the authorities to smooth exchange rate movements. However, in the 'high flexibility' regime, it seems plausible to expect that the central bank may refrain itself from doing so or make little response to the pressure. Nevertheless, given the fact that the EMP series changes sign during the sample period, we do not put constraint on the sign of the relation *ex ante* but only hypothesize that the flexibility index will respond asymmetrically to EMP in the two regimes.

The third explanatory variable that we consider is sovereign risk perceived by investors regarding the Chinese economy. To this end, we make use of the CDS spread. [16] During most of the sample period under examination, the CDS index is quite stable and at a relatively low level. The two drastic increases coincided with the two major economic shocks, i.e. the global financial crisis and the European sovereign debt crisis. Therefore, it closely tracks the markets' perception on the expected performance of the Chinese economy. Different from the previous two variables, the CDS spread is used as an exogenous variable in our model to account for the transition probabilities between regimes. Specifically, we hypothesize a negative association between the CDS spread and the RMB flexibility index as a higher CDS spread would result in a shift out of the high flexibility state.

The estimated MRS model could be written as in Eq. (2.6):

$$Fle\_Index_t = \mu(s_t) + \phi_i(Fle\_Index_{t-1} - \mu(s_{t-1})) + \sum_{j=1}^{3} \beta_j Z_{j,t-1} + \varepsilon_t \qquad (2.6)$$

where all the variables are defined identically as in the previous estimation. The only exception is that we use Z to represent the three possible explanatory variables. The estimation results are reported in Table 2.4.

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[16] The CDS data are sourced from Bloomberg.

The results generally support our hypotheses regarding the three candidate explanatory variables. Firstly, the interest rate differential reports a positive impact on the flexibility in both regimes, indicating that during the sample period the interest rate differential contributed to the increase of the exchange rate volatility, possibly through arbitrage activities. Moreover, the higher coefficient reported from the low flexibility regime seems to suggest the impact from the interest rate differential and the central bank intervention are both larger in amplitude, though the aggregate effect is still positive. Nevertheless, it is worthy to note that the coefficient of the interest rate differential is not statistically significant in neither regime.

Secondly, it is reported that EMP has a negative effect on the flexibility in both regimes, which might be reconciled with the fact that the Chinese authorities have displayed a cautious, maybe over-cautious, approach in preceding the reform. The presence of exchange market pressure on the Chinese currency tends to lead to a decrease in the authorities' willingness in increasing the flexibility of the RMB. What is more important is that the results confirmed our hypothesis that the flexibility index would respond asymmetrically to EMP: compared to the high-flexibility regime, the BOC_FED index responded more dramatically, nearly 18 times of the magnitude of the effect, in the low-flexibility regime.

Thirdly, the results imply that the CDS may serve as an early warning signal of regime shifts as a higher risk spread lowers the probability of staying in the high-flexibility state. However, the magnitude of this effect tends to be very limited.

Moreover, the high regime dependence once again highlights the fact that the Chinese authority still firmly controls the pace of the reform process, and accordingly the degree of RMB exchange rate flexibility.

Table 2.4 Markov Switching Model with Time-Varying Transition Probability

Panel A	Regime Varying Coefficients	
	Regime 1	**Regime2**
Constant	84.3 (5.60***)	154.4 (10.23***)
Int_Diff(-1)	0.40 (0.95)	0.19 (0.31)
EMP(-1)	-5.13 (-2.45**)	-0.29 (-0.47)
Regime Invariant Coefficients		
AR(1)	0.99 (265.86***)	
Log (SIGMA)	2.05 (122.86***)	
Log Likelihood	-6347.00	

Panel B	Time-varying Transition Probabilities	
	$P(i,k)=P(s(t)=k|s(t-1)=i)$	
P(1,1)=99.2%	P(2,1)=1.2%	
P(1,2)=0.8%	P(2,2)=98.8%	
Time Varying Expected Durations (Days)		
Regime 1	127.4 (1.4)	
Regime 2	121.3 (44.6)	
Transition Matrix Parameters		
P11-C	4.85 (13.30***)	
P11-CDS_1YR(-1)	0.02 (-0.81)	
P21-C	-5.25 (-10.44***)	
P21-CDS_1YR(-1)	0.017 (2.05**)	

Notes: This table presents the results of the two-state Markov switching model of the BOC_FED flexibility index. It is different from Table 2.1 because the transition probability is assumed to be time varying and dependent on CDS. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

2.5 Conclusions

This chapter investigates the behavior and dynamics of flexibility of the Chinese exchange rate regime since 2005 when the reform was launched to lift the RMB's dollar peg and to phase in a managed floating rate system. Defining currency flexibility as the degree of exchange rate variation in a relative way, this research examines the extent to which government control have hampered adjustment of the RMB exchange rate. Monthly data models prove inadequate for this task since government intervention rarely lasts months and an intervention's effects may be offset within the month. We focus on the result of government control, i.e. the market exchange rates, and develop flexibility measures based on the daily data. It represents a nuanced approach to measuring exchange rate flexibility and yields richer information about the evolving trait of China's exchange rate regime.

A Markov switching model with two states is then estimated utilizing the newly built daily flexibility index. The parameters in the high- and low-flexibility states differ noticeably for the RMB. In detecting the timing of regime shifts, we observe evidence of fear of floating in China. This empirical investigation also sheds lights on the possible drivers of the RMB flexibility in different states. The interest rate differential (between China and the US) seems to have a positive effect on the RMB flexibility in both regimes, though the coefficient is not statistically significant. Even though EMP has a negative effect on the RMB flexibility in both regimes, the magnitude of the effect decreased drastically from the high-flexibility regime to the low-flexibility regime. We also find that the CDS index, which indicates the risk that China is exposed to, may serve as an early warning signal for regime shifts of

RMB flexibility since a higher risk spread lowers the probability of RMB staying in the high-flexibility state. Last, while there is evidence of fear of floating in China, and the government control over the foreign exchange market remains considerable r, the flexibility enhancing process has already started. Along with the country's growing economic and financial influence, the cumulative effect of this process on international finance could be radical.

Chapter 3

NATREX as a Benchmark Exchange Rate for China's Managed Float

3.1 Introduction

Since July 2005, when China announced that it would reform its exchange rate system towards a managed floating regime, and stressed that the value of its currency (RMB) would be determined on the basis of market demand and supply with reference to a basket of currencies, there has been constant debate over the true nature of the new exchange rate regime. In contrast to the promising reform announcement, a large body of recent empirical research, as well as the International Monetary Fund (IMF), argues that China has maintained a *de facto* peg to the US dollar during the post-reform period. However, through building a new flexibility index of the RMB, we find clear evidence that China did make substantial effort to allow more market forces in the price-setting process of the RMB.

Nevertheless, looking ahead to the future of China's exchange rate regime, there remain a few crucial questions that require prompt answers. In this study, we focus on the question of whether the RMB has reached its equilibrium level during this post-reform period. The reasons for this are two-fold: first, given that it was consistent undervaluation of the RMB that resulted in the reform in the first place, it is then reasonable to assume that external pressure, notably from China's main

trading partners, would cease to exist, or have little ground, only when there was consensus that the RMB had reached its equilibrium level; second, it is important to note that when enforcing a managed floating regime, a key task for the monetary authority is to disclose to the market what the desired exchange rate level is, or at least what constitute the criteria used by them when assessing the current exchange rate. Only through these criteria can we hold the monetary authority responsible for their actions and build confidence among the market participants over time.

The attempt to identify equilibrium exchange rate has a long history in the literature, dating back to even before the introduction of Purchasing Power Parity (PPP), which asserts that the real equilibrium exchange rate should be a constant value and the variations of the nominal exchange rates can be attributed to the movements of the price levels at home and abroad. Although PPP benefits from its relatively straightforward methodology, it suffers from several fundamental theoretical limitations, which largely explains why it has received little support from an empirical standpoint. As summarized by Stein (1994), the PPP theory can neither define the equilibrium exchange rate nor provide a clear basis for interpretation. Following PPP, there have been several developments in modelling the equilibrium exchange rate, including popular choices like the monetary approach, FEER, DEER, and BEER. Although these differ from each other in the underlying methodology, they all share the idea from Nurkse (1945) that the equilibrium exchange rate is not defined without considering the external account of the economy in question. Instead of using these popular methods, in this study we have chosen the NATREX for the following reasons.

First, while the NATREX approach benefits from a strong theoretical base, it requires a relatively simple set-up in comparison with other models, and it can be tailored to suit the features of the currency concerned. Although it was originally proposed to investigate the US dollar, the NATREX has been proven successful in accounting for other economies that are fundamentally different from the US. Moreover, it aims at explaining the medium-run and long-run equilibrium exchange rate and hence ignores short-run speculative capital flows, which in turn makes the empirical investigation of the NATREX model easy to implement and interpret. Secondly, compared to models like FEER and DEER, the NATREX stands out as it represents a 'positive' rather than a 'normative' concept. It can be used to determine the effect of any policy on the real exchange rate, which is essential in assessing the maintenance of the so-called managed floating system. Thirdly, it assumes money neutrality, which enables the NATREX model to work irrespective of the nominal exchange rate system. This property is quite useful in the context of China, as we are not constrained by the announced regime shifts during the time concerned. Finally, it is suitable for the operational purpose of the managed floating regime.

Although the NATREX approach was first proposed during the 1990s, there has been scant effort to apply this methodology to the Chinese currency. To the best of this author's knowledge, the most recent notable exception can be found in You and Sarantis (2012), who extend the standard NATREX model in Stein (1994) by incorporating six unique features of the Chinese economy. However, compared to the results obtained by our own calculation, we are not fully convinced by some

assumptions made in You and Sarantis (2012), nor by its estimation methodology. For example, You and Sarantis (2012) claim that during the time period from 1982 to 2010, China enjoyed a net creditor status. However, employing two alternative calculation methods, we find that it was not until late 1994 that China began to report a positive net foreign asset position. Moreover, through empirical investigation detailed below, we find opposing evidence that casts doubt upon the accuracy of the other assumptions. For instance, though You and Sarantis (2012) contribute to the NATREX literature by imposing a structured NATREX model, we note that many of the fundamental variables proposed by You and Sarantis (2012) are not significant or correctly signed in the estimation, and were subsequently dropped from the final co-integration relationship. Therefore, in this study, instead of building a structured model, we stick to the standard empirical approach of the NATREX model, which is to find a stable reduced-form relation between the real exchange rate and the fundamental factors commonly used.

In the remainder of this chapter, section 2 briefly introduces the popular theories in calculating the equilibrium exchange rate and then presents the NATREX model in detail. Section 3 begins by introducing the modification that might be needed to explain the currency movements in China, and then derives the analytical solutions of the model. Section 4 is concerned with the empirics; we take steps to investigate the NATREX in both the long-run and medium-run and also provide analysis of the results. Section 5 provides concluding remarks.

3.2 Literature Review

3.2.1 Calculation of the Equilibrium Exchange Rate

In this section, we begin with a brief review of the most influential theories and methodologies that have been developed to model/estimate the equilibrium exchange rate. In this line of literature, the PPP theory can be considered as the starting point. Building on the famous notion of law of one price, Cassel (1916, 1918) is widely acknowledged as the first to formalize the concept of PPP as we know it today. In its simplest form, the PPP theory asserts that '*a unit of currency should be able to buy the same basket of goods in one country as the equivalent amount of foreign currency, at the going exchange rate, can buy in a foreign country*' (Taylor and Taylor, 2004,p.136). However, from an empirical standpoint, there is mounting evidence that the PPP theory did not work in the short-run, while the evidence for the long-run can be described as weak at best.

Building on the PPP theory, the next dominant model in explaining the exchange rate is often referred to as the monetary approach (Frenkel, 1976), which asserts that in addition to output and nominal interest rate at home and in the foreign country, the relative money supply and demand also play a crucial role in influencing the nominal exchange rate. However, similar to the PPP approach, there is no convincing evidence so far supporting the monetary approach.

In an attempt to find the equilibrium exchange rate that would bring both internal and external balance simultaneously in the sense that the economy operates in full employment and low domestic inflation state as well as enjoying a sustainable

external position, Williamson (1985) proposed a new notion of equilibrium exchange rate, namely the Fundamental Equilibrium Exchange Rate (FEER hereinafter). Compared to PPP and the monetary approach, FEER is different in several aspects: first, the time horizon considered in the FEER approach is medium-run and hence ignores the short-run cyclical and speculative factors; secondly, it argues that the real equilibrium exchange rate is not a constant as prescribed by PPP, but varies with the underlying fundamentals; thirdly, FEER is a normative concept, which aims to provide a reference exchange rate that is desirable given desired policy targets. In fact, one of the major reasons for developing FEER is to help each country determine an appropriate exchange rate level that not only benefits its own economy but also helps to restore balance in the international community. However, the FEER approach is criticized for its set of strong theoretical assumptions and for the difficulty in finding proper parameter values. For example, the level of sustainable current account, which is a key input of the calculation of FEER, is not easy to identify for the monetary authority, which makes the subsequent results quite sensitive to the imposed assumptions.

Desirable Equilibrium Exchange Rate (DEER), a notion closely related to FEER, gains its name from the fact that the equilibrium exchange rate obtained through this approach is desirable from the perspective of the monetary authority. In their influential paper, Bayoumi et al. (1994) emphasize that DEER should not be simply treated as an exchange rate level, but is better considered as a trajectory through which the sustainable exchange rate travels. Moreover, Bayoumi et al. (1994) point out that the result of DEER for one currency is largely dependent on the assumptions used.

Different from FEER and DEER, the Behavioural Equilibrium Exchange Rate (BEER) approach also takes into consideration the short-term variations of the real exchange rate. Hence, the idea of medium-run equilibrium is absent from BEER. Moreover, the focus of BEER is trying to explain the behaviour of the exchange rates with the observable fundamental variables, rather than trying to set a desirable current and capital account target as in FEER (MacDonald, 2000).

With the aim of assessing the current account and exchange rates in a unified framework, the IMF has recently developed a new approach, External Balance Assessment (EBA), as a successor to the previous CEGR framework that was first proposed in the mid-1990s (Phillips et al., 2013). EBA benefits from three previous methods, namely the Macroeconomic Balance (MB) approach, the Equilibrium Real Exchange Rate approach and the External Sustainability approach, and clearly sets out the difference between normative and positive aspects. For example, in the EBA terminology, the actual observed current account is decomposed into three parts: the normative portion, which could be obtained when all policies are at their desirable level, the contribution from the policy gaps, and the residuals. The innovation of the EBA approach is also reflected in the fact that it now includes a much broader set of explanatory variables, which can be roughly classified into three groups: the traditional factors that are commonly identified in other methods; cyclical and temporary factors; and financial factors. Hence, the estimation procedure of EBA is a much more complex task.

In addition to the approaches developed by academia, industry has also given much attention to calculating the equilibrium exchange rates, because of its obvious business needs. One famous example of such effort is the Goldman Sachs Dynamic Equilibrium Exchange Rate (GSDEER), used by Goldman Sachs to estimate a fair value of the currencies it covers (O'Neill et al., 2005). It differs from FEER in that it tries to find a persistent econometric relation between the real exchange rate and the relative productivity growth rate and a few other economic variables, depending on the currency concerned. In this sense, the GSDEER approach can be considered as an extension of the Balassa and Samuelson model (O'Neill et al., 2005).

In addition to the approaches reviewed in this study, there are other alternatives proposed in the literature, such as the Desired Long-run Equilibrium Real Exchange Rate (DRER). Montiel and Hinkle (1999, p.11) argue that DRER is the long-run equilibrium exchange rate (LRER), '*which is conditioned on optimal values of the policy variables, permanent values of the exogenous variables, and steady-state values of the predetermined variables*'. A similar idea can be found in the Permanent Equilibrium Exchange Rate (PEER), which can be considered as a variant of the BEER approach in the sense that the PEER is calculated based on the long-run sustainable levels of the fundamental factors identified from the BEER analysis.

3.2.2 NATREX Model

In addition to the approaches mentioned above, there is another option to calculate the reference exchange rate. Strongly promoted by Williamson (2005), the

NATREX method can be defined as in Allen (1995, p.6) as the '*equilibrium exchange rate that clears the balance of payments in the absence of cyclical factors, speculative capital flows, and movements in international reserves*'. In fact, Stein first introduced the NATREX model in the early 1990s, partly to offer an alternative to the PPP theory. In order to deal with the empirical failure of PPP, NATREX assumes that the real exchange rate is subject to a set of fundamental variables, and therefore the real exchange rate is not constant, as the underlying fundamental variables evolve over time.

The real exchange rate at time t, R_t, can be mathematically manipulated into the following:

$$R_t = \{R_t - NATREX_t\} + \{NATREX_t - R[Z_t^*]\} + R[Z_t^*].$$ (3.1)

Here $R[Z_t^*]$ denotes exchange rate in the steady state; $NATREX_t$ is the exchange rate that is assumed to prevail in the medium-run equilibrium, which can also be expressed as $R[K_t, F_t; Z_t]$, where K_t and F_t denote the real capital stock and net foreign debt (or asset) respectively. Z_t represents the real exogenous fundamental factors and Z_t^* denotes those factors at the steady state. Hence, the real exchange rate could be viewed as the combination of three elements: the short-run deviation between R_t and the medium-run equilibrium $NATREX_t$, the gap between medium- and long-run equilibrium rate, and the steady-state value $R[Z_t^*]$.

In order to fully appreciate the idea that embedded in the NATREX model, we first take a closer look at the model originally prescribed by Stein (1994) in the study of US dollars. As a starting point, he uses the following national income account equation to depict the NATREX approach in its medium-run equilibrium:

$$I - S + CA = 0 \qquad\qquad (3.2)$$

where I is the desired national investment, S is the desired national saving, and their difference implies the desired net long-term capital inflows, which is the opposite of CA, denoting the desired current account balance. The NATREX approach assumes that I and S are determined by existing capital stock, wealth and net foreign asset position. Then, it can be seen why NATREX would not remain constant in the medium-run: when there is a change to I, S or the CA, the capital stock and net foreign asset would change accordingly, which in turn calls for a new equilibrium exchange rate to clear the market.

The NATREX approach contributes to the real exchange rate determinant literature because it demonstrates how the medium-run equilibrium differs from the long-run equilibrium, and more importantly the trajectory between them. Specifically, the NATREX approach assumes that the endogenous stock variables, i.e. the capital stock and net foreign asset position, are determined by some exogenous factors in the long-run. In Stein (1994), the factors chosen are the changes of productivity and social thrift at home and abroad, although subsequent studies have also taken other factors into consideration. There are two channels for those exogenous factors to impact the NATREX (Allen, 1995). On one hand, similar to the medium-run situation described above, the exogenous factors affect the investment and saving

function, which produces a change to the NATREX in the medium-run. On the other hand, the trajectory of NATREX from its medium-term to the long-term equilibrium is largely influenced by those exogenous fundamentals as they could change the dynamics of the stock variables. In theory, it is only when the economy reaches its long-run equilibrium that the NATREX would remain at a constant level, while the stock variables, namely the capital, wealth and net foreign debt, all reaching their steady state values.

In addition to the national income account equation, other key equations in Stein (1994) include the following:

Market clearing:

$$Y = C + I + B \tag{3.3}$$

Investment:

$$I = dk/dt + nk \tag{3.4}$$

Capital Inflow:

$$dF/dt = I - S - nF = -(CA + nF) \tag{3.5}$$

Savings:

$$S = Y - r \cdot F - C \tag{3.6}$$

Portfolio Balance:

$$d(r - r^*)/dt = -\beta \cdot (r - r^*) \tag{3.7}$$

Here, Y denotes the real GDP; B is real trade balance; CA is real current account; C is real social consumption; S is the real saving; k is real capital intensity and n is the growth rate of effective labour; F is the net foreign debt position in real terms; r is real long-term interest rate at home country and hence $r \cdot F$ is the real interest payments. β represents a positive coefficient (to be estimated) for the real long-term interest rate differential. In Stein (1994), all of these variables are measured on the basis of per unit of effective worker, and * indicates the corresponding foreign variable.

Equation (3.3) stands for the equilibrium in the domestic goods markets when ignoring cyclical elements. The capacity output, which depends on the productivity and time preference, is equal to the aggregate demand consisting of consumption C, investment I, and the trade balance B. In equation (3.4), the total investment is defined as the sum of the rate of change in capital intensity dk/dt and $n \cdot k$ such that capital intensity is kept constant when effective labour is growing at a speed of n. In equation (3.5), the rate of change of the foreign debt per unit of effective labour dF/dt is calculated as investment (I) less saving (S) less nF. In equation (3.6), social saving S is calculated as output (Y) less interest payments to foreigners and social consumption C. Finally, equation (3.7) concerns portfolio balance. Assuming there are no capital controls, Stein (1994) suggest that there will be investment flows, aka portfolio substitution, when the real long-term interest rate differs between the home and foreign countries. To support this claim, Stein (1994) found that the expected change in the real exchange rate between the US dollar and

the other G-10 currencies was zero, and hence argued that the real interest rates would tend to converge.

It is worth noting that another feature differentiating the NATREX approach from conventional models is that it can reach endogenous stability without requiring perfect foresight (Stein, 1994). To illustrate this point, we note that economists normally use the maximum principle of Pontryagin to solve for the optimal rate of change in capital intensity. Then, a unique trajectory to the steady state can be derived in a backward manner. However, Infante and Stein (1973) point out that the trajectory is almost impossible to implement in reality, as we do not have full knowledge of the presumed steady state, nor the production and utility functions. Therefore, the expectation that the economy could travel along this unique path to converge to the steady state is almost doomed to fail. In fact, from the standpoint of control theory, the open-loop questions are widely criticized for the vulnerability to external shocks and the inability to act until the end of the operation. Luckily, Infante and Stein (1973) have developed a sub-optimal feedback control (SOFC hereinafter) to tackle this issue. In comparison, this SOFC represents the idea of a closed-loop control where the controller only needs to know the current variable value to maintain the stability of the system. More importantly, Infante and Stein (1973) proved that the SOFC could generate a trajectory, which asymptotically approaches the unique one given perfect knowledge of the system, for the system to converge to the unknown steady state. Particularly, Infante and Stein (1973) demonstrate that to arrive at the optimal situation it is sufficient to use Tobin's q ratio to proxy the rate of change in capital intensity.

The NATREX also differs from the conventional intertemporal optimization models (IOM hereinafter), as it is more generally applicable. To see this point, an intertemporal budget constraint is usually assumed in the study of a sustainable (or optimal) level of net foreign debt. This means a country that starts with a negative net foreign asset position has to produce current account surplus to repay the debt in full. However, in NATREX, the objective for the government is 'reduced' to prevent the foreign debt from exploding, and the intertemporal budget constraint is no longer needed. The dynamic system will regulate itself to converge to a steady level of net foreign debt F^*, under which situation the trade balance B^* needs only to fully cover the interest payments on the debt. Moreover, the present value of the net foreign debt, which will stabilize at a constant level in the steady state, becomes zero when the time horizon goes to infinity.

The analytical solution of the NATREX model mainly concerns two equilibrium scenarios. In terms of the medium-run equilibrium, it is marked by both a clearing of the domestic goods market, and a balance of portfolio holdings between home and foreign assets. Hence, the medium-run equilibrium exchange rate can be solved in the form of $R[k(t), F(t); Z(t)]$. Compared to the medium-run, where both capital stock and net foreign debt are taken as predetermined, the long-run system concerns the evolution of these two stock variables, as illustrated by equations (3.4) and (3.5). When the system reaches its steady state, all variables become constant.

To better understand the NATREX approach, we consider the following two cases, both starting at the hypothetical medium-run equilibrium. In the first case, suppose there is an exogenous increase of the domestic time preference parameter, which means domestic residents now prefer to consume more and save less. As a result, the real interest rate would rise, as there is less money available for investment. A higher interest differential would naturally induce more investment from foreign investors. The capital inflows would not only appreciate the domestic currency, but would also yield a current account deficit and a deteriorating net foreign asset position. In the long-run the rise in net foreign debt reduces wealth, and accordingly consumption, in the home country. However, domestic saving would now rise to meet investment needs. Since the net foreign debt is higher than its initial level, the real exchange rate needs to depreciate in order to produce a trade balance surplus and pay back the interest incurred on the foreign debt. To summarize, an increase of the home thrift parameter would appreciate the home currency in the medium-run, but result in a real exchange rate lower than its initial level.

Now let us look at the second case, where there is an increase of domestic productivity. Similar to the previous case, it will lead to a higher investment need relative to the available saving. As a result, we expect an inflow of capital and an appreciation of the home currency. However, a rise in productivity leads to a higher output and capital stock in the longer-run, which in turn result in a higher domestic saving level and decreased investment (the marginal productivity of capital is assumed to decrease when the capital level is high), respectively. In the longer-run, there will be an end to capital inflow and current account deficit, while domestic saving exceeds investment needs and the net foreign asset position improves.

Nevertheless, Stein (1994) notes that the net effect on the real exchange rate is not as clear-cut as in the first case.

The empirical results from the NATREX approach are promising so far. In addition to the successful launch by Stein (1994) in the study of the US dollar, the NATREX has proved effective in explaining the evolution of the real exchange rate in various countries, such as Australia (Lim and Stein, 1995), Germany (Stein and Sauernheimer, 1996), France (Stein and Paladino, 1999) and Italy (Gandolfo and Felettigh, 1998 and Federici and Gandolfo, 2002). Following the introduction of the euro, a few studies (e.g. Detken et al., 2002; Duval, 2002; Belloc and Federici, 2010) have applied the NATREX approach to the Eurozone as a whole. In addition to industrialized economies, the NATREX has also been applied to less-developed countries, such as Latvia (Ajevskis et al., 2012), Malaysia (Naseem et al., 2010) and Hungary (Karadi, 2003). Nevertheless, it is important to note that NATREX can come in different versions, depending on the relative size and influence of the economy concerned. For example, fundamental factors such as terms of trade are treated as endogenous for the United States, but are taken as exogenous for Australia. Therefore, it should be borne in mind that the '*NATREX approach is not a single model, but rather a family of models, each tailored to the particular characteristics of the country under consideration*' (Allen, 1995, p.3).

3.3 NATREX Model for China

Before we dive into the empirical investigation of the Chinese currency, the RMB, using the NATREX framework, it is necessary to specify exactly what theoretical model will be adopted in our study, as NATREX in essence represents a family of models. Hence, to reflect the uniqueness of the Chinese economy, we propose that the following modifications to the original model in Stein (1994) might be useful.

First, in contrast to the convergence found between the real long-term interest rates of the US and the G-10 countries in Stein (1994), recent studies have suggested that the UIP condition does not apply to China. This can be seen quite easily, as the Unit Root test (see Table 3.1 below) suggests that the long-term real interest rate differential between China and the US is not stationary within this sample period. In order to explain the consistent deviation, we follow Lane and Milesi-Ferretti (2001) and assume that the risk premium on the Chinese economy is inversely and linearly related to its net foreign asset position such that the higher the net foreign asset position is, the lower will be the risk premium and accordingly there will be a lower real interest rate differential. Therefore, we add a country risk premium in the portfolio balance equation as follows, where F denotes China's net foreign asset position:

$$r = r^* + h(F) \tag{3.8}$$

Secondly, despite the surge in China's influence in global trade, it is widely acknowledged that China still lacks power in negotiating the prices of its exports

and imports. Hence, we initially treat the terms of trade as an exogenous factor for China. To incorporate this into our model in its simplest form, we closely follow Lim and Stein (1995) and You and Sarantis (2012) in assuming that China produces an exportable good 1 and a non-tradable good n, while the foreign country (the US) produces an exportable good 2. The aggregate domestic consumption could then be decomposed into consumption of non-tradable good (C_n) and consumption of imported good (C_2). Similarly, production and capital are also divided into production of non-tradable good (y_n) and exportable good (y_1), and share of investment using non-tradable (I_n) and investment using imported (I_2), respectively.

The terms of trade (T) are defined as the relative price of exportable good 1 (p_1) to imported good 2 (p_2^*) when measured in a common currency. This can be expressed as in equation (3.9), where N is the nominal exchange rate measured as the units of RMB per unit of US dollar, and p and p^* represent the price level at home (China) and abroad (the US) respectively.

$$T = \frac{p_1}{N \cdot p_2^*}$$
(3.9)

The relationship between nominal and real exchange rate is then calculated as follows:

$$R = N(p^* / p) \tag{3.10}$$

Hence, a decrease of either N or R indicates an appreciation of the RMB and vice versa.

Let R_n denote the relative price of non-tradable good (p_n) to the exportable good (p_1).

$$R_n = p_n / p_1 \tag{3.11}$$

If we assume that a and b respectively denote the proportion of the non-tradable good in each country's whole production, we can decompose the price level of domestic and foreign country as in Eq. (3.12a) and (3.12b).

$$p = (p_n)^a (p_1)^{1-a} \tag{3.12a}$$

$$p^* = (p_n^*)^b (p_2^*)^{1-b} \tag{3.12b}$$

Then, the real exchange rate R can be expressed using R_n as:

$$R = N \cdot \frac{p^*}{p} = \frac{N \cdot [(p_n^*)^b (p_2^*)^{1-b}]}{[(p_n)^a (p_1)^{1-a}]} = \frac{(p_n^* / p_2^*)^b}{R_n^a \cdot T} . \tag{3.13}$$

We note that when expressed in logarithms, $(p_n^* / p_2^*)^b$ will become a random exogenous term in the intercept. So the real exchange rate R could be written as in equation (3.14) if we normalize the mean of this exogenous term at unity. From equation (3.14), we can see that the effect of terms of trade on the real exchange rate can be decomposed into two parts: a direct impact through which a higher T would lead to a lower R, and an indirect impact through R_n.

$$R = \frac{1}{R_n^a \cdot T} \tag{3.14}$$

We also note that changes in K^* and F^* will induce the relative price of the non-tradable good (R_n) to adjust to its steady state value (R_n^*) to restore the equilibrium in the goods market. [17]

$$C_n(R_n^*, k^*, F^*; Z) + I_n(R_n^*, k^*; Z) = y_n(R_n^*, k^*; Z) \tag{3.15}$$

$$R_n^* = R_n^*(Z) \tag{3.16}$$

$$dR_n^* / dZ = (\partial R_n / \partial k) / (dk^* / dZ) + (\partial R_n / \partial F) / (dF^* / dZ) + \partial R_n / dZ \tag{3.17}$$

$$R^* = 1 / T(R_n^*)^a = R^*(Z) \tag{3.18}$$

It is worth noting that Eq. (3.17) not only demonstrates how changes of the fundamentals in the long-run can impact R_n through changes in K^* and F^*, but also

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[17] Different from previous analysis, * in equations from Eq. (3.15) to Eq. (3.18) means the variables are in their steady-state values.

captures the direct impact of changes of the fundamentals on R_n in the medium-run, which in turn shows how fundamentals affect the long-run real exchange rate R^*.

Then if we assume that in the medium-run equilibrium the market for the tradable good always clears at the exogenous terms of trade, the equilibrium condition in the good market now implies that the demand for the non-tradable good, consisting of consumption C_n and investment using non-tradable I_n, should equal the supply of the non-tradable good y_n. Also, the current account (CA) is now calculated as exportable good (y_1) less the consumption and investment using imported good ($C_2 \& I_2$).

In summary, in addition to equation (3.8) describing portfolio balance, the modified NATREX equations for China are depicted as follows:

Investment:

$$I = dk/dt + nk \qquad (3.19)$$

Capital Inflow:

$$dF/dt = I - S - nF = -(CA + nF) \qquad (3.20)$$

Savings:

$$S = y + r' \cdot F - C \qquad (3.21)$$

Current Account Balance:

$$CA = y_1 + r^{'} \cdot F - m \cdot I - C_2 \tag{3.22}$$

Good Market Clearing in the Non-tradable sector:

$$C_n + I_n = y_n \tag{3.23}$$

3.4 Empirical Investigation

3.4.1 Data
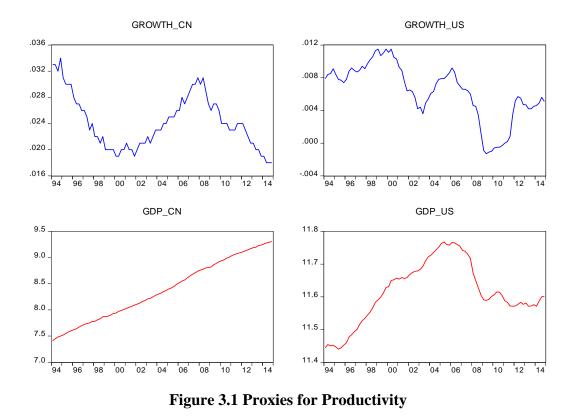
Subject to the nature of this study and data availability, the sample period is chosen to be from 1994Q1to 2014Q4, for two simple reasons. First, China only began to have a unified exchange rate in 1994, and second, 2014Q4 is the most recent time point at which all data are available. While the details of data used in this study are reported below in Table 3.1, the construction processes of some variables are worthy of special attention here.

Table 3.1 Data Summary

Data	Source	Freq.	Notes
Nominal Exchange Rate	IMF	Q	Series refer to period-average national currency units per US dollar.
CPI in China	OECD	Q	The index is on the basis of 2005 price level.
CPI in the US	OECD	Q	It is re-based to 2005.
GDP of China	Oxford Economics	Q	It is measured on the basis of 2005 price and adjusted seasonally.
US GDP	Oxford Economics	Q	It is re-based to 2005 and adjusted seasonally.
Private Consumption/GDP in China	Oxford Economics	Q	
Gov. Consumption/GDP in the US	Oxford Economics	Q	
Social Consumption/GDP in the US	Oxford Economics	Q	
Capital Stock in China	CSY	A	It is calculated based on Gu and Zhang (2012) and further interpolated to quarterly frequency.
Nominal Long-term Interest Rate in China	PBOC	M	It refers to the major loan rate on capital construction with maturities of 5 to 10 years.
GDP Deflator in China	Oxford Economics	Q	The index is on the basis of 2005 price level.
Nominal Long-term Interest Rate in the US	Oxford Economics	Q	It is proxied by the long-term interest rate on government bonds.
GDP Deflator in the US	Oxford Economics	Q	It is re-indexed to make the 2005 price level equal 100.
Term of Trade	PBOC	M	The quarterly series is obtained by using the average of the index within that quarter.

Notes: We use M, Q, and A to represent monthly, quarterly and annual frequency, respectively.

Since productivity and thrift cannot be directly measured, we need to find proxies

for them. To this end, the 12-quarter moving average of the growth rate of domestic

and foreign GDP in real terms are typically chosen for the productivity parameter, while thrift is proxied by the ratio of social consumption, consisting of both private and government consumption, to GDP. However, we argue that there are better choices. In Figure 3.1, we plot the real GDP of China and the US (in logarithm) as well as the 12-quarter moving-average of the growth rate of each country's real GDP.

Figure 3.1 Proxies for Productivity
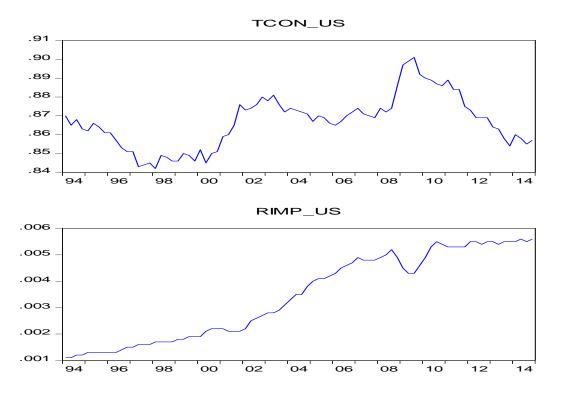
Notes: The upper sector shows the 12-quarter moving-average of the growth rate of real GDP of China and the US, while the lower sector displays the real GDP of China and the US in level.

There is a clear difference between these two proxies. Take China for example. As China has seen consistent economic growth during the period between 1994 and 2014, it is plausible to assume that the underlying productivity has also enjoyed an upward trend. This trend is well-captured by the real GDP series, while the 12-

quarter MA approach evidently fails to do so, possibly because of its tendency to prolong the impacts of temporary changes.

Though there is little doubt about using the ratio of social consumption to GDP to proxy time preference (or thrift), we note that the empirical work so far has unanimously left out the foreign thrift parameter in the estimation, usually citing the difficulty of obtaining an appropriate proxy. However, it is not an issue in this study, as we only focus on the exchange rate between the US and China. Specifically, we take into consideration two options: one is the US ratio of social consumption to GDP, and the other is the ratio of the US imports from China to its GDP.

As a preliminary check, we find a coefficient of 0.51 for the correlation between these two ratios, which seems to be at a reasonable level. In a further step, we plot the two ratios in the following figure and the difference becomes quite apparent. While the ratio of imports (from China) to the US GDP increases consistently, except for a temporary drop occurring in the 3rd quarter of 2008, reflecting the impact of the global financial crisis, the US ratio of social consumption to GDP is more volatile in comparison. We argue that the ratio of imports to GDP is a better proxy for the NATREX approach, as we are more interested in the foreign consumption of domestically produced goods rather than the aggregate social consumption.

Figure 3.2 TCON_US and RIMP_US

Notes: In the upper part, TCON_US is the US ratio of social consumption to its GDP, which is sourced from Oxford Economics. The ratio of the US import from China to GDP is depicted in the lower half and the data for US imports from China is from IMF.

3.4.2 Estimation Procedure

As discussed above, NATREX actually represents a family of models and the fundamentals Z does not necessarily need to be the same for all countries. For instance, Stein (1994) proposed four candidate factors, namely the productivity and thrift (aka social time preference) in both home and foreign country, while the foreign thrift parameter was actually left out in the subsequent estimation. In a later study of the Australian dollar, Lim and Stein (1995) suggested that terms of trade (TOT) and the real world interest rate should also come into play, as these can better capture the features of a small-open economy like Australia. Therefore, the first empirical objective for us is to find out the exogenous variables that have impacted

the real exchange rate of RMB during the sample period in the way predicted by the NATREX theory. In other words, we are aiming to test whether there exists a long-run relationship between the observed real exchange rate and the exogenous fundamentals. In addition, as the medium-run equilibrium exists only conceptually, the NATREX can never be observed and we should also test whether the actual real exchange rate converges to the moving NATREX.

Long-run Analysis

We start with the investigation into the longer-run equilibrium. As in essence we want to test whether there exists a long-run relationship of the variables concerned, we need to check the unit root properties first. According to Table 3.2, most of the exogenous variables are, not surprisingly, reported to be integrated to order 1; however, it is interesting to note that the proxy for the real world interest rate, the real long-term interest rate in the US (RIR_US), is reported to be stationary. Coupled with the fact that the real interest rate differential (RIR_DIFF) is I (1), this confirms that there is no convergence of the real long-term interest rate, but rather a consistent divergence between China and the US.

Table 3.2 ADF Unit-Root Test Results

Variable	Test Type	ADF statistic
RER	(c,t,2)	-1.75
ΔRER	(n,1)	-3.89***
GDP_CN	(c,0)	-0.86
ΔGDP_CN	(c,0)	-9.08***
GDP_US	(c,2)	-2.19
ΔGDP_US	(n,0)	-4.01***
TCONCN	(c,t,0)	-1.83
ΔTCONCN	(n,0)	-10.57***
TCONUS	(n,0)	-0.36
ΔTCONUS	(n,0)	-8.59***
IMPUS	(c,t,1)	-2.37
ΔIMPUS	(c,0)	-5.83***
RIR_US	(c,t,0)	-3.82**
RIR_CN	(c,4)	-2.17
ΔRIR_CN	(n,3)	-4.40***
RIR_DIFF	(c,4)	-2.56
ΔRIR_DIFF	(n,3)	-3.91***
TOT	(c,t,0)	-5.80***

Notes: To describe the type of unit-root test, we use c and n to denote whether a constant is included in the test or not. t denotes the case when a trend is also included in the test. The number in the parenthesis stands for the highest lag that appeared significant in the test. The significance of the ADF test is based on the MacKinnon (1996) one-sided p-values, where the null hypothesis is that there exists a unit-root in the time series. ***, **, * denote the 1%, 5%, and 10% significance levels, respectively. TCONCN and TCONUS denote the ratio of social consumption to GDP in China and the US respectively, while IMPUS is the ratio of US imports from China to its GDP. It is worth noting that RER, GDP_CN and GDP_US are all in their natural logarithm. Δ denotes the first difference of the variable concerned.

Hence, the alleged portfolio substitution channel warrants a closer look. To this end, we estimate the following equation:

$$RIR\_Diff_t = C + RIR\_Diff_{t-1} + NFA_t + \varepsilon_t \qquad (3.24)$$

where NFA is built based on Lane and Milesi-Ferretti (2001, 2007) and later interpolated from annual to quarterly frequency.[18] To make the coefficient more comparable, it is scaled down by the corresponding GDP in that quarter. The results are reported in Table 3.3.

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[18] In addition to the Lane and Milesi-Ferretti (2001, 2007) approach, we built an alternative measurement of the net foreign asset position for China, simply using the difference between the foreign reserve and debt to foreigners. However, it does not make any real difference to the findings.

Table 3.3 Estimation Results of Eq. (3.20)

Variable	Coefficient (S.E.)	t-statistics
Constant	NA	NA
$RIR\_Diff\,(-1)$	0.819 (0.075)	10.949***
NFA	0.007 (0.003)	2.348**
Diagnostic Test	F-Statistic	Probability
LM Test (6 lags)	0.389	0.883
ARCH Test (6 lags)	0.469	0.828
Jarque-Bera	3.419	0.181

Note: This table presents the estimated coefficients for the determinants of the real interest rate differential, and the standard errors are reported in the brackets. The constant is not significant in the estimation, so we dropped it. The Adjusted r^2 =0.749 with F-statistic 208.4. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

The most important result we get from Table 3.3 is that the real long-term interest rate differential is significantly impacted by the NFA, but the sign is opposite to our expectation. We hypothesized that given a higher net foreign asset position, a lower risk premium would be priced by investors, and hence we would expect a lower interest rate differential. Nevertheless, this result is not impossible to explain. In fact, the positive relationship between the real interest rate differential and the NFA can be attributed in large part to China's own economic situation and exchange rate policy. China and the US sit in difference phases of the business cycle, and it is notable that China experienced a few inflation hikes during the time in question.

Moreover, a tremendous volume of capital inflows[19] contributed to the growth of the Chinese economy and wealth accumulation. However, owing to the fear that a lower real interest rate would accelerate domestic inflation, China upheld its high interest rate level despite knowing that it would induce more speculative capital inflows, mostly on a short-term basis. Moreover, we note that China chose to fix its exchange rate against the US dollar for the first half of the sample period and allowed only gradual appreciation of the RMB in the second half. This was achieved by massive central bank intervention and tight capital control. Although the desirability of this policy mix is open to debate, we have witnessed exponential growth of China's foreign reserve and its NFA position. To conclude, we argue that the US real long-term interest rate, representing the real world interest rate in this study, is not an important exogenous factor in influencing the real interest rate in China, and therefore we exclude RIR_US from the subsequent long-run analysis.

Then, the task facing us is to find whether there exists a long-run relationship among the six exogenous variables: real exchange rate of RMB (RER), two productivity proxies (GDPCN and GDPUS), two thrift proxies (TCONCN and IMPUS) and terms of trade (TOT). However, the fact that TOT is tested to be I (0) renders the conventional Johansen approach ineffective. Following the study of Van Eden et al. (2001), we find the ARDL (Autoregressive-Distributed Lag) procedure is perfectly fit for this situation as it works irrespective of whether the variables are I(0) or I(1)

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[19] We do not differentiate the nature of capital inflows here. However, it is worth noting that in addition to the long-term based capital inflows, such as FDI, there is clear evidence that the short-term speculative inflows have taken an increasingly higher proportion (Yu, 2008).

or even fractionally integrated. The ARDL procedure, also commonly known as the Bounds Testing methodology (Pesaran et al., 2001), is preferable to VECM as it requires a simpler set-up and variables are allowed to enter the model with different lag-lengths.

Specifically, we formulate our model in the ARDL form as follows:

$$\Delta RER_t = \beta_0 + \sum \beta_i \cdot \Delta RER_{t-i} + \sum \gamma_j \cdot \Delta Z_{k,t-j} + \theta_0 Y_{t-1} + \theta_k X_{k,t-1} + \varepsilon_t \qquad (3.25)$$

where we use Z_k as an example of all the exogenous fundamental factors. Naturally, there could be thousands of specifications of the above equation for estimation, as the variables could enter the model with different lag-lengths; we have relied on AIC[20] as the appropriate information criterion to select the best one.

To ensure the robustness of the co-integration, we start with just the I(1) variables, namely RER, GDP_CN, GDP_US, TCON_CN and IMP_US. We set the maximum lag lengths to be 4 for each of the five variables, and the best model in terms of AIC selected is ARDL (4,2,4,0,0). Table 3.4 reports the detailed estimation results.

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[20] SC is another potential choice, but it tends to choose a simpler model specification.

Table 3.4 Estimation Results of the ARDL (4, 2, 4, 0, 0) Model

Variable	Coefficient (S.E.)	t-statistics
Constant	-1.118 (0.578)	-1.934*
RER(-1)	0.884 (0.123)	7.197***
RER(-2)	0.145 (0.158)	0.917
RER(-3)	0.106 (0.157)	0.677
RER(-4)	-0.239 (0.106)	-2.260**
GDPCN	0.030 (0.133)	0.226
GDPCN(-1)	-0.278 (0.162)	-1.719*
GDPCN(-2)	0.232 (0.130)	1.782*
GDPUS	0.660 (0.144)	4.567***
GDPUS(-1)	-0.554 (0.236)	-2.343**
GDPUS(-2)	-0.386 (0.238)	-1.620
GDPUS(-3)	0.210 (0.235)	0.895
GDPUS(-4)	0.192 (0.148)	1.300
TCON_CN	0.079 (0.071)	1.124
RIMP_US	-0.580 (6.700)	-0.087
Diagnostic Test	F-Statistics	Probability
LM Test (6lags)	1.358	0.247
ARCH Test (6 lags)	1.304	0.267
Jarque-Bera	1.987	0.370

Note: This table presents the estimated coefficients of the ARDL (4, 2, 4, 0, 0) model, and the standard errors are reported in the brackets. The Adjusted r^2 is 0.995 with F-statistic 276.393. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

The use of Bounds Test is conditional on there being no autocorrelation within the estimated residuals. Given the diagnostic test results, it is clear that the residuals of this model are serially independent, as LM test reports an F-statistic 1.358 with

probability 0.247. Therefore, we can continue to perform the Bounds Test, the results of which are reported in Table 3.5.

Table 3.5 Bounds Test of the ARDL (4, 2, 4, 0, 0) Model

Test Statistic	Value	k
F-stat.	3.226	4
	Critical Value Bounds	
Significance	I (0) Bound	I (1) Bound
10%	2.2	3.09
5%	2.56	3.49
1%	3.29	4.37

Note: The above F-statistic is computed for the null hypothesis that there is no long-run relationship between the variables in the above model.

Unlike the other tests, the Bounds Test is unique because we need to make inference based on the critical values on both lower and upper bounds: the former assumes that all variables are stationary, while the latter assumes that all variables are integrated to order 1. Pesaran et al. (2001) assert that the relevant critical value for a mix of I (0) and I (1) lies within these two critical values. Since in this test, all variables are tested to be I(1), we can see from Table 3.5 that the F-statistic is 3.226, which exceeds the upper bound only at the 10% significance level. Therefore, we conclude that there may exist a weak long-run relationship between these variables, which are reported as follows.

Table 3.6 Long-run Results of the ARDL (4, 2, 4, 0, 0) Model

Variable	Coefficient (S.E.)	t-statistics
D(RER(-1))	-0.014 (0.102)	-0.133
D(RER(-2))	0.132 (0.092)	1.430
D(RER(-3))	0.230 (0.092)	2.496**
D(GDPCN)	0.010 (0.088)	0.114
D(GDPCN(-1))	-0.227 (0.084)	-2.697***
D(GDPUS)	0.648 (0.130)	5.000***
D(GDPUS(-1))	-0.011 (0.147)	-0.077
D(GDPUS(-2))	-0.404 (0.143)	-2.822***
D(GDPUS(-3))	-0.211 (0.139)	-1.514
D(TCON_CN)	0.015 (0.105)	0.141
D(RIMP_US)	1.740 (8.616)	0.202
Co-intEq (-1)	-0.109 (0.025)	-4.364***
Long-run Coefficients		
Variable	Coefficient (S.E.)	t-statistics
GDPCN	-0.159 (0.150)	-1.061
GDPUS	1.180 (0.212)	5.580***
TCONCN	0.764 (0.786)	0.973
RIMPUS	-5.595 (63.889)	-0.088
C	-10.786 (3.079)	-3.503***

Notes: This table reports the estimated coefficients of the long-run co-integration relationship, and the standard errors are reported in the brackets. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

There are two important findings from the results in Table 3.6. First, as discussed above, the NATREX approach predicts that in the long-run, an increase in the home time preference would lead to a depreciation of the home currency and an increase in the home productivity would usually result in appreciation. In contrast, an

increase in the foreign time preference should lead to an appreciation of the home currency and an increase in the home productivity would usually result in depreciation. Table 3.6 lends strong support for this claim. Secondly, we note that the coefficient of the error correction term, denoted as Co-intEq(1) above, reports as highly significant and the sign is negative as expected.

However, we note that the long-run coefficients of a few variables do not report as significant and this prompts us to argue that they should be left out. Specifically, a parsimonious model is obtained after we drop the IMPUS and TCONCN, the two parameters for thrift at home and foreign country. The associated ARDL specification, Bounds Test and long-run results are reported in Tables 3.7, 3.8 and 3.9, respectively.

Based on AIC, we have chosen the specification of ARDL (1,6,3) for estimation. This model is clearly preferable to the previous case, as we now have a much larger F-statistic: 1486.305 compared to 276.393, which warrants the decision to drop IMPUS and TCONCN out of the long-run analysis. The following Bounds Test result adds further support to this claim: the F-test rejects the hypothesis that there is no co-integration at the 1% level. Now we can write the long-run relationship as follows:

$$RER = -14.797 - 0.270 * GDPCN + 1.673 * GDPUS \qquad (3.26)$$

Table 3.7 Estimation Results of the ARDL (1, 6, 3) Model

Variable	Coefficient (S.E.)	t-statistics
Constant	-1.277 (0.381)	-3.351***
RER (-1)	0.914 (0.039)	23.246***
GDPCN	-0.027 (0.123)	-0.216
GDPCN(-1)	-0.395 (0.163)	-2.422**
GDPCN(-2)	0.129 (0.169)	0.762
GDPCN(-3)	-0.018 (0.161)	-0.112
GDPCN(-4)	-0.197 (0.161)	-1.219
GDPCN(-5)	0.251 (0.165)	1.519
GDPCN(-6)	0.233 (0.134)	1.740*
GDPUS	0.499 (0.152)	3.291***
GDPUS (-1)	-0.315 (0.229)	-1.371
GDPUS (-2)	-0.330 (0.223)	-1.480
GDPUS (-3)	0.290 (0.131)	2.217**

Diagnostic Test	F-Statistics	Probability
LM Test (6 lags)	0.935	0.477
ARCH Test (6 lags)	1.356	0.246
Jarque-Bera	2.091	0.352

Notes: This table presents the estimated coefficients of the ARDL (1,6,3) model, and the standard errors are reported in the brackets. The Adjusted r^2 is 0.996 with F-statistic 1486.305. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

Table 3.8 Bounds Test of the ARDL (1,6,3) Model

Test Statistic	Value	k
F-stat.	11.607	2
	Critical Value Bounds	
Significance	I (0) Bound	I (1) Bound
10%	2.63	3.35
5%	3.1	3.87
1%	4.13	5

Note: The above F-statistic is computed for the null hypothesis that there is no long-run relationship between the variables in the above model.

Table 3.9 Long-Run Results of the ARDL (1,6,3) Model

Variable	Coefficient (S.E.)	t-statistics
D(GDPCN)	-0.027 (0.113)	-0.236
D(GDPCN (-1))	-0.398 (0.111)	-3.596***
D(GDPCN(-2))	-0.269 (0.110)	-2.446**
D(GDPCN(-3))	-0.287 (0.110)	-2.617**
D(GDPCN(-4))	-0.484 (0.114)	-4.255***
D(GDPCN(-5))	-0.233 (0.119)	-1.969*
D(GDPUS)	0.499 (0.125)	3.996***
D(GDPUS(-1))	0.040 (0.132)	0.305
D(GDPUS(-2))	-0.290 (0.122)	-2.379**
Co-intEq (-1)	-0.086 (0.012)	-6.969***
Long-run Coefficients		
Variable	Coefficient (S.E.)	t-statistics
GDPCN	-0.270 (0.051)	-5.309***
GDPUS	1.673 (0.317)	5.287***
C	-14.797 (3.151)	-4.696***

Notes: This table reports the estimated coefficients of the long-run co-integration relationship, and the standard errors are reported in the brackets. It is based on an ARDL (1, 6, 3) model. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

We then add the terms of trade (TOT) to the co-integration space. As TOT has already been tested to be I(0), we know for sure that TOT will be co-integrated with the RER, GDPCN and GDPUS. Hence, we focus more on the long-run results from the ARDL approach.[21] Again, based on the AIC, we have selected the specification of ARDL (1, 6, 3, 0) model, and report the long-run results in Table 3.10.

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[21] Given the ARDL (1,6,3,0) model, the Bound Test F-statistic reports 9.226 and it is significant at the 1% level.

In comparison with Table 3.9, there is literally no difference in terms of the results for GDPCN and GDPUS, while we find a highly insignificant coefficient for TOT. Previous studies, such as Lim and Stein (1995) and You and Sarantis (2008, 2012), suggest that an increase in terms of trade should have a positive effect on the appreciation of home currency. However, we argue that the failed result is simply due to the characteristics of these two data series, which are depicted in Figure 3.3. It is apparent that the series of TOT is much more volatile relative to RER, which in fact reflects the uniqueness of China. As discussed above, the Chinese government has the ultimate control over its exchange rate dynamics, while the terms of trade series is more in control of the market forces, which is why we assume it is an exogenous factor to China in the first place. Hence, the insignificance of TOT in our estimation should not be considered as strong opposition to the NATREX approach.

Table 3.10 Long-Run Results of the ARDL (1,6,3,0) Model

Variable	Coefficient (S.E.)	t-statistics
D(GDPCN)	-0.045 (0.117)	-0.388
D(GDPCN (-1))	-0.428 (0.119)	-3.612***
D(GDPCN(-2))	-0.287 (0.113)	-2.541**
D(GDPCN(-3))	-0.299 (0.111)	-2.688***
D(GDPCN(-4))	-0.459 (0.120)	-3.823***
D(GDPCN(-5))	-0.203 (0.126)	-1.620
D(GDPUS)	0.501 (0.125)	3.996***
D(GDPUS(-1))	0.042 (0.132)	0.319
D(GDPUS(-2))	-0.299 (0.123)	-2.435**
D(TOT)	0.000 (0.000)	-0.760
Co-intEq (-1)	-0.088 (0.013)	-6.980***
Long-run Coefficients		
Variable	Coefficient (S.E.)	t-statistics
GDPCN	-0.269 (0.052)	-5.211***
GDPUS	1.671 (0.320)	5.219***
TOT	0.000 (0.002)	-0.055
C	-14.762 (3.219)	-4.585***

Notes: This table reports the estimated coefficients of the long-run co-integration relationship, and the standard errors are reported in the brackets. It is based on an ARDL (1, 6, 3,0) model. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.
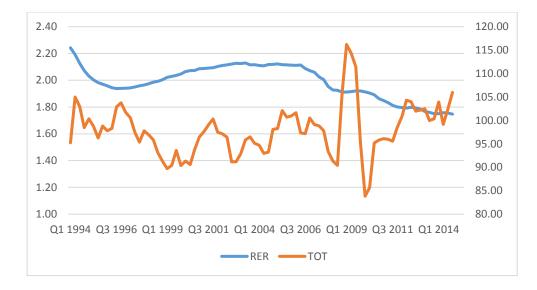
Figure 3.3 RER and TOT

Notes: This figure plots the real exchange rate (RER) and terms of trade (TOT) of China for the sample period from 1994Q1 to 2014Q4.

Medium-run Analysis

The analysis above has completed the first empirical objective, which is to identify which exogenous factors have impacted the real exchange rate of RMB in the manner prescribed by the NATREX approach. Although it has been stressed that the medium-run equilibrium is only a theoretical concept and the NATREX never prevails in the reality, empirical investigation is still needed to test whether the real exchange rate converges to the moving NATREX.

To answer this question, we note that in the medium-run the NATREX can be solved as a function of the capital stock in both home and foreign country, and the net foreign asset positions $NATREX_t = R[K_t, F_t; Z_t]$. In essence, we need a robust econometric approach to investigate the following dynamics.

$$\frac{dRER}{dt} = \beta_1 \cdot \frac{dK}{dt} + \beta_2 \cdot \frac{dK^*}{dt} + \beta_3 \cdot \frac{dNFA}{dt} + \beta_4 \cdot \frac{dZ}{dt} \qquad (3.27)$$

Here dK and dK^* are the change of the real capital stock in China and the US; $dNFA$ is the change of the net foreign asset position of China; and dZ denotes the change of the exogenous factors identified above.

Unlike the long-run analysis, which commonly adopts the co-integration approach, there is no consensus with regard to the choice of empirical methodology in the medium-run. In the pioneering work of Stein (1994), the following equation was estimated:

$$R = C(1) + C(2) \cdot R(-1) + C(3) \cdot MAGROWTH + C(4) \cdot MAFGROW + C(5) \cdot MACAGNP + C(6) \cdot USFINT(-1)$$

where R is the real exchange rate of the US dollar; MAGROWTH and MAFGROW are used to proxy the growth rate of real capital stock at home and abroad, respectively; MACAGNP denotes the growth of the real foreign debt; and USFINT is proxied by the real long-term interest rate difference between the US and the rest of the G-10 countries.

Although Stein (1994) employed both OLS and NLS to ensure the robustness of the estimation results, there is still some doubt over this approach. First, since Stein (1994) tested that all the variables listed above are integrated to order 1, neither OLS nor NLS is free from a concern of spurious regression. Secondly, Stein (1994) short-circuited the task of measuring those stock variables. Instead, he used the very same

variable, the 12-quarter moving average of the growth rate of real GDP, to proxy the growth of both capital and productivity.

Facing these two issues, on one hand, we argue that the co-integration is more appropriate in revealing the dynamics within this model. In a review of NATREX, Allen (1995, p. 6) lends some support to this by pointing out that '*This medium-run equilibrium, usually considered as the long-run equilibrium of most monetary models, is the starting point of a NATREX model*'. Therefore, we could still make use of the ARDL procedure. On the other hand, we have constructed individual measurements for each of the stock variables. Specifically, we have followed Gu and Zhang (2012) to build the Chinese capital stock until 2014, and used the Lane and Milesi-Ferretti (2001, 2007) method to calculate the net foreign asset position for China.

It is also interesting to note that Stein (1994) used a lagged US real long-term interest rate in the estimation not only to stand for the convergence of real interest rate, but also to try to capture any potential effects the exogenous factors might have on the real exchange rate in the medium-run. However, we find that the real long-term interest rate diverged between China and the US, which seems to suggest that the portfolio substitution channel does not apply to China. Nevertheless, the interest rate differential may still carry additional useful information for estimation, and it prompts us to find two interest rate series to proxy the medium-run interest rate differential.

The choice of ARDL procedure is validated, as the ADF Unit-Root test (reported in Table 3.11) suggests that there is one I(0) among all these variables, i.e. the medium-run interest rate differential (MRIR_DIFF).

Table 3.11 ADF Unit-Root Test

Variable	Test Type	ADF statistic
K_CN	(c,t,1)	-1.39
ΔK_CN	(c,t,0)	-3.27*
K_US	(c,1)	-1.96
ΔK_US	(n,0)	-2.86***
NFA	(c,5)	-1.64
ΔNFA	(c,t,4)	-4.56***
MRIR_DIFF	(n,0)	-2.44**

Notes: To describe the type of unit-root test, we use c, n to denote whether a constant is included in the test or not. t denotes the case when a trend is also included in the test. The number in the parenthesis stands for the lags chosen on the basis of SIC. The significance of the ADF test is based on the MacKinnon (1996) one-sided p-values, where the null hypothesis is that there exists a unit-root in the time period. ***, ** and * denote the 1%, 5%, and 10% significance levels, respectively. K_CN and K_US denote the real capital stock (in its logarithm) in China and the US, respectively. NFA is the net foreign asset position of China, scaled down by the GDP in the corresponding quarter. MRIR_DIFF represents the difference between medium-run real interest rate in China and the US. Δ denotes the first difference of the variable concerned.

Table 3.12 Estimation Results of the ARDL (4, 1, 1, 4, 0) Model

Variable	Coefficient (S.E.)	t-statistics
Constant	-3.436 (0.795)	-4.321***
RER(-1)	0.505 (0.119)	4.230***
RER(-2)	0.111 (0.130)	0.854
RER(-3)	0.306 (0.136)	2.241**
RER(-4)	-0.142 (0.091)	-1.569
K_CN	0.403 (0.175)	2.307**
K_CN(-1)	-0.435 (0.175)	-2.493**
K_US	1.810 (0.231)	7.828***
K_US(-1)	-1.514 (0.220)	-6.878***
NFA	-0.037 (0.014)	-2.624**
NFA(-1)	0.016 (0.015)	1.068
NFA (-2)	0.024 (0.015)	1.635
NFA(-3)	-0.033 (0.014)	-2.272**
NFA(-4)	0.026 (0.014)	1.883*
MRIR_DIFF	-0.011(0.047)	-0.229
Diagnostic Test	F-Statistics	Probability
LM Test (6 lags)	0.671	0.674
ARCH Test (6 lags)	0.588	0.738
Jarque-Bera	0.157	0.924

Note: This table presents the estimated coefficients of the ARDL (4, 1, 1, 4, 0) model, and the associated standard errors are reported in the brackets. The Adjusted r^2 is 0.997 with F-statistic1676.253. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

Table 3.13 Bounds Test of the ARDL (4, 1, 1, 4, 0) Model

Test Statistic	Value	k
F-stat.	7.233	4

Critical Value Bounds

Significance	I (0) Bound	I (1) Bound
10%	2.20	3.09
5%	2.56	3.49
1%	3.29	4.37

Note: The above F-statistic is computed for the null hypothesis that there is no long-run relationship between the variables in the above model.

Table 3.14 Long-Run Results of the ARDL (4, 1, 1, 4, 0) Model

Variable	Coefficient (S.E.)	t-statistics
D(RER(-1))	-0.275 (0.092)	-2.976***
D(RER(-2))	-0.163 (0.087)	-1.869*
D(RER(-3))	0.140 (0.075)	1.855*
D(K_CN)	0.403 (0.074)	5.407***
D(K_US)	1.807 (0.187)	9.671***
D(NFA)	-0.037 (0.011)	-3.261***
D(NFA(-1))	-0.017 (0.011)	-1.506
D(NFA(-2))	0.006 (0.011)	0.568
D(NFA(-3))	-0.026 (0.011)	-2.298**
D(MRIR_DIFF)	-0.026 (0.052)	-0.505
Co-intEq (-1)	-0.221 (0.032)	-6.796***
Long-run Coefficients		
Variable	Coefficient (S.E.)	t-statistics
K_CN	-0.145 (0.015)	-9.911***
K_US	1.344 (0.104)	12.920***
NFA	-0.018 (0.031)	-0.585
MRIR_DIFF	-0.049 (0.210)	-0.232
C	-15.576 (1.493)	-10.430***

Notes: This table reports the estimated coefficients of the long-run co-integration relationship, and the standard errors are reported in the brackets. It is based on an ARDL (4, 1, 1, 4, 0) model. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

Then the long-run equation should read:

$$RER = -0.145*K\_CN + 1.344*K\_US - 0.018*NFA - 0.049*MRIR\_DIFF - 15.576$$

Several comments can be made regarding the results. First, the residuals from the selected ARDL (4, 1, 1, 4, 0) model are tested to conform to white noise and render the subsequent Bounds Test effective. The F-statistic confirms that these variables

are co-integrated and we have a highly significant error correction term. Secondly, all estimated coefficients report signs as expected by the NATREX approach. K_CN reports a significant negative effect on the RER, suggesting that an increase in Chinese capital stock leads to a rightward shift of the IS curve. In response to the relative increase of investment demand, the real interest rate should rise to maintain the goods market equilibrium. As a result, investors would be encouraged to purchase and/or sell foreign securities, and this in turn would result in appreciation of the domestic currency. The above process would lead to an opposite impact on the RMB, as reflected by the positive coefficient of K_US. Following similar argument, it is also easy to understand that an increase of net foreign asset position (NFA) or the medium-run real interest rate differential (MRIR_DIFF) would exert an appreciation pressure on the RMB. However, the impacts of NFA and MRIR_DIFF are not statistically significant.

In light of the above results, we drop NFA and MRIR_DIFF from the ARDL procedure and arrive at a parsimonious specification, as reported in the following tables.

Table 3.15 Estimation Results of the ARDL (4, 1, 1) Model

Variable	Coefficient (S.E.)	t-statistics
Constant	-2.623 (0.630)	-4.162***
RER(-1)	0.620 (0.108)	5.725***
RER(-2)	0.061 (0.130)	0.470
RER(-3)	0.331 (0.135)	2.455**
RER(-4)	-0.192 (0.078)	-2.455**
K_CN	0.287 (0.140)	2.054**
K_CN(-1)	-0.312 (0.139)	-2.250**
K_US	1.702 (0.220)	7.743***
K_US(-1)	-1.474 (0.218)	-6.756***
Diagnostic Test	F-Statistics	Probability
LM Test (6 lags)	0.783	0.587
ARCH Test (6 lags)	0.685	0.663
Jarque-Bera	0.513	0.774

Note: This table presents the estimated coefficients of the ARDL (4, 1, 1) model, and the associated standard errors are reported in the brackets. The Adjusted r^2 is 0.996 with F-statistic 2743.059. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

Table 3.16 Bounds Test of the ARDL (4, 1, 1) Model

Test Statistic	Value	k
F-stat.	10.193	2
Critical Value Bounds		
Significance	I (0) Bound	I (1) Bound
10%	2.63	3.35
5%	3.1	3.87
1%	4.13	5

Note: The above F-statistic is computed for the null hypothesis that there is no long-run relationship between the variables in the above model.

Table 3.17 Long-Run Results of the ARDL (4, 1, 1) Model

Variable	Coefficient (S.E.)	t-statistics
D(RER(-1))	-0.200 (0.090)	-2.216**
D(RER(-2))	-0.139 (0.084)	-1.648
D(RER(-3))	0.192 (0.074)	2.606**
D(K_CN)	0.287 (0.060)	4.792***
D(K_US)	1.702 (0.181)	9.405***
Co-intEq (-1)	-0.179 (0.028)	-6.519 ***
Long-run Coefficients		
Variable	Coefficient (S.E.)	t-statistics
K_CN	-0.142 (0.012)	-12.198***
K_US	1.273 (0.080)	15.902***
C	-14.619 (1.116)	-13.101***

Notes: This table reports the estimated coefficients of the long-run co-integration relationship, and the standard errors are reported in the brackets. It is based on an ARDL (4, 1, 1, 4, 0) model. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

Without repeating the analysis, we can conclude that the medium-run equilibrium for the NATREX can be parsimoniously described as:

$$RER = -14.619 - 0.142 * K\_CN + 1.273 * K\_US . \qquad (3.28)$$

The relationship depicted in equation (3.28) can be considered parsimonious also in the sense that the recursive residuals are always within the bands of plus or minus two standard errors, as shown in Figure 3.4.

Forecast: RERF	
Actual: RER	
Forecast sample: 1994Q1 2014Q4	
Adjusted sample: 1995Q1 2014Q4	
Included observations: 80	
Root Mean Squared Error	0.010573
Mean Absolute Error	0.008371
Mean Abs. Percent Error	0.422244
Theil Inequality Coefficient	0.002670
Bias Proportion	0.000165
Variance Proportion	0.023897
Covariance Proportion	0.975937
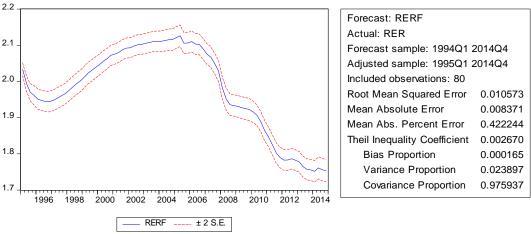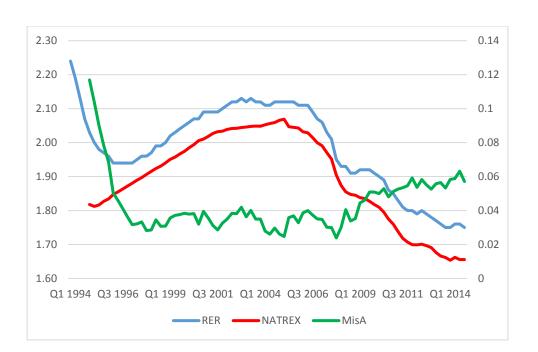
Figure 3.4 Recursive Residuals of the ARDL (4, 1, 1) Model

Notes: This figure plots the recursive residuals of the ARDL (4, 1, 1) Model.

Misalignment between RER and NATREX

Given the analysis above, we can see that the movements of real exchange rate of RMB can be explained by the NATREX model. Since NATREX is assumed to be the equilibrium exchange rate prevailing in the medium-run, we construct NATREX based on the coefficient results reported in Table 3.17. Instead of using the actual real exchange rates to denote the lagged R, we replace them with the equilibrium exchange rates that should have been prevailing by using the relationship depicted in equation (3.28) and the actual values of K_CN and K_US. Then we measure

the misalignment (in percentage) between the RER and the NATREX as follows. Hence, a positive misalignment means the RMB is undervalued compared to its NATREX value and vice versa.

$$MisA_t\% = \frac{RER_t - NATREX_t}{NATREX_t} * 100 \qquad (3.29)$$

Figure 3.5 RER, NATREX and the Misalignment

Notes: This figure plots the actual real exchange rate of RMB (RER) in the blue line, the NATREX in the red line, and the misalignment in the green line for the period from 1995Q1 to 2014Q4.

In Figure 3.5, we plot the actual real exchange rate of RMB, the newly estimated NATREX, and the misalignment. It is clear that the real exchange rate of RMB is consistently undervalued compared to its NATREX counterpart, although the degree of misalignment has undergone different phases. The deviation tightened up quickly from 11.7% at the beginning of 1995 to as low as 2.8% in 1998, possibly due to impacts of the Asian financial crisis. It is widely known that, unlike many

neighbouring countries, the Chinese authority chose not to devalue its currency against the US dollar. The misalignment remained relatively stable until it increased quite significantly in late 2008 when China was hit by another financial crisis. During this time period, the US dollar depreciated considerably against most currencies, while the Chinese authority had again frozen the nominal exchange rate because of the severity of the global financial crisis. However, in comparison, the performance of the Chinese economy was still strong. Hence, the misalignment increased again, to over 5% in 2010.

Compared to other studies such as Coudert and Couharde (2007) and Cline and Williamson (2009), the degree of undervaluation reported here is much smaller, which is not surprising as each study adopts a different estimation strategy or dataset. Nevertheless, this findings falls in line with You and Sarantis (2012) which asserts that there was only a moderate yet persistent undervaluation of the real effective exchange rate of RMB during 1982-2010. Moreover, You and Sarantis (2012) report that the extend of undervaluation rose sharply in 2009 and 2010, the trend of which is also present in our research.

It is also interesting to note that the 2005 exchange rate reform did contribute to closing the misalignment: it dropped from 3.6% in 2005Q3 to 2.4% in 2008Q1. However, this change is notably far less than the magnitude of appreciation of the nominal exchange rate. Nevertheless, we argue that this is because the medium-run equilibrium did not occur in the sample period; hence, the NATREX value we obtain here serves only as guidance.

3.5 Conclusions

China's global influence has been growing rapidly. In terms of global trade, China is already ranked first in exporting and second in importing. There is also clear evidence that the RMB has become more recognized outside China and is used for international transactions and payments. We have every reason to believe that this trend will continue and grow in the near future, especially given the fact that the RMB has joined the dollar, euro, pound and yen in the IMF's Special Drawing Rights (SDR) from Oct. 1, 2016, at a 10.92 percent weighting. However, as regards the Chinese exchange rate system reform, there remains much to be done. This study is devoted to calculating an appropriate reference rate for China, one of the two most important issues of the Reference Rate System[22]. To this end, we have adopted the NATREX approach.

Compared to the other work on the determination of real exchange rate, since its introduction by Stein in the early 1990s NATREX has stood out in several ways. First, by definition it avoids consideration of the speculative capital flows and cyclical impacts that are notoriously problematic for empirical investigation. Instead, the NATREX focuses on describing the equilibrium situations. Secondly, the NATREX approach contributes to the literature by proposing that there is a trajectory through which the NATREX (a medium-run concept) converges to its long-run equilibrium value. Thirdly, as Allen (1995) noted, the NATREX approach can be considered as a positive, rather than a normative concept. This is a quite desirable feature in terms of the Reference Rate System, where we need to

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[22] We in Chapter 5 discuss why the Reference Rate System might be a better option for China.

determine whether the policy is contributing to the maintenance of an equilibrium exchange rate.

The empirics of the NATREX have been conducted comprehensively in this study of the Chinese currency, RMB. In summary, we conclude that the NATREX model, in its canonical form, proves useful to account for the movements of the real exchange rate of the RMB, although not in the same way as occurred in other countries. We have not been bound by the previous studies, but have tried to overcome the difficulty of finding the most appropriate proxies and estimation method. For instance, because we could not find reliable data of the Chinese capital stock directly, we constructed the variable from scratch. Similarly, in order to get a better picture of the net foreign asset position, we built that variable as well. In terms of final results, we find that only the two productivity proxies have significantly impacted the RMB in the long-run in the way predicted by the NATREX model. The other exogenous factors were dropped from the parsimonious specification, either because they did not report as significant, or because they were wrongly signed. We also find evidence that the actual real exchange rate converges to the hypothetical medium-run NATREX value. Finally, we provide strong evidence that the portfolio balance channel did not work in China in the sample period. This could be explained by China's own economic situation and policy mix during that time.

However, we note that there are some limitations to the NATREX approach. For policy makers, the most obvious one is that the medium-run NATREX exists only conceptually, which makes it not particularly viable for the authorities to formulate policies. Moreover, the NATREX approach does not take into account of short-term

factors, such as speculative flows, which usually require prompt reaction from authorities in reality. From an empirical perspective, we also note that the estimation of the NATREX approach is subject to the data and methodology used. Despite the advances on both fronts, there is still room for improvement. For instance, the portfolio channel do not work for China, as opposed to what the canonical NATREX model would prescribe. We may need to refine our theoretical model by taking into consideration other factors established in other models, i.e. IMF's EBA approach.

Chapter 4

Optimal Control of the Chinese Official Intervention in a Heterogeneous Agent Framework

4.1 Introduction

Despite the ongoing debate over which is the optimal exchange rate regime, it is rare that the governing authorities leave the course of exchange rates in the hands of the market alone, even if the exchange rate itself is not their prime objective. Recently, the idea of an intermediate regime, alias managed floating, has regained its popularity among policy-makers and researchers, as it is widely believed that by adopting such a regime, a country could not only benefit from relatively stable exchange rates in normal times, but could also avoid costly commitments in troubling situations. However, there has been little research into the operational perspective of these intermediate floating regimes, which makes it even more necessary to explain their relatively short lives.

In terms of China, while financial under-development and extensive capital controls mean it mission impossible for China to adopt a free floating exchange rate regime, history also teaches the lesson that a fixed exchange rate regime is not viable for China as a world trading nation facing volatile international capital movements.

This leaves the managed floating exchange rate a sensible choice for China. However, despite much discussion, how to best manage the managed floating exchange rate in China remains a significant challenge for the country. To make things even worse, the lack of a well-functioning exchange rate regime has been a major stumbling block to China's drive to promote the RMB as an international currency.

In order to shed new lights on China's optimal management of an intermediate exchange rate regime, this study turns for help to the stochastic optimal control theory. This move is reasonable, as it is more realistic to consider the management of exchange rates as an ever-changing (dynamic) system: new information (or shocks) arrives stochastically and it is up to the policy-maker to select their action accordingly to achieve the best result. Although the optimal control theory has been developed over several years and tested successfully in many fields such as physics and engineering, the earliest attempt to apply this idea to the management of exchange rates was the study of Jeanblanc-Picque (1993). With help from stochastic impulse control, the optimal strategy obtained by Jeanblanc-Picque (1993) states that the monetary authority should refrain from intervening in the foreign exchange market when the exchange rate is within the explicitly pre-determined band, but stands ready to intervene whenever the exchange rate reaches the upper or lower edge such that an instantaneous jump is triggered to bring the exchange rate to a point within the band. Since then, some ensuing studies (e.g. Korn, 1997 and Cadenillas and Zapatero, 1999, 2000), have extended Jeanblanc-Picque's (1993) work in the management of exchange rates by bringing more realistic assumptions into play.

We note that one key assumption upheld in previous studies is that agents do not know the reaction functions of the central bank; in other words, they are not able to obtain the parameters of the central bank's action. This is to rule out the potential impact of agents' response to the government intervention on the exchange rate, which is essential to keep the solution tractable (Cadenillas and Zapatero, 1999). However, such an assumption is questionable, especially in light of recent literature on the central bank's intervention within the heterogeneous agent framework. Studies, such as Beine et al. (2009) and Maatoug et al. (2011), tend to support the notion that official intervention can be effective as it can increase the proportion of fundamentalists, which in turn stabilizes the exchange rate.

It is thus desirable and necessary to relax the assumption that agents do not react to central banks' intervention. This is particularly meaningful in the Chinese case. Under the current exchange rate arrangements, the central bank firmly controls the central parity, the benchmark RMB exchange rate, while market participants can only quote the trading price of RMB against foreign currencies within pre-determined limits around the central parity rate. It is also widely noted that the central bank may step in the market to directly place buying or selling orders or to give oral instructions to foreign exchange traders in state-controlled entities. Market participants can 'observe' the central bank's intervention operations and would normally follow the official intentions, though with some lags. As such, we follow Kercheval and Moreno (2009) and Bensoussan et al. (2012) to introduce a 'reaction

period' in the context for China, which modifies the standard impulse control strategy.

Specifically, we utilize the results from estimation of the heterogeneous agent framework to characterize the exchange rate process during the reaction period. Next, we empirically investigate the effect of central bank intervention on the reactions of market participants, who are classified according to their trading strategies. The results show that the PBOC intervention is effective in the sense that its signal is effectively conveyed to the market participants. Moreover, volatility of the exchange rate is significantly reduced after the intervention.

The subsequent quantitative evidence obtained from the optimal control framework provides important insights of how the monetary authority may best manage the managed floating rate regime. We establish the optimal width for the band within which the exchange rate is free to float, when intervention should take place, and by how much. These findings can be particularly useful for the authority interested in contemplating a 'Reference Rate Regime'. They bear important policy implications for the central bank's enhancement of its credibility in convincing the market that official intervention can be stabilising and also for the optimal adjustment of the fluctuating band, the width of which would be large enough to allow sufficient flexibility for the exchange rate while being sufficiently tight to reduce excessive volatility of the exchange rate.

The remainder of this chapter is organized as follows. Section 2 is devoted to a review of the optimal stochastic control theory in relation to the exchange rate management and the impact of central bank intervention on the market participants. Section 3 empirically investigates the intervention conducted by the Chinese central bank in a heterogeneous agent setting. Section 4 explains how to manage the managed floating exchange rate system and presents numerical evidence. Section 5 discusses policy implications and conclusions.

4.2 Literature Review

Two strands of the literature have emerged from existing studies in relation to exchange rate management through official intervention. The first involves the stochastic optimal control theory and the second concerns the study of the impact of central bank intervention within a heterogeneous agent framework.

Accompanying the debate of the optimal exchange rate regime, scholars have also devoted to finding if there exists an optimal exchange rate management (intervention) strategy to support the regime once adopted.

The earliest study can date back to Boyer (1978) who concluded that optimal policy is concerned with finding the optimal exchange rate flexibility level, which usually should lie within the interval of a hard fix and pure floating. The target-zone model, presented by Krugman (1991), is widely considered as the canonical theoretical framework for this strand of research. In fact, any exchange rate regime can be

simply viewed as a target-zone with different choice of band-width (López and Mendizabal, 2007). In the classic Krugman model, the exchange rate depends on only two fundamentals, namely money supply and a velocity shift term, implying that the monetary authority could constrain the exchange rate stay in a pre-determined band simply through adjusting the money supply.

Krugman (1991)'s model has inspired many following researches, with a majority of them focusing on reconciling the original theoretical model with observed stylized facts , though most empirical evidence so far has lent little support to the original model (Svensson, 1992). However, as noted by Mundaca and Oksendal (1998), rather than continuing in the direction of refining the model to fit the empirical findings that are at odds with Krugman's original model, scholars have recently shifted their focus to another important issue: the existence of optimal monetary policy to maintain the currency fluctuating band through various approaches.

One of the main approaches makes use of the optimal stochastic control theory, which can be further classified into different groups depending on the specific control applied. As reviewed later, we choose to adopt this approach mainly because it offers an operational strategy, which closely mirrors the exchange rate management problem faced in reality.

In addition to the stochastic control theory, there are also a few alternative methods proposed in literature. For instance, Cukierman et al. (2004) recognize that the adoption of exchange rate band in reality is a much more complicated issue. It compels policymakers to make key choices, such as the width of the fluctuation band, the level of the central parity rate, the method of intervention in support of the band and etc.. Aimed at achieving the optimal trade-off between the exchange rate flexibility (nominal exchange rate variability) and the credibility of the authority, Cukierman et al. (2004) provide a framework to determine the optimal exchange rate band. The key finding of their paper is that it analytically characterize the conditions under which a free float, a peg, or a band is optimal.

López and Mendizábal (2007) made similar effort where they incorporated the standard target-zone model with both intra-marginal interventions and the lack of credibility. Given a set of values for the parameters that characterize the model, López and Mendizábal (2007) applied numerical methods to find the loss function for exchange rate regimes with various degree of flexibility.

Lee and Lai (2011) have proposed a structural threshold model building on the idea of finding the optimal trade-off between obtaining the desirable exchange rate target and minimizing intervention cost. Compared to the optimal stochastic control approach, Lee and Lai (2011) has a clear advantage as the parameters for the structural threshold model can be directly estimated from the real data. However, Lee and Lai (2011) offers less clear guidance on how central bank should intervene, i.e. when is the best time to intervene and by how much. Nevertheless, Lee (2011)

tackled this limitation and demonstrated that under the managed floating the exchange rate can be modelled with two states: an 'intervention' state and a 'non-intervention' state. Moreover, Lee (2011) illustrated that under the assumption of rational expectations, an analytical solution of the exchange rate might be obtained.

4.2.1 Optimal Stochastic Control

It is not surprising that the theory of optimal stochastic control is traditionally widely used in the areas of mathematics and engineering; however, recently there has been a trend for studies to apply this method in various areas of economic studies, including capital injections (Eisenberg and Schmidli, 2011), insurance (Luo and Taksar, 2012), dividend pay-out policy (Dickson and Waters, 2004 and Cadenillas et al., 2006), and more recently interest rates (Mitchell et al., 2014).

The optimal stochastic control (in continuous time) can take various forms. Depending on the nature of the problem under consideration, it can be broadly divided into two sub-categories: classical control and impulse control. To clarify possible confusion that might arise in the following literature review, we use the following diffusion process to illustrate the difference between them.

Following the canonical setting in this line of literature, we assume that in the absence of control the state of the variable concerned can be modelled using a diffusion process as follows:

$$dX(t) = \mu(X(t)) + \sigma(X(t))dW(t) \tag{4.1}$$

$$X(t) = x + \int_0^t b(X(s))ds + \int_0^t \sigma(X(s))dW(s), 0 \leq t < \tau_1 \tag{4.2}$$

where μ and σ denote the drift and diffusion parameter of the process, respectively; τ_1 denotes the first time a control is applied.

The defining character of the classical control is that the controller has the ability to alter either the drift or diffusion parameter or both; whereas in the impulse control, the controller directly brings a jump to the state variable without affecting the drift or the diffusion parameter. The classical control is arguably preferable when the controller has large influence on the state process. Otherwise, where the controller has relatively less influence or when continuous intervention is too costly, the impulse control would be a better choice. Here, the controller only needs to decide whether to control or not, and if yes, the size of that control. Moreover, compared to the classical control, impulse controls are more suitable for modelling the scenarios in which the decisions are made less frequently, but the controller has the ability to bring discontinuity to the economic variables concerned. In this study, we consider the impulse control to be the type of control that brings direct change to the economic variable under consideration, while the classical control is defined as the control that focuses on the drift or the diffusion parameter.

Impulse Control

Jeanblanc-Picque (1993) was the first to apply the impulse control method to the management of exchange rates. In her setting, the exchange rate is modelled using a diffusion process where the drift and diffusion parameter are kept constant. The problem facing the central bank is to constrain the exchange rate stay within a pre-designated band (a, b), where the cost associated with each intervention is composed of a fixed term and another proportional term. Then the optimal strategy sought is such that the intervention cost is minimized in an infinite time horizon. Given rigorous proof, the optimal policy obtained can be summarized in the following figure: no intervention would be made when the exchange rate is in the band (a, b), aka the 'Continuation Zone', but when the process reaches the edge on either side, an intervention should be triggered such that the exchange rate would be moved to point α from a, or to point β from b, where $a < \alpha \leq \beta < b$. In this case, $(0, a)$ and $(b, +\infty)$ are formally referred to as the 'Intervention Zone'.
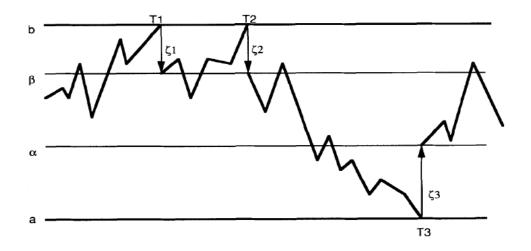
Figure 4.1 The Impulse Control of Exchange Rates

Notes : Adapted from Jeanblanc-Picque (1993), Figure 2.1, p. 164

125

Jeanblanc-Picque's model was later generalized by Korn (1997) by allowing random consequences depending on the intervention size. The randomness assumption is plausible in the cases where the intervention costs are not known prior to intervention, or where the consequences of a control depends on something else (Korn, 1997). In Cadenillas and Zapatero (1999), the assumed central bank objective is to keep the exchange rate as close as possible to a given target. In contrast to Jeanblanc-Picque (1993) and Korn (1997, 1999), the exchange rate band is not exogenously pre-determined. Another important but often overlooked feature of Cadenillas and Zapatero's (1999) model is that the exchange rate, rather than its underlying fundamentals, has a diffusion process as in Eq. (4.1). In addition to obtaining an optimal intervention strategy, Cadenillas and Zapatero (1999) was the first to present numerical simulations of the impulse control in exchange rate management.

Mundaca and Oksendal (1998) make two further extensions to Jeanblanc-Picque (1993). Firstly, rather than constraining the exchange rate in a given band, they propose a function to account for the cost of deviating from a given central parity exchange rate. Secondly and more importantly, they argue that in addition to the impulse control, which pertains to direct purchases (or sale) of foreign exchange, central banks have another important policy tool to influence exchange rates, i.e. the domestic interest rate level. Therefore, Mundaca and Oksendal (1998) formulate an optimal control strategy composed of both impulse control and the classical control, as the authority needs to select the level of domestic interest rate in a continuous manner.

Cadenillas and Zapatero (2000) also consider that the optimal intervention strategy should include both interest rate and foreign reserves. However, they argue that some of the assumptions in Mundaca and Oksendal (1998) do not hold in reality. First, exchange rates in a pure floating rate regime can be better modelled by a geometric Brownian motion rather than a standard one, since the latter includes negative values as well. Secondly, Cadenillas and Zapatero (2000) challenge the conclusion reached in Mundaca and Oksendal (1998) that the lower the domestic interest rate is, the better off the central bank. Instead, Cadenillas and Zapatero (2000) demonstrate that this statement only holds true when the domestic interest rate exceeds its target. Moreover, Cadenillas and Zapatero (2000) propose that the optimal intervention should be performed in the following fashion: when the exchange rate reaches the 'Intervention Zone', direct change of exchange rate is performed in a similar way as in Jeanblanc-Picque (1993); however, in the 'Continuation Zone', intervention through adjusting the interest rate shall be optimally determined continuously by weighing up monetary policy objectives against the exchange rate policy.

Based on Brazil's intervention experience during its floating exchange rate regime period from January 1999 onwards, Sliva (2010) contends that in real practice, monetary authorities do not continuously adjust the domestic interest rate just to accommodate pressures in the foreign exchange market. Hence, in his model interest-rate intervention is considered only during the financial crisis. Sliva (2010) notes that Brazil's central bank has also made use of other unconventional

intervention tools, such as transactions involving domestic-currency bonds or swaps, as complementary tools to defend against speculative attacks. As a result, use of such tools gives the authority higher intervention flexibility without the need to adjust interest rates. Therefore, Sliva (2010) concludes that an extended impulse control model fits better with the reaction for the Central Bank of Brazil during the 2008 global financial crisis period.

Kercheval and Moreno (2009) and Bensoussan et al. (2012) both point out another limitation of the previous impulse control models, i.e. they do not take account of market participants' reaction to the central bank intervention, which might have important effect on the dynamics of the exchange rate. This assumption seems somewhat unrealistic, especially in the light of recent literature on the role of central bank intervention within the heterogeneous agent framework. Therefore, in order to keep the solution tractable, both studies suggest that it is more realistic to assume that the market can detect large intervention operations by the central bank and respond accordingly. These two studies reach the same results that the optimal intervention strategy is impacted by market reaction. For instance, the optimal bandwidth needs to be widened if the exchange rate volatility increases temporarily after interventions.

Unlike the studies mentioned above (except Jeanblanc-Picque, 1993), which assume the exchange rate itself can be modelled using a diffusion process, another popular but more complex application of impulse control models the underlying factor(s) with a diffusion process, which is made possible by introducing another function to

account for the relation between the exchange rate and its underlying factor(s). For instance, Miller and Zhang (1996) studied whether there exists any optimal intervention solution for central banks in the target-zone framework where a proportional cost of intervention is assumed. Since the exchange rate is modelled as the discounted future fundamentals, they point out that the effect of possible intervention should also be taken into account. Through numerical analysis, Miller and Zhang (1996) lend support to the Exchange Rate Mechanism (ERM) by demonstrating that pre-commitment can sustain a bandwidth only half that of the one under discretion.

Following Miller and Zhang (1996), Im (2001) notes that there is a by-product of intervention of exchange rates in the target-zone framework, which involves volatility of the short-term interest rate. Hence, it would make sense to include the interest rate in the central bank's loss function. Then, Im (2001) seeks to find the optimal intervention strategy where proportional intervention cost in an infinite horizon are considered. The solution for optimal instantaneous control consists of two barriers related to the fundamentals. Intervention is executed when the fundamental touches the barrier and the fundamental is adjusted to its nearest boundary. Compared to the results reported in Miller and Zhang (1996), the width of the fluctuating band in Im (2001) is narrower, mainly because of a higher marginal deviation cost underlying the loss function. As a result, the authority is advised to act earlier than in the case considered by Miller and Zhang (1996). Im (2001) also lists the impact of the model parameters on the bandwidth. For instance, the volatility of the fundamental and the extent of preference of interest rate

deviation over exchange rate deviation both report positive effect on the width of the band.

Castellano and D'Ecclesia (2007) offer a similar perspective to Miller and Zhang (1996) and Im (2001), whereby the exchange rate is related to the fundamentals nonlinearly following a Brownian motion with a state-dependent drift. Specifically, Castellano and D'Ecclesia (2007) conjecture that the central bank could influence the dynamics of exchange rates by altering its monetary policy stance. Put in mathematical terms, the authority applies an instantaneous change to the drift parameter of the fundamental, therefore reversing the prevailing appreciation/depreciation trend in the exchange rate. As a result, the exchange rates display a regime-switching phenomenon. In addition, Castellano and D'Ecclesia (2007) empirically validates the theoretic model using the D-Mark/US dollar data over the period from January 1973 to January 2005.

Bar-Ilan et al. (2004) broadened the usage of impulse control models with the example of managing a country's foreign reserve stocks. It is argued that conventional impulse control would be sufficient under normal times, such as the case when international transactions account for only a relatively small proportion of a country's reserve stocks. Nevertheless, as history shows, crisis periods often see a sharp decrease in foreign reserve. In order to address the problem that the standard impulse control cannot account for both scenarios appropriately in the same setting, Bar-Ilan et al. (2004) proposed a generalized impulse control model,

where a combination of a Brownian Motion and a compound Poisson process with positive and negative jumps is used to capture both smooth and abrupt capital stock changes.

Drift Control

Similar to impulse control, drift control problems also originated from non-economic contexts,[23] but it was Bar-Ilan et al. (2007) who first introduced the methodology to an economic problem, i.e. the foreign reserve management. It is conventionally acknowledged that the central bank would use the buffer stock (BS) model to determine a target level of foreign reserve stock, which essentially represents an application of the impulse control method. However, Bar-Ilan et al. (2007) point out that the drift of the state variable, i.e. the rate of change of the international reserves in their study, is largely influenced by monetary policy or exchange rate policy. Hence, the drift is endogenously determined, which leads the authors to contend that the drift-control model can be considered as a generalized version of the traditional BS model. Based on the martingale stopping theory, Bar-Ilan et al. (2007) obtain explicit analytical solutions for the payoff functions with applications to foreign reserve management. Such a drift-control model has an advantage over the BS model in that the decision maker can control not only the state variable, but also two drift rates. Moreover, their results from subsequent

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[23] Interested readers could see Rath (1977), Chernoff and Petkau (1978) and Bar-Lev and Perry (1989) for some earlier examples, and Ata et al. (2005), Ghosh and Weerasinghe (2007), and Ormeci Matoglu and Vate (2011) for more technical discussion.

numerical simulations validate the prediction that drift control gives the authority more freedom in conducting intervention and that the cost saved is substantial.

Given this example, it seems fair to say that drift control can be considered as one sub-category of classical control, as it applies changes to the drift parameter in the diffusion process. Following Bar-Ilan et al. (2007), Castellano et al. (2011) present a drift-control model for a managed floating exchange rate system by assuming that the exchange rate is determined by the current aggregate fundamental, which is modelled as a Brownian motion with state-dependent drift and volatility. A disutility function is introduced to proxy for intervention costs when the monetary authority is assumed to keep the exchange rate level broadly in line with its time-varying target. The optimal management strategy is obtained by use of the Hamilton-Jacobi-Bellman equation in the viscosity sense, and the authors suggest that an optimal fluctuating band might be solved under certain conditions.

The usage of drift-control model has been extended in a number of ways since Bar-Ilan et al. (2007) first applied it to the foreign reserve management. One interesting direction is that the cost of changing the drift can be modelled to be dependent on both the current values of the drift and the reserve level. For example, Bar-Ilan and Marion (2013) find that agents tend to spend at a higher rate when they have a higher cash reserve. Another promising direction for the drift control is that it might be incorporated into a macroeconomic model where the central bank faces multiple objectives, which is helpful in understanding the linkages between various policies.

For example, Bar-Ilan and Lederman (2007) investigate the case where the objective function facing the monetary authority includes both output and inflation targets and the results are useful to both monetary policy and management of foreign reserve holdings. As a follow-up, Bar-Ilan and Marion (2009) consider a more complex model where the cost of a crisis is also included in the loss function for central banks. It is argued that this model better characterizes the behaviour of international reserves and inflation stabilization. In addition, it sheds light on how exchange-rate policy can be related to reserve accumulation. For instance, it rationalizes the policy mix upheld in China, whereby when output is below a potential level, it is optimal to promote export-led growth with a weak currency to achieve output and inflation stabilization, while the accumulation of reserve holdings can be seen as the natural by-product.

4.2.2 Heterogeneous Agent Model

Overview

Rational expectations began to lose its popularity in the 1990s. Scholars increasingly find that agents in the financial markets[24] do not fully fall in line with the rational expectations hypothesis, but tend to question whether the strong

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[24] In addition to the foreign exchange market, the HAM model has also achieved large success in many other financial markets, such as commodity markets (Reitz and Westerhoff, 2007), stock markets (Chiarella et al. 2012, 2014), option markets (Frijns et al., 2010), beef market (Baak, 1999), oil markets (Ter Ellen and Zwinkels, 2010), gold market (Baur and Glover, 2014), and CDS markets (Chiarella et al., 2015).

rationality assumptions, such as the availability of complete information and unlimited computing capacity, really hold in reality (Hommes, 2006). It is unlikely that a rational agent would know the beliefs of all the other agents. Instead, it seems more plausible to assume that agents are boundedly rational in the sense that they use rule of thumb strategies and adapt their forecasting rule as additional observations become available (Hommes, 2001).

Hommes (2006) notes that the switch from a representative, rational agent approach towards a behavioural, agent-based approach is driven mainly by the study of the exchange rate and several empirical anomalies or puzzles thereof. The first puzzle, raised implicitly by Meese and Rogoff (1983), is that a simple random walk model outperforms the much more sophisticated structural models in out-of-sample forecasting in the short horizon, i.e. no more than one year. This puzzle is formally referred to as the 'disconnect' puzzle in the sense that, according to subsequent studies, the exchange rate appears to be disconnected from its underlying fundamentals. One typical case is in Frankel and Froot (1986) that the large and persistent misalignment of the US dollar in the mid-eighties could not be explained by economic fundamentals. The second puzzle relates to the statistic distribution of the exchange rate. On one hand, the volatility of the observed exchange rates is much higher than the volatility of the underlying economic variables, while on the other hand, the distribution of the exchange rates is not normal as predicted by the standard rational models, which gives rise to the 'excess volatility' puzzle. LeBaron (2006) documents that the exchange rate returns display fat tails, which is not obvious in the underlying fundamental variables. Thirdly, the 'forward discount bias' was first detected by Froot and Frankel (1989). Another obvious but less mentioned

puzzle is the extremely large volume of currency trade worldwide. If the foreign exchange market is populated with homogeneous and rational agents, there will not be as many trades as observed nowadays in the foreign exchange market.

Various papers have proposed an array of approaches[25] to model the heterogeneity among agents. One crucial question remains to be addressed is its empirical validity. To this end, different methods have been developed, either directly or indirectly.

Among the studies using direct methods, earlier researches, e.g. Schmalensee (1976), employ experimental methods in the expectation formation processes. The results offer strong evidence that agents tend to follow trends even though they are aware of the random walk characteristic of the exchange rates. This idea is picked up and extended by De Bondt (1993), Bloomfield and Hales (2002), and Hommes et al. (2005).

Another commonly employed direct method is by qualitative or quantitative survey, which offers first-hand evidence of the presence of heterogeneous agents in the foreign exchange market and of how agents form expectation formation rules. In their pioneering study, Taylor and Allen (1992) report that a majority (90%) of the foreign exchange traders in the London market would use some form of technical

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[25] In this study, we focus on the most popular theoretical framework, i.e. the chartists and fundamentalists approach.

analysis to forecast exchange rates, especially for the short-term horizons. In the meantime, traders are better informed by making use of the fundamental analysis.

Many subsequent surveys have offered more insights into the heterogeneity in the foreign exchange market. In Jongen et al. (2012), the survey is conducted by Consensus Economics of London among major professional forecast agencies; it is conducted on a monthly basis and covers the most commonly traded currencies. Jongen et al. (2012) document that the degree of dispersion regarding the future exchange rate levels has highs and lows in different time periods, and the change can be attributed largely to the asymmetric information set and heterogeneity in forming exchange rate expectation, the latter of which means that traders adjust the weights of the three forecasting strategies (fundamentalists, chartists, and carry traders) depending on their most recent forecasting performance. Based on the same dataset, Goldbaum and Zwinkels (2014) confirm that the introduction of switching mechanism in the agents significantly improved the fit of the model, especially at the very short forecast horizons. Goldbaum and Zwinkels (2014) further argue that the choice of forecasting strategy is determined by both period specific factors and individual specific factors.

Dick and Menkhoff (2013) lend further support to the chartist and fundamentalist (C&F) approach. Different from other survey-based empirical investigations, they take a closer look at the information asymmetry between the individual investor and professionals. The results first confirm the C&F theory that chartists and fundamentalists do form exchange rate expectations differently; i.e. chartists change

their expectation according to the recent price movements, while fundamentalists pay more attention to the 'fundamental value' of the exchange rate. Secondly, they argue that persistent existence of chartists is reasonable, as fundamentalists do not outperform them in terms of forecasting.

Estimation results present further verification of the presence of heterogeneous agents. In order to circumvent the non-linear switching mechanism embedded in the C&F framework, two distinct methods have been used. On one hand, studies such as Vigfusson (1997), Westerhoff (2003), and Ahrens and Reitz (2005) employ a Markov regime-switching approach as proxy. On the other hand, Winker and Gilli (2001, 2004) propose that the coefficient estimates of the real financial data can be generated by fitting simulated data through minimizing the deviation between the actual and estimated kurtosis and ARCH statistics. In addition, there is a promising strand of literature emerging, which directly estimates a heterogeneous agent model with switching mechanism. For example, Boswijk et al. (2007) and De Jong et al. (2009) reformulated the model of Brock and Hommes (1997) and applied it to the S&P 500 index and the investigation of the Asian crisis, respectively. De Jong et al. (2010) extend the analyses of Boswijk et al. (2007) and estimate the model for the EMS period, which lends direct support to the existence of heterogeneous agents in the foreign exchange market. In addition, the validity of introducing the switching mechanism is confirmed, as its forecasting ability outperforms both the random walk model and the heterogeneous model without switching mechanism (De Jong et al., 2010).

Impacts of Central Bank Intervention on Heterogeneous Agents

Existence of heterogeneous agents in the foreign exchange market implies that exchange rate movements are at least partially endogenously determined, especially in the short-run. This provides more arguments for the necessity of government intervention. In terms of operational applicability, monetary authority can adjust the supply of foreign assets to influence the course of the exchange rate as suggested in the model of De Grauwe and Grimaldi (2006). However, the authors contend that it is almost impossible to estimate the effect of central bank intervention beforehand, as it depends on the prevailing risk perception and market structure, i.e. the weights of different agents. Nevertheless, simulation results suggest that systematic intervention is effective in eliminating bubbles in the foreign exchange market. Specifically, De Grauwe and Grimaldi (2006) consider two strategies. The first is usually referred to as 'leaning against the wind', such that the central bank is continuously active in the market, smoothing exchange rate movements or reinforcing the mean-reverting process, as a result of which it strengthens the impact of fundamentalists at the cost of chartists. It is shown by simulation that the exchange rate is forced to move more closely around its fundamental. The second intervention strategy is recognized as 'target intervention', whereby the central bank commits to intervene whenever the exchange rate deviates from the pre-determined target band. Simulation results show that this strategy works as well as the first one, although the frequency of intervention is remarkably lower.

Based on the C&F (chartist and fundamentalist) framework, Westerhoff (2003) shows that two common intervention strategies can be employed: one is known as

LAW (leaning against the wind), the central bank trades against chartists, and the other is aimed at supporting a target exchange rate. The results reveal that LAW generates mixed evidence: exchange rate fluctuations are dampened at the cost of more cycles. In addition, neither type of intervention is effective in altering the course of the long-run equilibrium exchange rate.

From a theoretical perspective, Reitz et al. (2006) investigate a low-frequency target-zone intervention and find that the mechanism operates such that it directly pushes the exchange rate towards its fundamental value, which in turn signals a new trend for both chartist and fundamentalist. The authors argue that target-zone intervention not only helps to reduce misalignments but also proves to be profitable.

Bauer et al. (2009) point out the necessity for agents to take regulatory policy explicitly into account when forming expectations, and hence investigate the dynamics of exchange rates when a credible target-zone policy is in place. Their results suggest that a target zone regime significantly discourages speculative activity in the foreign exchange market, and more importantly, the generated distribution of the exchange rate closely mimics the stylized fact that the exchange rate tends to stay close to the centre of the band, which implies that the need for intervention is greatly reduced.

From an empirical perspective, Beine et al. (2007) confirm that foreign exchange interventions, particularly secret interventions, increase heterogeneity in the

DEM/USD market. Beine et al. (2009) further investigate the effect of sterilized intervention with a two-state Markov switching model featuring a noise-trading framework. Using bi-weekly data (euro against the US dollar), they find that in the medium-run, central bank intervention tends to increase the proportion of fundamentalists in the foreign exchange market, which in turn helps to close the gap between market exchange rate and the central parity rate.

Following a similar approach, Maatoug et al. (2011) look into the effect of the intervention conducted by the Reserve Bank of Australia on the Australian dollar/ US dollar. However, unlike Beine et al. (2009), where the specification of chartists is derived from estimation, Maatoug et al. (2011) consider a moving-average rule. Based on daily rather than bi-weekly data, Maatoug et al. (2011) find new evidence that central bank intervention could increase the proportion of fundamentalists when chartists are dominating and hence the exchange rate is stabilized.

Though not following the standard C&F approach, Corrado et al. (2007) present a heterogeneous agent model of the currency market, which is categorized as 'bulls' and 'bears'. They show how the behaviour of those trades could change the course of exchange rate and generate excess volatility. More importantly, they contend that a monitoring band with non-sterilized intervention is effective in reducing the excess volatility by rewarding those traders who fall into line with the intended direction of government intervention.

Building on the idea of heterogeneous expectation, Reitz (2005) studied the effect of intervention by the Federal Reserve and the Deutsche Bundesbank by means of a Markov regime-switching model. In contrast to the usual findings, Reitz (2005) reports that the fundamentalists did not benefit from central bank intervention and the profit of chartists was enhanced, which seems to be plausible because the course of exchange rates was probably not fundamentally changed. However, in a later study, Reitz et al. (2010), using data from Consensus Economics, show that intervention by the Bank of Japan effectively eliminates heterogeneity among foreign exchange forecasts.

4.3 Empirical Evidence from the Chinese FX Market

4.3.1 A Simple HAM Model

Before we can formulate a sensible exchange rate management strategy, it is vital to establish some empirical evidence of the market micro-structure concerned. Following recent studies like Beine et al. (2009), in this study we assume two types of traders: fundamentalists whose expectation is driven by thedifference between the market rate and the central parity rate, and chartists who is purely dependent on past exchange rate movements. Specifically, the forecasting strategies of fundamentalists can be expressed as follows.

$$r_t^f = \psi \cdot (s_{t-1} - s_{t-1}^*) \tag{4.3}$$

where s_{t-1}^* is the central parity rate in period $t-1$, and the coefficient ψ represents the effect of the misalignment on fundamentalists' expectation. Normally ψ is

assumed to lie in the interval $(-1, 0)$ as in De Grauwe and Grimaldi (2006), but De Jong et al. (2010) argue that fundamentalists contribute to the mean-reverting as long as ψ is greater than -1.

It is well-documented that many different and complex technical trading strategies have been adopted in the foreign exchange market, among them one popular type was commonly referred to as Moving Average (MA), where traders rely on the difference between the short-term and long-term moving average. Specifically, their trading strategy is expressed as

$$r_t^{MA} = \lambda \cdot (MA_{t-1}^S - MA_{t-1}^L) \tag{4.4}$$

where MA_{t-1}^S and MA_{t-1}^L are the relatively short-term and long-term moving average of the exchange rates. This strategy is argued to destabilize the market if $\lambda > 0$, as agents expect the short-run deviations to continue. On the other hand, if $\lambda < 0$, the MA rule displays a stabilization effect, as agents expect the market exchange rate to return to its longer-run moving average. Though decisions on the length of the short and long term are somewhat arbitrary, literature (e.g. Vigfusson, 1997 and Reitz, 2005) suggests that traders commonly use the 14 days for the short-run and 200 days for the long-run moving-average. Hence, we choose a 14-200 day moving-average rule.

Dixon et al. (2016) provide evidence from a Markov switching model that the flexibility of the RMB has undergone two distinct regimes since the 2005 reform.

We follow the similar method to investigate the effect of central bank intervention in a heterogeneous agent setting. However, the model specification is largely different from the previous literature. Studies such as Beine et al. (2009) and Maatoug et al. (2011) implicitly assume that at any time point, only one forecasting rule is at work and the exchange rate regime switch is assumed to take place between a fundamentalist-only regime and a chartist-only regime. In other words, those studies impose a zero coefficient on fundamentalists in the chartist regime, and vice versa. This is too restrictive given mounting evidence that these two types tend to co-exist in the market irrespective of the time horizon concerned. To address this issue, in this study we include the two forecasting rules in both regimes.

Another difference of our investigation compared with previous studies lies in the fact that the Chinese monetary authority, the PBOC, does not disclose its intervention activities, while for other currencies the real intervention data are available (e.g. Beine et al., 2009; Maatoug et al., 2011). This prompts us to find a proxy for PBOC intervention and we employ the Flexibility Index developed in Dixon et al. (2016) to track the undisclosed intervention conducted by the PBOC. This index is computed to measure the extent to which the central bank allows the market forces to influence the price formation process of the RMB; hence, the higher the index value is, the lower is the intensity of central bank intervention.

Following the previous chapter, we take the RMB exchange rate data from the Bank of China as the market exchange rate and the central parity rate from the PBOC as the fundamental rate, covering the period from 22 July 2005 to 31 December 2014.

Before looking into the impact of central bank intervention, we estimate a baseline model where the impact from chartists and fundamentalists on the exchange rate return varies between two regimes. In addition, the transition probability between the two regimes is assumed constant, following a first-order Markov rule. Hence, the following specification is estimated

$$r_i = \begin{cases} \lambda_1 \cdot (MA_{t-1}^S - MA_{t-1}^L) + \psi_1 \cdot (s_{t-1} - s_{t-1}^*) + \varepsilon_t^1 \\ \lambda_2 \cdot (MA_{t-1}^S - MA_{t-1}^L) + \psi_2 \cdot (s_{t-1} - s_{t-1}^*) + \varepsilon_t^2 \end{cases} \tag{4.5}$$

where r_i is the exchange rate in regime i, i=1 or 2. It is calculated as the difference of the market exchange rate between two consecutive working days, and scaled up 100 times to make the interpretation easier. ε^1 and ε^2 are two *iid* error terms denoting the heterogeneous variance in these two regimes.

The results reported in Table 4.1 yield several important points. First, as expected, there are two distinct regimes to model the (market) exchange rate returns. Based on the estimated σ, we use Regime 1 and Regime 2 to denote the 'active' and 'calm' states respectively, because the exchange rate volatility in Regime 1 is more than 7 times larger than that in Regime 2. Secondly, we find that the coefficients of ψ and λ both report as highly significant in Regime 1, while neither chartists nor fundamentalists coefficient report significant in Regime 2, suggesting that the degree of impact of traders on the exchange rate is quite limited in Regime 2. Looking more closely, irrespective of the regime, fundamentalists play a stabilizing role as they drive the exchange rate towards the central parity rate, while MA traders expect short-run deviations of the exchange rate from its long-term trend to persist, as a positive λ indicates that the chartists push the exchange rate further away from

144

its long-run value and contribute to the misalignment. However, the MA traders in China may not play a non-stabilization role as found in other studies, such as Maatoug et al. (2011). Because the RMB was undervalued in much of the sample period, the MA traders were in fact helping the exchange rate to move to its equilibrium level. Finally, the transition probabilities are 98.3% and 93.8% for Regime 1 and 2, respectively, indicating an extremely high persistence of both regimes.

Table 4.1 Estimation of the Baseline Model

Panel A	Regime Varying Coefficients	
	Regime 1	**Regime2**
σ	0.115 (-117.670***)	0.016 (-90.888***)
ψ	-0.243 (-2.477)	-0.053 (-1.029)
λ	0.140 (6.596)	0.031 (1.540)

Panel B	Constant Transition Probabilities	
	$P(i,k)=P(s(t)=k|s(t-1)=i)$	
P(1,1)=98.3%		P(2,1)=6.2%
P(1,2)=1.7%		P(2,2)=93.8%
Transition Matrix Parameters		
P12-C		-4.036 (-15.568***)
P22-C		2.717 (11.201***)

Notes: This table presents the results of the two-state Markov switching model of the heterogeneous agent model consisting of fundamentalists and Moving-average traders. Regime 1 and Regime 2 denote the active and calm regime, respectively. In Panel A, we report the estimated coefficients for the regime-varying variables, with the corresponding z-statistics in parentheses. Panel B reports the constant transition probabilities between the two regimes and the transition matrix parameters. σ denotes the regime specific variance, ψ and λ are the parameters used in the fundamentalist and MA forecasting strategies respectively. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

4.3.2 The Impact of Central Bank Intervention

To highlight the impact of central bank intervention on the heterogeneous agents, we include central bank intervention in the modelling, specifically as a determinant variable of the transition probability. Specifically, we hypothesize that a higher value of the flexibility index will increase the probability of the system staying in Regime 1, and increase the probability of transiting out of Regime 2.

From Table 4.2, the estimated coefficients on P11_Int_Proxy and P21_Int_Proxy do not reject the hypothesis that a greater value of the flexibility index, denoting a lower intervention intensity, increases the probability of staying in the 'active' regime where both fundamentalists and chartists exert a statistically significant role in influencing the course of exchange rate. A higher flexibility index also increases the probability of transiting out of the 'calm' state, suggesting that a lower intervention intensity would lead to more activity among traders. Moreover, consistent with the results in Table 4.1, we find the coefficients of both trading strategies are much larger in absolute value in Regime 1 than in Regime 2, which contradicts the findings in other studies that the central bank intervention is effective such that it increases the impact of fundamentalists and/or decreases the impact of chartists. Nevertheless, we argue that this difference might occur because the central parity rate used in this study is not the ideal proxy for the equilibrium (fundamental) exchange rate level as used in other studies.

Table 4.2 Impacts of Intervention on the Fundamentalists and MA Traders

Panel A	Regime Varying Coefficients	
	Regime 1	**Regime2**
σ	0.115 (-117.362***)	0.016 (-90.398***)
ψ	-0.243 (-2.477**)	-0.052 (-1.008)
λ	0.140 (6.593***)	0.030 (1.529)

Panel B	Mean Time-varying Transition Probabilities	
	P(i,k)=P(s(t)=k|s(t-1)=i)	
P(1,1)=98.2%		P(2,1)=6.4%
P(1,2)=1.8%		P(2,2)=93.6%

Transition Matrix Parameters

P11-C	3.291 (5.359***)
P11_Int_Proxy	0.008 (1.178)
P21-C	-3.125 (-9.109***)
P21-Int_Proxy	0.004 (1.982**)

Notes: This table presents the estimation results of the impact of central bank intervention on the fundamentalists and Moving-average traders in a two-state Markov switching model. Intervention is proxied by the flexibility index and Regime 1 and Regime 2 denote the 'active' and 'calm' regime, respectively. Panel A shows the estimated coefficients on the regime-varying variable with corresponding z-statistics in parentheses. Panel B reports the time-varying transition probabilities between the two regimes and the transition matrix parameters. The outcome differs from Table 4.1 because the transition probability is now assumed to be time-varying, depending on the intervention occurring in the previous working day. σ denotes the regime specific variance; ψ and λ are the parameters used in the fundamentalist and MA forecasting strategies respectively. P11-Int_Proxy denotes the impact of Intervention on the transition probability from Regime 1 to Regime 1, while P21-Int_Proxy denotes the impact of Intervention on the transition probability from Regime 2 to Regime 1. ***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively.

4.4 Managing the Managed Floating Exchange Rate Regime

4.4.1 Baseline Optimal Exchange Rate Management Strategy

In this section, we present an optimal exchange rate management framework for the RMB by marrying the optimal stochastic control theory and the estimation results obtained from the model discussed above. China has publicly announced it would cease its interventionist policy and increase the influence of market forces in the exchange rate decision-making process, the progress of which has been at least partially confirmed by our empirical investigation above. Hence, the impulse control approach rather than the classical control is more suitable here. For one thing, although PBOC has the power and capacity to initiate the classical controls, it stands in opposition of its announced policy intentions to increase the role of market forces. Second, impulse control might be more effective in practice, as jumps of the exchange rate, rather than a change in the underlying driving factors, are easier to be picked up by market participants.

By adopting the canonical setting in this line of research such as Cadenillas and Zapatero's (1999) and Kercheval and Moreno (2009), we assume that in the absence of intervention, the exchange rate can be modelled using the following diffusion process $X(t)$. Let (Ω, F, P) be the probability space F_t together with a filtration F_t generated by a one-dimensional Brownian motion $W(t)$, and $X(t)$ denotes the domestic currency per unit of foreign currency at time t:

$$dX_x(t) = \mu_1(X_x(t))dt + \sigma_1(X_x(t))dW_t \qquad (4.6)$$

$$X_x(0^-) = x \qquad (4.7)$$

where $\mu_1(\cdot)$ and $\sigma_1(\cdot)$ are functions that satisfy the usual requirements for the existence and uniqueness of the solution to the diffusion process. Eq. (4.7) is written to emphasize that x is the exchange rate value at time 0 before any control is applied.

Suppose that intervention takes place at times $\tau_i, i \in N = \{1,2,3,...\}$, $0 \le \tau_1 < \tau_2 < \tau_3 < \cdots$ with each intervention resulting in a jump in the exchange rate. Now, following Kercheval and Moreno (2009), we assume that immediately after each intervention, a 'reaction period' is introduced because of the presence of the heterogeneous agents in the market. The reaction period is denoted as a bounded, random length of time $T_i, 0 \le T_i \le \bar{T}$, during which the exchange rate follows a new diffusion process as follows,

$$dX_x^i(t) = \mu_2^i(X_x^i(t))dt + \sigma_2^i(X_x^i(t))dW_t \qquad (4.8)$$

where x is the value of the process immediately after the $i-th$ intervention. For the sake of deriving the solution in a general form, we keep the assumption that μ_2^i, σ_2^i and T_i are independent of each other and of the rate process driver W_t. It is important to note that there is no new intervention allowed during the reaction period.

Hence in the presence of heterogeneous agents, the impulse control $v = (\tau_1, \tau_2, \ldots, \tau_n, \ldots; \xi_1, \xi_2, \ldots, \xi_n, \ldots)$ can be formally defined as a sequence of intervention times τ_i and intervention sizes ξ_i, which results in the controlled process X_x^v such that

$$0 \leq \tau_i \leq \tau_{i+1} \text{ a.s. for all } i \in N \text{ and } \tau_i < \tau_{i+1} \text{ a.s. if } \tau_i < \infty \tag{4.9}$$

$$X_x^v(0^-) = x \tag{4.10}$$

$$dX_x^v(t) = dX_x(t), t < \tau_1 \tag{4.11}$$

and for all $j \in N$

$$X_x^v(\tau_j) = X_x^v(\tau_{j^-}) - \xi_j \tag{4.12}$$

$$dX_x^v(t) = dX_{X_x^v(\tau_j)}^i(t), \ \tau_j \leq t < \tau_j + T_j \tag{4.13}$$

$$dX_x^v(t) = dX_{X_x^v(\tau_j + T_j)}(t), \ \tau_j + T_j \leq t < \tau_{j+1} \tag{4.14}$$

where τ_i is an infinite increasing sequence of stopping times with respect to the filtration F_t, and each $\xi_i : \Omega \to R$ is F_t measurable. The whole process is defined on the domain $(-t, +\infty), t > 0$ to make sense of the intervention possibility at time 0.

The objective that the central bank holds is to select a control v that minimizes the functional J defined as:

$$J^v(x) = E[\int_0^\infty e^{-rt} f(X_x^v(t))dt + \sum_{i=1}^\infty e^{-r\tau_i} K(X_x^v(\tau_{j^-}), \xi_j)] \tag{4.15}$$

where $f(\cdot)$ is the running cost function; $K(\cdot)$ is the intervention cost function, which depends on the state process and the intervention size ξ; r is the discount rate, and the Value Function is defined as:

$$V(x) = \inf_{v \in \Gamma} J^v(x) \tag{4.16}$$

where Γ denotes the set of all admissible controls.

The solution of an impulse control depends critically on the cost function, $K(\cdot)$ and $f(\cdot)$, i.e. the cost of intervention and the cost of no intervention. Without complicating the solution, we stick to the standard choices that the cost of no intervention, aka, the running cost, is modelled as:

$$f(x) = (x - \rho)^2 \tag{4.17}$$

where ρ is the target exchange rate for the central bank. It can be seen from Eq. (4.17) that the cost of no intervention increases sharply as the deviation of the market exchange rate from the target exchange rate increases.

The discussion of intervention cost calls for more elaborate modelling. If we do not consider the presence of heterogeneous agents, the cost of intervention usually takes the following form:

$$K(\xi) = \begin{cases} C + c\xi, \xi > 0 \\ \min(C, D), \xi = 0 \\ D - d\xi, \xi < 0 \end{cases} \qquad (4.18)$$

$$C, c, D, d, \rho \in (0, \infty)$$

where C and c represent the fixed and proportional cost respectively per intervention when the central bank aims at depreciating the currency; D and d represent the fixed and proportional cost respectively per intervention when the central bank aims at appreciating its currency. The proportional cost is assumed on the basis that intervention cost increases with the scale of the intervention. For instance, there is normally a proportional transaction cost incurred when the central bank directly purchases or sells foreign exchanges. To explain the presence of fixed intervention cost, both Cadenillas and Zapatero (1999) and Bensoussan et al. (2012) note that many interventions occur quickly and are sizable in relation to normal transactions observed in the foreign exchange market, which implies considerable work undertaken. The fixed cost can also be considered as the loss of central bank credibility, because the more the central bank intervenes, the less likely it is that market participants would believe that the government is abstaining from intervention.

However, because of the assumption that there is no intervention allowed during the reaction period, the intervention cost has to be modified to add the running cost incurred during the reaction period, which can be computed as

$$K_x = E[\int_0^T e^{-rt} (X_x(t) - p)^2 dt] \qquad (4.19)$$

where x denotes the value for the controlled process at the start of the reaction period.

4.4.2 Solution

The literature normally adopts the Quasi-Variational Inequalities (QVI) and the Verification approach to solve the problem described above. To this end, operators M and M are introduced respectively as:

$$M(\phi, x, \xi) = K(\xi) + K_{x-\xi} + E[e^{-rT}\phi(X_{x-\xi}(T)] \qquad (4.20)$$

and

$$\mathrm{M}\phi(x) = \inf_{\xi}\{M(\phi, x, \xi) : x - \xi > 0\}. \qquad (4.21)$$

To understand these two operators, suppose there exists an optimal strategy for each initial point. Then if the process starts at x and follows the optimal strategy, the associated cost is the $V(x)$ defined above. In contrast, if the process starts at x and selects the best immediate intervention and then follows an optimal strategy, the cost associated with this strategy is represented by $\mathrm{M}\phi(x)$. Then it is straightforward to see that $V(x) \leq \mathrm{M}\phi(x)$, with the equilibrium condition indicating the optimal time (s) to intervene.

The solution of the above impulse control problem proceeds in the following steps: First, we propose the potential form of the impulse control V and use it to construct

the value function that meets the QVI conditions listed above. Secondly, if the function ϕ and the control V satisfy the conditions specified in **Proposition 1**, we can safely prove that ϕ is the value function for the problem and V is the desired optimal strategy. Finally, we need only to solve the QVI (Kercheval and Moreno, 2009).

The QVI used in this study are stated as follows:

$$L\phi(x) + f(x) \geq 0 \tag{4.22}$$

$$\phi(x) \leq M\phi(x) \tag{4.23}$$

$$(L\phi(x) + f(x))(\phi(x) - M\phi(x)) = 0 \tag{4.24}$$

where we make use of the differential operator L given by

$$L\phi(x) = \frac{1}{2}\sigma_1^2(x)\frac{d^2\phi(x)}{dx^2} + \mu_1(x)\frac{d\phi(x)}{dx} - r\phi(x).$$

The potential impulse control form associated with the QVI can then be constructed as

$$\tau_1 := \inf\{t > 0 : \phi(X_x(t^-)) = M\phi(X_x(t^-))\} \tag{4.25}$$

and for every $n > 1$

$$\tau_n := \inf\{t > \tau_{n-1} + T_{n-1} : \phi(X_x^v(t^-)) = M\phi(X_x^v(t^-))\} \tag{4.26}$$

and

$$\xi_n = \arg\min\{K(X_x^V(\tau_n^-),\xi) + K(X_x^V(\tau_n^-)-\xi) + E[e^{-rT}\phi(X_{X_x^V(\tau_n^-)-\xi}(T)|F_{\tau_n^-})] : \xi \in \Re, X_x^V(\tau_n^-)-\xi > 0\}$$

$$(4.27)$$

The following proposition permits us to verify that a solution of the QVI and the associated admissible control solves the impulse control problem.[26]

Proposition 1: *Let* $\phi \in C^1$ *be a solution of the QVI and suppose there is a finite subset* $N \subset C^2$ *such that* $\phi \in C^2$. *If* ϕ *satisfies the growth conditions:*

$$E\int_0^\infty (e^{-rt}\sigma_i(X_x^V(t))[\phi'(X_x^V(t)))]^2 dt < \infty, i = 1, 2 \qquad (4.28)$$

$$\lim_{t\to\infty} E[e^{-rt} | L_2\phi(X_x^V(t)) | dt] < \infty \qquad (4.29)$$

$$E[\int_0^\infty e^{-rt} | L_2\phi(X_x^V(t)) | dt] < \infty \qquad (4.30)$$

where the operator L_2 *is defined by*

$$L_2\phi(x) = \frac{1}{2}\sigma_2^2(x)\frac{d^2\phi(x)}{dx^2} + \mu_2(x)\frac{d\phi(x)}{dx} - r\phi(x). \qquad (4.31)$$

For every process $X_x^V(t)$ *corresponding to an admissible impulse control* V, *then for every* x in the positive domain,

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[26] Proof of Proposition 1 is beyond the scope of this chapter; interested readers could refer to Section 5 of Kercheval and Moreno (2009).

$$V(x) \geq \phi(x). \tag{4.32}$$

Moreover, if the QVI-control corresponding to ϕ is admissible then it is an optimal impulse control, and for every x in the positive domain,

$$V(x) = \phi(x) \tag{4.33}$$

Given the QVI equations listed above, we conjecture that the solution would separate the exchange rate domain, $(0, \infty)$, into two disjoint zones: a Continuation Zone (CZ) where

$$CZ := \{x \in (0, \infty), v(x) < \mathrm{M}v(x) \,\&\, Lv(x) + f(x) = 0\} \tag{4.34}$$

and an Intervention Zone (IZ) where

$$IZ := \{x \in (0, \infty) : v(x) = \mathrm{M}v(x), Lv(x) + f(x) > 0\}. \tag{4.35}$$

Thus, the optimal impulse control strategy works such that the central bank will not intervene when the exchange rate remains in the Continuation Zone, and must wait at least until time T_i after the $i - th$ intervention. However, when the exchange rate reaches either edge of the band, an intervention operation would be taken instantaneously to bring the process to a point within that band: an intervention on the strong side would be to increase the exchange rate from a to α ; while an intervention on the weak side would be to decrease the exchange rate from b to β .

Given the proposed control strategy, we note that $\phi(x)$ meets the condition $L\phi(x) = f(x)$ when the exchange rate lies within the band (a,b). With $f(x)$ defined as above, we can obtain the following equations:

For $a < x < b$

$$\phi(x) = Ax^{\gamma_1} + Bx^{\gamma_2} + (\frac{1}{-\sigma^2 - 2\mu + r})x^2 - (\frac{2\rho}{r-\mu})x + \frac{\rho^2}{r} \qquad (4.36)$$

$$\gamma_1 = \frac{-\mu + \frac{1}{2}\sigma^2 - ((\mu - \frac{\sigma^2}{2})^2 + 2\sigma^2 r)^{1/2}}{\sigma^2} \qquad (4.37)$$

$$\gamma_2 = \frac{-\mu + \frac{1}{2}\sigma^2 + ((\mu - \frac{\sigma^2}{2})^2 + 2\sigma^2 r)^{1/2}}{\sigma^2} \qquad (4.38)$$

where $\phi(x)$ denotes the solution of the QVI associated with the problem, A and B are constants and remain to be solved.

Judging from the requirements of continuity and $\phi(x) = M\phi(x)$ at the two intervention points, the boundary conditions can be described as:

$$\phi(a) = C + c(\alpha - a) + K_\alpha + E[e^{-rT}\phi(X_\alpha(T))] \qquad (4.39)$$

$$\phi(b) = D + d(b - \beta) + K_\beta + E[e^{-rT}\phi(X_\beta(T))] \qquad (4.40)$$

where

$$\alpha = \arg\min\{C + c(\alpha - a) + K_\alpha + E[e^{-rT}\phi(X_\alpha(T))]\} \qquad (4.41)$$

$$\beta = \arg\min\{D + d(b - \beta) + K_\beta + E[e^{-rT}\phi(X_\beta(T))]\} \tag{4.42}$$

Moreover, the smooth pasting requirement of this impulse control offers the following conditions:

$$\phi'(a) = -c \tag{4.43}$$

$$\phi'(b) = d \tag{4.44}$$

$$\phi'(\alpha) = -c \tag{4.45}$$

$$\phi'(\beta) = d. \tag{4.46}$$

In order to prove rigorously that the above conjecture is valid, we make use of the following proposition.

Proposition 2:

Let A, B, a, b, α and β be the solution of the system and define the function $V(x)$ by

$$V(x) = \begin{cases} C + c(\alpha - x) + K_\alpha + E[e^{-rT}\phi(X_\alpha(T))], 0 \leq x < a \\ \phi(\mathrm{x}) = Ax^{\gamma_1} + Bx^{\gamma_2} + (\dfrac{1}{-\sigma^2 - 2\mu + r})\mathrm{x}^2 - (\dfrac{2\rho}{r - \mu})\mathrm{x} + \dfrac{\rho^2}{r}, a \leq x \leq b \\ D + d(x - \beta) + K_\beta + E[e^{-rT}\phi(X_\beta(T))], x > b \end{cases} \tag{4.47}$$

If the conditions, i.e. Eq. (4.48)-(4.52), are met, then $V(x)$ is the value function of the problem defined above and the optimal control is the QVI-control corresponding to $V(x)$, given by Eq. (4.53) ~ (4.55)

$$a < \frac{[c(\mu_1 - r) + 2\rho] - [4(\rho^2 - r(c\alpha + \Theta_\alpha))]^{1/2}}{2} \tag{4.48}$$

$$b > \frac{[d(r - \mu_1) + 2\rho] + [4(\rho^2 + r(d\beta - \Theta_\beta))]^{1/2}}{2} \tag{4.49}$$

$$-c < V'(x) < d, \alpha < x < \beta \tag{4.50}$$

$$V'(x) \geq d, \beta \leq x \leq b \tag{4.51}$$

$$V'(x) \leq -c, a \leq x \leq \alpha \tag{4.52}$$

where Θ_α and Θ_β are defined respectively as $\Theta_\alpha = C + K_\alpha + E[e^{-rT}\phi(X_\alpha(T))]$ and $\Theta_\beta = D + K_\beta + E[e^{-rT}\phi(X_\beta(T))]$.

$$\tau_1 = \inf\{t > 0, X(t) \notin (a,b)\} \tag{4.53}$$

$$\tau_i = \inf\{t \geq \tau_{i-1} + T_{i-1} : X^v(t) \notin (a,b)\}, i > 1 \tag{4.54}$$

$$X^v(\tau_i) = \begin{cases} \alpha = X^v(\tau_i^-) - \xi_i, X^v(\tau_i^-) = a \\ \beta = X^v(\tau_i^-) - \xi_i, X^v(\tau_i^-) = b \end{cases} \tag{4.55}$$

To prove **Proposition 2**, we first need to prove that V satisfies the QVI. From the discussion above we know the following equation applies

$$LV(x) + f(x) = \begin{cases} -c\mu_1 x - r\{C + c(\alpha - x) + K_\alpha + E[e^{-rT}\phi(X_\alpha(T))]\} + (x-\rho)^2, x < a \\ L\phi(x) + (x-\rho)^2, a \le x \le b \\ d\mu_1 x - r\{D + d(x-\beta) + K_\beta + E[e^{-rT}\phi(X_\beta(T))]\} + (x-\rho)^2, x > b \end{cases} \quad (4.56)$$

By construction, $\phi(x)$ satisfies the condition that $L\phi(x) + (x-\rho)^2 = 0$ in the interval $[a,b]$, while as outside the interval we would have the condition that $L\phi(x) + (x-\rho)^2 > 0$ because of the condition specified in Eq. (4.48) and (4.49).

Given the definition above, the cost associated with the best immediate intervention $M\phi(x)$ can be expressed as:

$$M\phi(x) = \begin{cases} C + c(\alpha - x) + K_\alpha + E[e^{-rT}\phi(X_\alpha(T))], x \le \alpha \\ \phi(x) + \min(C,D), \alpha < x < \beta \\ D + d(x-\beta) + K_\beta + E[e^{-rT}\phi(X_\beta(T))], x \ge \beta \end{cases} \quad (4.57)$$

Therefore, it is clear to see $V(x) - M\phi(x)$ is equal to zero in the Intervention Zone, i.e. $(0,a] \cup [b,\infty)$, and is negative in the Continuation Zone (a,b) because of the conditions Eq. (4.50)-(4.52).

It is also straight-forward to prove the optimal control obtained and the associated value function satisfy the **Proposition 1** and the following admissible conditions.

$$X_x^v(\tau_i) > 0 \text{ for all } i \in N, \quad (4.58)$$

161

$$T_i \leq \tau_{i+1} - \tau_i \text{ for all } i \in N, \tag{4.59}$$

$$E[\int_0^\infty e^{-rt} f(X_x^v(t)) dt] < \infty \tag{4.60}$$

$$E[\int_0^\infty (e^{-rt} X_x^v(t))^2 dt] < \infty \tag{4.61}$$

4.4.3 Quantitative Evidence

Since there is no analytical solution of the impulse control problem, we have to apply numerical methods, which can be summarized to solve the following six equations.

$$\phi(a) = C + c(\alpha - a) + K_\alpha + E[e^{-rT}\phi(X_\beta(T))] \tag{4.62}$$

$$\phi(b) = D + d(b - \beta) + K_\beta + E[e^{-rT}\phi(X_\beta(T))] \tag{4.63}$$

$$\phi'(a) = -c \tag{4.64}$$

$$\phi'(b) = d \tag{4.65}$$

$$\phi'(\alpha) = -c \tag{4.66}$$

$$\phi'(\beta) = d \tag{4.67}$$

where $\phi(x) = Ax^{\gamma_1} + Bx^{\gamma_2} + (\frac{1}{-\sigma^2 - 2\mu + r})x^2 - (\frac{2\rho}{r - \mu})x + \frac{\rho^2}{r}$ and $K(x)$ denotes the expected running cost incurred during the 'reaction period' defined as above.

To simplify the process, we now assume that μ_2, σ_2 and T are fixed, as a result, K_x turns out to be constant. To see this, we note that since μ_2, σ_2 and T are assumed to be independent of W_t, $X_x(t)$ would follow a Geometric Brownian Motion during the reaction period. Therefore, K_x can be integrated analytically as:

$$K_x = E[\int_0^T e^{-rt}(x^2 e^{2\mu t + \sigma_2^2 t} - 2\rho x e^{\mu t} + \rho^2)dt], x = \alpha, \beta \qquad (4.68)$$

The calculation of the expectation term $E[e^{-rT}\phi(X_x(T))], x = \alpha, \beta$ is somewhat complex but it can be divided into three parts:

$$e^{-rT}\{\int_a^b \phi(x)p(x;\alpha,T,\mu_2,\sigma_2)dx + \int_{-\infty}^a \phi(a)p(x;\alpha,T,\mu_2,\sigma_2)dx + \int_b^\infty \phi(b)p(x;\alpha,T,\mu_2,\sigma_2)dx\}$$

which can be computed individually given a set of parameters A, B, a, b, and α.

Note that $p(x;\alpha,T,\mu_2,\sigma_2)$ stands for the probability density of the Log-Normal distribution of $X_\alpha(T)$:

$$\log(X_\alpha(T)) \sim N(\ln(\alpha) + \mu_2 T - \frac{1}{2}\sigma_2^2 T, \sigma_2^2 T) \qquad (4.69)$$

In order to show how the management strategy works, we now provide some numerical evidence, in two steps. First, we find the optimal control strategy without

considering the reactions of market participants, which means Eq. (4.62) and Eq. (4.63) need to be modified as follows:

$$\phi(a) = C + c(\alpha - a) + \phi(\alpha) \tag{4.70}$$

$$\phi(b) = D + d(b - \beta) + \phi(\beta) \tag{4.71}$$

We set the important model parameters in Panel A, Table 4.3 such that the fixed and proportional intervention cost is the same on both sides. With the exception of target exchange rate, the parameters are set the same as in Cadenillas and Zapatero (1999). Then, all we need to do is to find numerical solutions to the system of equations from Eq. (4.64) to Eq. (4.67), and Eq. (4.70) and (4.71), which are reported in Panel B in Table 4.3.

Table 4.3 Parameters and Results When There is No Reaction Period

Panel A	Parameter Values for the Baseline Model	
Variables	Definition	Values
μ_1	The drift parameter in absence of intervention	0.1
σ_1	The diffusion parameter in absence of intervention	0.3
λ	Discount Rate	0.06
ρ	Target Exchange Rate	6.5
C	The fixed intervention cost on the strong side	0.5
D	The fixed intervention cost on the weak side	0.5
c	The proportional intervention cost on the strong side	0.2
d	The proportional intervention cost on the weak side	0.2
Panel B	Optimal Intervention Strategy for the Baseline Model	
a	Intervention trigger on the strong side/ lower edge of the Continuation Zone	4.5772
α	Re-starting value for the strong side intervention	5.9903
β	Re-starting value for the weak side intervention	6.4870
b	Intervention trigger on the weak side/ upper edge of the Continuation Zone	8.5283

Thus, the optimal exchange rate intervention is solved, as no central bank intervention is needed when the exchange rate is within the Continuation Zone, i.e. (4.5772, 8.5283); however, when the exchange rate reaches the lower edge an intervention operation is instantaneously triggered such that the exchange rate is brought up to the value of 5.9903; or when the exchange rate reaches the upper edge, an intervention should be instantaneously made such that the exchange rate is brought down to the value of 6.4870.

To further understand the results, we make use of Proposition 4.1 in Cadenillas and Zapatero (1999), which states that

$$P\{X_{\tau(a,b)=b}\} = \frac{x^{-(2\theta/\sigma_1^2)} - a^{-(2\theta/\sigma_1^2)}}{b^{-(2\theta/\sigma_1^2)} - a^{-(2\theta/\sigma_1^2)}}$$

$$P\{X_{\tau(a,b)=a}\} = \frac{b^{-(2\theta/\sigma_1^2)} - x^{-(2\theta/\sigma_1^2)}}{b^{-(2\theta/\sigma_1^2)} - a^{-(2\theta/\sigma_1^2)}}$$

where $\theta = \mu_1 - 0.5\sigma_1^2$ is the long-run growth rate of the exchange rate when there is no interventions and x is the starting value for the exchange rate.

We can calculate the probability that the exchange rate reaches b (the upper edge of the continuation zone) before it reaches a (the lower edge of the continuation zone) if the exchange rate starts at ρ is solved as 0.6545. Hence, the probability that the exchange rate reaches a before it reaches b is 0.3455 (=1-0.6545). The fact the former probability is larger means that the central bank is more willing to see the exchange rate remain near the strong side, and it is optimal for the central bank to

restart the exchange rate at a level lower than the target rate when the RMB is under devaluation pressure ($\mu_1 > 0$).

The next step is to present the optimal management strategy for China taking account of the presence of heterogeneous agents and the impact of PBOC intervention upon them. To this end, we first reiterate some general findings when the 'reaction period' is incorporated into the standard impulse control model. Further, we provide a sensitivity analysis of μ_2 and σ_2, i.e. the drift and the diffusion parameters of the exchange rate dynamics during the reaction period.

In order to study the effects of the reaction period, we first adopt the parameter values listed in Table 4.4 to characterize the standard impulse control as in Example 5.1 (Cadenillas and Zapatero, 1999). Then we provide sensitivity analysis on the parameters of μ_2 and σ_2.

Table 4.4 Baseline Variable Values

Variables	Definition	Values
μ_1	The drift parameter in absence of intervention	0.1
σ_1	The diffusion parameter in absence of intervention	0.3
λ	Discount Rate	0.06
ρ	Target Exchange Rate	1.4
C	The fixed intervention cost on the strong side	0.5
D	The fixed intervention cost on the weak side	0.7
C	The proportional intervention cost on the strong side	0.2
D	The proportional intervention cost on the weak side	0.4

In short, Table 4.5 looks at the effects of a changing σ_2 while the other parameters are fixed. In addition to the bandwidth of the Continuation Zone, we include the effects on a, b, α, β, $\alpha - a$, and $b - \beta$, where α is the restarting value of the strong-side intervention, β is the restarting value of the weak-side intervention, $\alpha - a$ is the size of intervention on the strong side and $b - \beta$ is the intervention size on the weak side. It can be clearly seen that if the volatility increases after the intervention in the 'reaction period', we could expect a wider 'Continuation Zone' compared to the case without 'reaction period': $b - a$ increases from 1.8361 to 1.8597 when σ_2 increases to 0.4 from 0.3, while $b - a$ tightens when σ_2 decreases.

In Table 4.6, we fix σ_2 and focus on the parameter μ_2. Compared to the results

found in Table 4.5, we note that the bandwidth of the Continuation Zone is rarely affected by change of μ_2. To see this point, we note that when μ_2 decreases by half, the bandwidth of $b-a$ changes from 1.8361 to 1.8364, while $b-a$ increases to 1.8597 when σ_2 increases by about 33.3%.

Given Tables 4.5 and 4.6, we are able to summarize the directional effect of a change in μ_2 or σ_2 in Table 4.7, where we use ↑ and ↓ to denote the increasing and decreasing directional effect, respectively. It is also quite interesting to note that a change in μ_2 or σ_2 may have a conflicting effect on one parameter. For example, a larger μ_2 implies a higher lower intervention edge while the effect of a smaller σ_2 is the opposite. Hence, a natural question arises as to what would be the aggregated effect of a larger μ_2 and a smaller σ_2.

To answer this question, we have conducted further numerical applications, where we consider 4 possible cases of the 'reaction period': a smaller μ_2 and σ_2, a smaller μ_2 but larger σ_2, a larger μ_2 but a smaller σ_2, and a larger μ_2 and σ_2. Specifically, we increase (or decrease) each parameter by 50% so as to figure out which parameter has a larger effect. The results are reported in Table 4.8 and it seems plausible to arrive at the following conjectures:

1) The parameter σ_2 has the dominant effect when it comes to the two intervention values, i.e. a and b, the size of strong-side and weak-side

intervention ($\alpha - a$ and $b - \beta$), and the bandwidth of the Continuation Zone, i.e. $b - a$.

2) The effect of μ_2 and σ_2 on the two restarting values has to be checked given a same level change. In other words, we cannot know the aggregated effect by considering only the change of σ_2. However, after a closer look, it seems plausible to conclude that the final directional change is determined by the larger parameter. For example, a higher μ_2 and a lower σ_2 would produce an opposite effect on α, but the final result suggests that an increased μ_2 outweighs the decreased σ_2. Table 4.9 presents a summary predicted effect of the parameters μ_2 and σ_2.

Table 4.5 Effects of Changes in σ_2 on the Optimal Control Strategy

Parameters	$\mu_2 = 0.1$				
	Baseline	$\sigma_2 = 0.1 < \sigma_1$	$\sigma_2 = 0.2 < \sigma_1$	$\sigma_2 = 0.4 > \sigma_1$	$\sigma_2 = 0.5 > \sigma_1$
a	0.5513	0.5671	0.5604	0.5415	0.5327
α	1.0823	1.0827	1.0824	1.0807	1.0785
β	1.2265	1.2320	1.2294	1.2213	1.2159
b	2.3874	2.3693	2.3774	2.4012	2.4145
$\alpha - a$	0.5310	0.5156	0.522	0.5392	0.5458
$b - \beta$	1.1609	1.1373	1.148	1.1799	1.1987
$b - a$	1.8361	1.8022	1.817	1.8597	1.8818

Note: For comparison purposes, the parameters in the baseline model are set in Table 4.4, the same as the 'Example 5.1' in Cadenillas and Zapatero (1999). It should also be noted that the diffusion parameter μ_2 in the 'Reaction Period' is set to the same value as μ_1. The duration of the 'Reaction Period' T is set to 1 in all the computations reported in this table. a and b are the lower and upper edge of the intervention zone, respectively. α is the restarting value of the strong-side intervention and β is the restarting value of the weak-side intervention. $\alpha - a$ is the size of intervention on the strong side, $b - \beta$ is the intervention size on the weak side, and $b - a$ is the bandwidth wherein the exchange rate is free from intervention.

Table 4.6 Effects of Changes in μ_2 on the Optimal Control Strategy

Parameters	$\sigma_2 = 0.3$				
	Baseline	$\mu_2 = 0 < \mu_1$	$\mu_2 = 0.05 < \mu_1$	$\mu_2 = 0.15 > \mu_1$	$\mu_2 = 0.3 > \mu_1$
a	0.5513	0.5459	0.5484	0.5528	0.5534
α	1.0823	1.0891	1.0861	1.0781	1.0660
β	1.2265	1.2335	1.2304	1.2214	1.2061
b	2.3874	2.3827	2.3848	2.3930	2.4120
$\alpha - a$	0.5310	0.5432	0.5377	0.5253	0.5126
$b - \beta$	1.1609	1.1492	1.1543	1.1716	1.2059
$b - a$	1.8361	1.8368	1.8364	1.8402	1.8585

Note: For comparison purposes, the parameters in the baseline model are set in Table 4.4, the same as the 'Example 5.1' in Cadenillas and Zapatero (1999). It should also be noted that the diffusion parameter σ_2 in the 'Reaction Period' is set to the same value as σ_1. The duration of the 'Reaction Period' T is set to 1 in all the computations reported in this table. a and b are the lower and upper edge of the intervention zone, respectively. α is the restarting value of the strong-side intervention and β is the restarting value of the weak-side intervention. $\alpha - a$ is the size of intervention on the strong side, $b - \beta$ is the intervention size on the weak side, and $b - a$ is the bandwidth wherein the exchange rate is free from intervention.

Table 4.7 Effects of Changes in μ_2 and σ_2 on the Optimal Control Strategy

	$\mu_2 \uparrow$	$\mu_2 \downarrow$	$\sigma_2 \uparrow$	$\sigma_2 \downarrow$
a	$\uparrow$	$\downarrow$	$\downarrow$	$\uparrow$
α	$\downarrow$	$\uparrow$	$\downarrow$	$\uparrow$
β	$\downarrow$	$\uparrow$	$\downarrow$	$\uparrow$
b	$\uparrow$	$\downarrow$	$\uparrow$	$\downarrow$
$\alpha - a$	$\downarrow$	$\uparrow$	$\uparrow$	$\downarrow$
$b - \beta$	$\uparrow$	$\downarrow$	$\uparrow$	$\downarrow$
$b - a$	$\uparrow$	$\uparrow$	$\uparrow$	$\downarrow$

Note: Based on the findings in Table 4.5 and Table 4.6, we summarize the effects of changes in μ_2 (or σ_2) on the results of the impulse control problem. a and b are the lower and upper edge of the intervention zone, respectively. α is the restarting value of the strong-side intervention and β is the restarting value of the weak-side intervention. $\alpha - a$ is the size of intervention on the strong side, $b - \beta$ is the intervention size on the weak side, and $b - a$ is the bandwidth wherein the exchange rate is free from intervention. $\uparrow$ and $\downarrow$ denote the increasing and decreasing effect, respectively.

Table 4.8 Effects of Changes in μ_2 and σ_2 on the Optimal Control Strategy

Parameter	Baseline	$\mu_2 \downarrow \sigma_2 \downarrow$ $\mu_2 = 0.05, \sigma_2 = 0.15$	$\mu_2 \downarrow \sigma_2 \uparrow$ $\mu_2 = 0.05, \sigma_2 = 0.45$	$\mu_2 \uparrow \sigma_2 \downarrow$ $\mu_2 = 0.15, \sigma_2 = 0.15$	$\mu_2 \uparrow \sigma_2 \uparrow$ $\mu_2 = 0.15, \sigma_2 = 0.45$
a	0.5845	0.5942	0.5704	0.5990	0.5727
α	1.1554	1.1608	1.1523	1.1516	1.1477
β	1.2702	1.2795	1.2627	1.2692	1.2576
b	2.3153	2.2967	2.3350	2.3055	2.3396
$\alpha - a$	0.5709	0.5665	0.5819	0.5526	0.5750
$b - \beta$	1.0451	1.0172	1.0723	1.0363	1.0819
$b - a$	1.7308	1.7024	1.7646	1.7065	1.7669

Note: For comparison purposes, the parameters in the baseline model are set as: $\mu_1 = 0.1, \sigma_1 = 0.3, r = 0.06, r = 1.4, C = 0.5, D = 0.5, c = 0.2, d = 0.2$ such that the fixed and proportional intervention cost is the same on both sides. The duration of the 'Reaction Period' T is set to 1 in all the computations reported in this table. a and b are the lower and upper edge of the intervention zone, respectively. α is the restarting value of the strong-side intervention and β is the restarting value of the weak-side intervention. $\alpha - a$ is the size of intervention on the strong side, $b - \beta$ is the intervention size on the weak side, and $b - a$ is the bandwidth wherein the exchange rate is free from intervention.

Table 4.9 Directional Effects of Changes in μ_2 and σ_2 on the Optimal Control Strategy

Parameter	$\sigma_2 \uparrow$	$\sigma_2 \downarrow$
a	$\downarrow$	$\uparrow$
α	TBC	TBC
β	TBC	TBC
b	$\uparrow$	$\downarrow$
$\alpha - a$	$\uparrow$	$\downarrow$
$b - \beta$	$\uparrow$	$\downarrow$
$b - a$	$\uparrow$	$\downarrow$

Note: This table reports the directional effects when μ_2 and σ_2 change simultaneously. $\uparrow$ and $\downarrow$ denote the increasing and decreasing effect, respectively. TBC means 'to be confirmed'. a and b are the lower and upper edge of the intervention zone, respectively. α is the restarting value of the strong-side intervention and β is the restarting value of the weak-side intervention. $\alpha - a$ is the size of intervention on the strong side, $b - \beta$ is the intervention size on the weak side, and $b - a$ is the bandwidth wherein the exchange rate is free from intervention.

To summarize the results reported above, the first important conclusion is that parameter σ_2 has a dominant effect over μ_2 when it comes to the two intervention triggers, i.e. a and b, the size of strong-side and weak-side intervention ($\alpha - a$ and $b - \beta$), and the bandwidth of the Continuation Zone, i.e. $b - a$. The results suggest that if market volatility drops after the central bank intervention, the bandwidth of the Continuation Zone is reduced, and vice versa. Another important finding is that the effect on the two restarting points, i.e. α and β, is subject to the change of both μ_2 and σ_2, while the results obtained so far suggest that the final directional change is determined by the parameter that has a larger value. For example, a higher μ_2 and a lower σ_2 would produce an opposite effect on α, but the final result suggests that an increased μ_2 outweighs the decreased σ_2.

The empirical findings in Section 3 make a convincing argument that the intervention conducted by the PBOC was effective during the sample time period in the sense that it helped to increase the proportion of fundamentalists and decrease the exchange rate volatility. Hence, we need to choose a smaller σ_2, while setting μ_2 to a value that reverses the previous trend. In essence, this suggests that we assign an opposite sign for μ_2 against μ_1, or at least a smaller value with the same sign. We choose three pairs of μ_2 and σ_2 for illustration, and the results are reported in Table 4.10.

Table 4.10 Numerical Illustration of the Modified Impulse Control

Parameter	Baseline	S1	S2	S3
a	4.5772	4.5950	4.5260	4.4940
α	5.9903	6.0121	6.1080	6.1534
β	6.4870	6.5258	6.6247	6.6740
b	8.5283	8.4731	8.4194	8.3916
$\alpha - a$	1.4131	1.4171	1.5820	1.6594
$b - \beta$	2.0413	1.9473	1.7947	1.7176
$b - a$	3.9511	3.8781	3.8935	3.8976

Notes: This table reports the numerical results of the impulse control that incorporates the reaction period, in other words taking account of the impact of PBOC intervention on the market participants, while the baseline model does not consider the reaction period. In addition to μ_2 and σ_2, we also set the length of the reaction period to 1 for all three scenarios: S1 stands for $\mu_2 = 0.05, \sigma_2 = 0.15$; S2 stands for $\mu_2 = 0, \sigma_2 = 0.15$, and S3 stands for $\mu_2 = -0.05, \sigma_2 = 0.15$.

A few interesting remarks can be made regarding Table 4.10. First, compared with the case where we do not consider the market participants' reaction to central bank intervention, the re-starting values α and β both increase as the prevailing trend, i.e. μ_1, is reversed or at least alleviated. However, there is opposite impact on the weak- and strong-side intervention. It can be seen that the size of the strong-side intervention ($\alpha - a$) increases, while the size of the weak-side intervention ($b - \beta$) decreases. Secondly, the size of the Continuation Zone tightens, mostly because of the drop in σ_2, the diffusion parameter. Thirdly, if we look only at the three 'reaction period' cases, we can see that the decrease in the drift parameter has led

to the decrease of the two intervention triggers: a and b both decrease, suggesting it is less likely that the exchange rate would depreciate substantially.

4.5 Conclusions

Recent literature generally suggests that managed floating exchange rate regime can be an appropriate choice for exchange rate arrangements in emerging economies such as China. The fixed exchange rate regime proves costly in the face of volatile movements of international capital, while a regime of free floating exchange rate is not feasible due to financial under-development in these economies.

It is also worth noting that since the 2005 reform announcement, the PBOC has substantially reduced its direct intervention in the market and the RMB is no longer considered to be largely undervalued; rather, it is close to its equilibrium level. Moreover, China has made important changes to its governing polices, such as increasing the daily trading limits and re-designing how the central parity rate should be determined. These all help China to pave its way towards more flexible exchange rates. Although recent studies have argued that the impact of market participants is still very much overshadowed by the central bank, nevertheless, we argue that in the near future, free floating remains undesirable for China, and we should focus on answering the crucial issue of how to manage the managed floating regime.

Given the potentially large cost of intervention (both monetary and non-monetary), in this study we assume that the central bank needs to find the optimal balance between the cost of intervention and the cost of not intervening in the market. To this end, we make use of the stochastic optimal control theory, as it is more suitable to model the economic decisions that are made less frequently and have the ability to introduce discontinuity. Moreover, we believe that for any optimal management framework to yield any sensible policy implication, it needs to fall in line with the real practice. We note that a key assumption upheld in this line of research is that agents are not aware of the reaction functions of the central bank (or they will not estimate the parameters by observing the actions of the central bank). This assumption seems to be unrealistic given the recent findings of literature of heterogeneous agents in the foreign exchange market. One important policy implication is that the foreign market is inherently unstable because of the interactions within different groups of traders. Luckily, the literature also contends that changes in the exchange rates are partly endogenous and the monetary authority could help the market transit out of a bubble more quickly, or even prevent the bubble from brewing, by intervention in the market.

In order to tailor the exchange rate management strategy to China, we first empirically investigate the case of the RMB using daily data from 22 July 2005 to 31 December 2014. By employing a Markov switching model, we find evidence that there have been two distinct regimes for the market exchange rate returns. In the 'active' regime, both fundamentalists and chartists display a significant effect, while in the 'calm' regime, no trading strategy reports as significant statistically. Moreover, we find evidence that the central bank intervention during the sample

period was effective in the sense that the volatility in the 'active' state is more than 7 times larger than that in the 'calm' state. However, if the government intervention objective was to close the gap between nominal exchange rate and the equilibrium exchange rate, the PBOC intervention in the 'calm' state is not as successful as in the 'active' state. We find that when the intervention intensity drops, which is proxied by an increase in the flexibility index, the probability of staying in an 'active' regime, or the probability of transiting out of the 'calm' regime, rises, whereby both fundamentalist and MA traders play a significant role in pushing the real exchange rate of RMB back to its equilibrium value. Nevertheless, we argue that this difference might occur because the central parity rate used in this study is not the ideal proxy for the equilibrium (fundamental) exchange rate level used in other studies.

Based on these results, we later present an optimal impulse control strategy that incorporates a 'Reaction Period' to take account of the presence of heterogeneous agents. With the help of numerical evidence, we show that the proposed impulse control strategy can effectively restrict the exchange rate to stay close to the central parity rate and a sensible width of the band within which the exchange rate is allowed to fluctuate. Moreover, the strategy provides practical guidance for the timing of intervention if a significant deviation do happen. These findings argue for China to adopt a target zone type exchange rate system with a narrower band within the officially announce band to allow for the reaction period that is generous enough for the market to find the appropriate price level and gives the room for the monetary authorities to step in to intervene.

Chapter 5

Towards a Reference Exchange Rate System for China

5.1 Introduction

Despite recent reforms to increase exchange rate flexibility, the design of regime arrangements for sound management of the managed floating exchange rate remains a significant challenge for China. It is well known that from 1994 China fixed its exchange rate against the US dollar for more than a decade, during which period the Chinese economy achieved a magnificent performance. However, this exchange rate policy, which played a vital role in bringing about the economic miracle, attracted wide concern and was ultimately deemed not sustainable. First, from a political point of view, the evidently huge surplus of both current and capital account from 2002 onwards led to accusations from China's major trading partners, led by Japan and the US, that the Chinese authority was manipulating its currency such that the RMB was severely and consistently undervalued, in order to achieve unfair competitive advantage (Goldstein, 2003; Coundert and Couharde, 2007). Secondly, fixing the exchange rate poses a risk to the Chinese macro-economy. Many studies have argued that by maintain the peg, the Chinese monetary authority essentially forfeited some flexibility in conducting its own policy, which has brought in instability to the Chinese economy in recent years (He, 2007).For

example, in a hope to slow down the foreign capital inflow, the central bank of China has been reluctant to raise domestic lending rates (which were presumed to be already high) even in a context of domestic inflation, which in turn has created excessive demand for loans and exacerbated inflation (Goldstein and Lardy, 2006).Thirdly, the cost of sterilizing government intervention increases over time, while the efficacy of sterilization is reported to decay over time.

Facing overwhelming pressure for greater currency flexibility, in July 2005 the Chinese authority finally announced that it would reform the exchange rate system, to move towards a managed float regime. The value of Renminbi (RMB) would be determined on the basis of market demand and supply with reference to a basket of currencies. However, despite what seemed to be promised in this announcement, there is doubt over the true nature of the reformed exchange rate regime. Some empirical studies, as well as the IMF, suggest that China has in fact maintained a peg to the US dollar, as clearly exemplified by the fact that the PBOC froze the RMB once again during the global financial crisis period. However, our own research finds that while the flexibility of the RMB has indeed increased since the reform, the pace of progression remains in the control of the central bank.

This finding leads us to argue that if the Chinese government truly wants to fulfil its commitment to allowing market forces to play a larger role and bring more flexibility to its currency, it must state explicitly what the 'managed floating regime' represents, including its objectives, the means to uphold the regime, and the boundaries of government intervention, such as the specific situations that warrant

central bank intervention. Failure to do so will damage investor confidence, thus making the survival (or success) of the regime highly costly, if not impossible. Taking the most recent incident as an example, on 11 August 2015 the global financial market was shocked by the sudden devaluation of the RMB, the largest one-day drop in two decades. Not surprisingly, the market was not fully convinced by the PBOC's explanation that the devaluation was merely the result of a policy change on how the central parity rate of RMB is derived. As a result, the PBOC was forced to intervene to stop the RMB from depreciating too rapidly, and significant loss of foreign reserves was incurred in a short period of time. Meanwhile, in a notable break from usual practice, top officials at the PBOC had to made frequent public appearances to defend the policy move.

Therefore, to inspire confidence in the ongoing reforms, we believe that it is both necessary and urgent to address the issue of low transparency of the current 'managed floating regime'. To this end, we argue that a 'Reference Rate' system might be an ideal solution for China. Such a system provides a simple, clear operation framework which explicitly lays out the boundaries of central bank intervention and makes it easy for the general public to check whether the government has fulfilled its commitments. At the same time, it is compatible with the reform objective in the sense that the Reference Rate system provides the optimal trade-off between the desire to let the exchange rate float freely and the need to keep the exchange rate in check.

In the remainder of this chapter, Section 2 introduces the 'Reference Rate Proposal', explaining the reasons behind it and its method of operation. Section 3 begins by explaining why neither the fixed nor the free-floating regime is suitable for China, and then discusses the prospects for the Chinese exchange rate system and the possible role of the Reference Rate Proposal. Section 4 provides concluding remarks.

5.2 The Reference Rate System

In literature, an exchange rate system can be labelled as 'intermediate' if it is neither completely fixed nor entirely floating: in the former a country's currency is fixed against another currency, while in the latter regime, the value of a country's currency is solely determined by traders in the foreign exchange market. There is a large body of literature debating the relative merits and drawbacks of these two classic 'polar' options, but the complexity and subtlety of the real world have also sparked substantial research into other possible choices, resulting in several intermediate exchange rate arrangements. In a series of studies of some popular intermediate regimes, Williamson (1999, 2000, and 2009) contends that not only the early 'Adjustable Peg',[27] but also the later, more generalized 'BBC'[28] type

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[27] The 'Adjustable Peg' system is one in which a country would normally have a fixed exchange rate but is allowed to make necessary changes in extreme circumstances.

[28] BBC is the acronym for 'Basket, Band and Crawl', formally proposed by Dornbusch and Park (1999). 'Basket' refers to the suggestion that, instead of pegging to a single currency, countries that trade diversely will be more successful in stabilizing their effective exchange rates if they peg to a basket of currencies, since this will decrease the likelihood of disturbance by radical changes in a single currency (Williamson, 2000). The 'band' is introduced not only to allow the parity to be adjusted in a way that does not destabilize the market, but also to leave ample room for the authoritiesto conduct necessary changes to monetary policy independently. Finally, the 'crawl' is most often used as a way to neutralize inflation differences and to adjust the expectation of Balassa-

regime have proven to be not viable in the face of high capital mobility. Hence, Williamson has proposed three modified versions: Soft Band[29] (or Soft Margins), Monitoring Band,[30] and the Reference Rate System.

In this review, we focus on the Reference Rate. As we will demonstrate, both the Soft Band and the Monitoring Band are essentially the same as the Reference Rate, but the Reference Rate provides a higher level of transparency in terms of operation rules.

5.2.1 The Origin

The Reference Rate system was first introduced by Ethier and Bloomfield in 1975 shortly after the major currencies were allowed to float, which tried to answer the

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Samuelson productivity bias in a fast-growing economy (Williamson, 2000).

[29] Under the Soft Band, government commitment to defend the edges of the band at all times is no longer an absolute requirement. The exchange rate is allowed to move outside the pre-determined band as long as the government believes this is only a temporary situation as the shocks to the fundamentals are expected to be short-lived. Nevertheless, the government still remains responsible to remind the market that it will plan to direct the rate back within the band when it is possible to do so.

[30] The Monitoring Band was originated by the Tarapore Committee of the Reserve Bank of India in 1997. Charged with considering the case for the Rupee to obtain full capital account convertibility, the committee came up with a suggestion that India should adopt a framework for its exchange rate management, as a complementary tool for accommodating capital account convertibility. The centre of the band, termed the 'neutral real effective exchange rate', represents an official, announced, estimate of the equilibrium exchange rate. The government is prohibited from intervening within a certain range around that rate. However, once the rate goes outside the band, there is an option reserved for the authorities to intervene (Williamson, 2000).

prevailing concern that there were no real governing rules in the international community at that time except the injunction against manipulating exchange rates. In fact, countries could choose its desirable exchange rate regime, ranging from float to fix, and any intermediate regime(s). Moreover, Ethier and Bloomfield (1975) pointed out that the consensus among the economies who adopt a floating regime was not dependable. Therefore, in order to tackle the possible conflicts of interest raised by individual countries' interventions, Ethier and Bloomfield (1975) addressed the necessity to form a set of internationally acceptable rules to regulate the management of floating exchange rates.

Specifically, Ethier and Bloomfield (1975, p.9) suggested the following general principles that measures pertaining to the managed float should: *(1) constitute a minimal reform program, broadly acceptable Intermediately and highly flexible to avoid the unresolved long-run issues; (2) contain formal regulations regarding official exchange intervention and not rely solely on central bank cooperation and consultation; (3) be designed to prevent the most egregious type of national conflict rather than any difficulty that could conceivably arise; and (4) specify when intervention is not permissible, rather than when it is mandatory. Moreover, (5) this specification should be in terms of concrete acts of intervention rather than in terms of the presumed motives for such acts; (6) these concrete acts should be compatible with simultaneous efforts to foster central-bank cooperation and to deal with the possibility of conflicts arising from policies other than intervention designed to influence exchange rates, and (7) they should not impede the evolution of a long-run reform of the international monetary system, whatever the shape that might take.*

Then, Ethier and Bloomfield (1975, p.10) summarized their 'Reference Rate Proposal' in two rules:

1) No central bank shall sell its own currency at a price below its Reference Rate by more than a certain fixed percentage (possibly zero) or buy its own currency at a price exceeding its Reference Rate by more than the fixed percentage. This is the sole restriction imposed upon central bank intervention.

2) The structure of Reference Rates shall be revised at periodic pre-specified intervals through some defined international procedure.

'Rule 1' is designed to reduce the likelihood of crises by limiting aggressive central-bank behaviour, which is essentially the most important difference between the Reference Rate and the central parity rate. This is also the key idea underlying the Soft Band and Monitoring Band, as none of the three systems carries any obligation for officials to defend any pre-determined rate or margin. It permits the exchange rate to float, but only within parameters that have been widely recognized by the international community. Meanwhile, interventions motivated by purposes other than pushing the market rate toward the Reference Rate are usually prohibited (Williamson, 2005). 'Rule 2' is designed to ensure an appropriate exchange rate can be maintained or achieved over time. Ethier and Bloomfield (1975) suggest the enforcement of 'Rule 2' would also help to build an adjustment mechanism internationally.

5.2.2 Operation

It is important to note here that intervention can be conducted in various forms, and hence all of them should be treated equally under the Reference Rate system (Williamson, 2007). For instance, in addition to direct purchase/sale in the foreign exchange market, monetary policies have also been employed to influence exchange rates. It is necessary to check whether the benchmark interest rate has been set appropriately. If not, we need to ask will the current interest rate policy lead to a convergence of the exchange rate and its reference or not? Williamson (2007) suggests that if the benchmark interest rate is not set properly solely for domestic objectives, then the government is not fully living up to its international duties. Another good example is 'oral intervention', whereby the authorities publicly express an opinion on where the exchange rate ought to be. Under a Reference Rate system, it would not be permitted to express support for a strong currency when the currency is already stronger than its Reference Rate (Williamson, 2007).

The operation of the Reference Rate can be illustrated more clearly using the following figure from Williamson (2007), which is originally titled as 'The Original Version of the Reference Rate Proposal'.
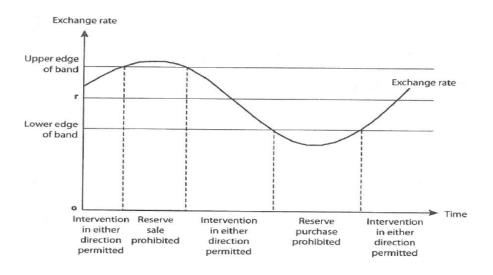
Figure 5.1 Operation of the Reference Rate Rule

Notes: This figure is adapted from Williamson (2007), Chapter 4, Figure 4.1.

In Williamson's (2007) view, the Reference Rate can be adopted in three slightly different forms. In the simplest version where there is no band imposed, the only explicit rule is that the authority should avoid any intervention practice that might contribute to the divergence between the exchange rate and its reference basis. However, as argued by Williamson (2007), given doubts that it might be unrealistic for the authorities to identify a 'right' rate, officials may feel more much comfortable with a rule that requires them only to name a band within which the equilibrium rate lies, rather than a particular rate.

The second version of the Reference Rate Proposal is the 'original version' envisaged by Ethier and Bloomfield (1975). Here, intervention is allowed in either direction within the band. The obligation to bring the exchange rate back toward its reference would apply only when deviation of the market rate from its Reference Rate exceeded a certain critical threshold.

189

The third variant envisages a band within which no central bank intervention would be allowed, except in the case where the deviation between the exchange rate and its reference rate exceeds a pre-determined critical threshold. Thus, within this band, the exchange rate is expected to float free from any government intervention, the idea of which closely follow the essence of the 'monitoring band' as discussed above.

Williamson (2007) holds that the 'original version' may be particularly attractive to a country that has high confidence in selecting a parity rate, while the 'monitoring zone' like is more appealing to countries that have little confidence in estimating the equilibrium exchange rate. Another point in favour of the 'original version' is that it might be possible to work alongside a bilateral peg. Provided that adjustments were made promptly and in small steps, a compromised system might emerge in which countries would still be able to maintain their traditional pegging policy but with an element of international discipline added. However, looking from a general view, Williamson (2007) argues that it might not be possible to allow some countries to adopt one variant of the proposal and others to adopt another

5.3 Reference Rate Proposal - the Solution for China

5.3.1 Unsuitability of Fixed and Free Floating Systems

Before we discuss why the Reference Rate Proposal could offer the way forward for Chinese exchange rate reform in the near future, it is worthwhile to revisit the reasons why neither a fixed nor a free floating system is suitable. On one hand, although the fixed exchange rate once helped China to build a booming export sector

and stabilized its economy during periods of high domestic inflation, it has become too costly and risky for China over time. The diversified and expanded Chinese economy no longer meets the conditions Williamson stated as necessary for a fixed exchange rate regime. Moreover, recent notable developments in the international economy render China's return to the 'fix' even more unlikely. In the early 2000s China initiated the internationalization process of RMB, and there is clear evidence that the currency has now become more recognized outside China and used for international transactions and payments. We have every reason to believe that this trend will continue and grow in the near future, especially given the fact that the RMB has joined the dollar, euro, pound and yen in the IMF's Special Drawing Rights (SDR) from Oct. 1, 2016, at a 10.92 percent weighting.

On the other hand, China is not yet prepared for a free floating exchange rate system. It is worth noting that free floating usually comes with free flow of capital, which is notorious for the trouble it can cause to the country of receipt. Compared to its advanced peers, China still lacks the necessary institutional arrangements to cope with a free float. Given the lessons learnt from the 1997 Asian financial crisis, it is no surprise that the Chinese authority would reject the idea of putting the exchange rate into the hands of the market alone at any point in the near future.

Recent studies have identified another major reason why a free float might not be an ideal solution, namely the presence of heterogeneous agents in the market. Following its introduction by Muth (1961), the rational expectations hypothesis

became the dominant paradigm in economics in the 1970s and 1980s.[31] However, as pointed out by Hommes (2006), in the 1990s more and more scholars began to question whether the strong rationality assumptions, such as the availability of complete information and unlimited computing capacity, hold in reality. It seems highly unrealistic to expect that a rational agent can know the beliefs of all other agents in a heterogeneous world. On the contrary, it seems more plausible to assume that agents possess bounded rationality and that they use rule of thumb strategies and adapt their forecasting rule as additional observations become available (Hommes, 2001). This raises two important questions: first, whether such heterogeneous agents are actually present which has been well argued in the previous chapter, and second, what is the policy implication of the presence of those heterogeneous agents?

To answer the second question, regarding the policy implications of the presence of heterogeneous agents, we first note that studies have presented convincing evidence that it is the behaviour of those heterogeneous agents that lies behind the anomalies observed in the market which cannot be explained in the conventional rational representative-rational agent framework, e.g. the disconnect puzzle (Meese and Rogoff, 1983; Frankel and Froot, 1986), the excess volatility and heavy tail of the exchange rate distribution (LeBaron, 2006), and the forward discount bias (Froot and Frankel, 1989). Hence, we can plausibly assume that in the absence of central bank intervention, aka in a free-floating regime, it is highly possible that there will

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[31] In fact, Hommes (2006) notes that many ideas in the boundedly rational agent approach date back to earlier than the rational expectation theory. See for example Simon (1957), Kahneman, and Tversky (1973).

be large exchange rate misalignment and excess exchange rate volatility, as brilliantly shown in the simulation work of De Grauwe and Grimaldi (2006). Since those factors are widely acknowledged as detrimental to an economy, and particularly to emerging market economies, it is easy to understand why China has ruled out free-floating in the short term.

5.3.2 Advantages of the Reference Rate Rule

The discussion above is important not only because it reinforces the argument that China needs an intermediate exchange rate regime, but also because it clearly identifies the factors that should be avoided, or at least be effectively dealt with, by a future exchange rate regime. To this end, we argue that the Reference Rate Proposal should be seriously considered.

According to Williamson (2007, 2010), the first benefit of adopting a Reference Rate system is that it would help the authorities of the country concerned to avoid large misalignments and harmful currency swings. For countries wishing to stabilize their exchange rate at a level close to the reference rate, the internationally recognized reference rate would leave little ground for the speculative attacks. In this regard, a Reference Rate system is particularly beneficial to countries adopting a floating rate, because it enhances the ability to influence exchange rates by oral intervention and reduces the danger of generating false signals (Williamson, 2007). In the context of China, the RMB is no longer considered to be substantially undervalued compared to the situation in 2005, but is more or less in line with its

equilibrium level. This creates a great opportunity to adopt the Reference Rate regime, as the lack of any strong basis for currency speculation would boost the market confidence in the reference rate (or the central parity rate) and the band.

A second potential benefit of the Reference Rate system is that it can help the private sector to form expectations of future exchange rates that are dependable in the long run, and thus valuable in managing their businesses. Williamson (2007) argues that because exchange markets are largely influenced by irrational behaviour rather than by fundamental expectations, it is extremely difficult to form long-term expectations confidently. Williamson (2007) believes that only once the monetary authority has built a track record that commands respect could one expect the private sector to start using the estimates. When that happens, it will be of great value to investment decisions.

The third potential benefit is that a Reference Rate system provides the international supervisory body, i.e. the IMF, with a meaningful basis for multilateral surveillance, aimed at improving global macroeconomic performance. The policies of the countries concerned would be closely inspected to see whether they were aimed at achieving the reference rate (Williamson, 2005). In this case, it would be straightforward to check whether a country's foreign reserves had changed suspiciously and whether indirect intervention measures had been employed, for example with regard to interest rates, trade restrictions or capital account regulations. A Reference Rate system also offers clear criteria to evaluate demand-management policy, which is essential in determining the current account balance. It would be

easier for the IMF to judge whether a given economy's policies are excessively contractionary or expansionary and whether the global outcome is acceptable (Williamson, 2005). Looking at the bigger picture, since the Reference Rate system is built on a large group of economies rather than any individual member country, adoption of the system might be a great opportunity to create a stronger and more disciplined cooperation between those countries.[32]

One critic of the Reference Rate system is that it might impair governments' commitment to Inflation Targeting,[33] as it has been widely assumed that for a monetary policy to be considered as credible in Inflation Targeting, a high degree of currency flexibility, i.e. where the government refrains from intervening, is essential (Masson, et al., 1997). However, Williamson (2007) stresses that unlike the traditional central rate, a reference rate imposes no obligation on the central bank to defend it, and hence, does not alter its course in managing the inflation rate. Hence, one does not have to choose between Inflation Targeting and the Reference Rate system, since they are easily compatible. Taylor (2001) lends some support to this point as he argues that the potential effect of exchange rates is already embedded in the standard Inflation Targeting framework and there is no need to

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[32] Williamson (2005) argues that the reason why countries might take note of IMF advice is that it would be part of the bargain needed to introduce a significant modification of the current non-system; they would understand that their counterparts could be constrained from adopting beggar-my-neighbour policies only if they too were willing to be constrained.

[33] According to the IMF (2004) definition, '*monetary policy decisions are guided by the deviation of forecasts of future inflation from the announced target, with the inflation forecast acting (implicitly or explicitly) as the intermediate target of monetary policy*'. See 'Classification of Exchange Rate Arrangements and Monetary Policy Frameworks'. [Online] Available at: https://www.imf.org/external/np/mfd/er/2004/eng/0604.htm. Accessed on: 1 September 2016.

explicitly consider the exchange rate. Moreover, recent research has yielded promising results from emerging market economies (EMEs hereinafter). For example, Ghosh et al. (2016) find that for EMEs, foreign exchange market intervention actually benefits the central bank's welfare and commitment to Inflation Targeting. Moreover, they suggest that interest rate policy and intervention in the foreign exchange market could be employed in concert to achieve both price-stability and exchange rate objective, especially in the face of volatile capital flows. In practice, as reported by Aizenman et al. (2011), the EMEs that commit to Inflation Targeting do respond to real exchange rate changes when setting the target interest rate, although the degree of response is reported to be less than that of the non-Inflation Targeting countries.

Another potential disadvantage is that people are sceptical as to whether the Reference Rate system exerts any real impact, given such a weak commitment. However, Williamson (2007) maintains that the system is as effective as any other existing regime. For example, if one accepts the evidence that the impact is stronger when intervention is concerted internationally, then international agreement on a Reference Rate can be expected to have a bigger impact than unilateral intervention.

In addition to the benefits for China to adopt a Reference Rate System, it is worth to mention the applicability of such a regime in reality as well. On one hand, compared to the pre-reform era, we have provided evidence that RMB has now moved substantially towards its equilibrium level through the NATREX approach, which also represents an useful tool for the market to check whether the prevailing policy is support the reference rate or not. On the other hand, we have proposed an

executable exchange rate management strategy, which fits naturally to the Reference Rate System. The Chinese monetary authority could set the reference rate according to the NATREX or any other universally recognized method. Then, aimed at achieving the minimized management cost, we could calculate how wide the band should be and when is the best time for the central bank to intervene and by how much. In summary, this represents a great opportunity to adopt the Reference Rate regime now, not only because of its theoretical benefits, but also because of its applicability.

5.4 Conclusions

It is well established that exchange rate policy plays a vital role in economic growth, and therefore it is important for the monetary authority to choose the optimal policy framework. Although there is no one regime that meets the needs of every economy, there is wide consensus that China needs to allow more flexibility to its currency. Despite the July 2005 announcement promising reform, the market was disappointed that China has not fully fulfilled its commitment. According to the IMF classification in 2014, China is still labelled as a soft peg regime and effectively pegs its currency to the US dollar.

In light of market incidents, we argue that one element missing from the ongoing reform is any clarification of the role played by the central bank, which in turn leads to loss of market confidence, exemplified by the foreign exchange market turmoil that occurred in August 2015. Therefore, it is high time for the Chinese authority to set out explicitly what is meant by the 'managed floating system'. To this end, we

argue that the Reference Rate Proposal offers a promising solution, as it presents a simple, clear operational framework of how the exchange rate is managed. It not only makes plain the objective and boundaries of central bank intervention, but also provides the necessary information for the general public to check whether the government has fulfilled its commitment. Hence, if the government actually follows the rules, we can expect more confidence from the market. Moreover, it is compatible with the PBOC's objective of ending its interventionist policy. On one hand, the Reference Rate system provides ample room for the exchange rate to float freely on the basis of market demand and supply. On the other hand, it also acknowledges the central bank's need to keep the exchange rate in check. In the presence of intervention rules, we could expect that intervention would be less risky and not as costly as it has been previously, while its effectiveness would remain strong. Moreover, the Reference Rate regime could cope well with the issues that make the fixed and free-floating exchange rate systems unsuitable for China.

Chapter 6

Conclusions

6.1 Research Findings and Implications

For the Chinese authority, the July 2005 reform can be seen as an acceptable compromise between bowing to reform pressure arising both internally and externally, and giving up the benefits of a fixed RMB. Instead of a one-time appreciation, the PBOC has chosen to allow only gradual appreciation of the nominal exchange rate when they see fit. Hence, while it acknowledges the need to enlarge the influence from market forces, the PBOC is criticized for its interventionist policy under the managed floating regime. We argue that this paradox explains why there is still no clear evidence in the literature on the reform progress, a full decade after the reform was first announced. Hence, we devote our research to providing a comprehensive evaluation of China's ongoing exchange rate regime, with the aim of shedding light on the controversial issues listed in the introduction.

The choice of exchange rate regime is of vital importance to the country concerned, especially for an economy in transition like China. Hence, at the outset of our research, we contend that an intermediate exchange rate regime is a desirable choice for China. It not only helps China to reap the benefits of a relatively stable exchange rate, but also allows the monetary authority to maintain its control over its economy.

The switch from a fixed system to the managed floating regime would, if completed, also have profound implications worldwide.

The key issue discussed in Chapter 2 is whether or not the flexibility of the RMB has increased following the July 2005 reform. We find that the existing measurements are not sufficient in the case of China, mainly because they depend upon monthly data, whereas government intervention is usually conducted at a higher frequency. Hence, the impact of central bank intervention might be disguised in the monthly data. To address this problem, we construct a daily-based flexibility indicator following the principle that it should reflect the true degree to which the market forces are hindered by the central bank intervention. The results suggest that this high-frequency index tracks the evolution of RMB flexibility well, and reveals richer information, which may otherwise remain hidden in the conventional models. For instance, at the very start of the post-reform era, the central parity rate for the current business day was based mainly on the previous day's closing price. This practice would lead to the accumulation of previous exchange rate changes, which would be quite sizeable given a consistent appreciation trend. Fearing a rapid appreciation of the exchange rate, on January 4, 2006 the government changed this pricing rule and chose to reset the central parity rate on the opening of every business day. These delicate developments are well-captured by the proposed flexibility index.

Then, we employ the Markov switching approach to model the clear up and downs of the RMB flexibility index. This proves successful, as we not only find two

distinct states of the RMB flexibility index, but also provide evidence of China's Fear of Floating, as the change in flexibility did not occur at the time announced by officials. Finally, in Chapter 2, we find a few potential determinants responsible for the changes of RMB flexibility. The interest rate differential between China and the US seems to have a positive effect on the RMB flexibility in both regimes, though the coefficients are not statistically significant. Even though EMP has a negative effect on the RMB flexibility in both regimes, the magnitude of the effect decreases drastically from the low-flexibility regime to the high-flexibility regime. We also find that the CDS index, which indicates the risk to which China is exposed, may serve as an early warning signal for regime shifts of RMB flexibility, since a higher risk spread lowers the probability of the RMB staying in the high-flexibility state.

The primary objective of Chapter 3 is to provide an estimate of the equilibrium exchange rate for RMB, which represents a key question that must be addressed if we want to have a clear idea about the progress, as well as the future, of the exchange rate reform. From a wide range of choices, we select the NATREX approach, because it not only offers a straightforward yet solid theoretical base, but also represents a 'positive' rather than a 'normative' concept. The latter is preferable in this study as we need to find a measurement that can help us determine the impact that one policy might have on the real exchange rate of the RMB. Compared to the very few previous studies that have applied the NATREX to China, our investigation process reflects the true essence of this idea. Specifically, we not only find the exogenous fundamental factors that have impacted the real exchange rate of RMB in the manner prescribed by the NATREX model, but also find that the presumed portfolio channel did not work effectively in China in the sample period,

as claimed in the previous studies. We argue that this is due mainly to China's capital control policies and China's own economic situation. We also find that the real exchange rate of RMB was undervalued compared to the estimated NATREX value during the time period concerned, adding more evidence of the necessity of the exchange rate reform. It is also interesting to note that the 2005 exchange rate reform did contribute to closing the misalignment, which dropped from 3.6% in 2005Q3 to 2.4% in 2008Q1. It is true that this change is notably far less than the magnitude of appreciation of the nominal exchange rate. Nevertheless, we argue that this is because the NATREX exists only conceptually and medium-run equilibrium did not occur once in the sample period, hence we need to be cautious when interpreting the estimated NATREX value.

Looking ahead, an intermediate exchange rate regime remains the only choice for China, which means the monetary authority is still charged with the task of monitoring the exchange rate movements. However, given its reform objective that it would cease normal intervention practice, what would be the appropriate management strategy for China to adopt in the near future? To explore this question, in Chapter 4 we extend the stochastic optimal control theory by taking the presence of heterogeneous agents into consideration.

First, we empirically confirm the existence of heterogeneous agents, modelled as fundamentalist and Moving-Average traders in the Chinese foreign exchange market. Although we utilize the Markov switching model for estimation, our results differ from those of previous studies. This is because, first of all, given the

appreciation trend of the nominal exchange rate, the MA traders actually helped the market exchange rate move back to the equilibrium level, thereby displaying a stabilizing impact as the fundamentalists. The second reason is that we have included both types of agents in the model at all times, in contrary to the previous studies which implicitly imposed the unrealistic assumption that at any time there is only one trading strategy in operation. Therefore, the estimation results should be interpreted carefully. On one hand, if the government objective was to decrease the exchange rate volatility, then the PBOC intervention can be considered successful, as the volatility in the 'active' state is more than 7 times larger than that in the 'calm' state, where both fundamentalists and MA traders play an insignificant role. On the other hand, if the government objective was to close the gap between the nominal exchange rate and the central parity rate, the PBOC intervention was not as successful in the 'calm' state as in the 'active' state. When the intervention intensity drops, which is proxied by an increase in the flexibility index, we could expect the probability of staying in an 'active' regime, or of transiting out of the 'calm' regime, to rise, whereby both fundamentalist and MA traders play a significant role in pushing the real exchange rate of RMB back to its equilibrium value. Nevertheless, we argue that this difference occurs because the central parity rate used in this study is not the ideal proxy for the equilibrium (fundamental) exchange rate level used in other studies.

Based on the empirical findings, we then extend the stochastic impulse control model by characterizing a 'reaction period' as introduced in Kercheval and Moreno (2009) and Bensoussan et al. (2012). The optimal exchange rate management strategy can be described as one in which the exchange rate domain is divided into

an intervention-free zone, aka a Continuation Zone, within which the exchange rate can float freely as in a pure floating regime, and two intervention zones. The strategy also determines when is the optimal time for intervention, and the size of intervention. It is demonstrated through simulation that this strategy, once adopted, effectively solves the problems inherent in a market made up of heterogeneous agents, such as excessive exchange rate volatility and large misalignment, thereby lowering the chances of official intervention. However, to fully operationalize this strategy, we have to be confident in quantifying the cost of intervention and the cost of no intervention.

Based on the results from previous chapters, it seems safe to contend that although the exchange rate reform has made some progress, the speed of that progress is far from satisfactory. Moreover, China faces significant challenges to maintain its managed floating regime. In order for China to achieve a market-orientated exchange rate system, we argue that the Chinese government must introduce more transparency as to what the 'managed floating regime' represents, including its objectives, the means to uphold the regime, and the boundaries of government intervention, such as the specific situations that warrant central bank intervention. Failure to do so will severely damage investor confidence, thus making the survival (or success) of the regime highly costly, if not impossible. Therefore, in Chapter 5, we contribute to the literature by arguing the reasons why a Reference Rate system could be a promising option for China. Its chief appeal is its ability to provide ample room for the exchange rate to fluctuate on the basis of market demand and supply, while avoiding the pitfalls of both a pegged rate and a freely floating rate. In the meantime, the Reference Rate system acknowledges the necessity and desirability

of central bank intervention but also explicitly lays out the objective and boundaries of the intervention, which serve as criteria for the market to check the central bank's practice.

6.2 Limitations and Future Research

This research represents a critical contribution to achieving a better understanding of China's ongoing exchange rate reform. However, despite the new light it sheds on the reform progress and the proposed optimal management strategy, several limitations do exist, which call for further research in the future.

From an empirical standpoint, there will be much scope for improvements to the investigation pertaining to China's intervention if the relevant intervention data become available in the future. For instance, we could use this data to double check the robustness of the flexibility index built in Chapter 2. Alternatively, we could use the dataset in an event study to break through some of the secrecy regarding China's true intervention practice.

Access to (or obtaining) first-hand survey data from the Chinese foreign exchange market would open the way to further improvements. Such data would enable us to take a closer look at the presumed heterogeneity among the market participants. In Chapter 4 we argue that if the intervention objective was to close the gap between the market exchange rate and the equilibrium (fundamental) exchange rate, then the PBOC intervention was not that successful, and we suggest that the reason for this

result is that the central parity rate we use cannot represent the underlying equilibrium exchange rate. However, there is another equally plausible explanation. Compared with its counterparts around the globe, the Chinese foreign exchange market stands out as the PBOC imposes strong control over the market participants. Hence, the market exchange rate we use, i.e. the exchange rate data from the BOC, might not be a proper proxy for the market exchange rate. However, if the survey data were to be available, we could directly confirm the existence of heterogeneous agents. Moreover, we could examine to what extent the government's control has impacted on the degree of heterogeneity.

Another potential improvement relates to Chapter 4, where we propose an optimal exchange rate management strategy. Although this represents the first attempt in the literature to use the stochastic optimal control theory on the RMB management, the potential usefulness of this strategy is limited by the cost structure we impose. First, we assume only one objective for the central bank, which is to keep the exchange rate as close as possible to the target exchange rate. However, the central bank may have other concerns over the exchange rate movements, such as the excess exchange rate volatility. Therefore, it will be interesting to include such concerns in the central bank's reaction function as well. Secondly, we assume that the intervention cost consists of both a constant and a varying component. However, the values we use for simulation are not drawn from empirical evidence. Hence, to enhance the operability of this management strategy, it is worth noting that more insights could be obtained by quantifying the cost of intervention and the cost of no intervention. Finally, although we have argued that the impulse control is preferable to the drift control as the benchmark management framework, it is nevertheless worth noting

the potential benefit of using the drift control. For example, Bar-Ilan et al. (2007) have concluded that drift-control is more cost efficient compared to the impulse control when considering foreign reserve management. It would be interesting to find out whether this statement also holds true for the exchange rate management.

Consistent with this line of research, it will also be interesting to consider a multi-objective monetary policy framework where both the impulse control and the drift control are available to be deployed. On one hand, we note that interest rate adjustment is reserved as an important weapon in the arsenal of the central bank. However, if it is used frequently simply to influence the exchange rate, it might result in a more dangerous situation for the monetary authority. To make matters worse, if the direct intervention in the foreign exchange market (by purchase/sale of foreign reserves) cannot be properly sterilized, it is likely to put pressure on the domestic money supply. Moreover, the monetary authorities also need to consider other issues, such as domestic inflation and economic growth. In practice, we observe that central banks respond to shocks from various sources.

On the other hand, recent studies, e.g. Ghosh et al. (2016), suggest that exchange rate policy can be obtained without jeopardizing other monetary policy objectives, including inflation targeting and output growth. The study of Wanasilp (2011) has shed some light in this regard, with results suggesting that when both managed floating and inflation targeting are included in the model, the optimal exchange rate intervention will depend heavily on the degree of openness: a higher degree of openness means the international trade would account for a large portion of real

output and general price. Therefore, stabilizing exchange rate would also help stabilize the real output and inflation, and consequently the central bank would tend to conduct more intervention. However, as suggested by Wanasilp (2011), we must ensure that the tools used are independent of each other.

We can build on the work of Wanasilp (2011) and try to generalize the objectives or the cost function for the central bank that adopts a managed floating regime. One possible macroeconomic framework is the Trilemma. Recent studies suggest that there is a strong trade-off between exchange rate stability, free capital movements and monetary autonomy. With massive accumulation of foreign reserves, the management problem is likely to get worse. It is worth noting that if the trilemma idea is applicable, we could further bring together the drift and impulse controls: the impulse control is only utilized on the interest rate and the drift-control model deals with the cost of direct intervention in the foreign exchange market. It is also worth noting that since sterilization can effectively cut the links between these two interventions, namely intervention in the foreign exchange market and adjustment of policy interest rate, we may still consider that these two controls are independent of each other.

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