Essays on Intervention, Speculation and Sentiment in the Foreign Exchange Market

Xuxin Mao

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Abstract

The purpose of this thesis is to analyse the interaction of currency intervention, speculation and sentiment, and their influence on the exchange rate dynamics across the developed and developing countries.

This thesis tackles the three factors attributable to the unsolved issues in the field, i.e., the lack of proper data set or proxies, theoretical foundation, and structural models. After reviewing the related literature, microstructure frameworks are built with theoretical set-ups, e.g., the international parities, the forward rate bias and central bank credibility. Then the transmission channels of currency interventions, the reaction functions of central banks, and the impacts of the speculators' activity and psychology are examined with cointegrated VAR methodology. In doing so, this thesis offers thorough structural and identified analyses of the developed and developing country currencies in a joint theoretical framework.

Therefore, this thesis fills some methodological, theoretical and empirical gaps in the field of international finance. Furthermore, it provides not only suggestions for future empirical and theoretical research but also policy implications for central banks across developed and developing countries.

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Delaration

I delare that, except where explicit reference is made to the contribution of others, that this dissertation is the result of my own work and has not been submitted for any other degree at the University of Glasgow or any other institution.

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Chapter 1

Introduction

Abstract

This chapter describes some fundamental aspects of the research on currency intervention, speculation and sentiment in the foreign exchange market, and provides an overview of the background, structure and findings of the main chapters.

1.1 Assessment of Unresolved Issues

After decades of economic research on exchange rates, it is still not easy to explain the mechanism of the exchange rate dynamics, with gaps in the field. Monetary authorities across developed and developing countries still need to understand the interactions between the exchange rate dynamics, market conditions and investors' positions, and through which channel their intervention policies can have impact. Investors, especially speculators, are adjusting their currency portfolio allocation according to the exchange rate movements and currency interventions. This thesis analyses currency intervention, speculation and sentiment to shed some light on the exchange rate dynamics.

1.1.1 Assessment of Issues related to Currency Intervention

Central banks began to conduct currency interventions even before the establishment of the classical gold standard era (Bordo et al., 2007). However, despite decades of practices and economic research, there is hardly any consensus on the effectiveness of currency interventions, with many questions related to currency intervention yet to be answered.

Vitale (2007) attributes the puzzling phenomena to several issues. Firstly, the adequate official intervention data is still sparse. Secondly, most analyses lack a theoretical foundation of the market microstructure to explain the interactions of currency interventions, currency values and market conditions. Thirdly, most studies on currency intervention are based on non-structural models which can not avoid simultaneity and identification problems. There have been few studies with identified models to analyse the effects of interventions on the exchange rate dynamics.

With a clear theoretical foundation and market microstructure, this thesis adopts identified and structural models to analyse currency intervention. We use only official intervention data from central banks, instead of data from balance sheets or news reports, which defines clear scales and directions of currency intervention. However, this means there are limited choices when it comes to analysing the effects of currency intervention and the reaction function of central banks. Hence this thesis focuses Japan and Mexico, the few countries with long and persistent interventions.

This thesis first adopts a Uncovered Interest Parity and Purchasing Power Parity framework proposed by Juselius and MacDonald (2004), to test the effectiveness of the Japanese currency interventions through the portfolio balance and signalling channels. Then it builds a market microstructure model to analyse the exchange rate dynamics through the coordination channel, and uses the stylised facts of the forward rate bias to further test the effectiveness of the signalling channel. The results on the currency interventions and exchange rate dynamics provide clear theoretical underpinnings for future studies.

In the spirit of early identified and structural studies, e.g., Kim (2003), Kearns and Rigobon (2005), this thesis uses cointegrated VAR models to systematically analyse the exchange rate dynamics, currency intervention and market conditions. Through the identified and structural approach, this thesis tests and formulates potential long-term relations with respect to the effectiveness of the transmission channels and the factors that influence central banks' reactions. Finally, the short- and long-run effects of currency intervention and market conditions on the exchange rate dynamics are examined.

1.1.2 Assessment on Issues related to Speculation and Sentiment

To further tackle the questions related to currency intervention raised by Vitale (2007), this thesis considers the activities and psychology of other market participants, especially the speculators. Some studies on currency intervention have noted the interactions between intervention, speculation and sentiment in the foreign exchange market. For example, Neuman (1984) suggests that the aim of currency intervention is to reduce the incentive for speculators. Ito (2005) also documents that currency speculators and central banks are at odds with each other in terms of the direction of exchange rate movements. While Dooley and Shafer (1983) and Le Baron (1999) find that currency speculators benefit from the market inefficiency created by the interventions, Ito (2002) demonstrates that central banks also generate revenues through their intervention operations.

However, largely due to the data availability problem, the research on speculation and sentiment in the foreign exchange market is still sparse. If transaction data can not be accessed, proxies for speculation have to be considered. Furthermore, indices are needed to reflect the expectations of speculators on the currency market conditions. To measure currency speculation and sentiment, this thesis proposes to use data from the Commitment of

Traders reports.

Although some researchers, e.g., Corrado et al. (2007), start using models motivated by recent developments in behavioural finance, most studies on currency intervention, speculation and sentiment still lack a solid theoretical foundation. With research progresses related to financial market microstructures, it is possible to construct microstructure models for the coordination channel. Based on theoretical settings of the forward rate bias and central bank credibility, this thesis also tests the effectiveness of the signalling channel.

Furthermore, there is no research employing structural relations of currency intervention, speculation and sentiment in identified models. It is important to tackle the simultaneity issue on currency intervention and identify the impact of speculation and sentiment under different market conditions. By constructing a structural and identified model this thesis provides a promising way to tackle the simultaneity problem. It also offers a new approach to formulate an identified model for currency intervention and the transactions and psychology of currency speculators.

1.2 Overview of Main Chapters

This section offers an overview of the main chapters of this thesis, covering chapters on literature review, theoretical and empirical analyses of currency intervention, speculation and sentiment.

1.2.1 Brief Overview of Chapter 2

Chapter 2 presents a review of related literature on currency intervention, speculation and sentiment, and illustrates the relations between the existing literature and the studies in the following chapters.

Currency intervention is a common occurrence in the foreign exchange market and becomes a prolific research topic in international finance. However, there are still many limitations in the current studies. Using non-structural models, traditional research on currency intervention focuses on developed country currencies and two transmission channels, i.e., the portfolio balance and signalling channels. There are few studies on currency intervention in developing and emerging countries because of the limited availability of the official intervention data.

Besides covering papers that adopt traditional time series and event study methods, this chapter reviews recent papers using identified methodology to systematically analyse the exchange rate dynamics with currency intervention and fundamental macroeconomic variables. Meanwhile, this chapter presents a detailed review on three transmission channels, including the coordination channel which incorporates market microstructure measuring interactions between central banks and currency speculators.

Although the activities and emotion of speculators can not be ignored when it comes to analysing the exchange rate dynamics, the related research has been limited by the data availability problem. Suitable indices for speculation and sentiment in financial markets are documented for empirical studies.

The chapter begins with a historical review of currency intervention across developed and developing countries. It then reviews the studies on the transmission channels of currency intervention, i.e., the portfolio balance, signalling and coordination channels. Some important theoretical set-ups and empirical findings related to the main channels are presented and compared. This chapter also presents four groups of estimation methods for analysing currency intervention, i.e., low-frequency time series, event study, high-frequency time series, and identified models. The sections on speculation and sentiment describes the interactions of currency intervention and speculation, and various sentiment measures in the foreign exchange market. In the end, this chapter describes the connections between the present literature and the main chapters of this thesis.

1.2.2 Brief Overview of Chapter 3

Chapter 3 analyses the effects of intervention, speculation and sentiment on the JPY/USD rate between April 1991 and August 2008. During the period, there were 318 days of solo interventions initiated by the Japanese monetary authorities, and 22 days of coordinated interventions conducted by Japan and the USA.

In Japan, the Ministry of Finance makes decisions on currency intervention, and the Japan's central bank, the Bank of Japan, implements interventions. While in the USA, the Treasury decides whether to step in the foreign exchange market, and, together with the Federal Reserve Bank of New York, imposes interventions.

Although numerous studies have addressed the effects of currency intervention on the JPY/USD rate, few are based on a solid theoretical framework. To remedy the problem, this chapter tests the portfolio balance effects of currency intervention in the context of the international parity framework proposed by Juselius and MacDonald (2004). While the effects of currency intervention are dependent on the market conditions, especially the activities and psychology of speculators, there have been few studies on the interactions of currency intervention, speculation and sentiment. This chapter addresses currency speculation with a COT sentiment index and test its effects together with currency intervention.

This chapter starts with a review of related literature on the portfolio balance and coordination channels, and currency speculation and sentiment. Then it presents a theoretical framework of international parity conditions for testing the portfolio balance channel, and offers a microstructure framework for testing the coordination channel with consideration of currency speculation and sentiment. After an illustration of related data and international parity conditions, the chapter shows the testing criteria for the transmission channels. Accordingly, it tests the long-run parity conditions to see whether the requirement for the effectiveness of the portfolio balance channel is fulfilled. With variables related to the currency intervention, speculation and sentiment, the effectiveness of the portfolio balance and coordination channels are examined.

This chapter generates some important results. While the U.S. currency interventions were not effective, the rejection of nonstationarity of the UIP condition provided prerequisite for the effectiveness of the Japanese currency interventions through the portfolio balance channel. Indeed, the Japanese interventions had both short- and long-term effects on the exchange rate through the portfolio balance channel. Furthermore, they were effective through the coordination channel.

The results provide suggestions for studies on the intervention, speculation and sentiment related to the JPY/USD rate. The Japanese interventions can be analysed in several regimes classified by intervention patterns. Furthermore, the effectiveness of the signalling channel should be analysed, and more factors, e.g., the forward rate bias, exchange rate volatility, could be considered to provide more explanatory powers of the dynamics of the JPY/USD rate.

1.2.3 Brief Overview of Chapter 4

This chapter offers a follow-up of the study on the Japanese currency intervention, speculation and sentiment in Chapter 3. It examines three separate intervention regimes between 1991 and 2004 in an innovative microstructure framework.

The official intervention data is available from 1991, and there have been only three official interventions since 2004 (Bordo et al., 2012). The first regime, from 1st April 1991 to 20th June 1995, was characterized by small-scale but frequent interventions (Ito, 2005). The second regime, between 21st June 1995 and 14th January 2003, featured very large-scale but infrequent interventions initiated by Eisuke Sakakibara and Haruhiko Kuroda

(Ito and Yabu, 2007). The third regime between 15th January 2003 and 16th March 2004 was labeled as the "Great Intervention" (Taylor, 2006), and characterised by large-scale and highly frequent interventions implemented by Zenbee Mizoguchi.

The main aim of this chapter is to jointly test on the coordination and signalling channels in an identified and structural framework. Firstly, it provides background information on the intervention regimes, and new theoretical frameworks to analyse the interactions of currency intervention, speculation and sentiment. Then it tests the effectiveness of the signalling channel by examining the forward rate bias and central bank credibility. Meanwhile, the tests on the coordination channel are based on a new microstructure model which considers the interactions between central banks and currency speculators. All the main empirical tests use the cointegrated VAR methodology, and the empirical results are summarised and compared for future research and policy implications.

There are several important findings based on the analysis of this chapter. Firstly, the shocks to the bond yield differential were the driving force of the dynamics of the JYP/USD rate, and had strong long-run impact on speculation and sentiment. Secondly, with respect to the reaction function of the central bank, the interventions happened in clusters, and were the reactions to the sharp JPY appreciation. Between 2003 and 2004, the central bank also reacted to the large speculation position and high sentiment on Yen's appreciation. Thirdly, the signalling channel was effective when the interventions were frequent. Fourthly, the speculation and sentiment showed strong effects on the changes in the exchange rate, and the coordination channel worked when the changes in exchange rate volatility were slow.

1.2.4 Brief Overview of Chapter 5

Using similar frameworks to those formed in Chapter 4 on the JPY/USD rate, Chapter 5 provides a unique examination on the Mexican currency interventions between 1998 and 2009, and compares exchange rate dynamic mechanisms across developed and developing countries. Together with the research in previous chapters, this chapter offers suggestions for related empirical and theoretical research and potential policy implications for central banks.

Contrary to the reduction of the currency interventions in advanced economies, interventions in developing countries are frequent and sometimes in very large amounts (Guimaraes and Karacadag, 2006). However, there have been few studies on currency intervention in developing countries, partially due to the lack of publicly available time series data (Menkhoff, 2013).

As an exception, the Mexican central bank has published its official intervention data since the Peso floated in December 1994. The Mexican interventions can also be classified into three regimes. The first period, from October 1997 to June 2001, featured small and infrequent interventions. In the second regime from May 2003 to mid September 2008, the interventions were small but frequent, and the exchange rate volatility was relativity low. The third regime covered September 2008 to December 2009, a period where the exchange rate volatility was very high. The interventions were large and frequent, but their volume was decreasing with the improving economic conditions.

As a corollary to the frameworks created in Chapter 4, Chapter 5 analyses the effects of Mexican currency intervention, speculation and sentiment using the same methodology, and produces some similar findings. While the signalling channel was effective when the Mexican interventions were frequent, the coordination channel was effective when there was no sharp change in the exchange rate volatility, and the small and infrequent currency interventions did not work through either channel.

However, the difference across developed and developing countries are hardly unnoticeable. While the Japanese monetary authorities mainly reacted to the sharp appreciation in YEN, their Mexican counterparts focused the high speculation and sentiment on Peso's appreciation and the increasing exchange rate volatility. While the bond yield differential drove the dynamics of the JPY/USD rate, currency speculation and sentiment played a similar role in changing the MXN/USD rate.

1.3 Summary

There have been many unanswered questions related to currency intervention, speculation and sentiment during the post Bretton Woods period. The lack of three factors, i.e., proper data set or proxies, theoretical foundations, and structural models, are the main obstacles of the empirical studies in the field.

This thesis tackles these issues, and reveals the powers of the identified cointegrated VAR modeling technique and microstructure framework to explain the exchange rate dynamics across developed and developing countries. By examining the transmission channels of currency intervention and the interactions between central banks and speculators, this thesis offers a new way to analyse intervention, speculation and sentiment in the foreign exchange market.

The study provides not only potential directions for related empirical and theoretical research, but also policy implications for central banks across developed and developing countries.

Chapter 2

Literature Review on Currency Intervention, Speculation and Sentiment

Abstract

Most studies on currency intervention focus on two transmission channels, i.e., portfolio balance and signalling channels. They normally use non-structural models to analyse the dynamics of developed country currencies. This chapter reviews the related research and recent developments in the area of currency intervention, speculation and sentiment. The recent advances include studies using identified methodology to systematically analyse the effects of interventions with fundamental variables. They also include studies on the coordination channel and market microstructure, which treat intervention as order flow of a central bank. Given that the order flow data is not always available, different sentiment indices are examined as potential proxies for currency speculation and sentiment. This chapter ends with suggestions for future research directions.

2.1 Introduction

Currency intervention has a long history and is still an important research topic in international finance. Using non-structural methods, numerous papers have analysed the effectiveness of traditional transmission channels, i.e., portfolio balance and signalling channels, for currency interventions in developed countries. Recently, identified models have been introduced to systematically analyse the effects of interventions with fundamental variables and a new transmission channel, the coordination channel, has emerged from market microstructure studies. While Order flows of speculators and central banks are needed, there is often a data availability problem. Therefore, different sentiment indices in the financial markets are reviewed and proxies for speculation in the foreign exchange market are proposed.

This chapter begins with a brief historical review of currency intervention across developed and developing countries. After reviewing the studies on the main transmission channels, i.e., portfolio balance, signalling, and coordination channels, it examines four groups of estimation methodology, i.e., low-frequency time series, even study, high-frequency time series, and identified models. The chapter ends with summarization of literature review and suggestions for future research.

2.2 Currency Intervention

2.2.1 Brief Historical Review of Currency Intervention

Currency intervention is defined as the purchases and sales of foreign currencies by the monetary authorities in order to influence the exchange rate level or volatility. It dates back to the time before the classical gold standard era was established (Bordo et al., 2007). Although both bimetallic U.S. and its European counterparts were involved in currency interventions, it was the European central banks that first developed some intervention techniques. The techniques were adopted in the currency interventions in the classical gold standard era (1870-1913) and the following gold exchange standard era until the Great Depression[1]. After active currency interventions during the Tripartite Agreement period (1934-1939)[2], currency interventions became rare until the last era of the Bretton Woods system (1961-1973).

The antecedents of modern currency interventions normally adopted administrative approaches to affect the gold import and export point positions. These approaches included direct restrictions on gold exchanges, and indirect monetary policy changes through changes in interest rate or purchases and sales of foreign currencies. The latter approach is still used by the modern unsterilised currency interventions. Although the fall of the gold exchange regime became inevitable with increasing misalignments of gold bloc currencies, currency interventions did have some effects in slowing down its collapsing speed.

The free float system (1973-1984) emerged with the ending of the Bretton Woods system. In this system, unsterilised currency interventions were frequently used, but not in large amounts. This contrasted with the managed float period (1985-1996), which was featured with large interventions. In September 1985, after a strong overvaluation of USD and devaluation of JPY, the G5[3] leaders made an agreement at the Plaza hotel in New York to bring down the highly appreciated USD through coordinated currency interventions. The G7 meeting in 1987 at Louvre led to an entente showing the intent of coordinated intervention on the low-valued US dollar. After the Plaza and Louvre currency accords, automatically sterilised currency interventions became regular and sometimes very heavy (Obstfeld, 1990). In the U.S., the Treasury made decisions with consultation of Federal Reserve Board. Then the Federal Reserve Bank of New York and the Treasury together conducted interventions. In Japan, the Ministry of Finance made

[1] Shortly after issuing the Yen, Japan adopted the gold standard from October 1897 to December 1931.

[2] An international gold settlements system was first established by French, UK and US to fix the exchange rates at the gold standard. Swiss, Netherlands and Belgium later joined the system.

[3] G5 (Group of Five) meant France, Japan, the United Kingdom and the United States. It became G7 in 1987 after including Italy and Canada, and G8 in 1997 with Russia as a new member.

decisions followed by interventions imposed by the Bank of Japan.

Japan initiated 340 interventions between 1991 and 2004, 22 of which were coordinated with the US. There have been three active intervention regimes in Japan since the Japanese official intervention data was disclosed in April 1991. The first regime between April 1991 and June 1995 was featured with frequent but small-scale interventions (Ito, 2005). The second regime started after Eisuke Sakakibara took charge of interventions on 21 June 1995 and was characterised by large-scale but infrequent interventions. Haruhiko Kuroda continued with the similar strategy while he was in charge of interventions between 8th July 1999 and 14th January 2003 (Ito and Yabu, 2007). The third regime, labelled as the "Great Intervention" (Taylor, 2006), covered the period between 15th January 2003 and 31th March 2004. The precarious economic condition in Japan forced Zenbee Mizoguchi to conduct frequent and large scale interventions.

Official currency interventions in advanced economies have been in steady decline. After March 2004, among all G7 central banks, only the Bank of Japan has conducted four solo currency interventions. Other G7 central banks only stepped in the currency market only once to support the Japanese counterpart after the Great East Japan earthquake (Bordo et al, 2012). However, the situation is quite different in developing countries. Canales-Kriljenko (2006) finds that 91 percent of the 76 responding central banks conduct currency interventions. The central banks in developing countries intervene in the foreign exchange market frequently and sometimes with very large amounts (Guimaraes and Karacadag, 2006). The interventions are aimed to correct currency misalignment in terms of levels or rates, smooth fluctuations by reducing exchange rate volatility, accumulate international reserves to fence off speculative attacks, or provide liquidity to the markets. There is severe lack of research on intervention in developing countries. This is partially due to the lack of publicly available official intervention data (Menkhoff, 2013) although about 65 percent of emerging market members of

IMF publish intervention data in some way (IMF, 2010).

As one of the few central banks of developing countries that regularly publish official intervention data, the Mexican central bank (Banxico) has been actively intervened in the foreign exchange rate market since the Peso was forced to float in December 1994. There have been three different intervention regimes in Mexico. From October 1997 to June 2000, while accumulating international reserves, Banxico undertook several daily USD sales up to 0.2 billion and some discretionary interventions to ease the volatility of the MXN/USD rate (Sidaoui, 2005). After the first intervention regime, there was no official intervention until May 2003. In the second regime from May 2003 to August 2008, Banxico sold USD directly in the foreign exchange market via daily auctions to slow down the pace of international reserve accumulation. The interventions of the third regime, started in September 2008, were to ease the impact of the financial crisis. Banxico sold USD through daily auctions and several discretionary interventions to provide liquidity and reduce exchange rate volatility (Quintanilla et al., 2012).

2.2.2 Theoretical Background: The Transmission Channels

Currency intervention can be classified either as unsterilised or sterilised. Unsterilised currency interventions influence the foreign exchange market mainly through the changes in the monetary supply. According to the open macroeconomic models, unsterilised intervention is not an independent policy tool but a standard monetary policy tool. On the contrary, sterilised currency interventions offset any changes in monetary base through immediate open market operations, e.g., buying or selling domestic bonds in the opposite direction. Therefore, they are widely regarded to be independent from monetary policies and may work through the main transmission channels, i.e., the portfolio balance, signalling, and coordination channels.

Although there were some exceptions in Japan between 2003 and 2004 when the currency interventions and monetary expansions were parallel (Ito, 2007), most currency interventions in Japan, the US and many other developed countries are sterilised (Sarno and Taylor, 2002). Sterilised interventions and their transmission channels are the focus of this thesis.

The Portfolio Balance Channel

As a classic transmission channel, the portfolio balance channel (Isard, 1980; Branson, 1984; and Kumhof, 2010) is based on the assumptions that the Ricardian condition[4] does not hold true and bonds in different currencies are not perfect substitutes. Within the portfolio balance framework, investors balance their portfolio among assets denominated in different currencies, based on the relative expected returns of their assets. Through the channel, sterilised interventions can alter the assets within the monetary authorities' balance sheets. Without changes in the monetary base, the domestic interest rates stay unchanged. Therefore, the spot exchange rate shifts in order to affect the domestic value of foreign assets and the expected returns from holding them (Sarno and Taylor, 2002).

The portfolio balance models can be seen as dynamic exchange rate determination models based on the interactions of asset markets, current account balance, and rates of asset accumulation. This idea can be illustrated with a simple exchange rate equation[5]:

$$s_t = X_t + \beta \left[E_t \left(s_{t+1} | \Omega_t \right) - s_t \right] + \varepsilon_t, \tag{2.1}$$

where s_t is the spot exchange rate, X_t the fundamental factors, e.g., interest rates, monetary supply, current account, and Ω_t the currently available information set. Hence, the exchange rate is determined by the fundamental

[4] Ricardian condition is that there are no effects of government borrowing on the interest rate when expected future tax payments of private agents, served as extra government debt, are offset against the bond holdings in terms of domestic currency.

[5] The equation and its derivation are based on the talk of Michel Beine at the University Paris 10 in February 2010.

factors X_t and the expected change in exchange rate $[E_t(s_{t+1}|\Omega_t) - s_t]$. Currency intervention works through the portfolio balance channel by influencing X_t.

It is really difficult to choose variables related to the non-monetary assets for the portfolio balance channel. There are two types of empirical tests for the channel. The first approach, the direct demand approach, is to test the intervention effects based on a reduced form of the portfolio balance channel. The second approach, the inverted demand approach, is to test the perfect substitutability of domestic and foreign assets based on risk premium[6]. Most studies within the portfolio balance framework, e.g., Kearney and MacDonald (1986), follow the second approach.

Loopesko (1984), an early empirical study using the inverted demand approach, estimates an equation for risk premium with explanatory variables of lagged exchange rates and cumulated currency interventions in G7 countries. The hypothesis of perfect asset substitutability is rejected and some supports for the short-run effectiveness of the portfolio balance channel is provided. Dominguez and Frankel (1993) use survey data to measure expectations on the DEM/USD and CHF/USD exchange rates and construct a risk premium from the deviation of the uncovered interest rate parity. They find that currency interventions have significant effects on the risk premium through the portfolio balance channel. In both papers, risk premium is measured by the deviation from uncovered interest parity and currency interventions reflect the relative asset supplies denominated in different currencies. These features mean that the empirical tests for the effectiveness of the portfolio balance channel should take account of intervention effects on the bond yield differentials and changes in exchange rates.

Although Dominguez and Frankel (1993) provide some empirical supports for the portfolio balance channel, most other studies are not very supportive (Frankel, 1982; Obstfeld, 1983; Rogoff, 1984; and Lewis, 1988). Although

[6] Risk premium can be measured by the deviations of the uncovered interest parity based on the changes in exchange rates and bond yield differentials.

the perfect substitutability of assets in different countries is rejected, interventions in most developed economies have been found to be not effective through the portfolio balance channel. Even in the cases that interventions are effective through the channel, their effects are very small in size and do not last long.

The Signalling Channel

The signalling channel was proposed by Mussa (1981), Kenen (1988), and Almekinders (1995). It became an influential approach with the works of Dominguez (1987), and Dominguez and Frankel (1993). The monetary authorities are assumed to have superior information than other agents of the foreign exchange market. Other participants can only know the superior information through operations of the central banks, e.g., currency interventions. Therefore, exchange rates are affected by the currency interventions through the new information they associate with. To be specific, the interventions change the agents' expectations on the actions and policies of monetary authorities, and hence their expectations on the exchange rates. The main point of the signalling channel can be presented by solving equation (2.1) with the following results:

$$s_t = \frac{1}{(1+\beta)} \sum_{j=0}^{\infty} \frac{\beta^i}{(1+\beta)^{i+1}} E_t(X_{t+j}) + \left(\frac{\beta}{1+\beta}\right)^{t+j+1} E_t\left(s_{t+j+1}\right), \tag{2.2}$$

where currency interventions have impact on exchange rates through the signalling channel if they can convey some information about future values of fundamentals $E_t(X_{t+j})$, or future exchange rate $E_t\left(s_{t+j+1}\right)$.

As a means by which a central bank conveys its inside information to the foreign exchange rate market, a currency intervention is empirically examined whether it is a leading indicator of the change in the monetary policy or influences the exchange rate expectations (Dominguez and Frankel, 1993). Under the efficient market hypothesis, Eijffinger and Gruijters (1991) propose that currency interventions will alter the expectations of the foreign exchange market participants, and therefore have immediate impact on the exchange rates through the signalling channel. They construct a testable regression function of exchange rates with explanatory variables of the interest rate differential and spot market interventions. Under the rational expectations hypothesis, Dominguez (1990) estimates an inverted portfolio balance equation of risk premium with interventions as explanatory variables.

The empirical results of previous signalling channel studies are mixed. While Dominguez (1987) and Dominguez and Frankel (1993) find that sterilised interventions have very substantial effects, Humpage (1989) and Eijffinger and Gruijters (1991) show that they are not effective.

The Coordination Channel

The coordination channel has been proposed by Taylor (1994, 1995) as an independent channel of influence, which is related to studies on the microstructure of the foreign exchange market. Unlike the signalling approach, the central bank is not assumed to be better informed than other foreign exchange market participants. The speculators basing their expectations on fundamental information are often able to coordinate with the central bank. However, amid strong and persistent non-fundamental misalignments of the exchange rates, they may lose their confidence, credibility, or even exhaust their liquidity. Therefore, monetary authorities should use currency interventions as coordination signals to encourage them to re-enter the foreign exchange market. By this means, the orders from the central bank and coordinating speculators may help to stabilize the exchange rate, smooth the exchange rate volatility, or reduce the size of deviation of the exchange rate from its equilibrium rate.

The new coordination approach has attracted some academic interests. Evans and Lyons (2002) use the net amount of foreign exchange orders initiated by buyers and sellers as an indirect measure of the order flows initiated by the central bank, i.e., interventions. They find that the interdealer order flows have significant and substantial effects on exchange rates: An intervention of one billion USD increases the DEM/USD rate by 0.5 percent.

Within the similar microstructure framework of Reitz and Taylor (2008), Reitz and Taylor (2012) empirically test the coordination approach with daily data from the JPY/USD exchange rate market. Spot and real exchange rates, price differentials, and currency interventions are used as the main variables. A smooth transition regression (STR)-GARCH procedure is adopted to estimate the effects of U.S. and Japanese currency interventions from April 1991 to March 2004. The coordination channel was effective in the US: A purchase of one billion USD appreciated the currency by 0.04 percent. However, Japan's Ministry of Finance failed to provide a credible coordination signal to speculators, and hence the exchange rate was not moving towards equilibrium.

Giradin and Lyons (2007) use daily order flows of traders from three different types of institutions to estimate the effects of the Japanese interventions between January 2003 and March 2004. Although non-financial corporations and unleveraged financial institutions shifted their positions according to the intervention direction, leveraged financial institutions, e.g. hedge funds and proprietary trading desks of large banks, did not follow the coordination signals provided by currency interventions. In a similar context, Marsh (2011) examines the behaviour of end-user order flows in the JPY/USD market. He also finds that, while corporate customers were more likely to act with the monetary authority, financial customers tended to be net buyers of JPY on the same days when Japan's Ministry of Finance was intervening to sell yen.

Although the order flow data is often not publicly available[7], the empirical studies related to the coordination channel have shown a promising picture of testing the effectiveness of currency intervention.

[7] In our research, currency futures contract positions are used as proxies for order flows to test their effects on exchange rates.

2.2.3 Estimating Effectiveness of Currency Intervention

Empirical studies on currency intervention are based on different econometric and statistical methodologies. Most of them can be classified into one of the four methodological groups, i.e., low-frequency time series, event study, high-frequency, and identified models.

The Low-Frequency Time Series Method

The low frequency time series method is a standard approach measuring the effects of currency intervention on the exchange rates, and has been widely used since the influential works of Rogoff (1984) and Dominguez and Frankel (1993)[8].

Typical equations to measure the effects of currency intervention include explanatory variables of interventions, interest rates and other variables, e.g., market news, and can be expressed as:

$$s_t = \alpha_1 + \beta_1 X_t + \gamma_1 CI_t + \varepsilon_t, \tag{2.3}$$

$$\triangle s_t = \alpha_2 + \beta_2 X_t + \gamma_2 I_t + \varepsilon_t, \tag{2.4}$$

where s_t is the exchange rate measured by units of domestic currency per foreign currency, normally in logarithm form, I_t and CI_t measure actual interventions and cumulative interventions respectively. X_t is a set of variables measuring changes in monetary policies, bond yields, inflation rates, and other factors which may have impact on exchange rates, e.g., macroeconomic news. The contemporaneous effects of cumulative interventions and actual interventions are interpreted as γ_1 and γ_2 respectively.

Evans and Lyons (2002) propose to use order flow data generated from interdealers as proxies for sterilised secret currency interventions and adopt

[8] Sarno and Taylor (2002) and Neely (2005a) provide a detailed literature review on the traditional low-frequency method.

the following equation:

$$\triangle s_t = \alpha + \beta(i_t - i_t^*) + \gamma x_t + \varepsilon_t, \tag{2.5}$$

where the order flow data x_t is constructed from the net interdealer order flow of buyers and sellers, $i_t - i_t^*$ is the domestic and foreign overnight interest rate differential.

Although the low-frequency approach is good at measuring the exact intervention effects on the exchange rate levels, it has some weak points. Interventions happen sporadically and often in clusters, which makes the effects of interventions hard to measure and interpret. Additionally, it is difficult to justify an inclusion of an explanatory variable as there is little consensus on exchange rate determination models (Obstfeld and Rogoff, 1995). Furthermore, there may exist endogenous relations among the variables, i.e., the simultaneity among changes in exchange rates, interventions and other variables.

Some researchers use the low-frequency approach to analyse the effects of intervention on the volatility of exchange rates[9]. Dominguez (1998) proposes two approaches to analyse the effects of currency intervention on the exchange rate volatility. The first approach is based on a GARCH (1,1) model and expressed as

$$\triangle s_t = \alpha + \beta X_t + \gamma I_t + \delta \sqrt{h_t} \varepsilon_t, \tag{2.6}$$

$$h_t = \phi_0 + \phi_1 \varepsilon_{t-1}^2 + \phi_2 h_{t-1} + \phi_3 I_t + \varepsilon_t, \tag{2.7}$$

$$\varepsilon_t | \, \Omega_{t-1} \sim N(0, h_t, \kappa), \tag{2.8}$$

where $\triangle s_t$ is the change in spot exchange rates measuring exchange rate returns, X_t is a set of variables influencing exchange rate volatility, which may vary in different cases. While I_t is an intervention variable capturing currency interventions known at time t, h_t measures conditional volatility of

[9] The related studies include Baillie and Humpage (1992), Almekinders and Eijffinger (1994), Bonser-Neal and Tanner (1996), Ramaswamy and Samiei (2000), Beine (2003), Frenkel, et al. (2005), Hillebrand and Schnabl (2008), et al.

exchange rates, and ε_t is t-distributed disturbance term with variance h_t and degree of freedom κ.

The second way to measure intervention effects on volatility is based on the implied volatility of option prices:

$$\triangle IV_t = \alpha + \beta X_t + \gamma I_t + IV_{t-1}, \tag{2.9}$$

where $\triangle IV_t$ measures the changes in the exchange rate volatility, and X_t is a set of variables influencing exchange rate volatility.

The GARCH-related volatility research is not subject to option pricing models which implied volatilities depend on, and are computationally simple with available econometric software. However, it does not take into consideration the market expectations embedded in option prices. On the other hand, the implied volatility related studies are subject to the data availability problem because the related option data of many developed economy currencies was available for only a few years, and not available for many developing economy currencies[10].

The Event Study Approach

The event study approach is introduced to deal with the issues related to the sporadic and clustered currency interventions. The key elements of an event study include defining events, windows around the events, and success criteria. An event is defined as interventions in the same direction within a short period. An event window is normally 2, 5, 10, 15, or 30 days to include one or more intervention episodes. The effects of intervention are analysed by comparison of exchange rate behaviour of pre- and post-event windows based on the direction or smoothing criteria (Humpage, 2000).

Based on direction criterion, Fatum and Hutchison (2003, 2006) analyse the German, Japanese and US interventions. They test and find statistically

[10] Currency option markets in many developing countries are not developed or liquid enough to provide suitable data for research.

significant changes in the exchange rates between pre- and post-intervention periods. They also find that the sterilised Japanese currency interventions systemically affect the exchange rate within one month, and large-scale (over $1 billion) and coordinated interventions tend to be effective.

Bordo, Humpage and Schwartz (2009, 2010) analyse the effectiveness of currency intervention using summary statistics, e.g., the percentage of successes and mean changes in the exchange rate. Based on smoothing criteria, they find the differences between pre- and post- event behaviour were statistically significant in some periods of the Volcker-Greenspan era. In other words, with only fleeting effects on the changes in the exchange rate, the US currency interventions might offer a means of calming market disorder.

The event study approach provides a simple but sound technique to measure the effects of sporadic and clustered currency interventions. It focuses on the non-zero observations and does not require exchange rate determination models as the basis for data analysis. Nevertheless, this methodology is not devoid of problems. The definition of an event is not formalized among researchers, which means it is difficult to construct comparable events. The longeval events with large number of continuous interventions are difficult to compare with ephemeral events with smaller number of interventions. At the same time, the methodology provides no hints on the effectiveness of specific transmission channels, and focuses mainly on short-term intervention effects. Furthermore, there is risk of endogenous problems among the variables in the event study models.

The high-Frequency Time Series Approach

The high-frequency time series method uses intraday exchange rates and intervention data to explain the intermediate intervention effects. It may provide more specific information difficult to grasp by low-frequency time series and event studies approaches (Vitale, 2007). However, the main problem vis-a-vis this approach is the limited availability of high-frequency transaction data on currency intervention. The Bank of Canada and the Swiss National Bank are the only central banks that provide intraday transaction data for limited research purposes (Menkhoff, 2010).

Intraday analyses of the interventions in Japan and the US and many other countries are on the basis of press reports, not official intervention data. Goodhart and Hesse (1993) analyse the high-frequency effects of interventions. Their analysis are based on Reuters headline news on the exchange rate quotes in frequency of 30 minutes for 12 weeks. Dominguez (2003, 2006) adopts an event study approach into a 5-minute frequency analysis. She finds that currency interventions have significant price impact and the impact increases with trading volume.

However, the studies based on news reports have some drawbacks as news reports are not always correct and tend to have serious delay (Fischer, 2006). For example, Frenkel, et al. (2004) find that 55% of Japanese currency interventions between January 1995 and December 1999 were not reported by major financial newspapers. Galati et al. (2005) also find that 23% of actual Japanese interventions between September 1993 and April 2000 were not reported by Reuters.

Another problem related to early high-frequency studies is the lack of identification. Simple linear regressions estimated by Payne and Vitale (2003) can not insulate the unexpected intervention effects from other exchange rate innovations. And the event study approach proposed by Fatum and King (2005) is also not free of the endogeneity problem. There is also an inference problem caused by the 'paucity of exact intervention timing' (Neely, 2005a).

Recently, there are some progresses in the high-frequency studies on the Japanese and US interventions. Based on daily transaction data of Japanese currency interventions between 1991 and 2004, Kim (2007) and Kim and Anh (2010) break down a trading day into three time zones, i.e., the Tokyo business hours, the London business hours, and the New York afternoon hours. They find that the interventions conducted during the Tokyo business hours significantly reduced the volatility of the JPY/USD exchange rate and reversed the undesirable trend of the exchange rate during the London and New York business hours. Due to the simultaneity bias, the interventions were not effective during the Tokyo business hours between January 1991 and June 1995: The interventions raised the level of the exchange rate volatility and failed to move the exchange rate towards the right direction. However, between June 1995 and March 2014, the simultaneity bias disappeared and the interventions were also effective during the Tokyo business hours.

In accordance with the microstructure framework proposed by Lyons (2001), some recent studies interpret currency interventions as order flows of a central bank. Giradin and Lyons (2007) analyse the daily effects of Japanese and US interventions with customer order flows of the Citibank, and find interventions significantly impact daily exchange rate levels even with the existence of other order flows. Although their research uses daily data instead of intraday data, it still sheds some light on related high-frequency studies.

The Identified Models

The identified approach explicitly models structural economic relations and identifies the intervention impact on the exchange rate behaviour. Kim (2003) uses an innovative unifying structural VAR framework to jointly analyse the impact of the US currency interventions and conventional monetary policies on the USD index in the post Bretton-Woods period. In order to overcome the omitted variable problem, various macroeconomic variables, e.g., the consumer price index, the Federal Funds rate, the industrial production index and the monetary aggregate are included in the VAR model:

$$\beta(L)\eta_t = u_t, \tag{2.10}$$

where the structural parameters are contained in $\beta(L)$, and the intervention and macroeconomic variables are included in η_t. The following two equations of the reduced form of the VAR model respectively measure the effects of interventions and analyse the reactions of the central bank:

$$s_t = \alpha_1 + \beta_1(L)s_{t-1} + \gamma_1(L)I_{t-1} + \delta_1(L)' X_{t-1} + \varepsilon_{1,t}, \tag{2.11}$$

$$I_t = \alpha_2 + \beta_2(L)s_{t-1} + \gamma_2(L)I_{t-1} + \delta_2(L)' X_{t-1} + \varepsilon_{2,t}, \tag{2.12}$$

where X_t includes a set of different macroeconomic variables.

Kim investigates a rich set of macroeconomic relations, policy interactions, and the interactions between monetary and intervention policies in the VAR model. He finds that currency interventions had more effects on the exchange rate than the conventional monetary policies. The intervention effects were from the signalling channel as the purchases of foreign currencies significantly decreased the future Federal Funds rates and increased the future U.S. monetary base. Kim's paper provides a new way to estimate contemporaneous interactions between currency interventions, monetary policies and exchange rate movements. However, Kim's approach is subject to improvement because some parameters in his VAR model are not identified and even in a wrong rank condition (Neely, 2005b).

Based on the reports on the Japanese and U.S. currency interventions from financial press, Ramaswamy and Samiei (2000) propose a simple cointegrated VAR model to analyse the short-term effects of interventions on the JPY/USD exchange rate with the following error correction form:

$$\triangle s_t = C + \sum_{i=1}^{3} \alpha_i \triangle s_{t-i} + \sum_{i=1}^{3} \beta_i (i_{t-i} - i^{\star}_{t-i}) + \gamma ECM_{t-1} + \sum_{j=1}^{N} I_j + \varepsilon_t, \tag{2.13}$$

where s_t denotes the JPY/USD exchange rate, $i_{t-i} - i^{\star}_{t-i}$ denotes the US and Japanese interest rate differential, ECM_{t-1} presents the long run relationship of exchange rates and interest rates $s_t = 0.165(i_t - i_t) + 0.0003t$, and I_t is an significant dummy variable reflecting specific Japanese and US interventions. They find that interventions had significant effects on the exchange rate. However, their analysis is based on the news reports and a more rigorous cointegrated VAR research based on official intervention data is needed.

Kearns and Rigobon (2005) use a nonlinear intervention model with simulated method of moments to estimate structural breaks of currency interventions. They find that Japanese currency interventions had significant and influential effects on the JPY/USD exchange rate: A sale of one billion USD appreciated JPY by two percent. Based on a friction model, Neely (2005c) estimates a system of equations to identify the cross-effects of interventions on the level and volatility of exchange rates.

The identified models provide a promising approach to analyse the intervention effects on exchange rates. Still at early stage, they are not without their problems and limitations. The models may be improved by taking into consideration the market microstructure and theoretical foundations (Vitale, 2007).

Summary

Although all the four approaches mentioned above offer useful methods of analysing currency interventions, they are with both advantages and disadvantages. In our research, a cointegrated VAR model is built to incorporate theoretical transmission channels and international parity conditions. In our model, both short- and long-term intervention effects are analysed. In order to understand the effectiveness of specific channels, a microstructure model with speculation data is built and tested, which may shed some light on more plausible theoretical models.

2.3 Speculation versus Intervention

Central bank intervention has been a common occurrence in the foreign exchange market. Therefore, currency speculators may adjust their behaviour according to central banks' policy and objectives. Meanwhile, central banks may take account of the expected reactions of the speculators to formulate their intervention policy.

Based on the signalling approach, the sales of the domestic currency signal future monetary easing, which is associated with the depreciation of the currency. To generate a credible signal, central banks are expected to earn profit from the interventions. However, as Dooley and Shafer (1983) noted, 'At worst, central bank intervention would introduce noticeable trends into the evolution of exchange rates and create opportunities for alert private market participants to profit from speculations against the central bank.'

Neumann (1984) further investigates the interventions of the German Federal Bank in the DEM/USD market between1974 and 1981. They find the Western German central bank tried to compress the total risk premium of DEM to reduce the incentive for speculation on DEM. LeBaron (1999) uses the intervention data from the Federal Reserve to analyse the activities of DEM/USD and JPY/USD markets. His empirical results suggest that speculators made money at the expense of central banks during the intervention periods. Ito (2005) uses the net long futures positions on currencies in the Chicago Mercantile Exchange as indicators for currency speculation. He finds that the net long yen positions and interventions had strong correlations: The large net long yen positions occurred with heavy yen-selling interventions. It suggest that the Japanese monetary authorities and currency speculators were at odds to control the direction of the yen.

In summary, both speculations and interventions play important roles in the foreign exchange market. In order to analyse the effects of currency intervention on the exchange rates, suitable speculation variables are needed. However, the limited availability of transaction data on currency speculation is the main hurdle for related empirical research. Therefore, new proxies for currency speculation in the foreign exchange markets are needed to conduct related research.

2.4 Potential Sentiment Measures for the Foreign Exchange Market

Speculative sentiment indices are created given the importance of behaviour of speculators on the effectiveness of currency intervention and the difficulty of measuring the actual volumes of speculation in the foreign exchange market. The indices not only reflect the expectations of speculative traders on the current market situations but also present hints on the overall market sentiment.

There is a large group of literature relating investor sentiment to asset prices and returns. Among early researchers in the area of investor expectations and behaviour, Shiller (2000) states that investor sentiment refers to simple expectations for price change or indicators of these expectations. It is difficult to have precise expectations for future changes over specific horizons. Therefore, it is critical to construct feasible measures of investor sentiment. In the following sections, three main groups of sentiment measures are reviewed.

2.4.1 Direct Sentiment Measures

The first group of indices refers to direct measures based on the surveys of investors, including surveys of the American Association of Individual Investors (AAII), the University of Michigan Consumer Sentiment Index, and the Investors' Intelligence (II) Index.

The direct measures of investor sentiment have important advantages. They tend to be precise as they directly measure the investors' expectations. However, the surveys are not immune from errors with respect to the interviewers, questionnaires or respondents (Groves, 1989). The survey results are often affected by problems relevant to inaccurate responses, non-responses and self-selecting biases of investors. Furthermore, the investors might change their mind shortly after a survey. Another potential problem is related to the low-frequency sampling. Many direct sentiment indices are based on surveys conducted on a monthly or even annual basis, and are not suitable to measure short-term investor sentiment affected by unexpected financial events.

2.4.2 Indirect Sentiment Measures

The second group of indices refers to indirect measures derived from market prices, volumes, or other objectively observable financial data related to sentiment. This group includes the Commitment of Traders (COT) index, the put/call ratio, the long/short interest ratio, and the closed-end funds discount (Pan and Poteshman, 2006).

Indirect sentiment indices are based on financial market data and can be easily constructed. Besides, it is easier to extract high-frequency sentiment and analyse it together with contemporaneous events. Nevertheless, current indirect sentiment indices are with some limits. It is difficult to choose the most relevant dataset out of many options. It is also hard to build up theory-related financial variables because the links between theory and empiricism in indirect sentiment measures are often omitted in current research.

Some indirect sentiment indices are based on the COT reports. The COT indices have been widely used for forecasting purposes in equity markets (Briese, 1994), energy markets, and recently in foreign exchange market (Saettele, 2008). The COT reports on currency futures are released weekly via the Commodity Futures Trading Commission (CFTC). The reports contain detailed information on the futures positons of traders in the Chicago Mercantile Exchange (CME). There are three main groups of traders in the reports: The non-commercials (mainly speculators[11]), commercials (mainly hedgers) and non-reportables (small traders).

Based on the COT reports, Wang (2004) transforms traders' positions

[11] The group of speculators refers mostly to large individuals traders and hedge funds.

into COT sentiment indices which are fairly intuitive and easy to compare across various financial markets. His empirical baseline sentiment model is expressed as

$$R_{t+k} = \alpha_1 + \beta_1 COT_t + e_t, \tag{2.14}$$

where R_{t+k} represents the returns of currency futures over the subsequent k weeks and COT_t is the sentiment index for either hedgers or speculators. He analyses the futures positions on main currencies including GBP, CAD, DEM, JPY, and CHF. His estimation results revealed positive correlations between speculators' sentiment and subsequent futures returns for all of the five currencies: A 1% increase in speculative sentiment was related to a 0.42% annualized return over the subsequent four weeks. The positive performance of speculators was explained by the market risk premium. In other words, the speculators were compensated for the high risk they held.

In summary, the indirect measures have been adopted to analyse the influential effects of sentiment in the financial markets. However, financial theories are still needed to justify the construction of sentiment measures and interpret the related empirical findings.

2.4.3 Big Data Sentiment Measures

In addition to the two standard categories of sentiment indices (Brown and Cliff, 2004; Qiu and Welch, 2004; and Beaumont et al., 2008), the third category of indices, the big data measures, is emerging with the availability of huge information. The measures are based on amalgams of information on big data in financial markets. The section reviews relevant literature about information supply and demand respectively.

Sentiment Measures of Big Data on Information Supply

The link between information supply and market movement has been noted by many economists (Fama and Roll, 1968; Fama et al., 1969). The link has been addressed by the mixture-of-distributions hypothesis (Clark, 1973; Epps and Epps, 1976) which imposes the dependence between volumes and returns on a latent information process. Therefore, the patterns of information supply are reflected by similar patterns in the observed market behaviour.

In order to measure the information effects that are not directly observable, some researchers examine the tones of financial news and quantify investor sentiment from news reports. Klibanoff et al. (1998) analyse salient news appearing on the front page of the New York Times, and find dramatic country-specific news lead some investors to react more quickly and significantly, which affects the prices of the closed-end country funds.

With contents from a daily Wall Street Journal column, Tetlock (2007) uses the method of principal components analysis to quantitatively measure the media pessimism. He finds significant intertemporal interactions between investor sentiment and stock prices: High media pessimism are followed by falling stock market prices and high trading volume. Extending the sample to all stories of the Wall Street Journal and Dow Jones News Service from 1980 to 2004, Tetlock et al. (2008) address the influences of negative words, and find that the accounting earnings and stock returns of a specific S&P 500 firm can be predicted by sentiment measures.

Recently, Uhl (2011) constructs a sentiment index based on a classified Reuters news database and test its correlation with the Dow Jones Industrial Average in a VAR framework. He finds that the sentiment index explains and predicts stock returns better than macroeconomic factors, and the sentiment effects remain significant over months.

Sentiment Measures of Big Data on Information Demand

Another group of big data measures focuses on information demand. As the internet makes information easily accessible at a very low cost, more investors turn to the internet for information they demand. Antweiler and Frank (2004) examine the messages in internet chat rooms related to stocks and characterize the message contents with buy, sell, or hold signals. They find strong correlations between message activity, trading volume and return volatility. Das et al. (2005) study the information flows on stocks by applying language-processing routines to message board posts and news. They create an "eInformation" sentiment measure and find strong relationship between online discussion, news activity, and stock returns. Using statistical and natural language-processing techniques, Das and Chen (2007) exact emotive contents from Yahoo! message board discussions on specific stocks and find similar empirical results.

Information demand can also be measured by the Search Volume Index (SVI) from Google Trends, "which is a real-time daily and weekly index of the volume of queries that users enter into google[12]" (Choi and Varian, 2012). Da, et al. (2011) approximate a novel and direct measure of investor attention using SVI, the aggregate search frequency data in Google. They find positive correlations between SVI and other sentiment measures in a vector autoregression (VAR) framework. They also document that SVI is strongly linked with the sentiment of less sophisticated retail investors, and a positive SVI is correlated with higher stock prices in the short term and price reversals in the long term, which supports the attention theory of Barber and Odean (2008).

Vlastakis and Markellos (2012) use SVI data of 30 largest stocks traded on NYSE and NASDAQ as a proxy for information demand. They find that information demand has significant effects on volatility and volume not only at the individual stock level but also on the overall market level. The effects become especially significant during periods of high returns. As one of the first studies on the big data sentiment in the currency market, Kita and Wang (2012) measure the investor information demand by SVI and examine its effects on exchange rate volatility. They find strong causal effects of

[12] Google is the most popular internet search engine with 65.4% of the US search market share in November 2009 according to the Nielsen Megaview Search Data.

information demands on volatility and strong correlation between information demand and carry trade returns.

In general, the big data measures are based on innovative methods of analysing large amount of financial information, and well-suited for the technological developments and internet applications. Like the indirect measures, a through theoretical foundation is needed to construct a big data sentiment measure.

Summary

This section reviews the main groups of sentiment measures in the financial markets. Although the related research in the foreign exchange market is still at its early stage and not devoid of drawbacks, it may provide a promising way of analysing the effects of currency speculation and sentiment.

2.5 Summary

This chapter reviews the related research on intervention, speculation and sentiment in the foreign exchange market. Based on this review, suggestions for future research in this area are provided.

Currency interventions are not recent phenomena. Numerous research efforts have been devoted into studies on currency intervention in developed country currencies. Meanwhile, research on currency interventions in developing countries is still sparse largely because of data availability problem.

Various methodologies have been used to analyse the intervention effects. However, there is need of research using identified models which provide a structural way of analysing interventions with fundamental variables in one framework. Furthermore, most studies are lack of a theoretical foundation or market microstructure. More research is needed to analyse the interactions of currency interventions, currency values and market conditions in a joint theoretical framework. Based on our review, the studies on the coordination channel and market microstructure, although at their early stage, may provide a promising way in that direction.

Speculation and sentiment play an important role in financial markets, and there are already several group of sentiment indices available for research purposes. However, few researchers have studied the influence of speculation and sentiment on the theoretical channels of interventions. In the same time, there are lack of systematic studies with respect to the effects of sentiment on the exchange rates.

The following chapters, i.e., Chapters 3, 4 and 5, aim to fill the methodological, theoretical and empirical gaps in the field. All the chapters adopt the cointegrated VAR methodology to conduct identified studies on currency intervention, speculation and sentiment. The methodology offers a coherent approach to test different hypotheses of the interactions of various variables and examine their short- and long-term dynamics. Therefore it provides a new way to jointly test reaction functions, separate transmission channels, and speculation effects in one framework, which provides a complete picture of exchange rate dynamics under various market conditions.

While Chapter 3 offers an examination of currency intervention, speculation and sentiment in a microstructure framework based on international parities e.g., PPP, UIP, the following two chapters are based on a new market microstructure model and theoretical set-ups, such as the forward rate bias and central bank credibility. The three transmission channels, especially the coordination channel, and the foreign exchange market microstructure are properly examined. In the meantime, all the three chapters consider the influences of speculation and sentiment, and market conditions on the exchange rate dynamics. In doing so, the three chapters provide systematic analyses of exchange rate dynamics, currency intervention, speculation and sentiment, and market conditions in a joint theoretical framework.

In order to fill the gap with respect to the studies on the developing and emerging market currencies, Chapter 5 presents an analysis on the MXN/USD rate in a similar theoretical and empirical framework as the analysis of the JPY/USD rate. The results across developed and developing countries are compared and summarised in Chapter 6 to provide policy implications for central bankers and suggestions for economic researchers.

Chapter 3

Intervention, Speculation and Sentiment: A Cointegrated VAR Analysis of the JPY/USD Rate

Abstract:

This chapter analyses the effects of currency intervention, speculation and sentiment on the JPY/USD rate between April 1991 and August 2008. Using the identified cointegrated VAR methodology, the research is the first to test the portfolio balance effects of currency intervention in the context of the international parity conditions. It is also the first to address the effects of speculation and effectiveness of the coordination channel with a COT sentiment index.

Main findings of this chapter include: (1) Most hypotheses of the stationary international parities, including UIP and PPP conditions, were rejected. The nonstationarity of the UIP condition is the prerequisite for the effectiveness of the portfolio balance channel. (2) The Japanese interventions had long-term effects on the yen through both the portfolio balance and coordination channels. An intervention of one billion USD is correlated with a monthly change in the exchange rate by 2.5% and 0.8% through the portfolio balance channel and the coordination channel respectively. (3) The Japanese interventions had short-run effects through the coordination channel. (4) The U.S. currency interventions were not effective through either the portfolio balance channel or the coordination channel. Based on the

detailed analysis, we suggest some directions for future research.

3.1 Introduction

During the period between April 1991 and August 2008, the Japanese monetary authorities initiated 340 interventions, 22 of which were coordinated with their US counterparts. In Japan, the interventions were decided by the Ministry of Finance and imposed by the Bank of Japan. While in the US, interventions are decided by the Treasury with consultation of Federal Reserve Board, and then implemented by the Federal Reserve Bank of New York and the Treasury.

This chapter focuses on the effects of currency intervention on the JPY/USD rate with consideration of speculation and sentiment. Although numerous studies have addressed the intervention effects on the currency pair, this chapter is the first to test the effectiveness of the portfolio balance channel in the context of the international parity conditions (Juselius and MacDonald, 2004). With a COT sentiment index, this chapter is also the first to address the speculation effects and effectiveness of the coordination channel in one framework.

The structure of the chapter is organized as follows: After reviewing related literature and theoretical framework, we analyse the effects of currency intervention, speculation and sentiment using the cointegrated VAR methodology. Long-run parity conditions are tested to find whether the Japanese and U.S. interventions provided them with more explanatory power and whether the requirement of the portfolio balance channel is fulfilled with the nonstationary UIP condition. Then the effectiveness of the portfolio balance and coordination channels are examined with consideration of speculative sentiment. The results may form a basis for analysing separate regimes of the Japanese currency intervention.

3.2 Literature Review

Currency intervention is defined as a purchase or sale of foreign currencies by the monetary authorities in order to influence the exchange rate level or volatility. Currency intervention in advanced economies has a long history and dates back to the time when the classical gold standard era was not established (Bordo et al., 2007). After the meetings at Plaza in 1985 and Louvre in 1987, sterilised interventions became regular and sometimes very heavy (Obstfeld, 1990). However, the US and Japanese authorities stopped active currency interventions at 1997 and 2004 respectively (Ito, 2007). This section reviews literature on relevant transmission channels, estimation methods, speculation and indirect sentiment measures with respect to the Japanese and US interventions.

3.2.1 The portfolio Balance and Coordination Channels

Although there were some exceptions in Japan between 2003 and 2004 when the currency interventions and monetary expansions were parallel (Ito, 2007), most currency interventions in Japan, the US, and many other developed countries were sterilised (Sarno and Taylor, 2002). Widely regarded to be independent from monetary policies, sterilised currency interventions offset any changes in the monetary base through immediate open market operations, e.g., buying or selling domestic securities in the opposite direction. While there are three potential transmission channels for sterilised interventions, namely the portfolio balance, signalling, and coordination channels, this chapter focuses on the portfolio balance and coordination channels.

The Portfolio Balance Channel

One assumption of the portfolio balance channel is that the assets in different currencies are not perfect substitutes. Based on the relative expected returns, investors balance their portfolio among the assets denominated in different currencies. Therefore, the assets within the monetary authorities' balance sheets are altered while the monetary base and the domestic interest rates are unchanged. Accordingly, the spot exchange rate shifts in order to affect the domestic value of foreign assets and the expected returns from holding them (Sarno and Taylor, 2002).

There are two types of empirical tests for the portfolio balance channel. The first approach, the direct demand approach, is to test the intervention effects based on a reduced form of the portfolio balance channel, which can be seen as a dynamic exchange rate determination model. However, it is really difficult to choose variables related to the non-monetary assets for the model. Therefore, the second approach, inverted demand approach, is introduced to test the perfect substitutability of domestic and foreign assets based on risk premia[1].

Most studies within the portfolio balance framework, e.g., Kearney and MacDonald (1986), follow the second approach. For example, Loopesko (1984) estimates an equation for risk premia with explanatory variables for exchange rates and currency interventions in the G7 countries. He rejects the hypothesis of perfect asset substitutability and provides some supports for the short-run effectiveness of the portfolio balance channel. Dominguez and Frankel (1993) use survey data to measure expectations on the DEM/USD and CHF/USD rates, and find that currency interventions have significant effects on the risk premia through the portfolio balance channel.

In both papers, risk premia are measured by deviations from the uncovered interest parity and currency interventions reflect the relative stock asset supplies denominated in different currencies. These features mean that the empirical tests on the effectiveness of the portfolio balance channel should take account of the effects on the bond yield differentials and changes in the exchange rates. Although Dominguez and Frankel (1993) provide some

[1]Risk premia can be measured by the deviations from uncovered interest parity based on the changes in exchange rates and bond yield differentials.

empirical supports for the portfolio balance channel, most other studies are not very supportive (Frankel, 1982; Obstfeld, 1983; Rogoff, 1984; and Lewis, 1988). Even the perfect substitutability of assets in different countries is rejected, the interventions were found to be not effective through the portfolio balance channel. In the cases that interventions were effective, their effects were very small in size and did not last long.

The Coordination Channel

The coordination channel has been proposed by Taylor (1994, 1995) as an independent transmission channel which is related to the studies on the microstructure of the foreign exchange market. Unlike the signalling approach, central banks are not assumed to be better informed than other market participants. Speculators trading on fundamental information are often able to coordinate with the central bank. However, amid strong and persistent non-fundamental misalignments of the exchange rates, they may lose confidence, credibility, or even liquidity. Therefore, the monetary authorities should use currency interventions as coordination signals to encourage them to re-enter the foreign exchange market. By this means, the orders from the central bank and coordinating fundamental speculators may help stabilize the exchange rate, smooth the exchange rate volatility, or move the exchange rate towards its equilibrium rate.

The coordination approach has attracted some empirical studies. Evans and Lyons (2002) use the net amount of buyer- and seller-initiated orders as an indirect measure of the order flows initiated by the central bank, i.e., interventions. They find that the interdealer order flows have substantial effects on exchange rates: A purchase of one billion USD increases the DEM/USD exchange rate by 0.5 percent. Reitz and Taylor (2008, 2012) empirically test the coordination approach with daily data from the JPY/USD exchange rate market in a microstructure framework. They adopt a smooth transition regression (STR)-GARCH procedure to estimate the effects of the US and

Japanese currency interventions from April 1991 to March 2004. They find that the coordination channel were effective for the US interventions: A purchase of one billion USD appreciated the currency by 0.04 percent. However, they find that the Japanese interventions failed to provide a credible coordination signal to fundamental speculators, and hence the exchange rate was not moving towards equilibrium.

Instead of estimating with the actual exchange rate data, Giradin and Lyons (2007) use daily customer order flows of traders to estimate the effects of the Japanese interventions between January 2003 and March 2004. Although non-financial corporations and unleveraged financial institutions shifted their positions towards the intervention direction, leveraged financial institutions, e.g., hedge funds and proprietary trading desks of large banks, did not follow the coordination signals. In a similar context, Marsh (2011) examines the behaviour of the end-user order flows in the yen market. He also finds that, while corporate customers were more likely to act with the monetary authority, financial customers were net buyers of JPY on the same days when the Japanese monetary authorities were intervening to sell the yen.

However, the related studies on the coordination channel are normally based on the rder flow data which are often not publicly available. To overcome the problem, this chapter uses futures contract positions in foreign exchange market as proxies for order flows.

3.2.2 Estimation of Effectiveness of Currency Intervention

Empirical studies on currency intervention are based on different econometric and statistical methodologies. Most of them can be classified into one of the four methodological groups, i.e., low-frequency time series, event studies, high-frequency, and identified models. The identified models, although still in their early stage, provide a way of structurally modelling the effects of currency interventions and fundamental variables in one framework. This chapter builds an identified cointegrated VAR model to incorporate both theoretical transmission channels and suitable international parity conditions. In order to understand the effectiveness of specific channels, a microstructure model is built and tested, which sheds more light on future studies.

3.2.3 Speculation versus Intervention

Currency interventions have been a common occurrence in foreign exchange markets. Therefore, currency speculators may adjust their behaviour accordingly. Meanwhile, central banks may consider the expected reactions of currency speculators to formulate their intervention policy.

Based on the signalling approach, current sales of the domestic currency signals future monetary easing and associates with the depreciation of the currency. In order to generate a credible signal, a central bank should earn profit from the interventions. However, while central banks tried to reduce the incentive for unfavourable currency speculation (Neumann, 1984), currency speculators profited at the cost of the central banks (Dooley and Shafer, 1983; LeBaron, 1999).

In summary, both speculation and intervention play important roles in the currency market. In order to identify the intervention effects on the exchange rates, suitable speculation variables are needed for the model. If the data on currency speculation is not available, a proxy for speculation should be created.

3.2.4 The COT Sentiment Measures

Speculative sentiment indices are created to reflect the expectation of speculative traders on the current market situations. The COT-related indices have been widely used to measure sentiment in various financial markets (Briese, 1994; Saettele, 2008). Wang (2004) transforms the trader's positions from the COT reports to a COT sentiment index, and finds strong positive correlation between speculative sentiment and currency futures returns.

3.2.5 Summary

This section briefly reviews the literature on the Japanese and US currency intervention, speculation and sentiment and discusses the previous research on the portfolio balance and coordination channels, methods of estimating intervention effects, speculation and sentiment measures.

3.3 Theoretical Framework: International Parities and Channels of Influence

Most studies on the intervention effects do not identify the effectiveness of specific channels in one coherent framework. This section provides theoretical foundations to jointly test the portfolio balance effects in the context of an international parity framework and address the effects of speculation and sentiment in the framework of the coordination channel.

3.3.1 The International Parities

Juselius and MacDonald (2004) provide a framework of the international parity conditions which are important to analyse the long run relations of price adjustments, interest and exchange rates fluctuations. I will present the parity conditions in this section, and test them with currency intervention, speculation and sentiment in later sections.

As the most well-known international parity, the purchasing power parity (PPP) is based on the idea that two currencies have the same purchasing power for the same goods. The logarithm version of the absolute PPP is

$$ppp_t = s_t - (p_t - p_t^{\star}), \tag{3.1}$$

where ppp_t is often denoted as real exchange rate, P_t and $P_t^{\star}$ are domestic and foreign prices respectively, and S_t is the nominal exchange rate. With a error term ε_t, the relative PPP can be defined as

$$s_t - (p_t - p_t^\star) = \varepsilon_t. \tag{3.2}$$

When PPP holds, the change in the nominal exchange rate has the same sign with the change of the relative price and the real exchange rate should mean-revert.

Under the efficient market hypothesis, market prices should already fully reflect information available to market participants, which makes it impossible for a trader to earn excess returns. The risk neutral agents should expect the expected returns, in terms of the expected exchange rate changes, to be offset by the opportunity cost of holding the assets in different currencies, i.e., the interest rate differential. This condition can be reduced to the uncovered interest rate parity (UIP):

$$E_t(\triangle s_{t+k}) = (i_t - i_t^\star), \tag{3.3}$$

where s_{t+k} is the logarithm of the spot exchange rate at time $t+k$ conditional on the information at time t, i_t is the domestic interest rate at time t with maturity at time $t+k$, and $i_t^\star$ is its foreign counterpart. If the rational expectations hypothesis (REH) exists, then we can derive a testable parity:

$$\triangle s_{t+k} = (i_t - i_t^\star) + u_t, \tag{3.4}$$

where u_t is a white noise error, which means agents do not make systematic forecasting errors.

In the context of the relationship between the spot and forward rates, the risk neutral arbitragers ensure that the exchange rate movements, at the maturity of the underlying assets in the forward markets, is covered by the interest rate differential between the two assets[2], which is presented by the covered interest rate parity (CIP):

$$f_t^{t+k} - s_t = (i_t - i_t^\star), \tag{3.5}$$

[2] For simplicity, we ignore transaction costs.

where f_t^{t+k} is the logarithm of the k-period forward rate[3]. Taylor (1987, 1989), Clinton (1988), and Burnside et al. (2006) find that deviations from CIP are generally small when taking transactions costs into account. However, there were large deviations from CIP in the aftermath of the 2008 financial crisis, which are resulted from the liquidity issues and counterpart risk (Mancini-Griffoli and Ronaldo, 2012).

Based on (3.4) and (3.6), if both the uncovered and covered interest parity hold true, the forward premium $f_t^{t+k} - s_t$ is equal to the expected exchange rate depreciation:

$$f_t^{t+k} - s_t = E_t(\triangle s_{t+k}), \tag{3.6}$$

and equivalently, the forward rate is equal to the expected future spot rate:

$$f_t^{t+k} = E_t(s_{t+k}). \tag{3.7}$$

The term spread parity measures the stationary link between the long- and short-term interests:

$$i_{l,t} - i_{s,t} = \nu_t, \tag{3.8}$$

where $i_{l,t}$ and $i_{s,t}$ are the long- and short-term interest rates respectively, and ν_t is a random error[4].

The interest rates can also be illustrated by the Fisher parity, a composition of real interests and expected price changes, as follows:

$$r_{l,t} = i_{l,t} - E_t(\triangle p_{t+l}), \tag{3.9}$$

$$r_{s,t} = i_{s,t} - E_t(\triangle p_{t+s}), \tag{3.10}$$

[3]The foreign currency is said to be at a forward premium relative to the domestic currency if $f_t^{t+k} > s_t$, forward discount if $f_t^{t+k} > s_t$.

[4]There is no consensus with respect to the stationarity of the term spread parity. Although Campbell and Shiller (1987) propose that the term spread should be stationary, empirical studies, e.g., Campbell (1995) show the existence of non-stationarity.

where $r_{l,t}$ and $r_{s,t}$ are long- and short-term real interest rates respectively, and $E_t(\triangle p_{t+l})$ and $E_t(\triangle p_{t+s})$ measure expected price changes.

Based on rational expectations, the above functions can be transformed into the real interest parity (RIP):

$$r_{b,t} - r_{m,t} = (i_{b,t} - E_t(\triangle p_{t+l})) - (i_{m,t} - E_t(\triangle p_{t+s})) = e_t. \tag{3.11}$$

If the goods prices are sticky, the real interest rate differentials are stationary because the short-term interest rates are set by monetary authorities. However, real interest rate parity does not hold in most cases (Hallwood and MacDonald, 1999).

3.3.2 Risk Premia and the Portfolio Balance Channel

The arbitrageurs in the foreign exchange market equate returns on assets denominated in domestic and foreign currencies:

$$i_t = i_t^{\star} + f_t^{t+k} - s_t. \tag{3.12}$$

Under the CIP condition and the assumption that the domestic and foreign bonds are perfect substitutes, the forward rate should equate to the expected spot exchange rate, which produces the UIP condition:

$$i_t = i_t^{\star} + E_t(s_{t+k}) - s_t. \tag{3.13}$$

If investors do not treat the domestic and foreign bonds as perfect substitutes, the forward rate is different from the expected spot rate by a risk premium rp_t to reflect the extra risk:

$$rp_t = f_t^{t+k} - E_t(s_{t+k}). \tag{3.14}$$

After substituting the risk premium into the UIP condition, we have

$$i_t = i_t^{\star} + E_t(s_{t+k}) - s_t + rp_t, \tag{3.15}$$

or equivalently

$$rp_t = (i_t - i_t^{\star}) - [E_t(s_{t+k}) - s_t]. \tag{3.16}$$

The core feature of the portfolio balance channel is the relative home to foreign bond supplies determined by risk premia (MacDonald, 2007):

$$\frac{B_t}{S_tF_t} = \rho(i_t - i_t^{\star}) - [E_t(s_{t+k}) - s_t], \tag{3.17}$$

where B_t is the domestic bond supply and S_tF_t is the supply of foreign bonds denominated in the domestic currency. The above condition can be inverted and rewritten as

$$(i_t - i_t^{\star}) - [E_t(s_{t+k}) - s_t] = \rho^{-1}(\frac{B_t}{S_tF_t}), \tag{3.18}$$

or a testable inverted demand function:

$$(i_t - i_t^{\star}) - [E_t(s_{t+k}) - s_t] = \alpha_0 + \alpha_1(\frac{B_t}{S_tF_t}) + \epsilon_{t+k}, \tag{3.19}$$

(3.20) can be adopted in the context of currency intervention by replacing the relative bond supplies with the official (cumulative) intervention data (Loopesko,1984; Dominguez and Frankel,1993):

$$(i_t - i_t^{\star}) - [E_t(s_{t+k}) - s_t] = rp_t = \alpha_0 + \alpha_1 I_t + \epsilon_{t+k}, \tag{3.20}$$

or

$$(i_t - i_t^{\star}) - [E_t(s_{t+k}) - s_t] = rp_t = \alpha_0 + \alpha_1 CI_t + \epsilon_{t+k}, \tag{3.21}$$

where I_t and CI_t are the actual and cumulative interventions to depreciate the domestic currency, and $E_t(s_{t+k})$ is constant because the relative bond supply is assumed to have no influence on the expected future exchange rate.

Through the portfolio balance channel, the sterilised interventions change the relative supplies of the domestic and foreign bonds, which alters the risk premia. We can illustrate the mechanism with Japanese currency interventions I_t. We assume that the purpose of interventions is to depreciate Yen against USD, i.e., a higher s_t. The Japanese interventions are financed by temporary sales of Treasury bills to the Bank of Japan, which are in essence prompt issuances of Treasury bills in the market. The Bank of Japan then sterilises the interventions by buying the correspondent US Treasury bills with USD, which causes an excess demand of US Treasury bills. Given the Japanese and US Treasury bills are not perfect substitutes, a higher risk premium rp_t is needed for investors to absorb the excess supplies of the Japanese bonds. The higher risk premium causes an increase in bill rate differential $(i_t - i_t^{\star})$ and spot exchange rate s_t through the following mechanism: The excess supply of Japanese bills tends to raise Japanese bill rate i_t and the excess demand of US bills lowers the US bill rate $i_t^{\star}$, which increases the demand on USD. Given that the expected spot exchange rate $E_t(s_{t+k})$ is unchanged, we can expect that the yen depreciates against the dollar.

3.3.3 Speculation, Microstructure and the Coordination Channel

With the assumption that exchange rates are determined in an order-driven market with heterogeneous agents (Bacchetta and van Wincoop, 2006; De Gauwe and Grimaldi, 2006), this section builds a microstructure model of the coordination channel. Unlike the signalling channel, there is no assumption that the central bank is better informed than private agents. Although the foreign exchange market is a decentralized market, it can still be analysed in a batched and centralized trading structure (Kyle, 1985; Evans and Lyons, 2002) because the batch structure may act as a proxy for the prevailing lack of transparency (Vitale, 1999).

In the Kyle framework, traders demand currency through market orders with an immediate transaction at the best available price. Depending on the demand level of the traders, the market maker fills their orders at an exchange rate shifted from the previous exchange rate. There are three distinctive sources of exchange rate variation, i.e., publicly available information that directly affects the market marker's price-setting decisions, indirect public information that may operate via induced order flows, and order flows unrelated to publicly available information (Reitz and Taylor, 2008 and 2012).

The main assumptions of the microstructure model of the coordination channel are as follows: The change in the exchange rate is determined by, among other sources, the net order flows from the central bank interventions, and the overall trades of the informed and uninformed private speculators, as the market maker can not observe them individually. Therefore, the log-linear function of exchange rate change may be expressed as

$$\triangle s_{t+1} = a^M (D_t^{In} + D_t^{Un}) + \epsilon_{t+1}, \tag{3.22}$$

where a^M denotes a positive coefficient of currency speculation and intervention determined by the market maker, D_t^{In} and D_t^{Un} denote net order flows of the informed and uninformed speculators respectively, and the noise term ϵ_{t+1} captures the direct public information.

3.3.4 Summary

This section builds a theoretical framework for testing the portfolio balance and coordination channels. Following this section, we illustrate the data on intervention, speculation and sentiment in the JPY/USD market and present testing criteria of the transmission channels.

3.4 Data Illustration and Hypothesis Testing Criteria

3.4.1 Data Description and Dummies

The right choice of data and variables is very important for our empirical analysis. Most of our variables are based on the data from the EconWin database. The exceptions are the Japanese and US Intervention data, which are from Bank of Japan and Federal Reserve Economic Data respectively, and the COT data, which is from the Commodity Futures Trading Commission. Japan and U. S. are labelled as home and foreign country respectively. We choose the duration to be from April 1991 to August 2008 for two reasons. Firstly, the official Japanese and US intervention data are jointly available only from April 1991. Secondly, our choice is economically meaningful because the period covers the lost years of Japanese economy and ends at the eve before the global economic recession started in September 2008.

Our initial model consists of the following variables[5]:

s_t= the logarithm of the spot JPY/USD rate[6],

p_t= the logarithm of the Japanese consumer price index,

p_t^*= the logarithm of the US consumer price index,

$r_{b,t}$= the Japanese 10 years bond rate/1200,

$r_{b,t}^*$= the US 10 years bond rate/1200,

$r_{m,t}$= the Japanese 3 months libor rate/1200,

$r_{m,t}^*$= the US 3 months libor rate/1200,

CI_t= the cumulated Japanese currency interventions defined by the net purchases of JPY or sales of USD in unit of billion USD,

CI_t^*= the cumulated US currency interventions defined as total net purchase of Japanese Yen or sales of US Dollar in unit of billion US Dollar,

COT_t= the long to short ratio of speculators' positions on the yen futures from the COT reports of the Chicago Mercantile Exchange.

The graphs of the exchange rate are shown in the upper part of Figure 3.1. We find that the yen appreciated steadily in the early 1990s and then depreciated until late 1998. While the former might be caused by coordinated currency interventions, speculations and the Kobe earthquake in the early 1995, the latter might be the result of continued injections from Bank of Japan to keep the stability of the financial markets. Accordingly, there were two impulses happened in August 1995 and October 1998[7]. The impulse dummy in August 1995 was related to a series of coordinated currency interventions. Except the dummy effects, the differenced exchange rate variable seemed quite stationary, which may suggest $s_t \sim I(1)$.

[5] All original annual interest rate variables (in %) have been divided by 1200 to be comparable with the price variables in logarithm.

[6] The exchange rate measures domestic currency units per unit of foreign currency. In our case, when JPY/USD is down, JPY appreciates against USD.

[7] A dummy is introduced if its standard residual error in the specific period is larger than 3.

The differenced price variables Δp_t and Δp_t^* reflect the inflation levels of Japan and USA respectively. The trend break in April 1997 reflected the sharp slowdown of the Japanese economy caused by a hike of consumption tax rate from 3% to 5%, which ended a short-lived economic recovery. There was a blip dummy in the US inflation rate in September 2006, which was related to the real estate bubbles in US. Based on the inflation graphs of Figure 3.1, both the levels and differences of price variables were not stationary, which might suggest p_t, $p_t^* \sim I(2)$.

$r_{b,t}$ and $r_{b,t}^*$ respectively measure the Japanese and US bond rates with the maturity of 10 years. The Japanese bond rate contained a steady downward trend from 1991 to 1998, and became relatively stable after a short mean shift period. In Figure 3.2, two impulse dummies appeared in the differenced Japanese bond rate in December 1998 and July 2007 to account for the sharp increases in the bond rate from 0.85% to 1.97% and from 0.94% to 1.46% respectively. Except for their effects, the differenced Japanese and US bond rate variables were fairly stationary, which indicated both $r_{b,t}$ and $r_{b,t}^*$ were I(1).

$r_{m,t}$ and $r_{m,t}^*$ stand for the Japanese and US libor rates with the maturity of 3 months[8]. After decreasing steadily in the first half of 1990s and then slowly in the second half with some minor shifts, the Japanese libor rate became steady around zero until 2006. The unusual phenomenon reflected the strong stimulative monetary policies of the Bank of Japan to promote investment and prevent further deterioration of economic conditions. However, this granted little space for the Japanese monetary authorities to impose further stimulative monetary policies. In the differenced US libor rate, there was one impulse dummy in February 2008, which reflected a sharp rate cut from 3.94% to 2.98% to fight for the economic recession. Except for this dummy, the differences of the Japanese and US interest rates in Figure 3.2 look quite stationary, which suggests that the libor rate variables $r_{m,t}$ and $r_{m,t}^*$ may also

[8] We use the federal funds rate to measure the US libor rate.

be I(1).

While the Japanese interventions were quite frequent and in clusters, the US ones were much less active. In our model, CI_t and CI_t^*, instead of I_t and I_t^*, are used for two reasons. Firstly, there were many months between 1991 and 2008 that were without interventions, especially the US ones. If we use I_t and I_t^*, the zero observations may cause our time series analysis hard to implement. Secondly, the cumulated intervention variable can be used to test the effectiveness of portfolio balance channel. CI_t and CI_t^*, in the unit of billion USD, were weakly exogenous variables[9].

COT_t, the long to short ratio of speculators' positions on the yen futures, is used to measure the currency speculation and sentiment because it has a strong contemporaneous relationship with the exchange rate movements (Klitgaard and Weir, 2004). As shown in Figure 3.1, during the 1991-2008 period, there were two peaks of JPY speculation activities in May 1993 and December 2003.

3.4.2 Illustration of International Parity Conditions

In this section, we illustrate the parities vis-a-vis exchange rates, prices and interest rates. In comparison of the mean-adjusted price differentials and nominal exchange rates in Figure 3.1, there are three main features: Firstly, the stochastic trend in the relative price between Japan and the US was downward sloping. Secondly, the nominal exchange rate evolved, with large persistent swings, around a similar trend as price differential. Thirdly, there was a trend break in April 1997 which had dynamic effects on prices and interest rates.

In Figure 3.3, the bond rate differential $i_{b,t}-i_{b,t}^*$ and libor rate differential $i_{m,t}-i_{m,t}^*$ were not stationary, which was related to the non-stationarity of risk premium rp_t. While the term spreads $i_{b,t}-i_{m,t}$ and $i_{b,t}^*-i_{m,t}^*$ showed strong

[9] In a cointergrated VAR model, a weak exogenous variable is a variable which affects long-run relations of other variables, without being influenced by them (Juselius, 2006).

non-stationarity, the Fisher parity conditions might hold true in Figure 3.4.

The graphical analysis reflects the non-stationarity of most parity conditions except the Fisher parity condition[10]. Frydman and Goldberg (2007) and Frydman, et al. (2008) suggest that rational but myopic risk-averse speculators make forecasts based on their imperfect knowledge, which drives the international parity conditions out of stationarity. Using I(2) cointegration tests, Johansen, et al. (2010) provides an empirical support for the imperfect knowledge interpretation of the PPP and long swing puzzles.

3.4.3 Hypothesis Testing Criteria of the Transmission Channels

While most studies on currency intervention do not identify the effectiveness of specific transmission channels in one coherent framework, this section proposes a new way to test them.

The core of the portfolio balance channel is the imperfect substitutability of domestic and foreign assets, which means there exist risk premia rp_t[11] measured by deviations from uncovered interest parity $(i_t - i_t^\star) - \triangle s_{t+1}$. If $(i_t - i_t^\star) \sim I(1)$ and $\triangle s_{t+1} \sim I(0)$, then $(i_t - i_t^\star) - \triangle s_{t+1} \sim I(1)$, which means that there exist risk premia through which the portfolio balance channel can be effective.

With the existence of risk premia, we should expect the interventions to appreciate JPY work through the portfolio balance channel. To be exact, the test of the portfolio balance channels is constructed of two steps. The first step is find the existence of risk premia and second is to find CI_t or $I_t > 0 \Longrightarrow \triangle s_t < 0$.

The main prerequisite for the effectiveness of the coordination channel is that the speculators coordinate with the central bank interventions: The speculation on domestic currency COT_t and currency intervention CI_t move in the same direction[12], e.g., CI_t or $I_t > 0 \Longrightarrow COT_t > 0$. Therefore, we include the

[10] The stationarity tests of parity conditions in the later sections justify our opinion.

[11] Risk premia depend on the relative asset supplies which be presented by the actual interventions I_t or cumulated interventions CI_t .

[12] The variable COT_t is used as a measure of the speculation and sentiment on the yen's appreciation, and

speculation variable COT_t into our model to reveal whether it moves together with currency interventions.

3.4.4 Summary

In this section, related data and parity conditions are illustrated and discussed before rigorous empirical analysis and statistical tests. The testing criteria of the transmission channels are also discussed. In the following sections, after discussion of the methodology adopted for empirical research, a detailed data analysis is presented.

3.5 The Cointegrated VAR Methodology

3.5.1 Introduction

It is very difficult to jointly test the effectiveness of separate transmission channels and effects of currency speculation in one framework. According to our literature review, most empirical studies use single equation regression analysis to measure the effects of intervention with respect to one channel, which has drawbacks of missing the whole structural picture of exchange rate movements and correlations of macroeconomic variables. At the same time, most empirical studies ignore the effects of speculation in the foreign exchange market. As the only research analysing the effects of intervention and speculation and testing transmission channels in one structural framework, this chapter adopts the cointegrated VAR methodology as it offers a coherent approach to test different hypotheses and examine long-run relationships and short-run dynamics.

3.5.2 Nominal-To-Real Transformation

Nominal variables are often modelled as I(2). The Nominal-To-Real transfor-

CI_t or I_t as interventions to appreciate the yen.

mation is to reduce the integration order of nominal variables, and transform them into empirically valid real variables in accordance with long-run price homogeneity while preserving the (polynomially) cointegration relations. After the transformation, we can directly conduct an I(1) analysis in stead of more complicated I(2) one.

We take the PPP-related variables p_t, $p_t^\star$ and s_t as examples. The price variables p_t and $p_t^\star$ are I(2), and therefore their differences$\triangle p_t$ and $\triangle p_t^\star$ are I(1). Given all other initial variables are I(1), we can cointegrate the common stochastic trend of price variables or their combinations of other variables into I(1). Based on economic theories and long-run price homogeneity, the relative prices $(p_t - p_t^\star) \sim I(1)$ and purchasing power parity $(p_t - p_t^\star - s_t) \sim I(1)$ need to be tested.

3.5.3 The Cointegrated VAR I(1) model

Engle and Granger (1987) initiate the concept of cointegration and Error Correction Models (ECM). The following univariate equation:

$$y_t = \alpha y_{t-1} + \beta_1 x_t + \beta_2 x_{t-1} + \mu_t, \tag{3.23}$$

where y_t and x_t are both non-stationary variables and μ_t is a white noise, can be represented as

$$\Delta y_t = \beta_1 \Delta x_t - (1-\alpha)\{y_{t-1} - (\beta_1 + \beta_2) x_{t-1}/(1-\alpha) - \gamma/(1-\alpha)\} + \mu_t, \tag{3.24}$$

where the steady state solution of the first order difference equation is achieved and the terms inside the brackets are the so-called ECM. An positive shock to y at time $t-1$ will decrease Δy_t by the adjustment coefficient $-(1-\alpha)$, which can bring y_t back to the long-run equilibrium.

The VAR model in levels can be re-parameterized to a multivariate ECM model as

$$\Delta X_t = \Pi X_{t-1} + \Sigma \Gamma_i \Delta X_{t-i} + \Phi D_t + \epsilon_t. \tag{3.25}$$

With the assumption that the errors are Gaussian, I start with a baseline VAR (2) model:

$$X_t = \pi_1 X_{t-1} + \pi_2 X_{t-2} + \varepsilon_t, \tag{3.26}$$

where X_t is a p vector of I(1) variables and ε_t is a p vector of white noises. The above equation can be formulated as

$$\Delta X_t = \Pi X_{t-1} + \Gamma \Delta X_{t-1} + \varepsilon_t, \tag{3.27}$$

where $\Pi = \pi_1 + \pi_2 - 1$ and $\Gamma = -\pi_2$.

If X_t is I(1), which means ΔX_t is stationary, Π should not be of full rank to guarantee the consistency of the equation. Hence, either $\Pi = 0$, or it has reduced rank: $\Pi = \alpha\beta'$ where α and β are $p \times r$ matrixes and $r < p$. Thus, under the I(1) hypothesis, the cointegrated VAR model is given by:

$$\Delta X_t = \alpha\beta' X_{t-1} + \Gamma \Delta X_{t-1} + \varepsilon_t, \tag{3.28}$$

where $\beta' X_{t-1}$ is an $r \times 1$ vector of stationary cointegration relations and $\varepsilon_t \sim N_p(0, \Omega)$.

As Theorem 5.1 in Johansen (1996) states, if $|A(z)| = 0$, which implies that $|z| > 1$ or $z = 1$ and $\text{rank}(\Pi) = r$, there exists a $p \times r$ matrix with rank r such that $\Pi = \alpha\beta'$. Therefore, the necessary and sufficient condition that $\Delta X_t - E(\Delta X_t)$ and $\beta' X_t - E(\beta' X_t)$ are stationary is that $\alpha'_\perp (I - \Sigma\Gamma_i)\beta_\perp$ has a full rank.

The individual columns of β define the linear combinations of the variables which are of reduced order of integration, and can be interpreted as the steady state cointegration relations in the system. On the other hand, the rows of α determine the way in which the deviations from the steady state relations influence the short-run dynamics of the dependent variables.

3.5.4 Rank Determination: Cointegration Vector Estimation

One commonly used estimation methods to determine the rank of the model is introduced by Johansen (1988, 1991). The main idea is to obtain a clean long-run adjustment model to estimate the coefficient vectors α and β. After eliminating the short-run effects, a regression of reduced rank is performed. The solution is based on the calculation of the eigenvalues which determine the likelihood value of the estimation. In other words, a likelihood ratio test is undertaken to tell the eigenvalues which are statistically equal to zero from those different from zero. The number of eigenvalues different from zero equals to the number of cointegration relations.

Firstly the residuals R_{0t} and R_{1t} are obtained from regressions of ΔX_t on ΔX_{t-1} and X_{t-1} on ΔX_{t-1}. The auxiliary regressions are defined according to the Frisch-Waugh theorem:

$$\Delta X_t = \hat{B}_1' \Delta X_{t-1} + R_{ot}, \quad (3.29)$$

$$X_{t-1} = \hat{B}_2' \Delta X_{t-1} + R_{1t}, \quad (3.30)$$

where $\hat{B}_1' = S_{02} S_{22}^{-1}$, $\hat{B}_2' = S_{12} S_{22}^{-1}$ and S_{ij} are covariance expressed as $S_{ij} = T^{-1} \Sigma R_{it} R_{jt}'$ for $i, j = 0, 1$. Hence, the concentrated model can be expressed as

$$R_{0t} = \alpha \beta' R_{1t} + error\ terms, \quad (3.31)$$

which is important for understanding both the statistical and economic properties of the VAR model. Accordingly, the "messy" empirical model is transformed into not only a clean statistical model which is also economically interpretable.

The Maximum-likelihood (ML) estimator is derived in two steps. The first step is to derive an estimator of α under the assumption that β and $\beta' R_{1t}$ are known, and transform the ML function into a function of β to calculate the maximizer $\hat{\beta}$. The second step is to solve the likelihood problem by calculating the eigenvalue function $|\lambda S_{11} - S_{10} S_{00}^{-1} S_{01}| = 0$. A solution of β can be found to minimize $|\hat{\Omega}(\beta)|$, from which the eigenvalues $1 > \hat{\lambda}_1 > \cdots > \hat{\lambda}_p > 0$ can be calculated. For a given choice of r, the ML function equals $L_{max}^{-2/T} = |S_{00}| \Pi_{i=1}^{r} (1 - \hat{\lambda}_i)$.

The likelihood test of the hypothesis $H(r^\star) : r \leq r^\star$ for some number $r^\star$ against the general unrestricted model $H(p) : r \leq p$ is given by

$$T(r^\star) = -2lnQ[H(r^\star) | H(p)] = -T \Sigma ln(1 - \hat{\lambda}_i), \quad (3.32)$$

where $T(r^{\star})$ follows a multivariate Dickey-Fuller distribution.

3.5.5 Identification of the Long-Run Structure

The estimated cointegration vectors can not be interpreted if they are not identified in any interpretable way. As a way to identify the vectors, structural tests on the cointegration space can be performed. Unlike the normal tests of a standard linear regression model, it is only possible to impose restrictions on the whole space of β, calculate the likelihood value once more with the restricted vectors, and compare whether the new likelihood value is statistically different from the original one which is asymptotically χ^2-distributed.

There are several types of tests on the long-run structure. A test with some β vectors are known is based on the hypothesis of $\beta = (b, \eta)$, where b is some known vectors and η is the matrix of unrestricted vectors. Furthermore, hypotheses on α can be tested to find whether the deviations from one cointegration relation affect the short-run changes in one specific variable.

3.5.6 Estimation of the Short-Run Dynamics

The cointegration relations are identified as r long-run simultaneous relationships between $p_1$variables which enter the cointegration space at the same time. The short-run equations consist of p equations of p current variables Δx_t, $p(k-1)$ lagged predetermined variables Δx_{t-i}, and r-lagged predetermined equilibrium errors, $(\hat{\beta}^c)' x_{t-1}$.

After the determination of long-run relations, a simple parsimonious structure of the short-run dynamics with lag number 2 can be expressed as

$$A_0 \Delta x_t = A_1 \Delta x_{t-1} + a(\hat{\beta}^c)' x_{t-1} + \mu_{0,a} + \mu_{1,a} t + v_t, \tag{3.33}$$

where $A_1 = A_0 \Gamma_1$, $a = A_0 \alpha$, $\mu_{0,a} = A_0 \mu_0$, $\mu_{1,a} = A_0 \mu_1$ and $v_t = A_0 \varepsilon_t \sim IN_p(0, \Sigma)$.

The parsimonious model is estimated by keeping the cointegration relations fixed, which is justified by the consistency of estimated β. To start out, this system is estimated by imposing $p-1$ just-identifying restrictions on each equation and zero restrictions on the off-diagonal elements of the A_0 matrix, i.e., $A_0 = I$. By doing so, simultaneous effects among variables are disregard. By removing insignificant lagged variables from the system based on F-tests and then insignificant coefficients from the equations based on the likelihood ratio tests, a parsimonious representation of the short-run dynamics can be achieved.

3.5.7 Summary

This section discusses the methodology to analyse the effects of currency intervention and speculation. The cointegrated VAR methodology provides a possible structure to identify possible long-run parity relations and test the effectiveness of intervention after considering the effects of speculation and macroeconomic fundamental variables. It also provides a way to analyse the short-run effects and identify the long-run impact of the intervention, speculation and sentiment.

3.6 Data Analysis with the Cointegrated VAR Methodology

This section implements an analysis on the long-run relations and short-run dynamics in a cointegrated VAR framework for the JPY/USD market from 1991 to 2008. After the basic model setup, we introduce new variables into our model and impose specific restrictions in the extended model. In our case, the model is extended from 5 main variables to 7 main variables with I(2) features considered. Using the prices, interest rates, and intervention variables, we test the long-run international parity conditions and the effectiveness of the portfolio balance channel, and analyse the effects of speculation and sentiment and the effectiveness of the coordination channel.

3.6.1 Choice of Main Variables

The relevant variables is chosen through Nominal-To-Real transformations, and misspecification and rank tests. The software package, Cats in Rats (Dennis et al. 2005) is used to analyse our data.

Basic Model Setup

Based on the 'specific-to-general' principle of choosing variables, we start with a basic variable vector $\{s_t, p_t, p_t^\star, i_{b,t}, i_{b,t}^*, CI_t, CI_t^*\}$. The price variables are included because of their close relationship with the nominal exchange rate. The long-term interest rates, instead of short-term interest rates, are chosen because they are more informative in terms of long-run movements of exchange rates. The intervention variables CI_t and CI_t^* are tested to be weakly exogenous with probability 0.64, which support the idea that interventions are set by the monetary authorities and not pushed by other macroeconomic variables.

There are some I(2) signals in the model related to price variables. Hence, Nominal-To-Real transformations are conducted by first testing whether relative price $(p_t - p_t^\star)$, and real exchange rate $(p_t - p_t^\star - s_t)$[13] are I(1). A necessary condition for $ppp_t \sim I(1)$ is that s_t is I(2) and cointegrated with pp_t. We test whether the condition holds true given its theoretical and empirical importance.

Based on a rank test of the I(2) model, the number of rank is set to be 3 with one $I(1)$ stochastic trend and one $I(2)$ stochastic trend. After imposing the rank condition, we test whether the PPP condition is acceptable in all cointegration relations of the I(2) model based on Johansen and Luetkepohl (2005). The results are mixed: the relative price $pp_t \sim I(1)$ was not rejected with a p-value of 0.09, but $ppp_t \sim I(1)$ was clearly rejected with a p-value of 0.00.

[13] Later pp_t and ppp_t will be used to stand for $(p_t - p_t^\star)$ and $(p_t - p_t^\star - s_t)$ respectively.

Hence my empirical analysis after Nominal-To-Real transformations is based on the following variable vector

$$\left\{pp_t, \triangle p_t,\ s_t,\ i_{b,t},\ i^*_{b,t},\ CI_t,\ CI^*_t\right\} \sim I(1), \tag{3.34}$$

where $\triangle p_t \sim\ I(1)$ is also included to consider the intervention effects on the domestic inflation levels. Based on the ML function with an additional penalising factor related to the number of estimated parameters, the Schwartz and the Hannan-Quinn information criteria suggest the number of lags $k = 2$, which is enough for a quite rich dynamic structure even in a small dimensional system (Juselius, 2006).

Let vector $X_t = \{X_{1,t},\ X_{2,t}\}$ where $X_{1,t}=\left\{pp_t, \triangle p_t,\ s_t,\ i_{b,t},\ i^*_{b,t}\right\}$, and sub-vector of weakly exogenous foreign intervention variables, $X_{2,t} = \{CI_t, CI^*_t\}$. Then our partial error correction representation of $VAR(2)$ model becomes

$$\begin{aligned} \triangle X_{1,t} &= \Gamma_{1,1}\triangle X_{t-1}+\alpha_1\beta' X_{t-1}+A_0\triangle X_{2,t}+\mu_0+\Phi D_t+\varepsilon_{1,t}, \\ \varepsilon_{1,t} &\sim N(0,\Sigma),\ t = 1991:04-2008:08. \end{aligned}$$

Based on the standard residual errors, there are impulse dummies in August 1995, April 1997, October 1998, December 1998, July 2003 and September 2005, which are ...,0,1,0,...dummies measuring permanent shocks. To take account of the trend-break effects of the consumption tax hike in April 1997, a shift dummy is added into the cointegration relations $\beta' X_{t-1}$, which is a ...,0,1,1,1,...dummy measuring a mean shift of the cointegration relations.

To check the statistical adequacy of the small model, some important misspecification test statistics are presented in Table 3.1[14]. We find that the normality[15] and no autocorrelation are rejected at the multivariate level with p-values smaller than 0.05. Given a cointegrated VAR model is robust to moderate AR effects and excess kurtosis, we continue with the current model specification.

[14] The significant test statistics are in bold face.

[15] The non-normality is mostly due to excess kurtosis in the interest rate equations.

Table 3.1: Misspecification and Rank Tests for the Basic Model

Multivariate Test Results					
Autocorrelation:	LM$_1$: $\chi^2(25) = 43.16$ with p-value 0.01				
	LM$_2$: $\chi^2(25) = 41.55$ with p-value 0.02				
Normality:	$\chi^2(10) = 20.30$ with p-value 0.03				
Univariate Test Results					
	$\triangle pp_t$	$\triangle^2 p_t$	$\triangle s_t$	$\triangle i_{b,t}$	$\triangle i^*_{b,t}$
ARCH(2)	0.27	**8.18**	2.84	**10.02**	0.41
Normality	3.38	**9.38**	0.87	**6.24**	2.16
Skewness	0.04	0.50	−0.04	0.00	0.24
Kurtosis	3.50	3.93	3.17	3.75	2.94
Trace tests	$r = 0$	$r = 1$	$r = 2$	$r = 3$	$r = 4$
p-value	0.00	0.00	0.00	0.02	0.22
Modulus of Five Largest Roots					
$r = 4$	1	0.85	0.85	0.62	0.31
$r = 3$	1	1	0.86	0.61	0.30
$r = 2$	1	1	1	0.63	0.28

The cointegration rank divides the variables into r relations towards which the system is adjusting and $p - r$ relations which are pushing the system. In order to determine the cointegration rank, the trace test statistics and the five largest roots of the characteristic polynomial are reported in Table 3.1. While the trace test statistics suggest borderlinely accepting the rank number to be 4, we set the rank number as 3, considering estimated characteristic roots.

I(2) Analysis and Nominal-To-Real Transformation

We examine potential I(2) features with the variable vector $\{s_t,\ p_t,\ p^\star_t,\ i_{b,t},\ i^*_{b,t},\ i_{m,t},\ i^*_{m,t},\ CI_t,\ C$ before conducting a cointegrated I(1) analysis. The I(1) trace tests of Table 3.2 suggest that the rank of the I(1) model can be either 3 or 4 with

Table 3.2: Rank Test Statistics under the I(1) Model Setup

I(1)**:Rank**	0	1	2	3	4	5	6
p-value	0.00	0.00	0.00	**0.06**	**0.17**	0.23	0.26
Modulus of Five Largest Roots							
$r = 5$	1	1	**0.97**	**0.93**	0.84	0.80	0.52
$r = 4$	1	1	1	**0.97**	**0.89**	0.83	0.50
$r = 3$	1	1	1	1	**0.95**	**0.88**	0.53

Table 3.3: Rank Test Statistics under the I(2) Model Setup

$p - r$	r	$s_2 =$	7	6	5	4	3	**2**	1	0
7	0		*	*	*	*	*	*	*	*
6	1			*	*	*	*	*	*	*
5	2				*	*	*	*	*	105.3 [0.12]
4	3					*	*	*	*	62.64 [0.55]
3	**4**						*	**65.12** [0.11]	49.20 [0.13]	37.20 [0.72]
2	5							41.51 [0.21]	26.37 [0.34]	20.11 [0.73]
1	6								11.51 [0.51]	7.99 [0.66]
p-values in brackets. Only p-values ≥ 0.05 are shown here.										

probability 0.06 and 0.17 respectively. However, based on the modulus of the largest roots, there exist two large roots for both rank $r = 3$ or 4, which means that there might be some I(2) features in the model. In order to confirm the existence of the I(2) features, we implement further rank tests for the I(2) model and present the test statistics in Table 3.3. With a p-value of 0.11, we can not reject the I(2) set-up of rank $r = 4$ with one I(1) trend and two I(2) trends.

As the price variables are I(2) processes, Nominal-To-Real transformations are needed to reduce their integration order. By imposing restrictions on all vectors, we find that the relative price $pp_t \sim I(1)$ is not rejected with a p-value

Table 3.4: Misspecification and Rank Tests for the Extended Model

Multivariate Test Results							
Autocorrelation:	LM$_1$: $\chi^2(49) = 73.01$ with p-value 0.02						
	LM$_2$: $\chi^2(49) = 61.01$ with p-value 0.12						
Normality:	$\chi^2(10) = 150.91$ with p-value 0.00						
Univariate Test Results							
	$\triangle pp_t$	$\triangle^2 p_t$	$\triangle s_t$	$\triangle i_{b,t}$	$\triangle i^*_{b,t}$	$\triangle i_{m,t}$	$\triangle i^*_{m,t}$
ARCH(2)	0.06	**8.05**	5.60	**10.22**	0.75	1.19	**11.63**
Normality	2.26	5.32	2.80	**6.07**	1.91	**108.2**	**20.9**
Skewness	0.01	0.36	−0.15	0.03	0.23	0.22	**−0.85**
Kurtosis	3.38	3.53	3.41	3.74	3.02	**8.29**	**4.26**
Trace tests	$r = 0$	$r = 1$	$r = 2$	$r = 3$	$r = 4$	$r = 5$	$r = 6$
p-value	0.00	0.00	0.00	0.00	**0.18**	0.29	0.18
Modulus of Five Largest Roots							
$r = 5$	1	1	0.94	0.94	0.82	0.55	0.34
$r = 4$	1	1	1	0.95	0.88	0.56	0.37
$r = 3$	1	1	1	1	0.91	0.60	0.33

of 0.052, while $ppp_t \sim I(1)$ is rejected with a p-value of 0.00. Therefore, we include the domestic inflation level $\triangle p_t \sim I(1)$ in the variable vector, which becomes

$$\{pp_t, \triangle p_t, s_t, i_{b,t}, i^*_{b,t}, i_{m,t}, i^*_{m,t}, CI, CI^*\} \sim I(1). \quad (3.35)$$

The Unrestricted Extended I(1) Model and Rank Tests

After defining the main variables, we conduct the misspecification and rank tests for the structure of the extended model and summarise the related results in Table 3.4.

At the multivariate level, the p-values of the LM tests with respect to the second order residual autocorrelations is 0.30, which indicates no significant second autocorrelation in my model. However, at the univariate level, there are some ARCH effects in the variables of the Japanese inflation and bond rates, and the US libor rate. From the results of normality tests, there is no normality at the multivariate level with a p-value of 0.0. The finding is supported by the findings at the univariate level that there are significant non-normality in the variables of the Japanese bond rate and US interest rate variables, and excess kurtosis in the libor rate variables. Nevertheless, the extended model shows much better validity than the basic model and is adopted given the robustness of the cointegrated VAR model.

From the rank test statistics and modulus of seven largest roots, the rank of my model is set as 4 with a p-value of 0.18. This means the inclusion of libor rates adds one more long-run stationary relation into the extended model.

Summary

This section sets up our main model. In the following sections, we will test the effects of currency intervention and speculation on the long-term parity conditions and the effectiveness of specific transmission channels.

3.6.2 Testing Hypotheses of Potential Parity Conditions

After imposing the rank condition in the extended model, the hypotheses of the long-run parities are tested to facilitate our search of best hypothetical relations. The hypothesis tests are of the form $\beta = (H\phi_1, \psi_1, \psi_2, \psi_3)$ to test whether a restricted relation $H\phi_1$ is in the β space with other three relations unrestricted. The main test results[16] are reported in Table 3.5.

$\mathcal{H}_{1.1}$ to $\mathcal{H}_{3.2}$ are hypothesis tests on pure parity conditions including the term spread parity ($\mathcal{H}_{1.1}$ and $\mathcal{H}_{1.2}$), the interest rate differential ($\mathcal{H}_{2.1}$ and $\mathcal{H}_{2.2}$), the Fisher parity ($\mathcal{H}_{3.1}$ and $\mathcal{H}_{3.2}$). Most hypotheses are rejected with $p-$values less than 0.05 except the Fisher parity conditions in Japanese case ($\mathcal{H}_{3.1}$ and $\mathcal{H}_{3.2}$) with a trend and trend break considered.

To find more empirically verifiable relations, $\mathcal{H}_{4.1}$ to $\mathcal{H}_{5.3}$ test extended parity relations by adding some variables. On the tests of parities with interest rates, the term spread parity in Japan combining with relative price, trend and trend break ($\mathcal{H}_{4.1}$) and the interest rate differential with some interest rate variables, a trend and trend break ($\mathcal{H}_{4.7}$ and $\mathcal{H}_{4.8}$) are not rejected. The combination of Japanese inflation rate and nominal exchange rate ($\mathcal{H}_{5.1}$) is also not rejected with a p-value of 0.33. Therefore, the hypothesis tests provide me with six candidates for the long-run cointegration relations.

From the above test statistics, most pure long-run parity conditions, including the UIP condition, are rejected, which fulfil the prerequisite for the effectiveness of the portfolio balance channel. We will explore the long-run structure of the extended intervention model and reveal the effectiveness of the portfolio balance channel in more details.

3.6.3 Portfolio balance Channel in a Cointegration Space

Before identifying long-run cointegration relations, we test the long-run weak exogeneity on individual variables to investigate the absence of long-run feed-

[16] The p-values in parentheses are for the hypothesis relations with a trend and trend break in 1997:04.

Table 3.5: Testing the Stationarity of Single Parity Conditions

	pp_t	$\triangle p_t$	$i_{b,t}$	$i^*_{b,t}$	$i_{m,t}$	$i^*_{m,t}$	$p-value$
Test of Term Spread Parity							
$\mathcal{H}_{1.1}$			1		-1		0.00 (0.0)
$\mathcal{H}_{1.2}$				1		-1	0.00 (0.0)
Test of Interest Rate Differential							
$\mathcal{H}_{2.1}$			1	-1			0.00 (0.0)
$\mathcal{H}_{2.2}$					1	-1	0.00 (0.0)
Test of Fisher Parity (Japanese Case)							
$\mathcal{H}_{3.1}$		-1	1				0.00 (**0.27**)
$\mathcal{H}_{3.2}$		-1			1		0.03 (**0.30**)
Tests of Parities with Interest Rates							
$\mathcal{H}_{4.1}$	1		1391 (14)		-1391 (-14)		0.00 (**0.64**)
$\mathcal{H}_{4.2}$	1			980 (0.6)		-980 (-0.6)	0.00 (0.02)
$\mathcal{H}_{4.3}$	1		175 (5.7)	-175 (-5.7)			0.01 (0.02)
$\mathcal{H}_{4.4}$	1				129 (0.06)	-129 (-0.06)	0.00 (0.02)
$\mathcal{H}_{4.5}$			1	-1.07 (-0.85)	-1	0.47 (0.21)	0.00 (0.01)
$\mathcal{H}_{4.6}$			1	0.43 (-0.33)	3.07 (1.76)	-0.43 (-0.33)	0.01 (0.00)
$\mathcal{H}_{4.7}$			1	-1	-6.99 (0.46)	0.64 (0.09)	0.01 (**0.38**)
$\mathcal{H}_{4.8}$			1	0.09 (-0.67)	0.16 (-0.05)	-0.16 (0.05)	0.01 (**0.48**)
Test of Combinations with Exchange Rate							
	$\triangle p_t$	s_t	$i_{b,t}$	$i^*_{b,t}$	$i_{m,t}$	$i^*_{m,t}$	$p-value$
$\mathcal{H}_{5.1}$	1	0.00					**0.33**
$\mathcal{H}_{5.2}$	1	0.00			-1		0.047
$\mathcal{H}_{5.3}$	1	-0.01	-1				0.00

Table 3.6: Tests of Long-Run Weak Exogeneity for the First Extended Model

Critical value	pp_t	$\triangle p_t$	s_t	$i_{b,t}$	$i^*_{b,t}$	$i_{m,t}$	$i^*_{m,t}$
$\chi^2(4) = 9.49$	18.01	78.50	**2.42**	23.29	13.32	41.70	30.35

back effects. This test is formulated as a zero row of α, i.e., H^i_α: $\alpha_{ij}= 0, j = 1, ..., r$. If the hypothesis that the variable x_i does not adjust to the equilibrium errors is accepted, the corresponding variable becomes a driving variable in the model while not being pushed in the system. From Table 3.6, the nominal exchange rate is weakly exogenous with $\chi^2(4) = 2.42$, smaller than the critical value 9.49.

With the consideration of the weakly exogenous exchange rate variable and previous hypothesis test results, we get the following full cointegration structure:

$$H_{full}\text{: } \beta = (H_1\varphi_1, H_2\varphi_2, H_3\varphi_3, H_4\varphi_4),$$

where the design matrices of H_1, H_2, H_3 and H_4 are respectively expressed as

$$\begin{bmatrix} \mathbf{1} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & \mathbf{1} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & \mathbf{-1} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \mathbf{1} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \mathbf{1} & 0 \\ 0 & 0 & 0 & 0 & \mathbf{1} \end{bmatrix}, \begin{bmatrix} 0 & 0 & 0 \\ \mathbf{1} & 0 & 0 \\ 0 & \mathbf{1} & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & \mathbf{1} \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}, \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ \mathbf{1} & 0 & 0 & 0 \\ \mathbf{-1} & 0 & 0 & 0 \\ 0 & \mathbf{1} & 0 & 0 \\ 0 & 0 & \mathbf{1} & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \mathbf{1} \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}, \begin{bmatrix} \mathbf{1} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \mathbf{1} & 0 & 0 & 0 & 0 \\ 0 & 0 & \mathbf{1} & 0 & 0 & 0 \\ 0 & 0 & 0 & \mathbf{1} & 0 & 0 \\ 0 & 0 & 0 & \mathbf{-1} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \mathbf{1} & 0 \\ 0 & 0 & 0 & 0 & 0 & \mathbf{1} \end{bmatrix},$$

where the four design matrices correspond to $\mathcal{H}_{4.1}, \mathcal{H}_{5.1}$, $\mathcal{H}_{4.7}$ and $\mathcal{H}_{4.8}$ respectively. The identified long-run structure is clearly not rejected with a p-value of 0.75.

The first β vector reflects a function of the Japanese term spread, relative price, the Japanese intervention, a trend and its break, and is presented as

$$(i_{b,t} - i_{m,t}) + 0.09(p_t - p_t^*) - 0.001CI_t$$
$$+0.0001T_{97:04} + 0.0001Trend + error = 0, \tag{3.36}$$

which means that the Japanese term spread, i.e., inflation expectation, is negatively related with the domestic price and positively with the US price level and domestic currency interventions.

The second vector is represented by a function of the Japanese inflation, exchange rate, and interventions:

$$\triangle p_t + 0.04s_t + 0.001CI_t + error = 0. \tag{3.37}$$

The main finding is that the Japanese interventions may have direct and significant effects on the nominal exchange rate through the portfolio balance channel, i.e., $CI_t > 0 \Longrightarrow \triangle s_t < 0$. A sale of one billion USD may appreciate the yen by 2.5%[17].

Representing the bond rate differential, libor rates and the US currency interventions, the third relation is expressed as

$$(i_{b,t} - i_{b,t}^*) - 6.88i_{m,t} + 1.12i_{m,t}^* + 0.0001CI_t^* + error = 0, \tag{3.38}$$

where the bond rate differential positively correlated with the Japanese libor rate but negatively with the US one.

The last relationship is about the libor rate differential, relative prices, bond rates, a trend and its break:

$$i_{b,t} - 0.6i_{b,t}^* + 0.02(p_t - p_t^*) - 0.05(i_{m,t} - i_{m,t}^*)$$
$$-0.001T_{97:04} + 0.0001Trend + error = 0, \tag{3.39}$$

[17] The rate of appreciation is calculated by $\frac{0.001}{0.04} * 100\%$.

where the Japanese bond rate is positively related to the US bond rate, libor rate differential and a trend break, and negatively related to the relative price and the trend.

In summary, the Japanese interventions to appreciate JPY, CI_t, may have long-term effects through the portfolio balance channel: A yen-purchasing intervention of one billion USD may appreciate the yen by 2.5%. However, there is no direct findings with respect to the effectiveness of the US interventions through the portfolio balance channel. The next section explores the effects of speculation and sentiment on the exchange rate and whether the interventions work through the coordination channel.

3.6.4 Transmission Channels with Speculation and Sentiment

This section includes the speculation and sentiment variable COT_t into the extended model[18]. Therefore, the new empirical analysis is based on the following variable vector:

$$\{pp_t, \triangle p_t, s_t, i_{b,t}, i^*_{b,t}, CI_t, CI^*_t, COT_t\} \sim I(1). \tag{3.40}$$

We then examine the long-run cointegration relations and short-run dynamics, and analyse the effects of currency intervention, speculation and sentiment through the coordination channel.

Long-term Effectiveness through the Coordination Channel

Based on the rank number=4, we construct a cointegration structure and discuss the two cointegration relations most relevant to the effectiveness of the coordination channel.

[18]The process and results of conducting misspecification and rank tests are similar to the previous sections. Hence we do not illustrate the detailed results here. Instead, we focus on main long-run relations and short-run dynamics related to intervention, specualtion and sentiment.

The first relevant relation focuses on the Japanese interventions and can be expressed as

$$\triangle p_t + 0.003 s_t - 0.0001 COT_t + 0.0001 CI_t + error = 0. \tag{3.41}$$

The above relation offers several interesting findings: Firstly, the Japanese interventions may be effective through the coordination channel, i.e., $CI_t > 0 \Longrightarrow COT_t > 0$. An intervention of one billion USD is correlated with an increase in the speculative sentiment by 1 unit, which means more speculators may coordinate with the Japanese interventions.

Secondly, during the whole period between 1991 and 2008, the overall intervention effects of one billion USD through the portfolio balance and coordination channels was around 3.3% change in the exchange rate[19], with around 0.8% out of the coordination channel.

The second relevant relation is on the long-term effectiveness of the U.S. interventions:

$$1.059 i_{m,t} - i^*_{m,t} - 0.537(i_{b,t} - i^*_{b,t}) - 0.005 COT_t - 0.0001 CI^*_t + error = 0. \tag{3.42}$$

The first finding of this relation is that the U.S. interventions did not work through the coordination channel. A yen-purchasing intervention of one billion USD was correlated with around 0.02 unit decrease of the speculation sentiment on JPY[20]. In other words, less speculators might coordinate with the central bank, $CI^*_t > 0 \Longrightarrow COT_t < 0$. The second finding is in line with the last section that there was no direct effects of the US interventions on the exchange rate.

In summary, by adding the speculation and sentiment variable into our long-term structure, the coordination channel is revealed to be another effective channel of the Japanese currency interventions. However, the US interventions failed to work through either the portfolio balance channel or the coordination channel, and had no direct effects on the exchange rate.

[19] The rate of appreciation is calculated by $\frac{0.0001}{0.003} * 100\%$.

[20] The rate is calculated by $\frac{0.0001}{0.005} * 100\%$.

Table 3.7: Short-Run Dynamics of Intervention, Speculation and Sentiment

	$Dp_{95:08}$	I_t	I_t^*
$\triangle COT_{t+1}$	$*$	0.04 [2.93]	$*$

Short-Run Dynamics of Intervention, Speculation and Sentiment

After analysing the long-term effects of intervention, speculation and sentiment, we present results on the a analysis of the short-run dynamics in Table 3.7[21].There were no short-term effects of the US interventions and the joint interventions in August 1995, i.e., $Dp_{95:08}$. However, the Japanese interventions had positive effects on the speculation and sentiment on JPY. A yen-buying intervention of one billion USD increased the rate of currency speculation and sentiment in the next month by 0.04 unit. In other words, the speculators tended to coordinate the Japanese central bank, which indicate the short-run effectiveness of the Japanese interventions through the coordination channel.

3.7 Summary and Proposal for Future Research

The chapter examines the effects of currency intervention, speculation and sentiment on the JPY/USD rate using the cointegrated VAR methodology. The main results vis-a-vis long-run parity conditions, currency intervention, and speculation and sentiment, are listed as follows:

1. The inclusion of an intervention variable did not increase the explanatory powers of the international parity conditions. Stationarity of most pure international parities, including UIP and PPP conditions, was rejected. This means that the standard parity conditions based on the rational expectations hypothesis were not good fit for the analysis of the JPY/USD rate.

[21] $*$ indicates the related coefficient is not significant with a t-value ≤ 2.6.

2. The Japanese interventions might have long-term significant effects on the exchange rate. An intervention of one billion USD was correlated with overall monthly change in the exchange rate by around 3.3%.

3. The nonstationarity of the UIP condition provided prerequisite for the effectiveness of the portfolio balance channel. The Japanese currency interventions might be effective through this channel: A sale of one billion USD was correlated with an appreciation of the yen by around 2.5%.

4. The Japanese currency interventions might have significant effects on both the long- and short-term JPY/USD rate movements through the coordination channel: An intervention of one billion USD, coordinated with the increasing speculation, was correlated with around 0.8% long-term JPY appreciation. The Japanese monetary authorities also managed to move the short-run speculations by 0.04 unit in the long-to-short JPY speculation ratio.

5. The US interventions were not effective through either the portfolio balance channel or the coordination channel. The sparse and small U.S. interventions during the 1991-2008 period might cause the ineffectiveness of the channels because they reflected that the US monetary authorities were inclined to influence the JPY/USD rate through spot currency interventions.

Based on the results of the chapter, some suggestions are provided on future research on the intervention, speculation and sentiment related to the JPY/USD rate:

1. Because the US interventions were much less frequent and effective compared with the Japanese counterparts, it reasonable to focus the Japanese interventions instead of U.S. ones.

2. As there were many days without any intervention, the whole Japanese intervention period can be separated into several active intervention regimes based on different intervention patterns. Therefore, the interventions in separate regimes can analysed and compared.

3. There might be more factors that influence the effectiveness of currency interventions and movements of the JPY/USD rate. We may include the forward rate bias and exchange rate volatility for future empirical analyses.

Figure 3.1: Exchange Rates, Prices, Speculative Sentiment and PPP

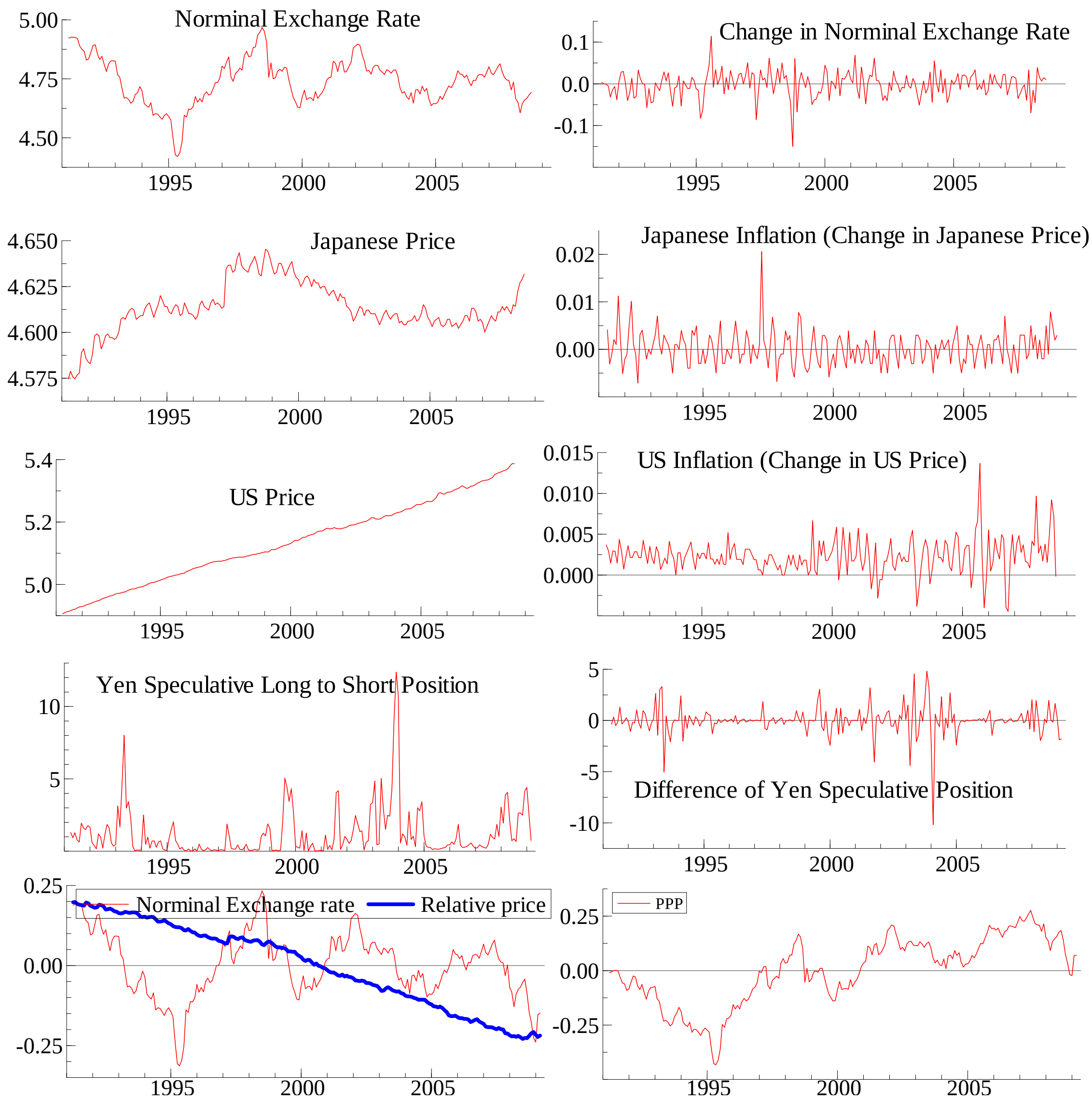


Figure 3.2: Interest Rates and Interventions

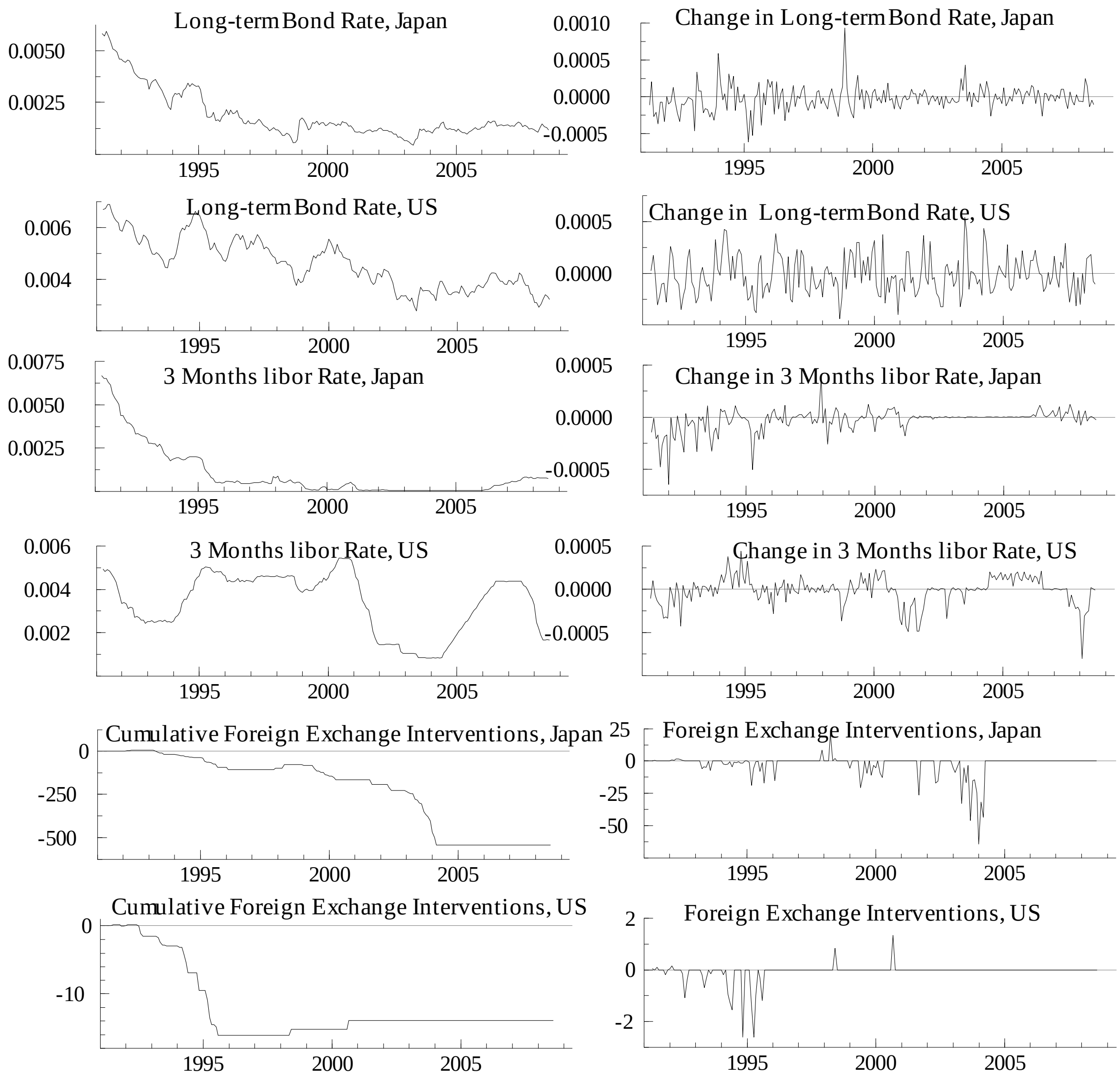


Figure 3.3: Interest rate Differentials

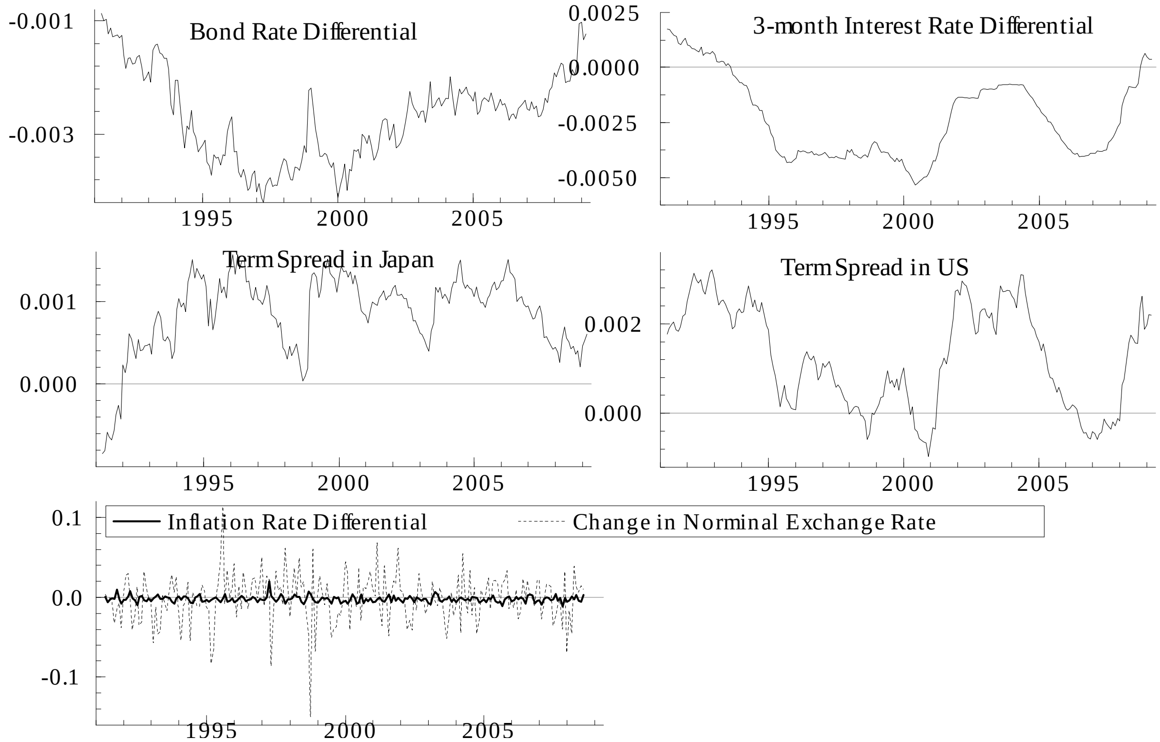
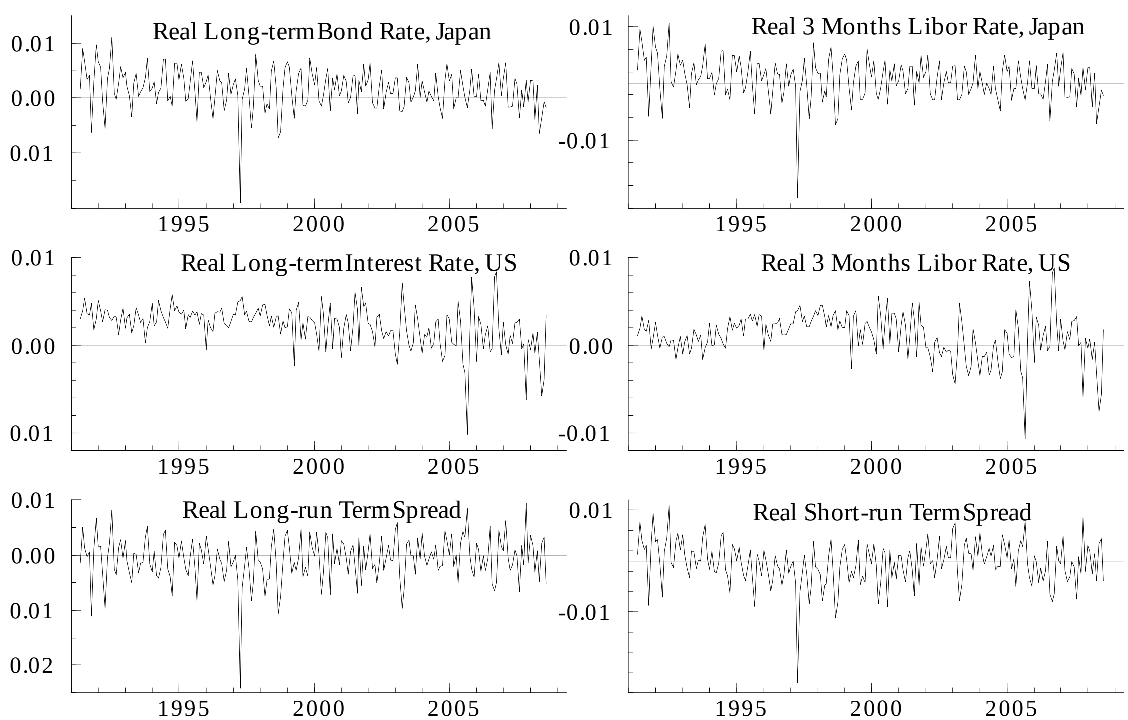


Figure 3.4: Real Interest Rates and Spreads



Chapter 4

Regimes of the Japanese Currency Interventions: A Microstructure Analysis with Speculation and Sentiment

Abstract:

This chapter provides a unique examination of three separate regimes of the Japanese currency interventions between 1991 and 2004. It is the first research to jointly test the co-ordination and signalling channels and the reaction function of central banks in an identified structural framework. The empirical research also involves testing an innovative microstructure framework considering fundamental and sentimental information.

There are several important findings based on the analysis of the paper. Firstly, the shocks to the bond yield differential were the driving force of the dynamics of the JYP/USD rate, and had strong long-run impact on speculation and sentiment. Secondly, with respect to the reaction function of the central bank, the interventions happened in clusters, and were the reactions to the sharp JPY appreciation. Between 2003 and 2004, the central bank also reacted to the large speculation position and high sentiment on the yen's appreciation. Thirdly, the signalling channel was effective when the interventions were frequent. Fourthly,

the speculation and sentiment showed strong effects on the changes in the exchange rate, and the coordination channel worked when the changes in exchange rate volatility were slow.

4.1 Introduction

This chapter analyses the Japanese currency intervention, speculation and sentiment in three separate intervention regimes between 1991 and 2004. It jointly tests the signalling and coordination channels in a structural framework with currency speculation and sentiment, exchange rate volatility and forward exchange rate bias. The empirical research is based on an innovative market microstructure model, and provides new information to unfold the myths of the JPY/USD rate.

This chapter is organized as follows: After providing background information about the regimes of the Japanese interventions, we survey the related literature. Then we build a new theoretical framework and iuse the identified cointegrated VAR methodology to conduct empirical analyses. We examine the effectiveness of the transmission channels, the influence of currency speculation and sentiment, and the reaction function of the Japanese monetary authorities. All the main empirical results are summarised and compared to provide suggestions for related research and policy implications for central banks.

4.2 Japanese Currency Intervention Regimes

Based on the official data of the Japanese currency interventions, the Japanese monetary authorities were active in the spot foreign exchange market after April 1991, and initiated 340 interventions until March 2004. After the active period, the Japanese authorities, led by Yoshihiko Noda, only intervened several times between 15 September 2010 and 4th November 2011 to fight against the sharp appreciation of JPY at the post-war high level, or the excess volatility after the Great East Japan earthquake in March 2011 (Bordo et al., 2012).

The Japanese interventions between 1991 and 2004 showed distinctive characteristics in size and frequency, and could be analysed in separate regimes. We summarise the statistics of the three different intervention regimes in Table 1.

The first regime between 1st April 1991 and 20th June 1995 was featured with small-scale but frequent interventions (Ito, 2005). In the regime, interventions happened in 10.71% days and the average amount per intervention day was 46.96 billion JPY.

The second regime between 21st June 1995 and 14th January 2003 was characterized by very large-scale but infrequent interventions. After Eisuke Sakakibara took charge as Director General of the International Finance Bureau of Ministry of Finance on 21 June 1995, the style of currency intervention was deliberately changed in order to change the level of the exchange rate by influencing the expectation and sentiment of the market (Sakakibara, 2000). Haruhiko Kuroda continued with the similar strategy while he was in charge of interventions between 8th July 1999 and 14th January 2003 (Ito and Yabu, 2007). In general, interventions only happened in 1.77% days of the days, but the amount per intervention day was increased to 519.5 billion JPY.

The third regime started on 15th January 2003 and continued until 16th March 2004. Featured with large-scale and highly frequent interventions, the regime was labeled as the "Great Intervention" (Taylor, 2006). When Zenbee Mizoguchi took charge of currency interventions, the precarious economic condition in Japan[1] forced him to take more active approach towards currency interventions. The frequent and large-scale interventions were to prevent the yen's sharp appreciation by moderating its appreciation speed so that the stagnant economy can be back on a recovery track. During the 2003-2004 period, interventions happened on 30.28% of total days, and the amount per

[1] The stock prices were in deep decline and the market mood was near-crisis.

Table 4.1: Japan's Intervention Regimes

Regimes	Regime 1	Regime 2	Regime 3
Intervention Days	165	49	129
Total Days	1541	2765	426
Ratio of Intervention Days	10.71%	1.77%	30.28%
Total Intervention Amounts	7747.9	25455.4	35256.4
Amounts per intervention day	46.96	519.50	273.31
Source of Intervention Data: Ministry of Finance, Japan			
Note: The unit of intervention data is billion yen.			

intervention day was 273.31 billion JPY.

In summary, this section presents the three intervention regimes of Japanese in details. Before we analyse them separately, we will review the related literature about the transmission channels, estimation methodology of the currency intervention, speculation and sentiment, and build a new microstructure framework.

4.3 Theoretical Framework of Currency Intervention, Speculation and Sentiment

This section sets up a theoretical framework to test the effectiveness of currency intervention through the signalling and coordination channels. A distinctive feature of our framework is the inclusion of the forward rate bias, speculation and sentiment. The section is organized as follows: The forward JPY/USD exchange rate bias is presented and adopted for tests of the signalling channel. The coordination channel and the reaction function of central banks are based on a market microstructure considering exchange rate volatility, speculation and sentiment. We conclude the section with empirical testing criteria.

4.3.1 Forward Rate Bias, Central Bank Credibility and the Signalling Channel

The section builds a framework for the signnalling channel. We discuss the forward rate bias and the central bank credibility which play important roles in testing the effectiveness of the signalling channel.

Forward Rate Bias

This section focuses on the forward premium puzzle caused by the bias of the forward exchange rate. Under the efficient market hypothesis, the risk neutral agents expect the future spot rate to be equal to the forward rate:

$$f_t^{t+k} = E_t(s_{t+k}). \tag{4.1}$$

In addition, if the agents form their expectations rationally, the future spot exchange rate can be expressed as

$$s_{t+k}= E_t(s_{t+k}) + \epsilon_{t+k}, \tag{4.2}$$

where $E_t(\epsilon_{t+k}) = 0$.

Accordingly, a prediction equation of future spot rate can be formed as

$$s_{t+k}= f_t^{t+k}+\epsilon_{t+k}, \tag{4.3}$$

or equivalently

$$(s_{t+k}-s_t) = (f_t^{t+k}-s_t) + \epsilon_{t+k}, \tag{4.4}$$

where $(s_{t+k}-s_t)$ denotes the change in the spot rate from period t to $t+k$, and $(f_t^{t+k} - s_t)$ is the forward premium or discount. The above equation can then be transformed into a testable regression function:

$$(s_{t+k}-s_t) = \alpha + \beta(f_t^{t+k}-s_t) + \epsilon_{t+k}. \tag{4.5}$$

If the forward contracts mature in the next period, the above regression function can be written as

$$(s_{t+1}-s_t) = \alpha + \beta(f_t^{t+1}-s_t) + \epsilon_{t+1}. \tag{4.6}$$

If the CIP condition holds, we have another function

$$(s_{t+1}-s_t) = \alpha + \beta(i_t-i_t^*) + \epsilon_{t+1}. \tag{4.7}$$

Under the joint market efficiency conditions, $(f_t^{t+1}-s_t)$ is a unbiased predictor, i.e., $\alpha = 0$ and $\beta = 1$. However, based on a vast amount of empirical studies for different currencies and time periods, there is little support for the forward rate unbiasedness, i.e., the coefficient $\beta << 1$, which is referred as the forward premium puzzle or forward rate bias puzzle (MacDonald and Taylor, 1989; Engel, 1996).

Using monthly data sample between December 1996 and April 2004, Frankel and Poonawala (2010) find that the pooled slope β estimates were negative for developed country currencies: The exchange rates not only failed to move in the direction indicated by forward discount, but moved in the opposite direction. Loring and Lucey (2013) confirm that the β estimate of JPY/USD was negative from December 1996 to September 2010, which is adopted as a stylized fact for later tests on the effectiveness of the signalling channel.

Central Bank Credibility

If the information is incomplete, market agents may depend on the near-term exchange rate movements as indications for future exchange rate movements. They may continue purchasing an appreciating currency or selling an depreciating currency, which enforces the exchange rate misalignments and increases exchange rate volatility. Therefore, the signalling channel works if currency interventions change the agents' expectations on the exchange rate movements.

Under the main hypothesis that central banks have information advantages (Humpage, 1986), they are expected to make profits through currency interventions at the expense of speculators against the monetary authority (Friedman, 1953). Therefore, the interventions without profits may fail to generate creditable signals to change the expectations of market agents and caused the ineffectiveness of the signalling channel.

We use the Japanese interventions to illustrate the above mechanism. The aim of currency intervention is to depreciate JPY. If the market agents expect the yen to depreciate, i.e., $(E_t(s_{t+1}|I_t) - s_t) > 0$, based on the new information through interventions, we can say that the Japanese interventions work efficiently through the signalling channel. In order to generate a creditable signal, Bank of Japan should make profits from the interventions, at least in the long-term. Here, I propose to use the following profit function to measure the central bank's profits:

$$\pi_K = \sum_{k=1}^{K} \left[I_k(s_t - s_k) - (i_k - i_k^{\star}) \sum_{j=1}^{K} I_j \right], \tag{4.8}$$

where π_K denotes the overall profits that the Japanese monetary authorities earn from the interventions between periods 1 and K, I_k denotes the amount of USD purchased during the period k, $(s_t - s_k)$ measures the change in the JPY/USD exchange rate, and $(i_k - i_k^{\star})$ denotes the short-term Japanese and U.S. interest rate differential, which measures the interest rate costs of Japanese intervention or the divergence of the Japanese and U.S. monetary policies.

If we focus one period ahead expected profit $E_t(\pi_{t+1})$ after the intervention, the above profit equation can be simplified as

$$E_t(\pi_{t+1}) = I_t \left[(E_t(s_{t+1}) - s_t) - (i_t - i_t^{\star}) \right], \tag{4.9}$$

where the change in the agents' expectations $((E_t(s_{t+1}|I_t) - s_t)$ is replaced by $(E_t(s_{t+1}) - s_t)$, the Japanese central bank's expected change in the exchange rate, because the two parties will have same information after interventions.

In general, the effectiveness of the signalling channel tends to increase with the profit probability of the central bank. Profitability is a criterion on the credibility of currency intervention, one important prerequisite for the effectiveness of the signalling channel. However, it is not for measuring the effects of currency intervention, especially when the central bank aims to stabilize the exchange rate (Edison, 1993).

Summary

Based on the above discussions, if the Japanese interventions are to depreciate JPY, e.g., $\triangle s_{t+1} > 0$, the prerequisite for the effectiveness of the signalling channel is that the market agents expect the yen to depreciate, i.e., $(E_t(s_{t+1}|I_t) - s_t) > 0$ or $(f_t^{t+1} - s_t) < 0$ with the existence of the forward rate bias. As the profitability of the currency interventions increases the credibility of the central banks, the criterion $(i_t - i_t^*) < 0$ may support the effectiveness of the signalling channel.

4.3.2 Market Microstructure Model of the Coordination Channel and Reaction Function

Introduction

The section starts with presention of one influential model of the coordination channel, then builds a new model with consideration of exchange rate volatility, speculation and sentiment, which provides theoretical foundation for studies on the coordination channel and reaction function.

The Reitz and Taylor Model

With the assumption that exchange rates are determined in an order-driven market with heterogeneous agents (Bacchetta and van Wincoop, 2006; De Gauwe and Grimaldi, 2006), Reitz and Taylor (2008 and 2012) build a microstructure model of the coordination channel. Unlike the signalling channel, there is no assumption that the central bank is better informed than private agents. Although the foreign exchange market is a decentralised dealer market, it can still be analysed in a batched and centralized trading structure

(Kyle, 1985; Evans and Lyons, 2002) because the batch structure may act as a proxy for the prevailing lack of information transparency (Vitale, 1999).

In the Kyle framework, traders demand currency through market orders which are filled immediately at the best available price. Depending on the demand level of the traders, the market maker fills the orders at an exchange rate divergent from the previous rate. There are three distinctive sources of exchange rate variation, i.e., publicly available information that directly affects the market marker's price-setting decisions, indirect public information that may operate via induced order flows, and order flows unrelated to publicly available information.

The main assumption of the microstructure model of the coordination channel is as follows: Changes in the exchange rate are determined by, among other sources, the net order flows from the central bank interventions, and the overall trades of the informed and uninformed speculators, as the market maker can not observe them individually. Therefore, the log-linear function of changes in the exchange rate can be expressed as

$$\triangle s_{t+1} = a^M (D_t^{In} + D_t^{Un}) + \epsilon_{t+1}, \tag{4.10}$$

where a^M denotes positive coefficient of speculation and intervention determined by the market maker, D_t^{In} and D_t^{Un} respectively denote the net order flows of the informed and uninformed speculators, and the noise term ϵ_{t+1} captures direct public information.

Speculators are assumed to be rational and risk-neutral. They take orders depending on their expected excess returns which consist of the expected changes in the exchange rate and the interest rate differentials. However, speculators many different expections of the exchange rate based on the same information.

Informed traders form their expectations of future exchange rate changes $\triangle s_{t+1}$ based on their analysis of fundamental information[2]. The order flows

[2] Reitz and Taylor propose to use the time-varying long-run equilibrium exchange rate ppp_t as fundamental

from informed speculators reduce the deviation $ppp_t - s_t$ and revert the exchange rate towards its long-run equilibrium with a time-varying coefficient w_t. Correlated with the confidence of the informed speculators in fundamentals, w_t is expressed as a function of past performances as well as interventions. Therefore, with the weighting coefficient w_t, the orders of informed speculators are determined by the deviations from the real exchange rate, or relative prices, and interest rate differentials:

$$D_t^{In} = a^I w_t(ppp_t - s_t) + b^{In}(i_t^* - i_t) = a^{In} w_t(p_t^\star - p_t) + b^{In}(i_t^* - i_t). \tag{4.11}$$

Uninformed speculators are assumed to be lack of complete information with respect to the underlining economic fundamentals, and may derive their orders from chartist or technical trading rules (Sager and Taylor, 2006). Given that the forecasting devices of most trading rules are based on historical exchange rates, with consideration of the interest rate differential, the following order equation is proposed by Reitz and Taylor (2008, 2012):

$$D_t^{Un} = a^{Un}(\triangle s_t) + b^{Un}(i_t^* - i_t). \tag{4.12}$$

In summary, the Reitz and Taylor model provides a simple but elegant microstructure for the coordination channel. However, their model has some limitations. Firstly, most studies have failed to support the existence of the purchasing power parity. Even if the relative prices $p_t^\star - p_t$ measures the deviations $ppp_t - s_t$, the CPI data are only available monthly[3], which makes it difficult to implement a high frequency analysis. Therefore, further studies on the microstructure of the coordination channel are still needed.

A new Microstructure Framework

With consideration of exchange rate volatility, speculation and sentiment, the

information.

[3] One exception is daily online price index from http://www.pricestats.com/. However, the data starts from 2007, and only the US and Argentina series are publicly available.

section builds a new market microstructure model based on Reitz and Taylor (2008 and 2012). The model provides theoretical foundations to explain the mechanism of the coordination channel and the reaction function of central banks.

There are several assumptions for our market microstructure model:

1. Exchange rates are determined in an order-driven market with heterogeneous agents (Bacchetta and van Wincoop, 2006; De Gauwe and Grimaldi, 2006).

2. The main purposes of the central banks' interventions are, with the coordination of speculators, to appreciate the domestic currency amid its sharp depreciation (or vice versa), or reduce exchange rate volatility.

3. Central banks are informed about economic fundamentals. However, there is no requirement for central banks to have information advantages over other market agents. The order flow of central bank convey indirect information reflecting economic fundamentals.

4. Speculators are rational and risk-neutral and can be classified into two groups, i.e., informed speculators and uninformed speculators. The market maker can not observe their individual orders but the overall trades of the informed and uninformed private speculator.

5. Informed speculators make their expectation of exchange rate change and volatility based on the direct fundamental information in the near future, e.g., prices, interest rates, and indirect information from the central bank activities, e.g. interventions. Unlike Reitz and Taylor (2008, 2012), informed speculators do not have information on long-term equilibrium exchange rate, e.g., real exchange rates.

The index i is used to represents the types of agents in the foreign exchange market, i.e., $i = M$ for overall orders of informed and uninformed speculators,

$i = In$ for informed speculators, $i = Un$ for uninformed speculators, and $i = A$ for central banks. The change in the exchange rate $\triangle s_{t+1}$ is determined by, among other sources, the net order flows from the central bank interventions, and the overall trades of the informed and uninformed private speculators $(D_t^{In}+D_t^{Un})$, as the market maker can not observe them individually. Therefore, the log-linear function of exchange rate change may be expressed as

$$\triangle s_{t+1}= a_t^M(D_t^{In}+D_t^{Un})+\epsilon_{t+1}, \tag{4.13}$$

where $a^M > 0$ denotes positive effects of speculations and intervention determined by the market maker, D_t^{In} and D_t^{Un} denote the net order flows of informed and uninformed speculators respectively, and the noise term ϵ_{t+1} captures effects of the direct public information.

We propose to use a variant type of standard mean-variance function (Engel, 1996) to express the order flows of informed speculators D_t^{In} with respect to risk-adjusted excess returns. The informed speculators are assumed to have direct short-term fundamental information and indirect information from the central bank activities, but not information on the long-term real exchange rates.

The order flows D_t^{In} increase with $\left[(E_t^{In}(s_{t+1}) - s_t) - (i_t - i_t^*)\right]$, the expected excess return rate, and decrease with the rate of expected exchange rate volatility $\triangle\sigma_t^{In}(s_{t+1})$. The expectations of excess returns can be separated into the expected exchange rate variation $E_t^{In}(s_{t+1}){-}s_t$, and the interest rate differential $(i_t^* - i_t)$. The variation $\left[E_t^{In}(s_{t+1}) - s_t\right]$ can be interpreted as a temporary deviation exploitable by speculators.

Without intervention effects, the initial speculation volume can be expressed as

$$D_t^{In}= a_t^{In}\left[E_t^{In}(s_{t+1}) - s_t\right] +b_t^{In}(i_t^* - i_t) + c_t^{In}\left[\triangle\sigma_t^{In}(s_{t+1})\right], \tag{4.14}$$

where a_t^{In}, b_t^{In} and c_t^{In} respectively measure the effects of the expected exchange rate variation, interest rate differential, and volatility on the speculation volume D_t^i at time t. According to the assumptions, we expect $a_t^{In} > 0$, $b_t^{In} > 0$ and

$c_t^{In} < 0$ so that informed speculators can maximise their risk-adjusted profits based on available information.

New fundamental information from the interventions I_t affects the informed speculators' expectations on the future spot exchange rate $E_t^{In}(s_{t+1})$ and volatility $\triangle\sigma_t^{In}(s_{t+1})$. With the existence of interventions, the order flows of informed speculators can be updated to

$$D_t^{In}= a_t^{In}\left[E_t^{In}(s_{t+1}|I_t) - s_t\right] + b_t^{In}(i_t^*-i_t) + c_t^{In}\left[\triangle\sigma_t^{In}(s_{t+1}|I_t)\right], \tag{4.15}$$

where $a_t^{In} > 0$, $b_t^{In} > 0$ and $c_t^{In} < 0$. If currency interventions effectively raise their expected exchange rate level $\left[E_t^{In}(s_{t+1}|I_t) - s_t\right]$, and reduce the rate of expected volatility $\triangle\sigma_t^{In}(s_{t+1}|I_t)$, informed speculators are likely to increase their positions in the direction of interventions. In other words, informed speculators tend to coordinate with currency interventions with increasing $E_t^{In}(s_{t+1}|I_t)$ and decreasing $\triangle\sigma_t^{In}(s_{t+1}|I_t) < \triangle\sigma_t^{In}(s_{t+1})$, vice versa.

In our framework, uninformed speculators are lack of fundamental information on both the long-term equilibrium exchange rate, and short-term exchange rate level and volatility. They tend to rely on chartist or technical trading strategies, rather than the publicly available information and information provided by interventions. Sager and Taylor (2006) find that many curreny managers derive their orders from chartist or technical trading rules based on historical exchange rates. Taylor and Allen (1992) also observe that a large mount of uninformed traders follow trend-following extrapolative strategies.

With consideration of the interest rate differential, we follow the proposition from Reitz and Taylor (2008, 2012) and express the order flows of uninformed speculators as

$$D_t^{Un}= a^{Un}(\triangle s_t) + b^{Un}(i_t^* - i_t), \tag{4.16}$$

where both a_t^{Un} and $b_t^{Un} > 0$, which means that the order flows of unformed speculators are positively correlated with changes in the exchange rate and the interest rate differential.

From the above equation, currency interventions have no effects on the order flows of uninformed speculators. In other words, the interventions have little impact on the behaviour of uninformed speculators. In order to work through the coordination channel, central banks have to coordinate with informed speculators.

We then model the orders of the central bank, interventions I_t, with a central bank reaction function to shed light on the behaviour of the central banks and to test certain theories related to currency interventions.

The central bank is assumed to implement 'leaning against the wind' interventions, i.e., the central bank buys (sells) foreign currency when the domestic currency has appreciated (depreciated). Fore example, most Japanese interventions fall in this group. The Japanese monetary authorities buy USD amid appreciation of JPY against USD. The central bank may also react if they expect the exchange rate volatility increase in the next period, $\triangle\sigma_t^A(s_{t+1})> 0$. Furthermore, the central bank may coordinate with the informed and uninformed speculators who are biding in the same direction, $(D_t^{In} + D_t^{Un})$. Therefore, the central bank's reaction function can be expressed as

$$I_t= \gamma_t(\triangle s_t) + \delta_t \left[\triangle\sigma_t^A(s_{t+1})\right] +\zeta_t(D_t^{In} + D_t^{Un}), \tag{4.17}$$

where I_t denotes the amount of interventions at time t, $\gamma_t< 0$ as the central bank bank implements 'leaning against wind' interventions, $\delta_t> 0$ to reflect the positive reaction of the interventions to the expected volatility changes, and $\zeta_t> 0$ to present the coordinations between the central bank and speculators.

Based on the stylised fact, the β estimates of the JPY/USD rate were always negative from December 1996 to September 2010. Accordingly, if the explanatory variable of the expected change in the exchange rate $[E_t^{In}(s_{t+1}|I_t) - s_t]$ is replaced by $\vartheta_t(f_t^{t+1}-s_t)$, we should expect the sign of the coefficient ϑ_t to be negative.

We can further assume that the central bank and informed speculators have the same expected volatility, i.e., $\sigma_t^A(s_{t+1}) = \triangle\sigma_t^{In}(s_{t+1}|I_t) = \sigma_t(s_{t+1})$. $\sigma_t(s_{t+1})$

can be represented by the implied volatility IV_t, which measures the expected exchange rate volatility implicit in currency option prices (Dominguez, 1998). IV_t not only provides an unbiased estimate for the expected exchange rate volatility if the options are efficiently priced but also measures the long-term exchange volatility as it is calculated from options that expire in future.

After considering the forward rate bias and implied volatility, the new microstructure model is concluded with the following equations:

$$\triangle s_{t+1} = a_t^M (D_t^{In} + D_t^{Un}) + \epsilon_{t+1}, \tag{4.18}$$

$$D_t^{In} = a_t^{In} \vartheta_t (f_t^{t+1} - s_t) + b_t^{In} (i_t^* - i_t) + c_t^{In} [\triangle IV_t], \tag{4.19}$$

$$D_t^{Un} = a^{Un} (\triangle s_t) + b^{Un} (i_t^* - i_t), \tag{4.20}$$

$$I_t = \gamma_t (\triangle s_t) + \delta_t [\triangle IV_t] + \zeta_t (D_t^{In} + D_t^{Un}), \tag{4.21}$$

where a_t^M, a_t^{In}, b_t^{In}, a_t^{Un}, b_t^{Un}, δ_t and $\zeta_t > 0$; ϑ_t, c_t^{In}, and $\gamma_t < 0$.

Therefore, based on the above setups with the forward rate bias and implied volatility, we can present empirical testing criteria for the effectiveness of the coordination channel. If the Japanese currency interventions are with commitment of depreciating domestic currency, $\triangle s_{t+1} > 0$, the main criteria is that $(D_t^I + D_t^U) > 0$.

As it is only informed speculators that are supposed to coordinate with the information provided by the central bank, we should expect that $D_t^{In} > 0$. However, as the orders of informed speculators and uninformed ones are assumed to be indistinguishable, we can not find the real volume of D_t^{In}. Therefore, the following supporting criteria, i.e., $(i_t - i_t^*) < 0$, $(f_t^{t+1} - s_t) < 0$ and $\triangle IV_t < 0$ may support the effectiveness of the coordination channel. With respect to the reaction function of the central bank, we assume expect to find $\triangle s_t < 0$, $\triangle IV_t > 0$, $(D_t^{In} + D_t^{Un}) < 0$.

As mentioned in the literature review section, actual speculation data is not always available and sentiment measures may be needed as proxies. We can use the COT sentiment index, COT_t, defined by the net long speculators'

Table 4.2: Test Criterion of Currency Intervention

Channel	Main Criteria	Supporting Criterion
Signalling	$(f_t^{t+1} - s_t) < 0$	$(i_t - i_t^*) < 0$
Coordination	$COT_t < 0$	$(i_t - i_t^*) < 0, (f_t^{t+1} - s_t) < 0, \triangle IV_t < 0$
Reaction Function:	$\triangle s_t < 0, \triangle IV_t > 0, COT_t > 0$	

positions on JPY futures from the Commitments of Traders reports as a measure of the total speculations on the decrease in the JPY/USD rate, i.e., $-(D_t^I + D_t^U)$. Hence, the equtions (3.18) and (3.21) are changed to

$$\triangle s_{t+1} = -a_t^M COT_t + \epsilon_{t+1}, \tag{4.22}$$

$$I_t = \gamma_t(\triangle s_t) + \delta_t [\triangle IV_t] - \zeta_t COT_t. \tag{4.23}$$

Accordingly, the main testing criterion of the coordination channel becomes $COT_t < 0$ and, for the reaction function, $\triangle s_t < 0$, $\triangle IV_t > 0$, $COT_t > 0$ may be needed.

4.3.3 Testing Criteria for Channels and Reaction function

This section summarises the testing criteria for the effectiveness of the signalling and coordination channels and the factors attributable to the reactions of central banks. Table 4.2 lists the testing criteria for transmission channels and reaction function if the Japanese currency interventions are with commitment of depreciating JPY.

For the effectiveness of the signalling approach, the main criterion is that forward and spot rate differential decreases. Meanwhile, the main prerequisite of the effectiveness of the coordination channel is that speculators coordinate with the central bank's interventions. In other words, the speculation on JPY appreciation decreases, $COT_t < 0$, with the interventions.

It seems that the effectiveness of the signalling and coordination channels are related as both $(f_t^{t+1} - s_t) < 0$ and $(i_t - i_t^*) < 0$ increase the possibility of excess returns for the speculators. Accordingly, they may be more willing to coordinate with the central bank. At the same time, the decrease of expected change of volatility, measured by the change of the implied volatility $\triangle IV_t < 0$, may reduce the risk of the speculation and support the coordination of speculators and the central bank.

Table 4.2 also shows the test criteria for the central bank's reaction function. The tests are to find whether the Japanese monetary authorities were responding to the yen's sharp appreciation, $\triangle s_t < 0$, excess exchange rate volatility, $\triangle IV_t > 0$, or increase in speculation on the yen's appreciation, $COT_t > 0$.

After the theoretical discussions, the following sections present the cointegrated VAR methodology and conduct related empirical analysis for separate intervention regimes.

4.4 Variable Description of the Three Regimes

The first issue for empirical analysis is the right choice of variables. Based on our previous empirical findings, it is important to include a variable on currency speculation and sentiment into the analysis together with the fundamental variables such as exchange rates, long- and short-term interest rates. If the relevant data on the forward rate bias and exchange rate volatility is available, it is useful to consider them given their importance in the microstructure model. Accordingly, the main variables we consider are as follows:

$\triangle s_t =$ the weekly percentage change in the spot JPY/USD rate[4],

$(f_t^{t+1} - s_t) =$ the weekly forward premium rate[5],

$(i_{s,t} - i^*_{s,t}) =$ the difference of the Japanese and US treasury bill rates with maturity of 3 months,

[4]The variable is in the form of 100 times the differential of logarithm of the exchange rate in terms of the units of JPY per USD.

[5]It is measured by 100 times the difference between the logarithm of the forward rate with maturity of one week and the logarithm of the spot exchange rate

$(i_{l,t} - i^*_{l,t})$ = the difference of the Japanese and US treasury bond rates with maturity of 10 years,

$\triangle IV_t$= the weekly percentage change in the implied volatility of the JPY/USD rate,

I_t = the weekly amount of the Japanese currency interventions to depreciate JPY, defined as a purchase of USD in unit of billion USD,

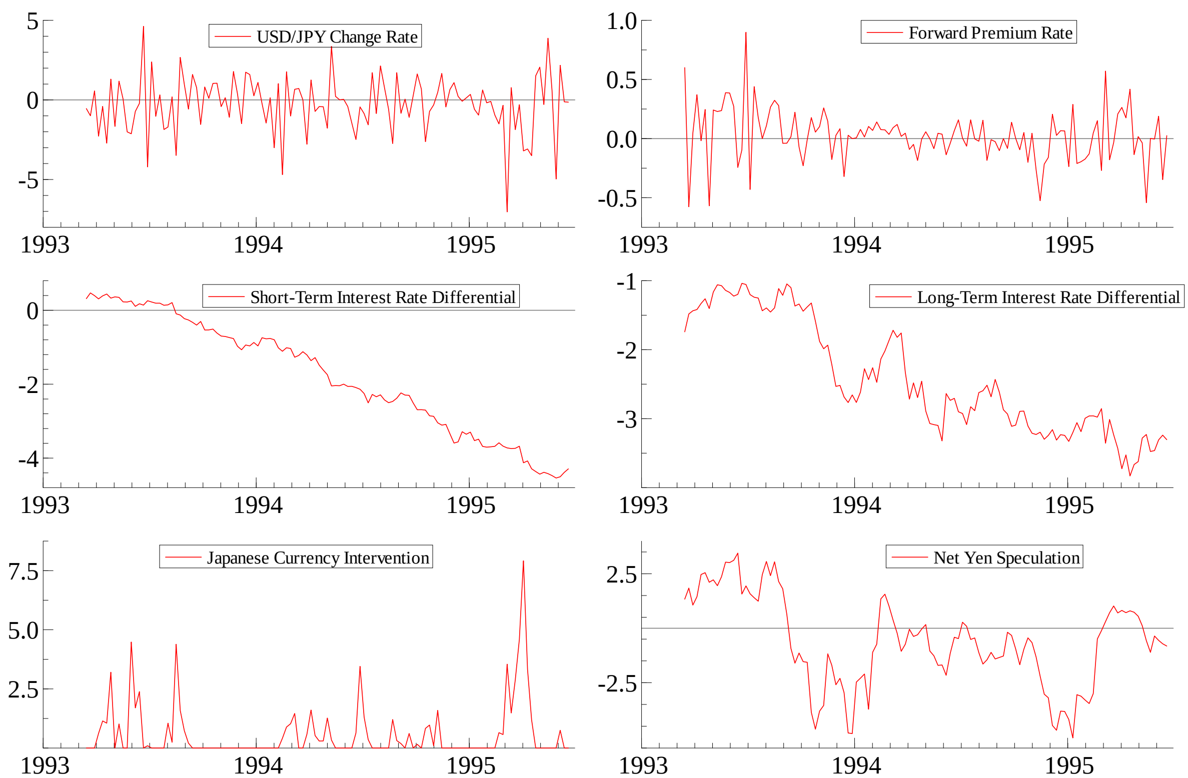
COT_t= the weekly net long speculators' positions on JPY futures from Commitments of Traders reports of the Chicago Mercantile Exchange, which is a good measure of the total speculations on decrease of the JPY/USD rate, i.e., $-(D^I_t + D^U_t)$, and the sentiment of speculators[6].

The main data source is Bloomberg because it provides data in weekly frequency which is not available from traditional sources like International Financial Statistics of IMF. The exceptions are the intervention data, which is from Japan's Ministry of Finance, and the speculation and sentiment which is based on the data from the US Commodity Futures Trading Commission. All the data is based on the end-of-the-day values on Tuesdays in order to accommodate the COT reports which breakdown the JPY futures positions every Tuesday.

The following sections provide a detailed cointegrated VAR analysis to find the long-run relations, short-run dynamics, and long-run impact of the currency intervention, speculation and sentiment. The analysis is conducted in different regimes of the Japanese currency interventions to identify the factors that the Japanese monteary authorities reacted to, the channels through which the interventions were effective.

[6] COT_t measures the speculation activities in the foreign exchange market as it has a strong contemporaneous relationship with exchange rate movements (Klitgaard and Weir, 2004). Meanwhile, central banks have used it as a quantitative measure to assess speculative activities in the currency market (Ito, 2005). As a widely used indirect sentiment index, COT_t can also measure the sentiment of currency speculators (Wang, 2004).

Figure 4.1: Main Variables in the First Regime, 1993-1995



4.5 Analysis of the First Intervention Regime

4.5.1 Variable Description and Model Setup

For the first regime between 1st April 1991 and 20th June 1995, our analysis covers the period from 16th March 1993 to 20th June 1995 and uses the following variables: $\triangle s_t$, $(f_t^{t+1} - s_t)$, $(i_{s,t} - i^*_{s,t})$, $(i_{l,t} - i^*_{l,t})$, I_t, and COT_t are considered[7].

In Figure 1, changs in the JPY/USD rate and the forward premia were stationary around zero expect for the period between 1993 and 1995. The short- and long-term interest rate differentials both had downward trends, which meant that the Japanese interest rates decreased more than the U.S. ones. Given the Japanese interventions happened quite frequently, I_t is used

[7] The volatility data was not available between 1st April 1991 and 20th June 1995. While the data on the weekly short-term interest rates was only available from 29th March 1992, there was no intervention between March 1992 and March 1993.

instead of the cumulated interventions. Meanwhile, the speculation and sentiment variable COT_t had big swings in this period, with a double-bottom pattern appearing at the end of 1993 and 1994.

The empirical analysis with the variable vector $X_t \sim I(1)$, is based on the maximal value of the likelihood function with an additional penalising factor related to the number of estimated parameters. The Schwartz and the Hannan-Quinn information criteria suggest the number of lags to be 2. Accordingly, the error correction representation for our VAR(2) model becomes

$$\begin{aligned} \triangle \mathrm{X}_t &= \Gamma \triangle \mathrm{X}_{t-1} + \alpha_1 \beta' \mathrm{X}_{t-1} + \mu_0 + \Phi \mathrm{D}_t + \varepsilon_{1,t}, \\ \varepsilon_{1,t} &\sim N(0, \Sigma),\ t = 1993:03:16 - 1995:06:20. \end{aligned}$$

Based on the standard residual errors, there were impulse dummies, namely dum930427p and dum950307p, on 27th April 1993 and 7th March 1995, which are ...,0,1,0,...dummies measuring permanent shocks on the forward premia and exchange rates.

Table 4.3 presents some important multivariate and univariate misspecification test statistics, with significant test statistics in bold face. Based on LM tests, there was no serious residual autocorrelation at the multivariate level with p-value of larger than 0.05. This result was supported at the univariate level as only the forward premia showed some sign of ARCH effects. However, normality was rejected at the multivariate level with p-value of 0. The non-normality was mainly due to excess kurtosis in the forward premium, currency intervention, and speculation and sentiment. Given a cointegrated VAR model is robust to moderate AR e⊠ects and excess kurtosis, the current model specification is kept for further analysis.

The cointegration rank divides the variables into r stationary relations towards which the system is adjusting and $p - r$ nonstationary relations which are pushing the system[8]. We first report the degrees of integration of each

[8]According to main assumptions of a cointegrated VAR model, we should expect to find r stationary

variable based on the ADF unit root tests. If the t-statistics larger than the critical value 2.89, we reject the null hypothesis of unit root at the 5% level of significance, which indicates that the respective variable is stationary I(0). If not, the variable is nonstationary I(1). Accordingly, we find that $\triangle s_t$, $(f_t^{t+1}-s_t)$, I_t ~ $I(0)$ and $(i_{s,t}-i^*_{s,t})$, $(i_{l,t}-i^*_{l,t})$, COT_t ~ $I(1)$. Table 4.3 also reports the trace test statistics which suggest accepting $r=3$[9].

We conduct tests of weak exogeneity on individual variables to investigate the absence of the feed-back effects. If the hypothesis that the variable X_i does not adjust to the equilibrium errors is accepted, the corresponding variable becomes a driving variable in the model while not being pushed in the system. We find that the short- and long-term interest rate differentials are weakly exogenous with their χ^2 test statistics 2.438 and 2.577 smaller than the critical value 7.82.

4.5.2 Testing Transmission Channels and Reaction Function

This section tests hypotheses on transmission channels of currency intervention and the reaction function of the central bank after imposing $r=3$. The hypothesis tests are in the form of $\beta=(H\phi_1,\psi_1,\psi_2)$, where the relation $H\phi_1$ is restricted and other two relations ψ_1 and ψ_2 are unrestricted. This procedure facilitates the search of best hypothetical relations. We can find the main results on the hypothesis tests in Table 4.4.

$H_{1.1.1}$ to $H_{1.1.4}$ are hypothesis tests on the effectiveness of the signalling channel. The tests are based on the variables of forward premia $(f_t^{t+1}-s_t)$, interest rate differentials $(i_{s,t}-i^*_{s,t})$ and $(i_{l,t}-i^*_{l,t})$, and interventions I_t. We find that, combined with effects of interest rate differentials, the increase in currency intervention was significantly correlated with an increase in forward premia. Therefore, the results rejected the long-run effectiveness of the sig-

variables without unit root and p-r variables with a unit root.

[9] The rank test results confirm our findings based on ADF unit root tests. In the remaining sections of my thesis, similar ADF and rank tests are adopted to help us find right number of cointegrating vectors.

Table 4.3: Misspecification and Rank Tests, 1993-1995

Multivariate Misspecification Tests						
Autocorrelation:	LM$_1$: $\chi^2(36) = 30.70$ with p-value 0.72					
	LM$_2$: $\chi^2(36) = 28.45$ with p-value 0.81					
Normality:	$\chi^2(12) = 130.60$ with p-value 0.00					
Univariate Misspecification Tests						
	$\triangle^2 s_t$	$\triangle(f_t^{t+1} - s_t)$	$\triangle(i_{s,t} - i^*_{s,t})$	$\triangle(i_{l,t} - i^*_{l,t})$	$\triangle I_t$	$\triangle COT_t$
ARCH(2)	0.93	**16.79**	0.47	3.61	2.72	0.10
Normality	4.18	**9.60**	1.10	3.34	**118.26**	**6.32**
Skewness	-0.19	-0.07	-0.17	0.04	**2.53**	0.20
Kurtosis	3.69	**4.24**	3.15	3.58	**12.56**	**3.94**
Univariate Stationarity Tests						
	$\triangle s_t$	$(f_t^{t+1} - s_t)$	$(i_{s,t} - i^*_{s,t})$	$(i_{l,t} - i^*_{l,t})$	I_t	COT_t
Unit Root	**13.12**	**11.41**	0.11	1.33	**6.04**	2.29
Process	$I(0)$	$I(0)$	$I(1)$	$I(1)$	$I(0)$	$I(1)$
Rank Tests						
	$r = 0$	$r = 1$	$r = 2$	$r = 3$	$r = 4$	$r = 5$
p-value	0.00	0.00	0.014	**0.31**	0.39	0.69

Table 4.4: Testing Stationarity of Single Relations, 1993-1995

	$\triangle s_t$	$(f_t^{t+1} - s_t)$	$(i_{s,t} - i^*_{s,t})$	$(i_{l,t} - i^*_{l,t})$	I_t	COT_t	*Trend*	*p-value*
Tests on the Signalling Channel								
$H_{1.1.1}$		1	-0.044		-0.091			0.851
$H_{1.1.2}$		1	0.024		-0.083		0.003	0.861
$H_{1.1.3}$		1	-0.023	-0.042	-0.080			0.904
$H_{1.1.4}$		1	0.037	-0.039	-0.075		0.003	1
Tests on the Coordination Channel								
$H_{1.2.1}$					-4.353	1		0.533
$H_{1.2.2}$					-3.237	1	0.028	0.891
Tests on the Reaction Function								
$H_{1.3.1}$	2.381				1	0.119		0.989
$H_{1.3.2}$	5.279				1	0.675	0.014	0.983

nalling channel in the 1993-1995 period.

The tests of the effectiveness of the coordination channel were related to the $H_{1.2.1}$ and $H_{1.2.2}$. With an increase in yen-depreciating currency intervention, currency speculation COT_t increased, which was against the effectiveness of the coordination channel.

The tests on the reaction function of the central bank, $H_{1.3.1}$ and $H_{1.3.2}$, are to find whether the central bank react to the yen's appreciation, $\triangle s_t < 0$, or the increasing speculation and sentiment, $COT_t > 0$. We find that the interventions were reacting to the JPY appreciation. However, the central bank implemented more interventions when speculation and sentiment on JPY were low.

All the above hypotheses are not rejected with the p-value larger than 0.05. The hypothesis tests provide candidates for the long-run cointegration relations. Based on the test results, we will identify the long-run structure to reveal the reaction function and the effectiveness of the transmission channels.

Table 4.5: Identified Long-Run Structure, 1993-1995

	$\triangle s_t$	$(f_t^{t+1} - s_t)$	$(i_{s,t} - i_{s,t}^*)$	$(i_{l,t} - i_{l,t}^*)$	I_t	COT_t	$Trend$
$ecm_{1,t}$		1	-0.021	-0.047	-0.075		
$ecm_{2,t}$				-1.263	-2.836	1	
$ecm_{3,t}$	3.527				1	0.349	0.007

4.5.3 Identified Long-Run Structure

The search of a well-specified long-run structure is based on the Π matrix of the unrestricted model and the previous hypothesis tests. We adopt the automatic procedure "CATS Mining" of the tailor made toolbox, CATS in RATS, version 2 (Dennis, et. al., 2005), to facilitate our seach of most feasible long-run structure. The algorithm is based on Omtzigt (2002) for constructing long run structures with CATS. It begins with the most restricted relations, adds new varialbes into cointegrating vectors only until stationarity is obtained, and reports all plausible restricted models with potential cointegrating relations[10].

We then manually select our models based on the following criteria: Firstly, the p-value of the candidate should be normally larger than 0.20 to ensure the stability of the cointegrating vectors which is essential for being economically meaningful (Juselius, 2006). Secondly, the sign of coefficients of the long-run relations should be the same as our theory and hypothesis tests suggest. Finally, the absolute values of the coefficients should be reasonable, not extravagant.

Based on the Cats-mined results and our selection criteria, we accept the cointegration structure listed in Table 4.5 with a p-value of 0.77.

The first long-run cointegration relation focuses on the effectiveness of the

[10] For more technical details of the algorithm, please refer to the section B.8 of Dennis, et. al. (2005) and Omtzigt (2002).

signalling channel:

$$(f_t^{t+1} - s_t) - 0.021(i_{s,t} - i^*_{s,t}) - 0.047(i_{l,t} - i^*_{l,t}) - 0.075 I_t + error\ term = 0. \tag{4.24}$$

The interpretation is that the forward premium rate is positively related to currency intervention and the short- and long-term interest rate differentials. According to the testing criteria in Table 4.2, the positive relationship between the forward premium rate and currency intervention meant that the signalling channel was not effective between 1993 and 1995.

The second relation is mainly about the effectiveness of the coordination channel:

$$COT_t - 1.263(i_{l,t} - i^*_{l,t}) - 2.836 I_t + error\ term = 0. \tag{4.25}$$

The speculation and sentiment variable COT_t was positively correlated with currency intervention. In other words, an increase in currency intervention was related to an increase in speculation and sentiment. Therefore, in the first regime the main criterion of the effectiveness of the coordination channel was not fulfilled.

The third relation reveals the central bank's long-run reaction function:

$$I_t + 3.527 \triangle s_t + 0.349 COT_t + 0.007 Trend + error\ term = 0. \tag{4.26}$$

The Japanese interventions were negatively correlated with changes in the JPY/USD exchange rate, which supported the 'leaning against the wind' assumption. However, the negative relation between currency intervention and the speculation and sentiment variable meant that interventions were not reactions to the speculation and sentiment on JPY.

In summary, between 1993 and 1995, there was no supportive evidence for the long-run effectiveness of the signalling and coordination channels. The Japanese central bank reacted to the yen's appreciation with 'leaning against the wind' interventions. There were no evidence that the central bank implemented interventions against the speculation and sentiment on JPY.

Table 4.6: Short-Run Dynamics,1993- 995

	$\triangle^2 s_t$	$\triangle(f_t^{t+1} - s_t)$	$\triangle I_t$	$\triangle COT_t$
$\triangle^2 s_{t-1}$				0.033
$\triangle(f_{t-1}^t - s_{t-1})$	-0.888	0.142	0.559	
$\triangle(i_{s,t-1} - i^*_{s,t-1})$			-1.114	
$\triangle(i_{l,t-1} - i^*_{l,t-1})$			-1.144	
$\triangle I_{t-1}$	0.230			
$ecm_{1,t-1}$		-1.237		1.310
$ecm_{2,t-1}$		0.019	0.204	
$ecm_{3,t-1}$	0.380			
Constant		0.172	-0.168	-0.214
dum930427p		-0.666	2.002	
dum950307p	-6.09	0.537	2.283	
Notes: The coefficients are significant with p<0.05.				
The *ecm* variables represent (4.24)- (4.26) respectively.				

4.5.4 Short-Run Dynamics

After identification of the long-run structure, we analyse the short-run dynamics and summarise the key results in Table 4.6. We discuss the second, fourth and fifth columns of the table because they are closely related to the transmission channels and the reaction function.

The second column showed that the Japanese currency interventions were effective: an intervention of one billion USD reduced the rate of JPY change by 0.23% in the following week and the same amount of excess interventions by another 0.38%. The impressive effects of interventions in reducing the yen's appreciation speed may come from either the signalling or coordination channel. Meanwhile, the negative relationship between the forward premium rate and the rate of the exchange rate change confirmed the previous findings of the forward rate bias.

The fourth column revealed the short-term dynamics of the reaction function. The excess speculation and sentiment $ecm_{2,t-1}$ had positive effects on currency intervention: The central bank reacted to the extreme speculation and sentiment on JPY. Meanwhile, an increase in forward premia $(f_{t-1}^{t} - s_{t-1})$ caused more interventions, which indicated a negative correlation between the changes in the exchange rate and interventions based on the forward rate bias. In other words, the central bank implemented interventions in reaction to short-term JPY appreciations.

The fifth column revealed the factors affecting speculation and sentiment and the effectiveness of the coordination channel. We found that the speculation and sentiment is positively related to the JPY depreciation, which meant the order flows of uninformed speculators and the central bank were in the opposite direction. Meanwhile, the positive correlation between excess forward premium $ecm_{1,t-1}$ and the speculation and sentiment showed that the informed speculators did not coordinate with the interventions. Therefore the coordination channel failed to work during the 1993-1995 period. It was the signalling channel through which currency intervention worked.

The results on the short-run dynamics are summarised as follows: Firstly, the Japanese monetary authorities implemented interventions in response to the sharp short-term JPY appreciation. Secondly, the interventions were effective in the short-term through the signalling channel. The interventions greatly reduced the speed of the JPY appreciation: An intervention of one billion USD reduced the rate of JPY change in the next week by as much as 0.61%. Thirdly, the coordination channel failed to work because the speculators did not coordinate.

4.5.5 Long-Run Impact of Shocks

After the description of the short-run dynamics, this section illustrates the long-run impact of a shock to our model. As we are interested in the final impact of a permanent shock to the variables, the estimates of the impact

Table 4.7: Long-Run Impact, 1993-1995

	$\sum \varepsilon_{\triangle s_t}$	$\sum \varepsilon_{(f_t^{t+1}-s_t)}$	$\sum \varepsilon_{(i_{s,t}-i^*_{s,t})}$	$\sum \varepsilon_{(i_{l,t}-i^*_{l,t})}$	$\sum \varepsilon_{I_t}$	$\sum \varepsilon_{COT_t}$
$\triangle s_t$		-0.22		0.17		-0.18
$(f_t^{t+1} - s_t)$		0.03	0.56			0.02
$(i_{s,t} - i^*_{s,t})$			0.85			
$(i_{l,t} - i^*_{l,t})$				0.92		
I_t		0.37		-0.47		0.30
COT_t		1.13		1.31		0.94
Notes: Only significant coefficients with t-value>1.96 are shown.						

matrix are reported in Table 4.7.

Based on column-wise inspections, while the shocks to changes in the exchange rate and interventions were insignificant. However, the shocks to the bond yield differential $\sum \varepsilon_{(i_{l,t}-i^*_{l,t})}$ had strong impact on the exchange rate, currency intervention, speculation and sentiment, which meant the bond yield differential worked as the driving force of the whole system.

While the impact of forward premium, currency speculation and sentiment on changes in the exchange rate was negative, their impact on the forward premium were positive. This not only supported the forward rate bias, but also reflected the significance of currency speculation and sentiment on the movements of the JPY/USD rate. A one billion USD long JPY position in the futures market appreciated JPY by 0.18% during the 1993-1995 period.

Based on row-wise inspections, the positive impact of the forward premium on currency intervention revealed that the central bank reacted to JPY appreciation. Similarly, the speculation and sentiment on JPY had large impact on currency intervention. The Japanese central bank intervened 0.37 billion USD in reaction to a speculative futures position of one billion USD. The shocks to the long-term interest rate also had positive impact on currency intervention, which increased the profitability and credibility of the central bank.

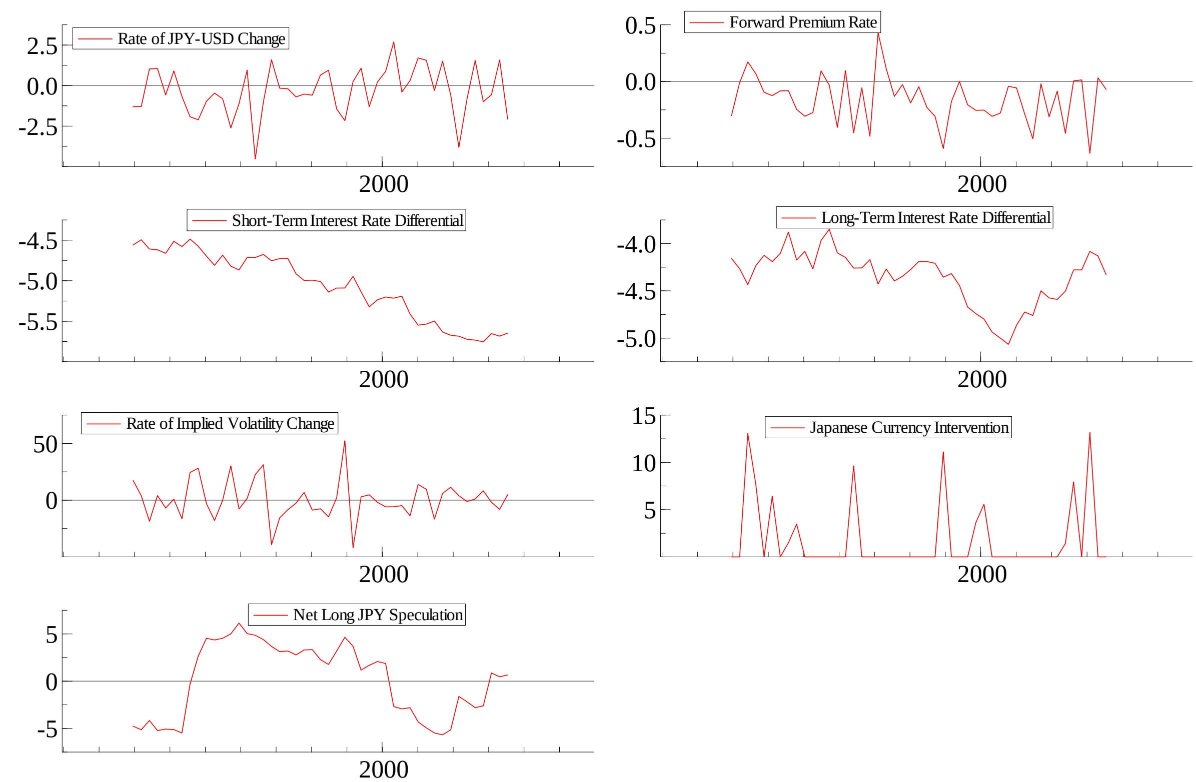
The last row measured the long-term impact of shocks on currency speculation and sentiment. In accordance with equation (4.19), the shocks to the forward premium had positive impact on currency speculation and sentiment, which meant informed speculators reduced their long JPY/USD positions in response to expected JPY appreciation. Similarly, the positive impact of bond yield shocks supported the equations (4.19) and (4.20): Both informed and uninformed speculators increased their long JPY futures positions with widening bond yield differential.

The main results of the long-term shocks are summarised as follows: The central bank reacted to sharp JPY appreciation and large speculation with 'leaning against the wind' interventions. While the intervention shocks had no long-run impact on the JPY/USD rate movements, the speculation on JPY increased with shocks to the forward premium and bond yield differential, and had significant effects on the exchange rate.

4.5.6 Summary

The analysis of the first Japanese intervention regime focuses on the frequent but small interventions. The Japanese monetary authorities reacted with 'leaning against the wind' interventions to both short- and long- term JPY appreciation. The short-term effects of currency intervention came from the signalling channel and an intervention of one billion USD reduced the rate of JPY appreciation in the next week by as much as 0.61%. However, the interventions were ineffective in the long-term. The shocks to the bond yield differential were the driving force of the whole system and had strong long-term impact on most other variables.

Figure 4.2: Main Variables in the Second Regime, 1999-2000



4.6 Analysis of the Second Intervention Regime

4.6.1 Variable Description and Model Setup

The second intervention regime covered the period, between 21st June 1995 and 14th January 2000, under the leadership of Eisuke Sakakibara and Haruhiko Kuroda. Given the implied volatility data was not available until 1998 and there were few interventions from early 1998 to early 1999 and from early 2000 to early 2003, our analysis of the second intervention regime covers the period between 1 June 1999 and 18th April 2000 and adopts the following variables: $\triangle s_t$, $(f_t^{t+1} - s_t)$, $(i_{s,t} - i^*_{s,t})$, $(i_{l,t} - i^*_{l,t})$, $\triangle IV_t$, I_t, and COT_t.

As Figure 4.2 shows, changes in the JPY/USD rate and the forward premium rate were not as stationary as in the period of 1993-1995. There were some fluctuations in September 1999 and March 2000. There was a relatively stable downward trend in the short-term interest rate differential in the whole period. Meanwhile, there was a potential trend shift of the long-term interest rate differential in the early 2000. The change in the implied volatility was relatively stationary around 0. Although the second intervention period was featured with large but infrequent interventions. We continue to use I_t instead of cumulated interventions because there were enough intervention observations in our 1999-2000 sub-example. The speculation and sentiment variable COT_t had big swings and stayed positive in late 1999.

Table 4.8 presents some important misspecification test statistics. There was no serious residual autocorrelation: Only the speculation and sentiment term showed some sign of ARCH effects. However, largely due to excess kurtosis in currency intervention, speculation and sentiment, normality is rejected at the multivariate level with a p-value of 0.01. Nevertheless, we kept the current model setup as its robustness to moderate AR effects and excess kurtosis.

Based on the univariate stationarity tests, we find that $\triangle s_t$, $(f_t^{t+1} - s_t)$, $\triangle IV_t$, I_t ˜ $I(0)$ and confirm our finding that the rank condition $r = 4$ from the trace test statistics. Meanwhile, we find the weak exogeneity of the short- and long-term interest rate differentials as their χ^2 test statistics smaller than the critical value of 9.49.

4.6.2 Testing Transmission Channels and Reaction Function

We conduct hypothesis tests on the effectiveness of the transmission channels and the reaction function, and reports main results in Table 4.9. Based on $H_{2.1.1}$ to $H_{2.1.5}$, while currency intervention increased, the forward premium rate increased and the short-term interest differential decreased, which rejected the long-term effectiveness of the signalling channel.

$H_{2.2.1}$ to $H_{2.2.4}$ tested the effectiveness of the coordination channel. With an increase in currency intervention, the speculation on JPY decreased. At the same time, $H_{2.2.3}$ and $H_{2.2.4}$ showed the negative relationship between currency

Table 4.8: Misspecification and Rank Tests, 1999-2000

Multivariate Misspecification Tests							
LM_2 Test on Autocorrelation: $\chi^2(49) = 46.11$ with p-value of 0.59							
Normality: $\chi^2(14) = \mathbf{28.82}$ with p-value of 0.01							
Univariate Misspecification Tests							
	$\triangle^2 s_t$	$\triangle(f_t^{t+1} - s_t)$	$\triangle(i_{s,t} - i^*_{s,t})$	$\triangle(i_{l,t} - i^*_{l,t})$	$\triangle^2 IV_t$	$\triangle I_t$	$\triangle COT_t$
ARCH(2)	3.01	3.04	1.03	0.64	0.81	1.34	**8.77**
Normality	1.65	1.04	0.33	0.31	2.06	**7.37**	**15.59**
Skewness	0.43	-0.32	-0.17	-0.06	0.48	**0.96**	0.40
Kurtosis	2.92	2.65	2.77	2.36	2.97	**4.82**	**5.54**
Univariate Stationarity Tests							
	$\triangle s_t$	$(f_t^{t+1} - s_t)$	$(i_{s,t} - i^*_{s,t})$	$(i_{l,t} - i^*_{l,t})$	$\triangle IV_t$	I_t	COT_t
Unit Root	**5.85**	**7.65**	0.59	1.70	**7.70**	**7.26**	1.65
Process	$I(0)$	$I(0)$	$I(1)$	$I(1)$	$I(0)$	$I(0)$	$I(1)$
Rank Tests							
	$r = 0$	$r = 1$	$r = 2$	$r = 3$	$r = 4$	$r = 5$	$r = 6$
p-value	0.00	0.00	0.00	0.01	**0.14**	0.33	0.85

Table 4.9: Testing Stationarity of Single Relations, 1999-2000

	$\triangle s_t$	$(f_t^{t+1} - s_t)$	$(i_{s,t} - i^*_{s,t})$	$(i_{l,t} - i^*_{l,t})$	$\triangle IV_t$	I_t	COT_t	$Trend$	*p-value*
Test of the Signalling Channel									
$H_{2.1.1}$		1	-0.211			-0.183			0.059
$H_{2.1.2}$		1	-2.62			-0.116		-0.007	0.821
$H_{2.1.3}$		1	-0.125		0.024	-0.011			0.916
$H_{2.1.4}$		1		1		0.349			0.059
$H_{2.1.5}$		1	-0.116	-0.293		-0.065			0.086
Test of the Coordination Channel									
$\mathcal{H}_{2.2.1}$						2.814	1		0.609
$\mathcal{H}_{2.2.2}$						2.901	1	0.309	0.501
$\mathcal{H}_{2.2.3}$					0.307	2.820	1		0.548
$\mathcal{H}_{2.2.4}$					0.275	2.784	1	0.018	0.410
Test of Reaction Function									
$\mathcal{H}_{2.3.1}$	3.365					1	0.742		0.975
$\mathcal{H}_{2.3.2}$	3.370				0.116	1	0.736		0.992

Table 4.10: Identified Long-Run Structure, 1999-2000

	$\triangle s_t$	$(f_t^{t+1} - s_t)$	$(i_{s,t} - i^*_{s,t})$	$(i_{l,t} - i^*_{l,t})$	$\triangle IV_t$	I_t	COT_t	$Trend$
$ecm_{1,t}$	4.256				0.152	1	0.802	-0.032
$ecm_{2,t}$	0.480			1	0.022	-0.033		
$ecm_{3,t}$		1	-0.120		0.024	-0.011		
$ecm_{4,t}$			77.159		0.888	5.001	1	

intervention and changes in exchange rate volatility. The test results meant that, through the coordination channel, currency interventions were effective and reduced the exchange rate volatility.

The tests on the reaction, $H_{2.3.1}$ and $H_{2.3.2}$ showed that the Japanese monetary authorities reacted to the sharp JPY appreciation. However, the interventions happen more likely when the exchange rate was less volatile and speculation and sentiment on JPY were low.

The hypothesis tests provide us with candidates for identified long-run cointegration relations. We will explore the long-run structure of the model based on the test results and reveal the reaction function of the central bank and whether the intervention channels are effective.

4.6.3 Identified Long-Run Structure

Based on previous hypothesis tests, we obtain an identified long-run structure with a p-value of 0.39, and list the relations in Table 4.10. Related to $H_{2.3.2}$, the first relation focuses on the reaction function of the central bank:

$$I_t + 4.256 \triangle s_t + 0.152 \triangle IV_t + 0.802 COT_t - 0.032 Trend + error\ term = 0. \qquad (4.27)$$

We found that interventions increased amidst sharp JPY appreciation, which supports the 'leaning against the wind' assumption. Meanwhile, there were more interventions when the exchange rate volatility and the speculation and sentiment were low.

With regard to the intervention effects, we found that an intervention of one billion USD might effectively depreciate JPY by about 0.07% from the second relation:

$$(i_{l,t} - i^*_{l,t}) + 0.480 \triangle s_t + 0.022 \triangle IV_t - 0.033 I_t - 0.01 Trend + error\ term = 0. \quad (4.28)$$

A one billion intervention may effectively depreciate JPY by about 0.07%. However, the Japanese interventions seem to be positively related to exchange rate volatility, which means that there may not a long-term relationship that interventions reduce volatility in the same period.

Based on $H_{2.1.3}$, the third relation is about the effectiveness of the signalling channel:

$$(f^{t+1}_t - s_t) - 0.12(i_{s,t} - i^*_{s,t}) + 0.024 \triangle IV_t - 0.011 I_t + 0.02 Trend + error\ term = 0. \quad (4.29)$$

The forward premium rate was positively related to the currency interventions, which meant that the signalling channel was not effective. Furthermore, the Japanese currency interventions could not reduce the JPY/USD rate volatility.

Corresponding the hypothesis tests $H_{2.2.3}$, the fourth relation is mainly about the effectiveness of the coordination channel:

$$COT_t + 77.159(i_{s,t} - i^*_{s,t}) + 0.888 \triangle IV_t + 5.001 I_t + error\ term = 0. \quad (4.30)$$

The negative relation between the speculation and sentiment and the Japanese interventions meant that the main criteria of the effectiveness of the coordination channel was fulfilled. Furthermore, currency intervention was negatively correlated with the short-term interest rate differential and rate of the volatility change, which supported the effectiveness of currency intervention through the channel.

In summary, the Japanese central bank reacted to the sharp JPY appreciation with ‘leaning against the wind’ interventions. There was strong supportive evidence on the effectiveness of the coordination channel, and an intervention of one billion USD depreciated JPY by about 0.07%. Meanwhile, the long-run effectiveness of the signalling channel was rejected.

Table 4.11: Short-Run Dynamics,1999-2000

	$\triangle^2 s_t$	$\triangle(f_t^{t+1} - s_t)$	$\triangle^2 IV_t$	$\triangle I_t$	$\triangle COT_t$
$\triangle^2 s_{t-1}$	0.277	0.054			-0.422
$\triangle(f_{t-1}^t - s_{t-1})$				-5.143	
$\triangle(i_{s,t-1} - i_{s,t-1}^*)$		-0.457		9.129	-4.583
$\triangle(i_{l,t-1} - i_{l,t-1}^*)$			3.493	-5.504	
$\triangle^2 IV_{t-1}$	-0.016	0.004	0.449		
$\triangle I_{t-1}$				0.669	
$\triangle COT_{t-1}$					0.149
$\triangle(i_{l,t} - i_{l,t}^*)$					3.218
$ecm_{1,t-1}$		-0.019			-0.274
$ecm_{2,t-1}$	-2.464				4.223
$ecm_{3,t-1}$	0.997	-0.921	-8.696	6.906	-1.879
$ecm_{4,t-1}$		0.007	-0.376	-0.155	0.049
Constant	-11.666	2.574	-11.796	-5.502	6.327
dum990914	-3.374			2.002	
dum000307	-3.447	0.443		-6.304	1.947
di000104	-1.132				2.159
Notes: Only significant coefficients with $p < 0.05$ are shown.					
The *ecm* variables are based on (4.27)-(4.30) respectively.					

4.6.4 Short-Run Dynamics

We analyse the short-run dynamics of the second regime and present the results in Table 4.11. Based on the rows of interventions $\triangle I_{t-1}$ and excess interventions $ecm_{1,t-1}$, the Japanese interventions tended to happen in clusters. Furthermore, the excess interventions $ecm_{1,t-1}$ had negative effects on changes in speculation and sentiment $\triangle COT_t$, which supported the short-run effectiveness of the coordination channel.

Revealed from the rows on $\triangle COT_{t-1}$, and the excess speculation and sentiment $ecm_{4,t-1}$, currency speculation and sentiment showed a clustering behaviour. Meanwhile, the excess speculation and sentiment had positive effects on the rate of forward premium change, which meant the excess speculation increased the rate of JPY appreciation.

The fifth column offers findings related to the reaction function of the central bank: Interventions happened in clusters. Meanwhile, the excess forward premium $ecm_{3,t-1}$ had positive impact on the rate of intervention change, which meant that he Japanese monetary authorities reacted with more interventions amidst excess JPY appreciation, which is in line with the 'leaning against the wind' assumption. However, the excess speculation and sentiment had negative impact on the rate of the intervention change, which reflected that the Japanese central bank reacted with less interventions amidst excess speculation and sentiment.

In summary, with the existence of the forward rate bias, the interventions were effective in the short-term through the coordination channel. The Japanese interventions happened in clusters. The 'leaning against the wind' interventions were reactions to sharp JPY appreciation, not excess speculation and sentiment.

4.6.5 Long-Run Impact of Shocks

After the description of the short-run dynamics, this section illustrates the long-run impact of shocks and report the results in Table 4.12. The long-run impact on the reaction function of the central bank was based on the inspection of the seventh column. The cumulative shocks to the change in the exchange rate $\sum \varepsilon_{\triangle s_t}$ and to the speculation and sentiment $\sum \varepsilon_{COT_t}$ had negative long-run impact on currency intervention, while the cumulative shocks to currency intervention had positive impact on itself. This was in line with the finding in the short-run dynamic structure: The 'leaning against the wind' interventions happened in clusters. The central bank did not react to the excess speculation and sentiment.

Table 4.12: Long-Run Impact, 1999-2000

	$\sum \varepsilon_{\triangle s_t}$	$\sum \varepsilon_{(f_t^{t+1}-s_t)}$	$\sum \varepsilon_{(i_{s,t}-i_{s,t}^*)}$	$\sum \varepsilon_{(i_{l,t}-i_{l,t}^*)}$	$\sum \varepsilon_{\triangle IV_t}$	$\sum \varepsilon_{I_t}$	$\sum \varepsilon_{COT_t}$
$\triangle s_t$				-1.41			
$(f_t^{t+1} - s_t)$			0.90		-0.003		-0.04
$(i_{s,t} - i_{s,t}^*)$			0.88				
$(i_{l,t} - i_{l,t}^*)$				0.79			
$\triangle IV_t$			-7.03		0.10		1.64
I_t	-0.53	3.36	-7.54		-0.04	0.09	-0.55
COT_t				1.14			0.79
Notes: Only significant coefficients with t-value>1.96 are shown.							

While the shocks to currency interventions, speculation and sentiment had no long-term impact on the exchange rate, the shocks to the short- and long-term interest rate differentials were the main driving forces of the system, which had strong impact on most variables, including the change in the exchange rate.

4.6.6 Summary

The second intervention regime was featured with large but infrequent interventions. The Japanese monetary authorities reacted to sharp JPY appreciation with 'leaning against the wind' interventions in clusters. They did not react to large exchange rate volatility, and excess speculation and sentiment. It was the shocks to the interest rate differentials that drove the change in the JPY/USD rate. Interventions were effective in both short-term and long-term through the coordination channel. In the long-term, an intervention of one billion USD depreciated JPY by about 0.07%.

Figure 4.3: Main Variables in the Third Regime, 2003-2004

4.7 Analysis of the Third Intervention Regime

4.7.1 Variable Description and Model Setup

The analysis of the third regime covers the weekly observations between 21 January 2003 and 30th March 2004 and focuses the following variables, i.e. , $\triangle s_t$, $(f_t^{t+1} - s_t)$, $(i_{s,t} - i^*_{s,t})$, $(i_{l,t} - i^*_{l,t})$, $\triangle IV_t$, I_t, and COT_t.

Based on Figure 4.3, the forward premium rate and changes in the JPY/USD rate were relatively stationary. Except for some fluctuations in early and mid-2003, both the short- and long-term interest rate differentials had a relatively steady upward trend. The rate of the implied volatility change was relatively stationary around 0, except for two possible dummies. The Japanese interventions were large and frequent, especially between late 2003 and early 2004 when the speculative futures volume was high.

There were impulse dummies, namely dum030624, dum030923, and dum040224, on 24th June 2003, 23rd September 2003, and 24th February 2004 respectively. The dummy dum030624 measured shocks on the short- and long-term interest rate differentials, dum030923 on the change of the exchange rate, the forward premium rate, and the change in the implied volatility, and dum040224 on the change in the exchange rate change, and speculation. There was also a transitory dummy, namely di030311, on 11th March 2003, measuring transitory shocks on the short- and long-term interest rate differentials.

Table 4.13 lists some important misspecification test results. Residual autocorrelation at the multivariate level was rejected with p-value of 0.09, and only the speculation and sentiment term showed some sign of ARCH effects. However, multivariate normality was rejected due to the excess kurtosis in currency intervention, speculation and sentiment. Nevertheless, we kept the current model specification and choose the cointegration rank number to be 3 based on the rank tests and findings of univariate stationarity tests. Meanwhile, the short- and long-term interest rate differentials, and the speculation and sentiment variable were weakly exogenous based on their χ^2 statistics.

4.7.2 Testing Transmission Channels and Reaction Function

Table 14 reports the results of the hypothesis tests on the reaction function and the effectiveness of transmission channels. Based on $H_{3.1.1}$-$H_{3.1.4}$, and $H_{3.2.1}$-$H_{3.2.2}$, currency intervention was positively correlated with the forward premium rate and the speculation and sentiment, which rejected the long-run effectiveness of the signalling and coordination channels. The positive relationship between currency intervention and changes in exchange rate volatility meant that the Japanese interventions could not reduce the exchange rate volatility.

The tests results on the reaction function of the central bank are revealed by $H_{3.3.1}$ and $H_{3.3.2}$. While $H_{3.3.1}$ showed that the central bank reacted to the

Table 4.13: Misspecification and Rank Tests, 2003-2004

Multivariate Tests							
LM_2 Test on Autocorrelation: $\chi^2(49) = 62.99$ with p-value 0.09							
Normality: $\chi^2(14) = \mathbf{39.21}$ with p-value 0.00							
Univariate Tests							
	$\triangle^2 s_t$	$\triangle(f_t^{t+1} - s_t)$	$\triangle(i_{s,t} - i_{s,t}^*)$	$\triangle(i_{l,t} - i_{l,t}^*)$	$\triangle IV_t$	$\triangle I_t$	$\triangle COT_t$
ARCH(2)	**13.41**	3.97	4.40	5.35	0.99	2.47	0.88
Normality	0.547	1.37	**12.31**	0.67	**6.43**	3.90	4.81
Skewness	0.17	0.18	0.87	0.22	-0.63	0.41	-0.66
Kurtosis	2.55	3.23	**5.71**	2.92	**4.35**	3.78	3.81
Univariate Stationarity Tests							
	$\triangle s_t$	$(f_t^{t+1} - s_t)$	$(i_{s,t} - i_{s,t}^*)$	$(i_{l,t} - i_{l,t}^*)$	$\triangle IV_t$	I_t	COT_t
Unit Root	2.81	**8.78**	2.10	2.35	**10.11**	**5.37**	2.17
Process	$I(1)$	$I(0)$	$I(1)$	$I(1)$	$I(0)$	$I(0)$	$I(1)$
Rank Test							
	$r = 0$	$r = 1$	$r = 2$	$r = 3$	$r = 4$	$r = 5$	$r = 6$
p-value	0.00	0.00	0.03	**0.14**	0.42	0.65	0.68

Table 4.14: Testing Stationarity of Single Relations, 2003-2004

	$\triangle s_t$	$(f_t^{t+1} - s_t)$	$(i_{s,t} - i_{s,t}^*)$	$(i_{l,t} - i_{l,t}^*)$	$\triangle IV_t$	I_t	COT_t	$Trend$	*p-val*
Tests on the Signalling Channel									
$H_{3.1.1}$		1			0.02	−0.01			1.00
$H_{3.1.2}$		1			0.02	−0.02		0.001	1.00
$H_{3.1.3}$		1	0.18		0.02	−0.02			1.00
$H_{3.1.4}$		1	0.12		0.02	−0.02		0.001	1.00
Tests on the Coordination Channel									
$H_{3.2.1}$					1.26	−1.13	1		0.58
$H_{3.2.2}$					1.52	−1.92	1	0.18	0.91
Tests on the Reaction Function									
$H_{3.3.1}$	37.28				−1.06	1	−0.27		0.94
$H_{3.3.2}$	−13.31				−0.68	1	−0.57	−0.14	0.99

Table 4.15: Identified Long-Run Structure, 2003-2004

	$\triangle s_t$	$(f_t^{t+1} - s_t)$	$(i_{s,t} - i_{s,t}^*)$	$(i_{l,t} - i_{l,t}^*)$	$\triangle IV_t$	I_t	COT_t	$Trend$
$ecm_{1,t}$		1	0138		0.023	-0.020		0.001
$ecm_{2,t}$	-14.931			1	0.241	-0.139		
$ecm_{3,t}$	32.200				-1.131	1	-0.359	

appreciation of JPY, the increasing exchange rate volatility and speculation, $H_{3.3.2}$ did not support the 'leaning against the wind' assumption.

4.7.3 Identified Long-Run Structure

We find a well-specified long-run structure with p-value of 0.93 and list the identified cointegration relations in Table 4.15. The first relation is based on $H_{3.1.4}$ and about the effectiveness of the signalling channel:

$$(f_t^{t+1} - s_t) + 0.138(i_{s,t} - i_{s,t}^*) + 0.023 \triangle IV_t - 0.02 I_t + 0.001 Trend + error = 0, \quad (4.31)$$

where currency intervention was positively related to the forward premium rate which meant that the signalling channel was not effective. Meanwhile, currency intervention was positively related to changes in the exchange rate volatility, which meant the interventions might increase the exchange rate volatility. The same result can be found from the second cointegration relation:

$$(i_{l,t} - i^*_{l,t}) - 14.931 \triangle s_t + 0.241 \triangle IV_t - 0.139 I_t + error\ term = 0. \tag{4.32}$$

The Japanese interventions seem to be positively related to exchange rate volatility, which means that there might not be a long-term relationship that interventions reduce volatility in the same period.

Based on the hypothesis test $H_{3.3.1}$, the third relation focuses on the reaction function of the central bank:

$$I_t + 32.2 \triangle s_t - 1.131 \triangle IV_t - 0.359 COT_t + error\ term = 0, \tag{4.33}$$

where the negative relationship between currency intervention and the change in the exchange rate supported the 'leaning against the wind' assumption. Furthermore, currency intervention was positively related to the exchange rate volatility and currency speculation and sentiment, which indicated that the central bank aimed to reduce exchange rate volatility and fence off speculative attacks.

In summary, the Japanese central bank reacted to sharp JPY appreciation, large exchange rate volatility and excess speculation and sentiment with 'leaning against the wind' interventions. However, the long-run effectiveness of the signalling and coordination channel was not supported.

4.7.4 Short-Run Dynamics

This section focuses on the short-run dynamics and summarise related results in Table 4.16. The rows of $\triangle I_{t-1}$ and excess interventions $ecm_{3,t-1}$ are on the short-run effects of the interventions in the dynamic system. The Japanese interventions tended to happen in clusters. Meanwhile, the excess interventions might have positive effects on changes in the exchange rate through the signalling channel.

Based on the second column, changes in the speculation and sentiment $\triangle COT_t$ had negative effects on the rate of exchange rate change: The negative coefficient of -0.44 meant that an increase in speculative futures position by one billion USD increased the rate of JPY appreciation by 0.44%.

From the fourth column, we found that the excess interventions $ecm_{3,t-1}$ and changes in speculation and sentiment $\triangle COT_{t-1}$ had large positive effects on the rate of the volatility change. This meant the speculation and sentiment increased the volatility of the exchange rate, and the Japanese interventions failed to reduce the exchange rate fluctuations.

The fifth column is related the reaction function. Besides the finding that interventions happened in clusters, we noticed that currency intervention was negatively impacted by the rate of exchange rate change and implied volatility. While the former results reflected the 'leaning against the wind' assumption, the latter implied that the Japanese interventions were not reactions to sharp increasing exchange rate volatility.

In summary, the Japanese interventions happened in clusters and reacted to the excess JPY appreciation in a 'leaning against the wind' way. They had strong and positive effects on the rate of the exchange rate change through the signalling channel. However, they were not reactive to the excess exchange rate volatility correlated with speculation, and were not able to reduce the exchange rate fluctuations in the third regime.

4.7.5 Long-Run Impact of Shocks

After the description of the short-run dynamics, this section analyses the final impact of a permanent shock to the variables, and reports the results in Table 4.17. Noticeably, the intervention shocks had positive long-run impact on the exchange rate: Shocks to an intervention of one billion USD had a long-run impact of 0.01% depreciation in JPY. Furthermore, the intervention

Table 4.16: Short-Run Dynamics, 2003-2004

	$\triangle^2 s_t$	$\triangle(f_t^{t+1} - s_t)$	$\triangle^2 IV_t$	$\triangle I_t$
$\triangle^2 s_{t-1}$			-3.208	-1.162
$\triangle^2 IV_{t-1}$				-0.231
$\triangle I_{t-1}$				0.168
$\triangle COT_{t-1}$			1.239	
$\triangle COT_t$	-0.438			
$ecm_{1,t-1}$	0.499	-1.118		
$ecm_{2,t-1}$	0.096	-0.025	0.648	
$ecm_{3,t-1}$		-0.015	0.791	
Constant	0.397	-0.344		-2.197
dum030923	-3.839	-0.297	6.755	-6.000
dum040224		-0.346	7.596	1.811
Notes: The coefficients are significant with $p<0.05$.				
The ecm variables represent (40)-(42) respectively.				

Table 4.17: Long-Run Impact, 2003-2004

	$\sum \varepsilon_{\triangle s_t}$	$\sum \varepsilon_{(f_t^{t+1} - s_t)}$	$\sum \varepsilon_{(i_{s,t} - i^*_{s,t})}$	$\sum \varepsilon_{(i_{l,t} - i^*_{l,t})}$	$\sum \varepsilon_{\triangle IV_t}$	$\sum \varepsilon_{I_t}$	$\sum \varepsilon_{COT_t}$
$\triangle s_t$	0.05				0.01	0.01	0.03
$(f_t^{t+1} - s_t)$	-0.03				-0.003	-0.01	
$(i_{s,t} - i^*_{s,t})$	0.02		1.08				
$(i_{l,t} - i^*_{l,t})$				1.14			
$\triangle IV_t$	2.08				0.22	0.50	
I_t	1.94				0.21	0.46	1.14
COT_t				10.14			1.03
Notes: Only significant coefficients with t-value>1.96 are shown.							

shocks had negative impact on the forward premium rate, which reflected the effectiveness of the signalling channel.

The seventh column revealed the long-run impact of shocks on the reaction function of the central bank: The interventions happened in clusters and were reactions to the high exchange rate volatility, and large speculation and sentiment.

The cumulative shocks to the long-term interest rate differential $\sum \varepsilon_{(i_{l,t}-i^*_{l,t})}$ had positive effects on the speculation and sentiment COT_t which positively influenced the exchange rate. However, the coordination channel failed to work as the intervention shocks had no influence on the speculation and sentiment.

In summary, there might exist a causal chain of variables with respect to the long-term impact of the cumulative shocks: $(i_{l,t}-i^*_{l,t}) \rightarrow COT_t \rightarrow I_t \rightarrow (\triangle s_t$, $(f^{t+1}_t-s_t)$, and $\triangle IV_t)$. The shocks to the relative increase of the Japanese bond yield, the main driving force of the system, stimulated more speculation and sentiment on JPY, which in return forced the Japanese central bank to react with more interventions. Although The intervention shocks caused more volatility, they decreased the rate of JPY appreciation, which was reflected by the increase of $\triangle s_t$ and the decrease of $(f^{t+1}_t-s_t)$.

4.7.6 Summary

As the main driving force, the cumulative shocks to the bond yield differential stimulated speculation and sentiment on JPY, which caused the frequent and large-scale interventions. The interventions were also reactive to the sharp JPY appreciation and had short-term effects on the change in the exchange rate through the signalling channel: An intervention of one billion USD increased the long-term exchange rate by 0.01%.

4.8 Summary

This chapter reviews the power of the identified cointegrated VAR modeling technique and microstructure framework to explain a complex phenomena in international finance. The empirical analysis provides detailed results with respect to three regimes of the Japanese interventions between 1991 and 2004. It is the first research to jointly test separate transmission channels in an identified structural framework with various factors such as speculation and sentiment, exchange rate volatility and forward rate bias. The empirical research also involves testing an innovative microstructure framework, with findings potentially helpful to unfold the myths of JPY/USD rate movements.

The interventions in the three regimes respectively show features of being small but frequent, very large but infrequent, large and highly frequent. There are several interesting findings with respect to the reaction function. The Japanese monetary authorities reacted to sharp JPY appreciation with 'leaning against the wind' interventions in all regimes. In the second and third regimes, the interventions happened in clusters. In the third regime between 2003 and 2004, the interventions happened amid increasing exchange rate volatility and speculation on JPY appreciation.

The signalling channel were effective in the first and third regimes when interventions were frequent. In the first regime, the interventions had significant short-term effects via signalling channel: An intervention of one billion USD reduced the rate of JPY appreciation by 0.61%. In the third regime, the interventions had both short- and long-term effects on the change in the JPY/USD rate: A yen-purchasing intervention of one billion USD increased the weekly rate of JPY depreciation by 0.01%.

While speculation and sentiment show strong effects on changes in the exchange rate, the coordination channel was only effective in the second regime when changes in exchange rate volatility were relatively small: An intervention of one billion USD increased weekly change in the exchange rate by about 0.07%. However, in the first and third regimes when the market was volatile, the interventions failed to decrease the exchange rate volatility, which deferred speculators from coordinating with the central bank[11].

The fundamental factors played important roles in the exchange rate movements. In all three regimes, the shocks to the bond yield differential had strong long-run impact on speculation and sentiment, and changes in exchange rate. The shocks to the yield difference pushed speculation and sentiment on JPY, and worked as the driving force of the whole system.

While offering policy implications for central banks, this chapter suggest some directions for future research: More studies are needed to explore the microstructure framework of the foreign exchange market and analyse the developing country currencies to explain the interactions of exchange rate dynamics with currency intervention, speculation and sentiment.

[11] Our findings are supported by Ito (2005) and Marsh (2011).

Chapter 5

Currency Intervention, Speculation and Sentiment in Developing Countries: An Analysis of the MXN/USD Rate

Abstract:

This chapter provides a unique examination of three separate regimes of the Mexican currency interventions between 1998 and 2009. It is the first research to jointly test the coordination and signalling channels in an identified structural framework for a developing country currency. The empirical research also involves testing an innovative microstructure framework formed in the previous chapter, with findings potentially helpful to understand the difference in exchange rate dynamic mechanisms across developed and developing countries and provide prospective policy implications for central banks in developing countries:

(1) Banxico intervened to depreciate MXN as reactions not to changes in the exchange rate, but to the high speculation and sentiment on MXN and sharp increases in the exchange rate volatility.

(2) The signalling channel was effective when interventions were frequent in the second and third regimes from 2003 to 2009.

(3) The market conditions affected the effectiveness of the coordination channel. When market was less volatile and with less risk, the coordination channel was effective as the speculators tended to coordinate with the central bank.

(4) The effects of small and infrequent currency interventions were not from the coordination and signalling channels but dependent on accommodative monetary policies.

(5) The clustering speculation and sentiment on MXN worked as the main driver of the whole system and had significant effects on change in the exchange rate in all regimes.

5.1 Introduction

Official currency interventions in advanced economies have been in steady decline. After March 2004, among the G7 central banks, it was only the Bank of Japan that conducted four solo currency interventions. Other G7 central banks only stepped in the currency market once to support the Japanese counterpart after the Great East Japan earthquake. However, the situation is quite different in developing countries. Canales-Kriljenko (2006) finds that 91 percent of the 76 central banks in their survey conduct currency interventions.

The central banks in developing countries intervene in the foreign exchange market frequently and sometimes in very large amounts (Guimaraes and Karacadag, 2006). The interventions are aimed to correct currency misalignment in terms of levels or rates, smooth fluctuations by reducing exchange rate volatility, accumulate international reserves to fence off speculative attacks, or provide liquidity to the markets.

The chapter begins with a brief literature review and identification of three regimes of Mexican currency interventions. After describing the main variables, we conduct a detailed analysis on the separate intervention regimes to examine the effectiveness of the transmission channels, the influence of currency speculation and sentiment, and the reaction function of the central bank. All the main empirical results are summarised and compared to provide suggestions for related research and policy implications for central banks in emerging economies.

5.2 Literature Review

Before empirical analysis on the Mexican currency interventions, we review literature related to the effectiveness of transmission channels, methods of estimating intervention effects, and offers suggestions for related studies.

5.2.1 Transmission Channels and Estimation Methods

Currency interventions in advanced economies have a long history and date back to the time when the classical gold standard era was not established (Bordo et al., 2007) and have been subject to extensive studies[1]. The studies on the developed economy currencies have examine the effectiveness of the three main transmission channels of currency intervention, i.e., the portfolio balance, signalling, and coordination channels using one of four groups of estimation methodology, i.e., low-frequency time series, even study, high-frequency time series, and identified models. Some studies focus on the different intervention regimes to analyse the interventions with distinctive features.

There is severe lack of research on intervention in developing countries[2]. This is partially due to the lack of publicly available official intervention data (Menkhoff, 2013) although at least 65 percent of emerging market members of IMF publish intervention data in some way (IMF, 2010). As one of the few central banks of developing countries that regularly publish official intervention data, the Mexican central bank (Banxico) has been actively intervened in the foreign exchange rate market since the Peso was forced to float in De-

[1] Sarno and Taylor (2002), Neely (2005a) and Chapter 2 of this thesis provide detailed literature reviews on the currency interventions in developed countries.

[2] Disyatat and Galati (2007) and Menkhoff (2013) provide extensive literature reviews on the currency intervention in emerging markets.

cember 1994 and have attracted some research interests on its interventions.

While Kumhof (2010) proposes the Mexican currency interventions were effective in exchange rate level and volatility through the portfolio balance channels, most other studies on the Mexican currency intervention focus on the signalling channel. Domac and Mendoza (2004) examine the daily MXN interventions between August 1996 and June 2001 within an exponential GARCH framework. They find that a sale of one billion USD appreciated MXN by 0.08%. They found the USD-selling interventions reduced the MXN/USD exchange rate volatility but not vice versa, which was supported by the similar findings of Guimaraes and Karacadag (2006) who analyse the daily intervention effects on volatility between August 1996 and June 2003. Recently, Berganza and Broto (2012) and Broto (2013) analyse the currency interventions in Latin American countries and find that both USD purchases and sales helped to moderate the MXN/USD exchange rate volatility between July 1996 and June 2011 through the signalling channel.

With a unique panel data set, Adler and Tovar (2011) employ a panel fixed effects model to examine the intervention effects in Latin American countries. They find that the interventions had significant effects on the changes in the exchange rates between January 2004 and December 2010. However, they did not identify through which transmission channel the interventions worked.

In summary, most studies on the Mexican currency interventions have not adopted identified models to jointly analyse the effects of currency intervention. There have been no research on the effectiveness of the coordination channels, examinations of foreign exchange market microstructure, or the analyses of different intervention regimes.

By taking into consideration the market microstructure and theoretical foundations (Vitale, 2007), our research adopts an identified and cointegrated VAR model to incorporate the transmission channels, reaction functions, and analyse the short- and long-term effects of currency intervention, speculation and sentiment[3].

5.3 Regimes of Mexican Currency Interventions

As one of few central banks of developing countries that regularly publish official intervention data, the Mexican central bank (Banxico) has been actively intervening in the foreign exchange rate market since the peso was forced to float in December 1994. Based on the official data of the Mexican currency interventions, we can classify the whole intervention period into three different intervention regimes.

From October 1997 to June 2000, while accumulating reserves, Banxico undertook several daily USD sales up to 0.2 billion and some discretionary interventions to ease the volatility of the MXN/USD rate (Sidaoui, 2005). Therefore, the first period was featured with small and infrequent currency interventions.

After the first intervention regime, there was no official intervention until May 2003. In the second regime from May 2003 to August 2008, Banxico sold USD directly in the foreign exchange market via daily auctions to slow down the pace of international reserve accumulation. The currency interventions during the period were small but frequent.

The interventions of the third regime, started in September 2008, were to ease the impact of the financial crisis. Banxico sold USD through daily auctions and several discretionary interventions to provide liquidity and reduce exchange rate volatility (Quintanilla et al., 2012). The interventions were large and frequent but their volume decreased when market conditions improved.

In summary, we categorise the Mexican currency interventions with differ-

[3] Given the important role speculation plays in the currency market, and the limited availability of transaction data on currency speculation, we need to adopt a COT-related proxy for currency speculation to conduct related research.

ent features into three regimes. Under the microstructure framework adopted in Chapter 4, we will describe the variables, and analyse the Mexican currency intervention, speculation and sentiment using the cointegrated VAR methodology.

5.4 Variable Description

It is very important to include suitable variables for empirical analysis. For our specific research with respect to the Mexican currency intervention, speculation and sentiment, we should consider not only the standard fundamental economic variables such as exchange rates and interest rates, but also variables measuring market speculation and sentiment. Conditional on data availability, variables related to the forward rate bias and exchange rate volatility are incorporated into our microstructure model. Therefore, the main variables considered for empirical analysis are:

$\triangle s_t$= the weekly percentage change in the spot MXN/USD rate[4],

$(f_t^{t+1} - s_t)$ = the weekly forward premium rate[5],

$(i_{s,t} - i^*_{s,t})$ = the difference of the Mexican and US treasury bill rate with 3 months maturity,

$(i_{l,t} - i^*_{l,t})$ = the difference of Mexican and US treasury bond rate with 10 years maturity,

$\triangle IV_t$= the weekly percentage change rate of the implied volatility of the MXN/USD rate.

I_t = weekly amounts of the Mexican currency interventions to depreciate MXN, defined as net purchase of USD in unit of billion USD,

COT_t= Weekly net long speculators' positions on MXN futures from the COT reports, which measures currency speculation on the decrease of the

[4]The variable is in the form of 100 times the differential of logarithm of the exchange rate in terms of the units of MXN per USD.

[5]It is measured by 100 times the difference between the logarithm of the forward rate with maturity of one week and the logarithm of the spot exchange rate

MXN/USD rate, i.e., $-(D_t^I+D_t^U)$, and the sentiment of the speculators.

The data resource of most variables is Bloomberg. The exceptions are the intervention data, which is from Banxico, and the speculation and sentiment variable which is based on the data from the US Commodity Futures Trading Commission. In order to accommodate the COT reports, we use end-of-the-day values on Tuesdays.

5.5 Analysis of the First Mexican Intervention Regime

5.5.1 Variable Description and Model Setup

We focus on the period between 17th February 1998 and 23 November 1999, when almost 60% volume of the interventions of the first regime happened. As we can not get access to the data related to long-term interest rates and exchange rate volatility, our analysis is based on the following variables: $\triangle s_t$, $(f_t^{t+1}-s_t)$, $(i_{s,t}-i^*_{s,t})$, I_t, and COT_t.

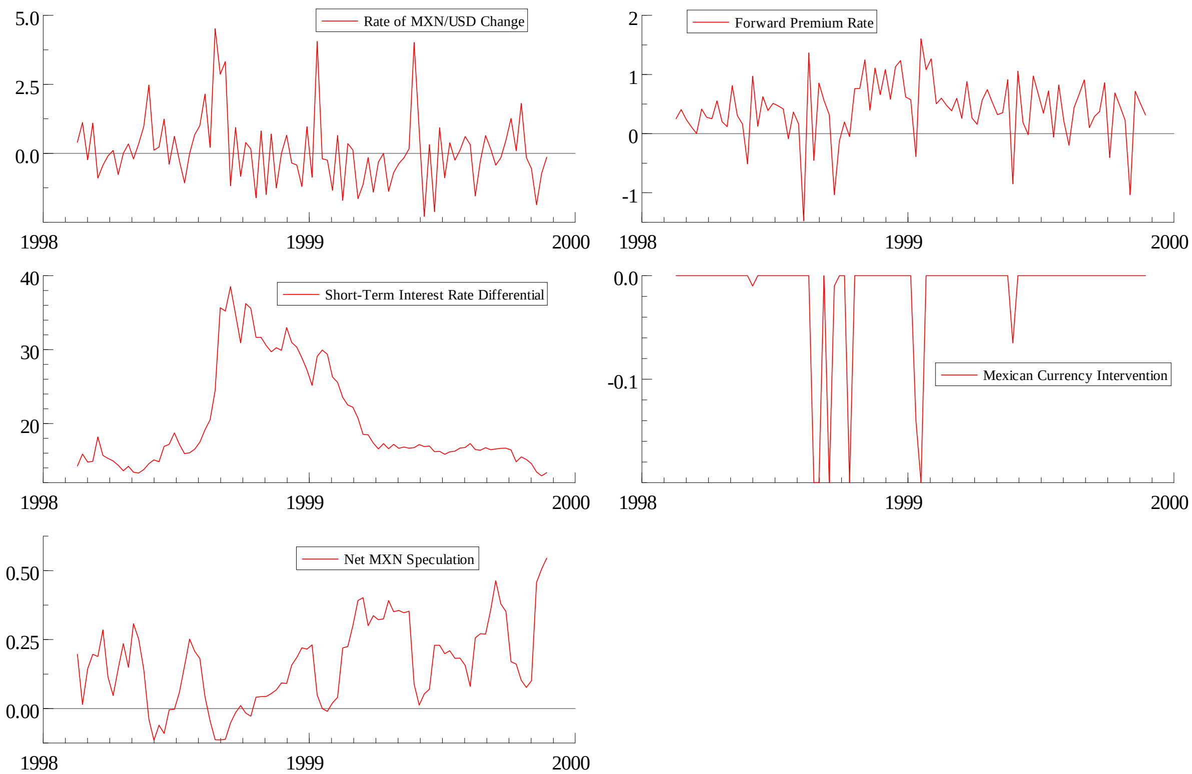
In Figure 5.1, the changes in the JPY/USD and forward premia were relatively stationary although there might exist impulse dummies between August and October 1998, January 1999 and May 1999. The short-term interest rate differential increased until September 1998 and then reversed, while the speculation and sentiment on MXN showed a roughly opposite pattern.

With the variable vector X_t, i.e., $\triangle s_t$, $(f_t^{t+1}-s_t)$, $(i_{s,t}-i^*_{s,t})$, I_t, and COT_t, the error correction representation of VAR model with lag number=2 can be expressed as:

$$\begin{aligned} \triangle X_t &= \Gamma \triangle X_{t-1}+\alpha_1\beta' X_{t-1}+\mu_0+\Phi D_t+\varepsilon_{1,t}, \\ \varepsilon_{1,t} &\sim N(0,\Sigma),\ t = 1998:02:17-1999:11:23. \end{aligned}$$

Based on the standard residual errors, there were impulse dummies, namely dum980811p, dum980825p, dum980901p, dum980922p, dum981006p, dum990112p,

Figure 5.1: Main Variables in the First Regime, February 1998-November 1999



and dum990525p, on 11th August 1998, 25th August 1998, 1st September 1998, 22nd September 1998, 6th October 1998, 12th January 1999, and 25th May 1999 respectively. While the impulse dummies of dum980811p and dum980922p captured the impulse forward premium shocks, dum980901p and dum981006p measured the shocks on the short-term interest rate differential, and dum980825p on the exchange rate shocks. Furthermore, dum990112p measured the shocks on the exchange rates and interest rates, while dum990525p on the exchange rate, forward premium, and speculation and sentiment. The dummies of dum980825p, dum980901p and dum990112p also included the shocks to currency intervention which might impact other variables.

The test results about the statistical adequacy of the model are shown in Table 5.1 where the significant test statistics are in bold face. Normality and no autocorrelation are rejected at the multivariate level with p-values smaller than the critical value 0.05. The non-normallity and non-stationarity mainly came from the forward premia and currency intervention. Given a cointegrated VAR model is robust to moderate AR effects and excess kurtosis, we continue with current model specification.

The cointegration rank divides the variables into r stationary relations towards which the system is adjusting and $p-r$ nonstationary relations which are pushing the system. We first report the degrees of integration of each variable based on the ADF unit root tests. If the t-statitics larger than the critical value 2.89, we reject the null hypothesis of unit root at the 5% level of significance, which indicates that the respective variable is stationary I(0). If not, the variable is nonstationary I(1). Accordingly, we find that $\triangle s_t$, $(f_t^{t+1}-s_t)$, I_t ˜ $I(0)$ and $(i_{s,t}-i_{s,t}^*)$, COT_t ˜ $I(1)$. Table 5.1 also reports the trace test statistics which suggest accepting $r=3$. We also conduct tests of weak exogeneity on individual variables and find that the speculation and sentiment variable is weakly exogenous with its $\chi^2(3)$ test statistics 2.115 smaller than the critical value 7.815.

5.5.2 Testing Transmission Channels and Reaction Function

This section tests hypotheses on transmission channels of currency intervention and the reaction function of the Mexican central bank after imposing the rank=3 condition. In the form of $\beta=(H\phi_1,\psi_1,\psi_2)$, we test whether a single restricted relation is in the β space with other two relations unrestricted and report the results in Table 5.2.

$H_{4.1.1}$ to $H_{4.1.2}$ are hypothesis tests to check whether the signalling channel was effective in the long-term. We consider the variables of forward premium rate $(f_t^{t+1}-s_t)$, interest rate differential $(i_{s,t}-i_{s,t}^*)$, and interventions I_t for the tests expressed as:

$$(f_t^{t+1}-s_t)-0.27(i_{s,t}-i_{s,t}^*)-131.24I_t+error\ term=0, \tag{5.1}$$

$$(f_t^{t+1}-s_t)-0.09(i_{s,t}-i_{s,t}^*)-29.09I_t-0.002Trend+error\ term=0, \tag{5.2}$$

Table 5.1: Misspecification and Rank Tests, February 1998-November 1999

Multivariate Test Results					
Autocorrelation:	LM$_1$: $\chi^2(25) = \mathbf{48.71}$ with p-value 0.00				
	LM$_2$: $\chi^2(25) = \mathbf{47.06}$ with p-value 0.00				
Normality:	$\chi^2(10) = \mathbf{83.47}$ with p-value 0.00				
Univariate Test Results					
	$\triangle^2 s_t$	$\triangle(f_t^{t+1} - s_t)$	$\triangle(i_{s,t} - i^*_{s,t})$	$\triangle I_t$	$\triangle COT_t$
ARCH(2)	0.75	0.63	0.27	0.32	0.81
Normality	1.06	**9.64**	**9.35**	**57.91**	5.05
Skewness	0.14	−0.80	0.45	**−2.48**	0.50
Kurtosis	3.17	**4.64**	4.51	**13.92**	3.83
Univariate Stationarity Tests					
	$\triangle s_t$	$(f_t^{t+1} - s_t)$	$(i_{s,t} - i^*_{s,t})$	I_t	COT_t
Unit Root	**8.56**	**10.41**	1.25	**7.21**	2.19
Process	$I(0)$	$I(0)$	$I(1)$	$I(0)$	$I(1)$
Trace Tests					
	$r = 0$	$r = 1$	$r = 2$	$\mathbf{r = 3}$	$r = 4$
p-value	0.00	0.00	0.00	**0.05**	0.11

Table 5.2: Testing Stationarity of Single Relations, February 1998-November 1999

	$\triangle s_t$	$(f_t^{t+1} - s_t)$	$(i_{s,t} - i^*_{s,t})$	I_t	COT_t	$Trend$	*p-value*
Test of the Signalling Channel							
$H_{4.1.1}$		1	-0.27	-131.24			0.98
$H_{4.1.2}$		1	-0.09	-29.09		-0.002	1
Test of the Coordination Channel							
$H_{4.2.1}$				-21.01	1		0.13
$H_{4.2.2}$				-16.09	1	-0.002	0.08
Test of Reaction Function							
$H_{4.3.1}$	-0.39			1	-0.39		0.98
$H_{4.3.2}$	-2.82			1	–2.18	-0.003	1

where the increase in interventions was significantly correlated with increase in the forward premium rate with p-values larger than 0.05. The results reject the hypothesis of the long-run effectiveness of the signalling channel.

The test results with respect to the effectiveness of the coordination channel are related to $H_{4.2.1}$ and $H_{4.2.2}$ with the following relations:

$$COT_t - 21.01 I_t + error\ term = 0, \tag{5.3}$$

$$COT_t - 16.09 I_t - 0.002 Trend + error\ term = 0, \tag{5.4}$$

where the speculation on MXN increased with currency intervention to depreciate MXN, which did not support the long-run effectiveness of the coordination channel.

The tests of the reaction function of the central bank, $H_{3.1}$ and $H_{3.2}$, are to find whether the central bank reacted to the appreciation of MXN $\triangle s_t < 0$, or the increasing speculation and sentiment on MXN appreciation $COT_t > 0$, with interventions:

$$I_t - 0.39 \triangle s_t - 0.39 COT_t + error\ term = 0, \tag{5.5}$$

$$I_t - 2.82 \triangle s_t - 2.18 COT_t - 0.003 Trend + error\ term = 0. \tag{5.6}$$

Table 5.3: Identified Long-Run Structure, February1998-November1999

	$\triangle s_t$	$(f_t^{t+1} - s_t)$	$(i_{s,t} - i^*_{s,t})$	I_t	COT_t	$Trend$
$ecm_{1,t}$		1	-0.04	-17.82		
$ecm_{2,t}$				-25.11	1	-0.001
$ecm_{3,t}$	-0.01			1	-0.05	

In both relations, the central bank reacted to the speculation and sentiment on MXN appreciation. However, instead of 'leaning against the wind', the interventions were reactions to the MXN depreciation, i.e., $I_t > 0$ when $\triangle s_t > 0$.

5.5.3 Identified Long-Run Structure

The search of well-specified long-run structure is based on the information from Π matrix of the unrestricted model and the previous hypothesis tests. The search of a well-specified long-run structure is based on the Π matrix of the unrestricted model and the previous hypothesis tests. The automatic procedure "CATS Mining" of the tailor made toolbox, Cats in Rats, version 2 (Dennis, et al., 2005), facilitate us in the model section by providing we with all plausible restricted models with potential cointegrating relations. We obtain a cointegration structure listed in Table 5.3 with a p-value of 0.06.

Based on the hypothesis test $H_{4.1.1}$, the first identified cointegration relation is about the effectiveness of the signalling channel:

$$(f_t^{t+1} - s_t) - 0.04(i_{s,t} - i^*_{s,t}) - 17.82 I_t + error\ term = 0. \tag{5.7}$$

The positive relationship of currency interventions and the forward premium rate means the signalling channel was not effective in the long-term according to the testing criterion in Table 4.2.

Based on the hypothesis test $H_{4.2.2}$, the second long-run relation is about the effectiveness of the coordination channel:

$$COT_t - 25.11 I_t - 0.001 Trend + error\ term = 0. \tag{5.8}$$

The Mexican interventions were positively related the speculation and sentiment on MXN appreciation, which means that the coordination channel did not work in the long run.

Based on the hypothesis test $H_{4.3.1}$, the third relation focuses on the Banxico's reaction function:

$$I_t - 0.01 \bigtriangleup s_t - 0.05COT_t + error\ term = 0. \tag{5.9}$$

The Mexican currency interventions were positively correlated with the rate of exchange rate change, i.e., interventions increased when the peso depreciated, which did not support the 'leaning against the wind' assumption. Meanwhile, the positive relationship between currency intervention and currency speculation and sentiment means that, in the long-term, there were more interventions to depreciate MXN when the speculation and sentiment on MXN appreciation were high. The latter relationship support the hypothesis that the central bank intervened to fence off speculative attacks.

In summary, the long-run effectiveness of the signalling and coordination channel was not supported. The Mexican central bank reacted to not the sharp MXN appreciation, but to high speculation and sentiment on MXN.

5.5.4 Short-Run Dynamics

After identifying the long-run cointegration relations, we analyse the short-run dynamics analysis. With the weakly exogenous interest rate differential variable, the short-run dynamics summarised in Table 5.4 is accepted with a p-value of 0.99.

We first examine the fifth and tenth rows with respect to interventions $\bigtriangleup I_{t-1}$ and excess interventions $ecm_{3,t-1}$, and the intervention-related dummies, i.e., dum980825p, dum980901p and dum990112p. While the interventions had no effects on changes in the MXN/USD rate, the excess interventions, dum980901p and dum990112p had strong positive effects on the movements of the MXN/USD rate. In the latter case, an intervention of one billion USD

Table 5.4: Short-Run Dynamics, February 1998-November 1999

	$\triangle^2 s_t$	$\triangle(f_t^{t+1} - s_t)$	$\triangle(i_{s,t} - i^*_{s,t})$	$\triangle I_t$
$\triangle^2 s_{t-1}$	-0.13		-0.29	
$\triangle(f_{t-1}^t - s_{t-1})$	-0.28	-0.08		-0.01
$\triangle(i_{s,t-1} - i^*_{s,t-1})$	0.17	-0.02		-0.004
$\triangle I_{t-1}$			-4.59	
$\triangle COT_{t-1}$			3.64	
$\triangle COT_t$	-7.26	0.81	-5.31	0.03
$ecm_{1,t-1}$		-0.96	0.37	0.02
$ecm_{2,t-1}$			-7.22	1.01
$ecm_{3,t-1}$	4.88		-4.24	0.07
Constant	0.32	-0.48		
dum980811p	0.99	-1.82		
dum980825p			3.74	-0.18
dum980901p	2.66		10.98	-0.14
dum980922p		-2.38	-2.22	
dum981006p			6.14	
dum990112p	2.86	-1.02	3.20	-0.15
dum990525p	2.34	-1.07		-0.06
Notes: Only significant coefficients with $p < 0.05$ are shown.				
The *ecm* variables are based on (5.7)- (5.9) respectively.				

increased the rate of MXN depreciation by 4.88% in the following week. While there was no sign that the interventions worked through the coordination channel or the signalling channel, the negative correlation between the excess intervention and the change in interest differential might indicate that the interventions changed the monetary policies which moved the exchange rate.

The short-run effects of speculation and sentiment are presented in the sixth, seventh and ninth rows, with $ecm_{2,t-1}$ as the excess speculation and sentiment. We find that changes in speculation and sentiment significant short-run effects on changes in the MXN/USD rate: An increase of speculation on the peso futures increased the appreciation rate of the peso by 7.26% in the same week. Meanwhile, it changes in speculation and sentiment decreased the rate of the forward premium $\triangle(f_t^{t+1}-s_t)$ by 0.81%, which supported the existence of the forward rate bias.

In terms of the short-run structure of the reaction function, the Mexican monetary authorities reacted to high speculation on the MXN. The speculation and sentiment on the MXN appreciation had positive effects on the interventions: An increase in speculation on MXN by one billion USD increased currency intervention by 0.03 billion in the same week and 1.1 billion in the following week. Another finding is that the excess intervention had small but significant short-run effects on the interventions in the following week. An increase in intervention by one billion USD caused more intervention by 0.07 billion USD in the next week, which meant that the interventions tended to happen in clusters.

The results of the short-run dynamic analysis can be summarised as follows: Firstly, the Mexican monetary authorities implemented interventions in response to increasing speculation and sentiment on the peso, and the interventions tended to happen in clusters. Secondly, the interventions were effective: A sale of one billion USD increased the rate of MXN depreciation by 4.88% in the following week. Thirdly, the interventions were not independent from monetary policies, and failed to work through the coordination

Table 5.5: Long-Run Impact, 1998-1999

	$\sum \varepsilon_{\triangle s_t}$	$\sum \varepsilon_{(f_t^{t+1}-s_t)}$	$\sum \varepsilon_{(i_{s,t}-i^*_{s,t})}$	$\sum \varepsilon_{I_t}$	$\sum \varepsilon_{COT_t}$
$\triangle s_t$					-0.65
$(f_t^{t+1} - s_t)$		0.05	0.05		0.84
$(i_{s,t} - i^*_{s,t})$	0.59	1.08	0.97	10.45	
I_t					0.30
COT_t					1.13
Notes: Only significant coefficients with t-value> 1.96 are shown.					

or signalling channels. Fourthly, with the existence of the forward rate bias, there were significant short-run effects of the speculation and sentiment on changes in the MXN/USD rate: An increase in speculation on MXN by one billion USD increased the appreciation rate of the peso by 7.26% in the same week.

5.5.5 Long-Run Impact of Shocks

This section illustrates the final impact of permanent shocks to the variables and presents the related results in Table 5.5. Based on the column-wise inspections, the shocks to currency speculation and sentiment had significant long-run impact on most variables, hence worked as the driving force of the whole system. In the first regime, a long MXN futures position of one billion USD increased the rate of MXN appreciation by 0.65%. Meanwile, the speculation and sentiment had opposite impact on changes in the exchange rate and the forward premium, which reflected the existence of the forward rate bias.

The Mexican central bank mainly reacted to the high speculation and sentiment on the peso's further appreciation. Banxico reacted to an increase of speculation on MXN with an interventions of 0.3 billion dollar. However, the shocks to interventions failed to impact the MXN/USD rate, and negatively affacted the interest rate differentials, which did not support the effectiveness of either the signalling channel or the coordination channel.

We also notice that the speculation and sentiment were only affected by the shocks to themselves. The speculators showed some herding behaviour and speculation on MXN happened in clusters.

The main results of this section are summarised as follows: The speculation and sentiment on MXN were the main driving force in the first regime. The speculation and sentiment happened in clusters and had substantial effects on changes in the MXN/USD rate. The central bank only reacted to the speculation and sentiment on MXN, and their interventions failed to work through either the signalling channel or the coordination channel.

5.5.6 Summary of Results of the First Regime

The first regime focuses on the small and infrequent Mexican interventions between February 1998 and November 1999. The speculation and sentiment on MXN appreciation happened in clusters, and drove the exchange rate, interest rates and interventions of the first regime. The speculative activities on MXN had significant short- and long-term effects on the MXN/USD exchange rate: A long MXN position of one billion USD increased the appreciation rate of MXN by 7.26% in the short-run and 0.65% in the long run.

The Mexican monetary authorities reacted with interventions only to the currency speculation and sentiment, not to changes in the exchange rates. A long MXN position of one billion USD caused Banxico to intervene 0.3 billion USD in the long-run and 1.13 billion USD in the short-run. The currency interventions happened in clusters and had significant short-term effects on the MXN/USD exchange rate. An intervention of one billion USD increased the intervention amount and the rate of MXN depreciation in the following week by 7% and 4.88% respectively . The interventions were not effective through the coordination or signalling channel. The effectiveness of Mexican interventions during this period was dependent on accommodative monetary policies.

5.6 Analysis of the Second Mexican Intervention Regime

5.6.1 Variable Description and Model Setup of the Second Regime

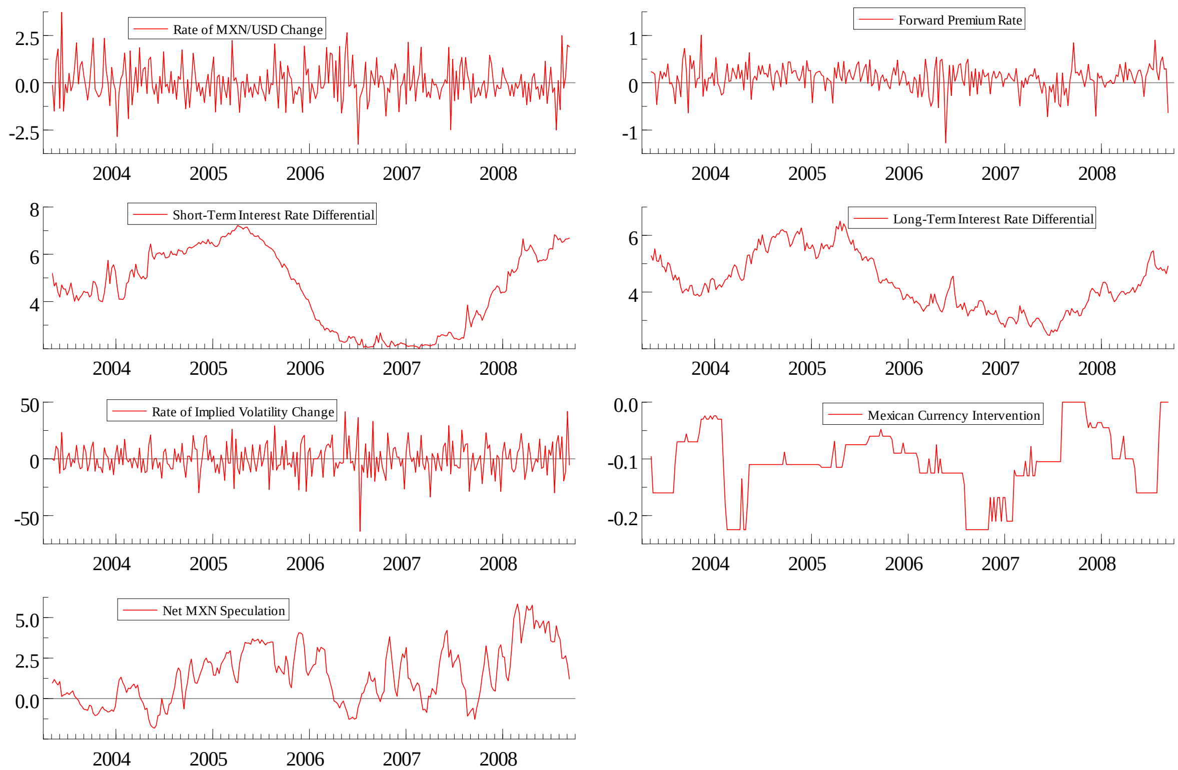
The second regime covers the period between 6th May 2003 and 8th September 2008, which features small but frequent interventions before the peak of the global financial crisis. With the data availability of the long-term interest rate and implied volatility, we now have the following variables, i.e., $\triangle s_t$, $(f_t^{t+1} - s_t)$, $(i_{s,t} - i^*_{s,t})$, $(i_{l,t} - i^*_{l,t})$, $\triangle IV_t$, I_t, and COT_t, which are illustrated in Figure 5.2. While the variables with respect to change in the exchange rate, forward premium and exchange rate volatility are relatively stationary, the interest rate differentials and speculation and sentiment are not. Both interest rate differential increases from mid 2003 to mid 2005, then decreased steadily for two more years before they resumed upward trend from mid 2007. The speculation and sentiment on MXN appreciation showed some swings during the period.

With the variable vector X_t, we present the error correction representation of the VAR model with lag number=2:

$$\begin{aligned} \triangle X_t &= \Gamma \triangle X_{t-1} + \alpha_1 \beta' X_{t-1} + \mu_0 + \Phi D_t + \varepsilon_{1,t}, \\ \varepsilon_{1,t} &\sim N(0, \Sigma),\ t = 2003:05:06 - 2008:09:09. \end{aligned}$$

Based on the results of the standard residual errors of the seven variables, we find the following impulse dummies, i.e., dum030610p, dum031111p, dum040106p, dum060523p, dum060704p, dum070918p and dum071211p, measuring permanent shocks on 10th June 2003, 11th November 2003, 6th January 2004, 23rd May 2006, 4th July 2006, 18th September 2007, and 11th December 2007 respectively. To be specific, while dum030610p measures a exchange rate shock, dum031111p dum070918p and dum071211p capture sud-

Figure 5.2: Main Variables in the Second Regime, May 2003 - September 2008



den forward premium rate shocks. Furthermore, dum040106p measures the shocks on exchange rate and long- and short- term interest rate differentials, dum060523p on exchange rate and forward premium rate, and dum060704p on exchange rate and rate of volatility change. There is a transitory dummy, a ...,0,1,-1,0,... dummy dum070821t, measuring transitory effects on the short-term interest rate differential on 21st August 2007.

Misspecification tests of the above model are shown in Table 5.6. At the multivariate level, the residuals are not autocorrelated. However, multivariate normality does not exist largely due to the excess kurtosis of short-run interest differential, the rate of volatility change and interventions. Given the cointegrated VAR model is robust to moderate AR effects and excess kurtosis, we can stick with current model specification. The results from the univariate stationarity tests and trace tests suggest that the rank number of 4 with probability 0.81.

5.6.2 Testing Hypotheses of Channels and Reaction Function

After imposing the rank condition, various hypotheses are tested with respect to the signalling and coordination channels and reaction function. The hypothesis test results reported in Table 5.7 based on the form of $\beta = (H\phi_1, \psi_1, \psi_2, \psi_3)$ to test whether a single restricted relation is in the β space with other three relations unrestricted.

We first check the long-term effectiveness of the signalling channel. The tests, $H_{1.1}$ to $H_{1.5}$, with variables of forward premium rate, $(f_t^{t+1} - s_t)$, interest rate differentials $(i_{s,t} - i^*_{s,t})$ and $(i_{l,t} - i^*_{l,t})$, volatility rate $\triangle IV_t$ and interventions I_t. The relations presenting $H_{1.1}$ to $H_{1.5}$ can be expressed as:

$$(f_t^{t+1} - s_t) - 0.04(i_{s,t} - i^*_{s,t}) + 0.49 I_t + error\ term = 0, \tag{5.10}$$

$$(f_t^{t+1} - s_t) - 0.02(i_{s,t} - i^*_{s,t}) - 0.12 \triangle IV_t + 1.3 I_t + error\ term = 0, \tag{5.11}$$

$$(f_t^{t+1} - s_t) - 0.06(i_{l,t} - i^*_{l,t}) + 0.24 I_t + error\ term = 0, \tag{5.12}$$

Table 5.6: Misspecification and Rank Tests, May 2003 - September 2008

Multivariate Test Results							
Autocorrelation:	LM_1: $\chi^2(49) = 48.16$ with p-value 0.51						
	LM_2: $\chi^2(49) = 53.48$ with p-value 0.31						
Normality: $\chi^2(14) = 250.78$ with p-value 0.00							
Univariate Test Results							
	$\triangle^2 s_t$	$\triangle(f_t^{t+1} - s_t)$	$\triangle(i_{s,t} - i^*_{s,t})$	$\triangle(i_{l,t} - i^*_{l,t})$	$\triangle^2 IV_t$	$\triangle I_t$	$\triangle COT_t$
ARCH(2)	1.92	**8.83**	3.33	3.19	3.44	**16.11**	6.71
Normality	5.71	4.14	**20.63**	0.41	**21.77**	**85.51**	6.05
Skewness	0.35	-0.18	0.56	0.07	0.10	0.43	-0.12
Kurtosis	3.24	3.47	**4.68**	3.04	**4.48**	**9.91**	3.65
Univariate Stationarity Tests							
	$\triangle s_t$	$(f_t^{t+1} - s_t)$	$(i_{s,t} - i^*_{s,t})$	$(i_{l,t} - i^*_{l,t})$	$\triangle IV_t$	I_t	COT_t
Unit Root	**18.97**	**15.41**	0.83	1.77	**20.82**	2.80	**2.93**
Process	$I(0)$	$I(0)$	$I(1)$	$I(1)$	$I(0)$	$I(1)$	$I(0)$
Trace Tests							
	$r = 0$	$r = 1$	$r = 2$	$r = 3$	$r = \mathbf{4}$	$r = 5$	$r = 6$
p-value	0.00	0.00	0.00	0.01	**0.81**	0.89	0.99

Table 5.7: Testing the Stationarity of Single Relations, May 2003 - September 2008

	$\triangle s_t$	$(f_t^{t+1} - s_t)$	$(i_{s,t} - i^*_{s,t})$	$(i_{l,t} - i^*_{l,t})$	$\triangle IV_t$	I_t	COT_t	$Trend$	*p-value*
Test of the Signalling Channel									
$\mathcal{H}_{1.1}$		1	-0.04			0.49			0.67
$\mathcal{H}_{1.2}$		1	-0.02		-0.12	1.30			0.99
$\mathcal{H}_{1.3}$		1		-0.06		0.24			0.35
$\mathcal{H}_{1.4}$		1		-0.05	-0.09	0.93			1
$\mathcal{H}_{1.5}$		1	-0.03	-0.01		0.47			0.54
Test of the Coordination Channel									
$\mathcal{H}_{2.1}$						-8.80	1		0
$\mathcal{H}_{2.2}$						-2.40	1	-0.01	0
$\mathcal{H}_{2.3}$					-3.56	26.48	1		1
$\mathcal{H}_{2.4}$					-3.22	24.06	1	-0.003	1
Test of Reaction Function									
$\mathcal{H}_{3.1}$	-9.85					1	-0.88		0.99
$\mathcal{H}_{3.2}$	-9.49					1	–0.82	-0.001	0.97

$$(f_t^{t+1} - s_t) - 0.05(i_{l,t} - i_{l,t}^*) - 0.09 \triangle IV_t + 0.93 I_t + error\ term = 0, \tag{5.13}$$

$$(f_t^{t+1} - s_t) - 0.03(i_{s,t} - i_{s,t}^*) - 0.01(i_{l,t} - i_{l,t}^*) + 0.47 I_t + error\ term = 0. \tag{5.14}$$

All the five long-run relations show that the increase of interventions was significantly correlated with decrease of the forward premium rate, $(f_t^{t+1} - s_t) < 0$, with p-values larger than 0.05. Therefore, the main criteria of the long-run effectiveness of the signalling channel is fulfilled. However, the interest rate differentials $(i_{s,t} - i_{s,t}^*)$ and $(i_{l,t} - i_{l,t}^*)$ were positively related with the increase of interventions, which does not support the effectiveness of the signalling channel. Furthermore, the exchange rate volatility increases with the interventions, which means that the interventions did not reduce the volatility of the exchange rate through the signalling channel.

The test results with respect to the effectiveness of the coordination channel are shown in the rows from $H_{2.1}$ to $H_{2.4}$ with the following relations:

$$COT_t - 8.8 I_t + error\ term = 0, \tag{5.15}$$

$$COT_t - 2.4 I_t - 0.01 Trend + error\ term = 0, \tag{5.16}$$

$$COT_t - 3.56 \triangle IV_t + 26.48 I_t + error\ term = 0, \tag{5.17}$$

$$COT_t - 3.22 \triangle IV_t + 24.06 I_t - 0.003 Trend + error\ term = 0. \tag{5.18}$$

The first two long-run relations show that speculation on MXN appreciation COT_t increases with the currency intervention to depreciate MXN. The relations were rejected with p-vaule equal to 0. Meanwhile, based on the last two long-run relations, we can not reject the negative relations between intervention and speculation and the sentiment with p-vaule=1. Therefore, the long-run effectiveness of the coordination channel was also fulfilled. However, the positive relationship between intervention and volatility still persisted, which reflected that the interventions failed to smooth the volatility of MXN/USD rate.

$H_{3.1}$ and $H_{3.2}$ are to test whether the central bank reacts to the appreciation of MXN, $\triangle s_t < 0$, or the increasing speculation and sentiment on MXN

Table 5.8: Identified Long-Run Structure, May 2003 - September 2008

	$\triangle s_t$	$(f_t^{t+1} - s_t)$	$(i_{s,t} - i^*_{s,t})$	$(i_{l,t} - i^*_{l,t})$	$\triangle IV_t$	I_t	COT_t	$Trend$
$ecm_{1,t}$		1	-0.04	-0.003		0.60		
$ecm_{2,t}$					-4.1	37.66	1	-0.004
$ecm_{3,t}$	-0.71				-0.08	1	-0.05	
$ecm_{4,t}$	1		0.01	-0.01	-0.04		0.10	

appreciation, $COT_t > 0$, with interventions:

$$I_t - 9.85 \triangle s_t - 0.88 COT_t + error\ term = 0 \tag{5.19}$$

$$I_t - 9.49 \triangle s_t - 0.82 COT_t - 0.001 Trend + error\ term = 0 \tag{5.20}$$

In both relations, the central bank reacts to the increasing speculation and sentiment on MXN appreciation. However, instead of 'leaning against the wind', the interventions were reactions to the MXN depreciation, i.e., $I_t > 0$ when $\triangle s_t > 0$.

5.6.3 Identified Long-Run Structure of Channels and Reaction Function

Based on the previous hypothesis tests and the information from Π matrix of the unrestricted model, an identified long-run structure is established in this section. Firstly, the short- and long-term interest rate differentials and intervention variables are found to be weakly exogenous with their $\chi^2(4)$ test statistics 1.75, 5.56 and 6.70 smaller than the critical value 9.49. After excluding weakly exogenous variables from the short-run dynamic analysis, a full cointegration structure H_{full}: $\beta = (H_1\varphi_1, H_2\varphi_2, H_3\varphi_3, H_4\varphi_4)$ is found with the long-run cointegrations listed in Table 5.8. The long-run structure is not rejected with probability 0.06.

Based on the hypothesis test $H_{1.5}$, the first identified cointegration relation is about the effectiveness of the signalling channel:

$$(f_t^{t+1} - s_t) - 0.04(i_{s,t} - i^*_{s,t}) - 0.003(i_{l,t} - i^*_{l,t}) + 0.6I_t + error\ term = 0. \tag{5.21}$$

Although there was no accommodative monetary policies, the negative relationship of currency interventions and the forward premium rate means the signalling channel was effective in the long-term

Based on the hypothesis test $H_{2.4}$, the second long-run cointegration relation is about the effectiveness of the coordination channel:

$$COT_t - 4.1 \triangle IV_t + 37.66I_t - 0.004Trend + error\ term = 0. \tag{5.22}$$

Although the exchange rate volatility increased with interventions, the Mexican interventions were negatively related to the speculation and sentiment on MXN appreciation, which means that the coordination channel worked in the long run as the interventions to depreciate MXN managed to reduce the speculation and sentiment.

Based on the hypothesis test $H_{3.2}$, the third relation focuses on the reaction function of the central bank's interventions:

$$I_t - 0.71 \triangle s_t - 0.08 \triangle IV_t - 0.05COT_t + error\ term = 0. \tag{5.23}$$

The Mexican currency interventions were positively correlated with the rate of exchange rate change, i.e., interventions increase with the depreciation of MXN, which does not support the 'leaning against the wind' assumption. The positive relationship between the interventions and rate of implied volatility, speculation and sentiment variables means that, in the long-term, there were more interventions to depreciate MXN when the exchange rate volatility and speculation and sentiment on MXN appreciation were high. The latter relationship supports the hypothesis that the central bank intervened to fence off sharp exchange rate volatility and speculative attacks

The fourth long-run relation is to reflect whether the change in the MXN/USD rate was affected by fundamental variables, e.g., interest rate differentials, and exchange rate volatility, and speculation and sentiment:

$$\triangle s_t + 0.01(i_{s,t} - i^*_{s,t}) - 0.01(i_{l,t} - i^*_{l,t}) - 0.04 \triangle IV_t + 0.1COT_t + error\ term = 0. \quad (5.24)$$

The most striking feature of the relation is that the rate of MXN depreciation, $\triangle s_t$, is negatively and significantly correlated with the speculation and sentiment on the MXN appreciation: One billion speculation on MXN appreciation increased the rate of MXN appreciation by 0.1 percent. While the short-run interest rate spread decreased the rate of MXN depreciation, the long-run counterpart had the opposite effects. The rate of exchange rate volatility were positively correlated with the rate of MXN depreciation, which may show that MXN was vulnerable to high risk.

The long-run structure of the model shows that the long-run effectiveness of the signalling and coordination channel between May 2003 and December 2008 was supported, though the interventions failed to decrease exchange rate volatility. The Mexican central bank did not react to the sharp MXN appreciation, but the exchange rate volatility and speculation and sentiment on MXN appreciation. While the interest rates and exchange rate volatility had significant effects on the rate of MXN depreciation, it was mainly the speculation and sentiment on MXN appreciation that moved the exchange rate in the long-run.

5.6.4 Short-Run Dynamics of the Second Regime

With identified long-run cointegration relations, the short-run dynamics of the model is analysed. With weakly exogenous short- and long-term interest rate differentials and intervention variables, the short-run dynamic structure summarised in Table 5.9 is accepted with probability 0.99.

From the second column, the changes of short- and long-term differentials had no short-run effects on the change in exchange rates. However, based on the values in the 7th row, the change in interventions $\triangle I_{t-1}$ had significant

Table 5.9: Short-Run Dynamics, May 2003 - September 2008

	$\triangle^2 s_t$	$\triangle(f_t^{t+1} - s_t)$	$\triangle^2 IV_t$	$\triangle COT_t$
$\triangle(f_{t-1}^t - s_{t-1})$			-4.81	
$\triangle(i_{s,t} - i_{s,t}^*)$		0.13	7.62	
$\triangle(i_{s,t-1} - i_{s,t-1}^*)$			6.50	
$\triangle(i_{l,t} - i_{l,t}^*)$			7.95	-0.77
$\triangle(i_{l,t-1} - i_{l,t-1}^*)$		-0.17		
$\triangle I_{t-1}$	7.85	-1.11		-2.29
$\triangle^2 IV_{t-1}$			0.16	
$\triangle COT_{t-1}$	-0.15		-6.52	0.30
$ecm_{1,t-1}$	0.33	-1.03		
$ecm_{2,t-1}$			1.99	-0.57
$ecm_{3,t-1}$			-3.65	2.56
$ecm_{4,t-1}$	-4.32		-2.7	4.56
Constant	1.06	-0.26	10.42	-0.48
dum030610p	1.88			
dum031111p		0.91		
dum040106p	-1.64	0.48	3.65	
dum060523p	2.23	-1.32		
dum060704p	-2.40		7.74	
dum070918p		0.76		-1.32
dum071211p		-0.88		0.94
dum070821t			7.22	-0.99
Notes: Only significant coefficients with $p < 0.05$ are shown.				
The *ecm* variables are based on (5.21)-(5.24) respectively.				

positive effects on the change of the MXN/USD rate, i.e., one billion increase of Mexican intervention to depreciate MXN increased the rate of MXN depreciation by 7.85% in the following week. The short-term interventions were effective through both the signalling and coordination channels as the change in interventions not only decreased the rate in forward premium rate but also the speculation and sentiment on MXN appreciation, i.e., one billion increase of Mexican intervention decreased the currency speculation in the following week by 2.29 billion.

The short-run effects of speculation and sentiment on other variables are presented in the ninth row. The change of speculation and sentiment $\triangle COT_{t-1}$ had significant short-run effects on the change of the MXN/USD rate and exchange rate volatility in the following week. While one billion more speculation on MXN appreciation in the futures market increased the appreciation rate of the currency by 0.15% in the following week, it reduced the rate of exchange rate volatility by 6.52%. One billion speculation on MXN appreciation increased the speculation in the following week by 0.3 billion, which indicates that speculation and sentiment in this regime happened in clusters in the short-term. The results about effects of excess speculation and sentiment $ecm_{2,t-1}$ based on the 11th row confirmed the findings that the clustering speculation on MXN appreciation smoothed the exchange rate fluctuations.

In summary, there was no significant short-term effects of interest rates on exchange rates, the Mexican interventions $\triangle I_{t-1}$ were effective through both coordination and signalling channels: One billion increase of Mexican intervention to depreciate MXN increased the rate of MXN depreciation by 7.85% and decreased the currency speculation by 2.29 billion in the following week. Additionally, the speculation and sentiment $\triangle COT_{t-1}$ happened in clusters had significant short-run effects on the change of the MXN/USD rate and smoothed the exchange rate fluctuations. One billion more speculation on MXN appreciation caused 0.3 billion more speculation, and increased the appreciation rate of the currency by 0.15% and reduced the rate of exchange

Table 5.10: The Estimates of the Long-Run Impacts, May 2003 - September 2008

	$\sum \varepsilon_{\triangle s_t}$	$\sum \varepsilon_{(f_t^{t+1}-s_t)}$	$\sum \varepsilon_{(i_{s,t}-i^*_{s,t})}$	$\sum \varepsilon_{(i_{l,t}-i^*_{l,t})}$	$\sum \varepsilon_{(\triangle IV_t)}$	$\sum \varepsilon_{I_t}$	$\sum \varepsilon_{COT_t}$
$\triangle s_t$			-0.09	0.04		0.85	
$(f_t^{t+1} - s_t)$			0.04			-0.62	
$(i_{s,t} - i^*_{s,t})$			0.92				
$(i_{l,t} - i^*_{l,t})$			-0.14	1.02			
$\triangle IV_t$			0.17			7.85	
I_t						0.99	
COT_t			0.91	-0.40		-5.23	
Notes: Only significant coefficients with t-values$>$ 1.96 are shown.							

rate volatility by 6.52% in the following week.

5.6.5 The Long-Run Impact of Shocks

This section discusses the long-run impact of a permanent shock to variables after describing of the long-run structure and short-run dynamics of the system with respect to the reaction function of Banxico, channels of the interventions and effects of currency speculation and sentiment. The related empirical results are illustrated in Table 5.10.

Based on the column-wise inspections, the shocks to the change in exchange rate, forward premium rate, and currency speculation and sentiment have no significant long-run impact , while the shocks to currency interventions and the short-run interest differential had significant long-run impact on most variables in the second regime.

The shocks to the short-term interest rate differential $\sum \varepsilon_{(i_{s,t}-i^*_{s,t})}$ had significant positive and negative impact on change in exchange rate and forward premium rate respectively, which confirmed the existence of forward rate bias. The shocks to the currency interventions $\sum \varepsilon_{I_t}$ have significant positive impact on the change in exchange rate, i.e., one billion currency intervention to depreciate MXN deceased the rate of MXN appreciation by 0.85%, which means the currency interventions were effective and had lasting effects on the exchange rate movements in the second regime.

The shocks to interventions had long-term negative impact on both forward premium rate $(f_t^{t+1} - s_t)$ and speculation and sentiment COT_t, which supports the effectiveness of both signalling and coordination channels. One billion intervention decreased speculation on MXN appreciation by 5.23 billion. Furthermore, the opposite signs of effects of interventions on change in exchange rate and forward premium rate supported the existence of forward rate bias.

From the seventh row, the shocks to the interventions $\sum \varepsilon_{I_t}$ had positive and significant impact on themselves, i.e., the shock of one billion intervention caused 0.99 billion more intervention. The results reflected that the interventions were clustering in the second regime.

Based on the above empirical results, the long-term shocks to the variables are summarised as follows: The shocks to currency interventions and the short-run interest differential had significant impact on most variables in the model in the second regime. The Mexican currency interventions happened in clusters and were effective through not only the coordination channel but also the signalling channel with the existence of the forward rate bias. One billion currency intervention managed to decease the rate of MXN appreciation by 0.85% and speculation on MXN appreciation by 5.23 billion.

5.6.6 Summary of Results of the Second Regime

The second Mexican intervention regime features small and frequent interventions and relative low exchange rate volatility and the results can be summarised as follows: The Mexican central bank conducted interventions in clusters to react to the increase of exchange rate volatility and currency speculation and sentiment. Although the interventions failed to smooth the exchange rate fluctuations, they were effective both in the short- and long-term through the coordination and signalling channels. In the short term, one billion of intervention increased the rate of MXN depreciation by 7.85% and decreased the currency speculation by 2.29 billion in the following week. In the long term, the shocks of one billion amount of intervention deceased the rate of MXN appreciation by 0.85% and speculation on MXN appreciation by 5.23 billion.

While the interventions and short-term interest rate differentials had significant long-term impact on most variables, the clustering speculation and sentiment on MXN appreciation had significant short-term effects on the change of the MXN/USD rate and exchange rate volatilities. One billion more speculation on MXN appreciation increased the rate of the currency appreciation by 0.15% while reducing the rate of exchange rate volatility by 6.52%.

5.7 Analysis of the Third Mexican Intervention Regime

5.7.1 Variable Description and Model Setup of the Third Regime

The third regime is between 16th September 2008 and 29th December 2009, which covers the period of global financial crisis after the collapse of Lehman Brothers. The set X_t with the following variables, i.e. , $\triangle s_t$, $(f_t^{t+1}-s_t)$, $(i_{s,t}-i^*_{s,t})$, $(i_{l,t}-i^*_{l,t})$, $\triangle IV_t$, I_t, and COT_t, are available and illustrated in Figure 5.3.

Similar to the second regime, the changes in the exchange rate forward premium were relatively stationary except for some spikes. However, the exchange rate volatility showed larger fluctuations, which was a main feature of the exchange rate dynamics during the financial crisis. Both the short- and long-term interest rate differentials showed a downward trend after staying at high value until early 2009. While the volume of frequent interventions was decreasing after some large interventions in late 2008, the speculation and

Figure 5.3: Main Variables in the Second Regime, September 2008 - December 2009

sentiment on MXN appreciation showed a different picture with relatively low volume until early 2009 and relatively high volume in the later in the year.

The error correction representation of variable vector X_t in the VAR format with lag number=2 can be presented as follows:

$$\begin{aligned} \triangle X_t &= \Gamma \triangle X_{t-1} + \alpha_1 \beta' X_{t-1} + \mu_0 + \Phi D_t + \varepsilon_{1,t}, \\ \varepsilon_{1,t} &\sim N(0, \Sigma),\ t = 2008:09:16 - 2009:12:29. \end{aligned}$$

Based on the results of the standard residual errors of the seven variables, there exist the following impulse dummies, i.e., dum081007p, which captures the shocks to change in exchange rate, forward premium rate, and exchange rate volatility on 7th October 2008, dum090317p, which measures shocks to change in exchange rate on 17th March 2009, dum090901p, which reflects a spike of speculation volume on 1st September 2009, and dum081209t, which demonstrates transitory effects on the forward premium rate on 9th December 2008.

The results of following misspecification tests of the above model setup are presented in Table 5.11. There exists some degree of residual autocorrelation and non-normality in the multivariate level based on the LM and Normality tests, which were caused mostly by the excess kurtosis of exchange rate and intervention variables. As mentioned the previous sections, the cointegrated VAR model is robust to moderate AR effects and excess kurtosis, which permits us of testing rank conditions under the current model specification. Based on the results of trace tests and univariate stationarity tests, the rank number are chosen to be 4 with probability 0.54.

5.7.2 Testing Hypotheses of Channels and Reaction Function

After setting the rank condition of the model, this section tests the hypotheses of the effectiveness of the channels and the reaction function of the Banxico to set the foundations for valid long-run cointegration relations. The main results of the hypothesis tests are included in Table 5.12.

To check whether the signalling channel was effective in the long-term, hypothesis tests were conducted with the variables of forward premium rate, $(f_t^{t+1}-s_t)$, interest rate differentials $(i_{s,t}-i^*_{s,t})$ and $(i_{l,t}-i^*_{l,t})$, volatility rate $\triangle IV_t$, interventions I_t for the tests. The relations $H_{1.1}$ to $H_{1.5}$ can be respectively expressed as:

$$(f_t^{t+1}-s_t) - 0.10(i_{s,t} - i^*_{s,t}) - 0.03I_t + error\ term = 0, \tag{5.25}$$

$$(f_t^{t+1}-s_t) + 0.16(i_{s,t} - i^*_{s,t}) - 0.07 \triangle IV_t - 1.33I_t + error\ term = 0, \tag{5.26}$$

$$(f_t^{t+1}-s_t) - 0.17(i_{l,t} - i^*_{l,t}) + 0.32I_t + error\ term = 0, \tag{5.27}$$

$$(f_t^{t+1}-s_t) - 0.57(i_{l,t} - i^*_{l,t}) - 0.12 \triangle IV_t - 1.93I_t + error\ term = 0, \tag{5.28}$$

$$(f_t^{t+1}-s_t) - 0.37(i_{s,t} - i^*_{s,t}) + 0.78(i_{l,t} - i^*_{l,t}) - 0.49I_t + error\ term = 0. \tag{5.29}$$

Table 5.11: Misspecification and Rank Tests, September 2008 - December 2009

Multivariate Test Results							
Autocorrelation:	LM_1: $\chi^2(49) = 91.33$ with p-value 0						
	LM_2: $\chi^2(49) = 56.01$ with p-value 0.23						
Normality: $\chi^2(14) = 34.51$ with p-value 0.00							
Univariate Test Results							
	$\triangle^2 s_t$	$\triangle(f_t^{t+1} - s_t)$	$\triangle(i_{s,t} - i_{s,t}^*)$	$\triangle(i_{l,t} - i_{l,t}^*)$	$\triangle^2 IV_t$	$\triangle I_t$	$\triangle COT_t$
ARCH(2)	0.19	1.36	0.94	1.90	0.49	2.48	3.27
Normality	**7.88**	4.53	0.84	0.76	0.51	**13.01**	5.47
Skewness	-0.26	0.21	-0.26	0.13	0.17	0.48	-0.14
Kurtosis	**4.33**	3.84	2.81	3.08	2.58	**5.15**	3.96
Univariate Stationarity Tests							
	$\triangle s_t$	$(f_t^{t+1} - s_t)$	$(i_{s,t} - i_{s,t}^*)$	$(i_{l,t} - i_{l,t}^*)$	$\triangle IV_t$	I_t	COT_t
Unit Root	**8.54**	**9.26**	0.69	2.02	**6.63**	**5.14**	1.42
Process	$I(0)$	$I(0)$	$I(1)$	$I(1)$	$I(0)$	$I(0)$	$I(1)$
Trace Tests							
	$r = 0$	$r = 1$	$r = 2$	$r = 3$	$r = \mathbf{4}$	$r = 5$	$r = 6$
p-value	0.00	0.00	0.00	0.07	**0.54**	0.94	0.96

Table 5.12: Testing the Stationarity of Single Relations, September 2008 - December 2009

	$\triangle s_t$	$(f_t^{t+1} - s_t)$	$(i_{s,t} - i^*_{s,t})$	$(i_{l,t} - i^*_{l,t})$	$\triangle IV_t$	I_t	COT_t	$Trend$	*p-value*
Test of the Signalling Channel									
$\mathcal{H}_{1.1}$		1	-0.10			-0.03			0.27
$\mathcal{H}_{1.2}$		1	-0.16		-0.07	-1.33			1
$\mathcal{H}_{1.3}$		1		-0.17		0.32			0.08
$\mathcal{H}_{1.4}$		1		-0.57	-0.12	-1.93			1
$\mathcal{H}_{1.5}$		1	-0.37	0.78		-0.49			1
Test of the Coordination Channel									
$\mathcal{H}_{2.1}$						-20.30	1		0.02
$\mathcal{H}_{2.2}$						296.45	1	-1.09	0.02
$\mathcal{H}_{2.3}$					-0.51	-13.67	1		0.92
$\mathcal{H}_{2.4}$					-0.63	-17.64	1	0.02	0.86
Test of Reaction Function									
$\mathcal{H}_{3.1}$	2.01					1	0.66		0.16
$\mathcal{H}_{3.2}$	-1.89					1	-0.37	-0.03	0.15

All the five potential long-run relations are not rejected with p-values larger than 0.05. However, different setup of the tests on the signalling channels revealed different pictures. While $H_{1.3}$ showed the interventions decreased the forward premium rate which means the effectiveness of the signalling channel, the other four tests did not support the conclusion as the sign of the related coefficients was opposite. Hence, a suitable relation will be chosen based on more information in the following sections.

The test results with respect to the effectiveness of the coordination channel are shown in the rows from $H_{2.1}$ to $H_{2.4}$ with the following relations:

$$COT_t - 20.30I_t + error\ term = 0, \tag{5.30}$$

$$COT_t + 296.45I_t - 1.09Trend + error\ term = 0, \tag{5.31}$$

$$COT_t - 0.51 \triangle IV_t - 13.67I_t + error\ term = 0, \tag{5.32}$$

$$COT_t - 0.63 \triangle IV_t - 17.64I_t + 0.02Trend + error\ term = 0. \tag{5.33}$$

While the first two potential long-run relations, $H_{2.1}$ and $H_{2.2}$, are rejected with probability 0.02, the hypotheses with the form of $H_{2.3}$ and $\mathcal{H}_{2.4}$ can be rejected with probability more than 0.05. The latter potential relations shows that the speculation on MXN appreciation COT_t increase with the currency intervention to depreciate MXN, which means that the long-run effectiveness of the coordination channel was not fulfilled in the second regime. Nevertheless, there exists a negative relationship between intervention and exchange rate volatility, which reflects that the interventions could smooth the volatility of MXN/USD rate in the second regime.

To find the long-run structure of the reaction function of Banxico, we test with $H_{3.1}$ and $H_{3.2}$ whether the central bank react to the appreciation of MXN or the increasing speculation and sentiment. The potential long-run relations can be respectively expressed as follows:

$$I_t + 2.01 \triangle s_t + 0.66COT_t + error\ term = 0, \tag{5.34}$$

$$I_t - 1.89 \triangle s_t - 0.37COT_t - 0.03Trend + error\ term = 0. \tag{5.35}$$

Table 5.13: Identified Long-Run Structure, September 2008 - December 2009

	$\triangle s_t$	$(f_t^{t+1} - s_t)$	$(i_{s,t} - i^*_{s,t})$	$(i_{l,t} - i^*_{l,t})$	$\triangle IV_t$	I_t	COT_t	$Trend$
$ecm_{1,t}$		1	-0.30	0.58		0.58		
$ecm_{2,t}$					-0.37	-10.30	1	-0.004
$ecm_{3,t}$	-0.02				0.04	1	-0.10	
$ecm_{4,t}$	1		0.07	-0.94	-0.06		0.07	

While both relations were not rejected with probability larger than 0.05, the sign of the coefficients were just in the opposite. While $\mathcal{H}_{3.1}$ shows that the interventions was increasing with appreciating MXN, $H_{3.2}$ reflected that the central bank was 'leaning with the wind'. We will also explore more information in the following section to choose which hypothesis to be the foundation of a long-term reaction function of Banxico.

5.7.3 Identified Long-Run Structure of Channels and Reaction Function

Similar to the analysis on the previous regimes, weakly exogenous variables are excluded from short-run dynamic analysis before identifying long-run cointegration relations of our model. The short-run interest rate differential is tested to be weakly exogenous with its $\chi^2(4)$ test statistics 8.82 smaller than the critical value 9.49. A full cointegration structure H_{full}: $\beta = (H_1\varphi_1, H_2\varphi_2, H_3\varphi_3, H_4\varphi_4)$ is not rejected with probability 0.09 , and the related long-run cointegrations listed in Table 5.13.

Similar to the format of the hypothesis test $H_{1.3}$, the first identified cointegration relation is about the effectiveness of the signalling channel:

$$(f_t^{t+1} - s_t) - 0.30(i_{s,t} - i^*_{s,t}) + 0.58(i_{l,t} - i^*_{l,t}) + 0.58 I_t + error\ term = 0. \tag{5.36}$$

Although the short- and long-term interest rate differentials showed conflicting effects on the forward premium rate, the negative relationship of currency interventions and the forward premium rate means the signalling channel was effective in the long-term.

Based on the hypothesis test $H_{2.3}$, the second long-run cointegration relation is on whether the interventions worked through the coordination channel:

$$COT_t - 0.37 \bigtriangleup IV_t - 10.30I_t + \; error\ term = 0. \tag{5.37}$$

Although the interventions were negatively correlated with exchange rate volatility, the coordination channel was not effective in the long run as the Mexican interventions were positively related the speculation and sentiment on MXN appreciation.

Based on the hypothesis test $H_{3.2}$, the third long-run cointegration relation focuses the reaction function of the central bank's interventions:

$$I_t - 0.02 \bigtriangleup s_t + 0.04 \bigtriangleup IV_t - 0.10COT_t + error\ term. \tag{5.38}$$

The Mexican currency interventions were 'leaning against the wind' as they were positively correlated with the depreciating MXN. In the same time, central bank intervened to fence off speculative attacks reflected by the positive relationship between the interventions and speculation and sentiment variables. From the negative relations between change in exchange rate volatility and interventions, the interventions were not reacting to the high exchange rate volatilities.

The fourth long-run relation is to analyse the long term relationship between fundamental variables, e.g., interest rate differentials, and exchange rate volatility and speculation and sentiment, on the change in the MXN/USD rate:

$$\bigtriangleup s_t + 0.07(i_{s,t} - i^*_{s,t}) - 0.94(i_{l,t} - i^*_{l,t}) - 0.06 \bigtriangleup IV_t + 0.07COT_t + error\ term = 0. \tag{5.39}$$

While the short- and long-term interest rate differentials have opposite effects on the changes in exchange rates, the rate of MXN depreciation, $\bigtriangleup s_t$, is negatively and significantly correlated with the speculation and sentiment on the MXN appreciation, similar to the respective relation in the second regime. One billion speculation on MXN appreciation increased the rate of MXN appreciation by 0.07 percent. The rate of MXN depreciation was positively correlated with the rate of exchange rate volatility, which may reflect that MXN was vulnerable when the market risk was high.

The main findings based on the analysis on the long-run structure of the model are listed as follows: The Mexican currency interventions during this period were to react to high speculation and sentiment and change in the change rate, not to the large exchange rate fluctuations. Although the interventions failed to work through the coordination in the long run, they were effective through the signalling channel and reduced the exchange rate volatility. Besides intervention effects, the speculation and exchange volatility also have strong long-run relationship with the change in exchange rate. The more speculation on MXN depreciation and change in exchange rate volatility, the more depreciation of MXN in the long run.

5.7.4 Short-Run Dynamics of the Third Regime

With the weakly exogenous short-term interest rate differential variable and identified long-run structure, this section analyse the short-run dynamics and summarise the relevant results in Table 5.14. The short-term dynamics structure were accepted with probability 0.93.

The sixth column of Table 5.14 is about the short-run reaction function of Banxico. The interventions to depreciate MXN were reactions to sharp MXN appreciation and high exchange rate volatility. A 1% appreciation of MXN in terms of increase of change in exchange rate $\triangle^2 s_{t-1}$ and excess change in exchange rate $ecm_{4,t-1}$ increased interventions to depreciate MXN by 0.16 billion. In the mean time, a 1% increase of the change in exchange rate volatility $\triangle^2 IV_{t-1}$ caused Banxico to intervene 0.004 billion MXN in the following week.

Table 5.14: Short-Run Dynamics, September 2008 - December 2009

	$\triangle^2 s_t$	$\triangle(f_t^{t+1} - s_t)$	$\triangle(i_{l,t} - i_{l,t}^*)$	$\triangle^2 IV_t$	$\triangle I_t$	$\triangle COT_t$
$\triangle^2 s_{t-1}$					-0.01	
$\triangle(f_{t-1}^t - s_{t-1})$	-0.45					
$\triangle(i_{s,t} - i_{s,t}^*)$	0.86	0.59				
$\triangle(i_{s,t-1} - i_{s,t-1}^*)$			0.33			
$\triangle(i_{l,t-1} - i_{l,t-1}^*)$		0.86		4.33	-0.18	0.50
$\triangle^2 IV_{t-1}$	-0.04	-0.01	-0.004		0.004	
$\triangle I_{t-1}$	-4.61	0.76	-0.54	-8.61		
$\triangle COT_{t-1}$	-0.84		0.09			0.30
$ecm_{1,t-1}$		-1.06	-0.10	-6.07	0.12	
$ecm_{2,t-1}$				6.18		1.45
$ecm_{3,t-1}$	5.15	-2.67				5.53
$ecm_{4,t-1}$		-0.49		3.86	-0.15	
Constant	1.35	-1.10	0.17	5.34	-1.14	1.60
dum081007p	1.71	-1.51	0.58	2.34	0.56	
dum090317p	-7.88		-0.37	2.89	-0.41	
dum090901p	4.33	-0.83		1.34		-1.55
dum081209t		-1.85	-0.46		0.24	
Notes: Only significant coefficients with $p < 0.05$ are shown.						
The *ecm* variables are based on (5.36) - (5.39) respectively.						

From the eighth and twelfth rows with respect to interventions $\triangle I_{t-1}$ and excess interventions $ecm_{3,t-1}$, the combined effects of interventions had significant short-term effects on the dynamics of the MXN/USD rate. One billion change in intervention to depreciate MXN increased the rate of MXN depreciation by 0.51% and reduced the change in exchange rate volatility by 2.43% in the following week. The effectiveness of the interventions were through the signalling channel with the combined negative effects of interventions on the forward premium rate, i.e., one billion change in interventions decreased the forward premium rate by 1.91% in the following week. However, the interventions were not effective through the coordination channel as one billion change in interventions to depreciate MXN increased speculation on MXN by 5.53 billion.

The ninth and eleventh rows reflects the short-term effects of change in speculation and sentiment $\triangle COT_{t-1}$ and excess speculation and sentiment $ecm_{2,t-1}$. While one billion increase of speculation on MXN appreciation $\triangle COT_{t-1}$ increased the rate of MXN appreciation by 0.84% in the following week, one billion excess speculation $ecm_{2,t-1}$ increased the change in exchange rate volatility $\triangle^2 IV_t$ by 6.18%. Noticeably, the speculation and sentiment shown some clustering behaviour as the one billion increase in speculation and one billion excess speculation have combined short-term effects of 1.75 billion more speculation in the following week.

The main findings with respect to the short-run dynamics of our model can be summarised as follows: Firstly, the Mexican interventions were in response to sharp MXN appreciation and high exchange rate volatility. Secondly, the interventions were effective only through the signalling channel. One billion intervention increased the rate of MXN depreciation by 0.51% and reduced the change in exchange rate volatility by 2.43% in the following week. Thirdly, the coordination channel failed to work during the last financial crisis as one billion intervention increased speculation by 5.53 billion. Fourthly, the clustering speculation and sentiment on MXN have strong short-term effects

Table 5.15: The Estimates of the Long-Run Impacts, September 2008 - December 2009

	$\sum \varepsilon_{\triangle s_t}$	$\sum \varepsilon_{(f_t^{t+1}-s_t)}$	$\sum \varepsilon_{(i_{s,t}-i^*_{s,t})}$	$\sum \varepsilon_{(i_{l,t}-i^*_{l,t})}$	$\sum \varepsilon_{(\triangle IV_t)}$	$\sum \varepsilon_{I_t}$	$\sum \varepsilon_{COT_t}$
$\triangle s_t$		-0.04	0.14	0.21			-0.05
$(f_t^{t+1} - s_t)$		0.03		-0.18			0.05
$(i_{s,t} - i^*_{s,t})$			1.44				
$(i_{l,t} - i^*_{l,t})$			0.44	0.72	-0.01		0.02
$\triangle IV_t$				-7.82	0.05		
I_t				0.28			0.10
COT_t						1.09	1.14
Notes: Only significant coefficients with t-values$>$ 1.96 are shown.							

on the exchange rate dynamics. One billion speculation on MXN appreciation increased the rate of MXN appreciation and the change in exchange rate volatility by 0.84% and 6.18% respectively in the following week.

5.7.5 The Long-Run Impact of Shocks

After analyzing the long-run cointegration relations and the short-run effects, this section examines the long-run impact of a permanent shock to the variables. The results are reported in Table 5.15.

Based on the column-wise inspection, the shocks to the speculation and sentiment and bond yield differential, i.e., $\sum \varepsilon_{COT_t}$ and $\sum \varepsilon_{(i_{l,t}-i^*_{l,t})}$, were the drivers of the whole system as they have long-run significant impact on most the variables in our model. The interventions were also reactions to the large shocks to the bond yield differential, and speculation and sentiment. Shocks of one billion speculation on MXN appreciation increased the Banxico's intervention by 0.1 billion.

A shock to the interventions $\sum \varepsilon_{I_t}$ had no long-run impact on the exchange rate dynamics. The reason might be the failure of the coordination channel as a shock to interventions on MXN depreciation had significant positive impact on the speculation and sentiment on MXN appreciation, i.e., a permanent shock to one billion intervention caused 1.09 billion more speculation.

The impact of shocks on the change in exchange rate, $\triangle s_t$, and the forward premium rate, $(f_t^{t+1}-s_t)$, showed different sign which supports the existence of the forward rate bias. The speculation and sentiment shocks had significant impact on the change of the exchange rate. Shocks of one billion speculation on MXN appreciation caused the MXN appreciation by 0.05 percent.

It also noticeable that the shock to the speculation and sentiment on MXN appreciation had a significant positive impact on itself, which reflects the herding behaviour of the speculators speculating on MXN appreciation.

Therefore, the main results of the long-term shocks to the variables can be summarised as follows: The speculation and sentiment on MXN appreciation and bond yield differential were the main driving forces in the third regime where the last financial crisis was at the peak. The speculation and sentiment happened in clusters and significantly affected the change in the MXN/USD rate, which stimulate Banxico to react with interventions. However, the intervention shocks failed to influence the exchange rate dynamics efficiently because they only increased the speculation and sentiment on MXN appreciation, i.e., the coordination channel failed to work.

5.7.6 Summary of Results in the third Regime

The third Mexican intervention regime was featured with large and frequent interventions and relative high exchange rate volatility. The main findings of the related empirical analysis can be summarised as follows:

Firstly, after the collapse of Lehman Brothers, while Banxico intervened in the foreign exchange market mainly to react to the high speculation and sentiment, in the short-term it also reacted to the high exchange rate volatility.

Secondly, the interventions were effective through the signalling channel and reduced the exchange rate volatility. One billion intervention increased the rate of MXN depreciation by 0.51% and reduced the change in exchange rate volatility by 2.43% in the following week.

Thirdly, the interventions failed to work through the coordination channel as one billion intervention increased speculation by 5.53 billion in the short-run and 1.09 billion in the long-term.

Fourthly, the clustering speculation and sentiment on MXN have strong and significant effects on the change in exchange rate and worked as a main driver of the whole system. The speculators shown some herding behaviour. While one billion speculation on MXN appreciation increased the rate of MXN appreciation by 0.84% in the following week and a shock of one billion speculation had long-term impact of 0.05% MXN appreciation.

5.8 Summary

Following from the previous chapter, an unique analysis of currency intervention, speculation and sentiment for an emerging economy currency with a identified cointegrated VAR model in a microstructure framework. Separate intervention channels are jointly tested in an identified structural framework with various factors for an emerging country currency pair. The empirical analysis provides detailed results with respect to different regimes of Mexican interventions between 1998 and 2009, which also covers the financial crisis after the collapse of Lehman Brothers. Additionally an innovative microstructure framework formed in the previous chapter is tested to help explain the differences of exchange rate dynamics and effects of intervention, speculation and sentiment across developed and emerging country currencies.

The three Mexican intervention regimes are respectively featured with small and infrequent interventions, small but frequent interventions and relative low exchange rate volatility, and large and frequent interventions and relative high exchange rate volatility.

With respect to the reaction function of the Banxico, in all regimes the interventions to depreciate MXN were reactions to the high speculation and sentiment on MXN appreciation, and vice versa. Banxico intervened in the foreign exchange market to react to the increase of exchange rate volatility from 2003 when the volatility data was available.

Similar to the findings of the last chapter on Japanese interventions, the signalling channel were effective when the interventions were frequent in the second and third regimes. In the second regime, through both the coordination and signalling channels, one billion of intervention increased the rate of MXN depreciation by 7.85% in the short term and deceased the rate of MXN appreciation by 0.85% in the long-term. In the third regime between 2008 and 2008, through the coordination channel, one billion intervention increased the rate of MXN depreciation by 0.51% and reduced the change in exchange rate volatility by 2.43% in the following week.

Contrary to the findings of the last chapter that the coordination channel tended to be effective when the Japanese interventions were large but infrequent between 1999 and 2000, the channel only worked between 2003 and 2008 when Mexican interventions were small but frequent. In the third regime when the last financial crisis was at its peak, instead of reducing the speculation and sentiment, one billion intervention increased speculation by 5.53 billion in the short-run and 1.09 billion in the long-run. Noticeably, the coordination channel were effective when the change in volatility of the JPY/USD rate between 1999 and 2000, and MXN/USD rate between 2003 and 2008 were quite small, and not effective amid the sharp increase of volatility of the JPY/USD rate between 2003 and 2004 and the MXN/USD rate after the collapse of Lehman Brothers. The results indicate that it is not the pattern of interventions but the market condition that matters the effectiveness of the coordination channel: The speculators tend to coordinate with the central banks when markets are less volatile and with less risk, and vice verse.

The small and infrequent currency interventions between 1998 and 1999 were not effective through the coordination and signalling channels and their short-term significant effects on the change in the MXN/USD rate were dependent on accommodative monetary policies.

In stead of bond yield differentials, it was the clustering speculation and sentiment on MXN appreciation drove most variables and had significant effects on the change in exchange rate in all regimes. In the first and third regimes, one billion long position on MXN respectively increased the appreciation rate of MXN by 7.26% and 0.84% in the short-run and 0.65% and 0.05% in the long run. In the second regime, one billion speculation on MXN appreciation increased the rate of the currency appreciation by 0.15% while reducing the rate of exchange rate volatility by 6.52%.

Together with the analysis on the JPY/USD market in the previous chapters, this chapter provides a relatively complete picture of the exchange rate dynamics under currency intervention, speculation and sentiment across the developed and emerging countries. Our research provides a new way to not only analyse the currency intervention, speculation and sentiment, but also examine the transmission channels and reaction functions of monetary policies of central banks, which offers a potential direction for further related empirical and theoretical research.

Chapter 6

Conclusion

This chapter summarise the main empirical findings of this thesis, provide several policy implications for central banks across the developed and developing countries, and offers potential directions for future research on currency intervention, sentiment and speculation in the foreign exchange market.

6.1 Summary of Key Results

After an introductory chapter providing the research background, Chapter 2 reviews the theoretical and empirical literature in the filed of currency intervention, speculation and sentiment. Previously, with greater availability of data sets and advances of econometric modelling technique, there has been important progressto shed more light on the dynamics of exchange rates across developed and developing countries but three important issues remained to be solved:

(1) There is an absence of structural analyses of the links between currency intervention, exchange-rate dynamics and market conditions measured by currency speculation and sentiment. While most studies on currency interventions rely on traditional estimation methods, e.g., low- and high-frequency time series and event studies, only several studies, e.g. Kearns and Rigobon (2005), Kim (2003) and Neely (2005b,c), use structural models to identify

interactions between currency interventions, monetary policy and exchange rate dynamics. However, there is no research with identified models considering the market conditions influenced by currency speculation and sentiment, largely due to the limitation of data availability.

(2)There is a lack of clear theoretical foundation and consideration of market microstructure to analyse the effects of currency intervention, speculation and sentiment on the exchange rate dynamics. As it is very difficult to define the proper model of exchange rate determination, few empirical studies of currency intervention are based on clear structural relations or theoretical models. Although currency intervention has been intertwined with currency speculation and sentiment, few studies have been conducted to analyse the microstructure of foreign exchange markets considering the activities of the speculators and central bank in the same framework. The main problems are the difficulty of finding available currency speculation data or properly defined proxy of currency speculation and sentiment.

(3)While there are numerous papers on the currency intervention, speculation and sentiment on developed country currencies, the related research on developing and emerging country currencies is still sparse. Given that currency interventions happen more often in developing countries than developed ones and speculation on the emerging country currency is very large, research on developing and emerging country currencies is highly needed. Furthermore, there might be different features with respect to exchange-rate dynamics across developed and developing countries. However, we need to overcome the data availability problem to conduct data analysis and result comparison.

The three core chapters examines these questions. Chapter 3 analyses the effects of currency intervention, speculation and sentiment on the JPY/USD rate between 1991 and 2008 with a identified cointegrated VAR model. This chapter structurally examines effects of interventions through the portfolio balance channel in the context of the international parity conditions and also addresses the effectiveness of the coordination channel with a COT sentiment index measuring speculation and sentiment on JPY. Not surprisingly, the small and infrequent US interventions were not effective through either channel. Contrary to the previous findings (Frankel, 1982; Obstfeld, 1983; Rogoff,1984; Lewis, 1988; Dominguez and Frankel, 1993) that there are no long-term effects through the portfolio balance channel, i.e., one billion USD Japanese currency intervention is correlated with long-term monthly change in the exchange rate by around 2.5% through the channel. The Japanese currency interventions have both short- and long-term effects on the JPY/USD rate through the coordination channel. One billion USD Japanese currency intervention, coordinated with the increase of JPY speculation, is correlated with around 0.8% long-term JPY appreciation.

Chapter 4 continues the research on the JPY/USD rate in a new theoretical and empirical framework by separating the whole periods into three regimes with active interventions as there are many periods without any intervention between 1991 and 2008. After building an innovative microstructure framework we structurally identify and analyse the relation between currency intervention, speculation and sentiment and exchange-rate dynamics. In all regimes, it was the shock to the bond yield spread differential that drove the whole system of the JPY/USD market. The Japanese monetary authorities intervened in the currency market to react to sharp JPY appreciation in all regimes between 1991 and 2004. We find the similar results as Ito (2005) that the Japanese monetary authorities also reacted to the high exchange rate volatility and large speculation on JPY appreciation between 2003 and 2004. With respect to the transmission channels of interventions, the signalling channel, with existence of the forward rate bias, was effective when the interventions were frequent in the first and third regimes, and the coordination channel were effective in the second regime when the exchange rate volatility was low. Similar to Ito (2005), Giradin and Lyons (2007) and Marsh (2011), the speculators in the foreign exchange market were not coordinating with the Japanese interventions.

There has been few research on the currency intervention, speculation and sentiment in developing countries. With availability of Mexican data, Chapter 5 analyses the MXN/USD market to shed more lights on different features of the exchange rate dynamics across developed and developing countries. It was the speculation and sentiment on the MXN appreciation, not bond yield differential, that drove the whole exchange rate system. Furthermore, the Mexican monetary authorities reacted to the high speculation and sentiment on MXN appreciation and the increasing exchange rate volatility, not to the change in the exchange rate. However, we do find similar results across the developed and developing country currency pairs. In both JPY/USD and MXN/USD markets the effectiveness of transmission channels were dependent on the frequency of interventions and market conditions. To be specific, while the signalling channel is effective with frequent interventions and the coordination channel is effective amid low exchange rate volatility, they are not effective channels for the small and infrequent interventions.

Based on adequate data, Chapters 2-5 provide a literature review, clear theoretical frameworks and detailed structural analyses of the factors affecting the exchange rate dynamics across developed and developing countries. Our studies also have clear policy implications for monetary authorities in both developed and developing countries, which are discussed in the next section.

6.2 Policy Implications for Central Banks

There are several policy implications draw on the findings of this thesis. This section discusses the potential implications for central banks across developed and developing countries respectively.

Based on the studies on Japanese currency intervention, speculation and sentiment, the main purpose of Japanese currency interventions was to control the change in JPY/USD rate, although sometimes the interventions were reactions to sharp change in exchange rate volatility and high speculation and sentiment on JPY appreciation. Therefore, Japanese monetary authorities were implementing intervention policies without a target value of JPY/USD rate. Between 1991 and 2008, while cumulative Japanese interventions worked through the portfolio balance channel in the long-term, the frequent interventions worked through the signalling channel, and coordination channel was effective when the exchange rate volatility were low. Small and infrequent interventions were not effective.

The findings on the Mexican foreign exchange market confirm that the conditions on which the signalling and coordination channels are effective are the same as in the Japanese case. However, the Mexican monetary authorities stepped in the foreign exchange market when the speculation and sentiment on MXN appreciation were high and exchange rate volatility was increasing fast. Further more, the speculation and sentiment on the MXN appreciation have driven the whole MXN/USD exchange rate system since the Peso begun to float in mid-1990s.

Therefore, the main proposals for central banks across developed and developing countries to conduct successful interventions are as follows:

(1) The monetary authorities should rely on large and frequent interventions to change the long-term level of the exchange rate through the portfolio balance channel.

(2) If the central banks plan to send a clear signal to the other agents in the foreign exchange market on future monetary policy or value of the exchange rate, they should act more frequently and constantly during the intervention period.

(3) In terms of the effectiveness of interventions through the coordination channel, the central banks should consider the change in expected exchange rate volatility. To be specific, they should intervene when they and other market agents expect there will be no huge change in the exchange rate

volatility.

(4) Specific market conditions including activities and phycology of the currency speculators should be taken into consideration before policy implication. In the Japanese case, the monetary authorities should make sure the dynamics of the bond market does not hurdle the efforts of central bank interventions as the bond yield differential is the main driver of the JPY/USD market. With respect to Mexican interventions, the Banxico should adjust the course of the speculation and sentiment on the MXN and make the speculators coordinate with interventions.

6.3 Proposal for Future Research

This thesis suggests further research on currency intervention, speculation and sentiment.The relationship between actual and oral interventions should be examined further, as while the actual interventions in major developed countries are less frequent now than in the past, the major central banks tend to influence the foreign exchange rate via oral interventions. Fratzscher (2006) propose that the oral interventions are substitutes for actual interventions as oral interventions of the major central banks tend to move the exchange rate in the desired directions by affecting exchange rates over a 6 month horizon and also lowering exchange rate volatility. In contrast to the substitution hypothesis, Beine et al. (2009) state that, while oral interventions provide a powerful instrument for central bank, they are complements of the actual interventions. Their proposal is supported by the findings that the oral interventions in terms of statements reduced the probability of counterproductive interventions in terms of exchange rate level and volatility. Given the limited research progress, more research is needed to test the interaction hypotheses between oral and actual interventions to provide better theoretical explanation and policy implication.

More research could be developed to contrast developed and developing countries. In some developing and emerging countries, e.g., Czech Republic, Mexico, Turkey, et al., currency interventions are quite active. However, as Menkhoff (2013) finds, the literature devoted to developing and emerging countries is sparse. Furthermore, there has been little investigation to compare the transmission channels of interventions between the developed and developing countries and there are conflicting views on the effectiveness of the transmission channels, this thesis shows that the Mexican currency interventions are effective through the signalling and coordination channels.

Another area for future research would be to examine interventions in the option foreign exchange markets. Previously, most research on currency interventions examines interventions in the spot market, while the options market has not been analysed as closely. There is a gap in the literature about the advantages and disadvantages of the interventions through options across developed and developing countries.

Extra attention could be paid to interactions between currency interventions and monetary policies. Sterilised interventions offer an unique instrument other than monetary polices. Kaminsky and Lewis (1996) raise the question of whether currency interventions signal future monetary policy and Watanabe and Yabu (2013) examine the relationship between the currency intervention and the quantitative easing policy of the Bank of Japan between January 2003 and March 2004. However, there is no research on the interventions in interaction with unconventional monetary policies during the last financial crisis. More research is needed to find their relationship and distinctive effects on the exchange rate especially during the financial crisis periods.

The fifth potential research area is the profitability of central banks and speculators during the intervention periods. Ito (2005) note that the Japanese interventions between 1991 and 2002 generate profits for the monetary authorities. While LeBaron (1999) find that currency speculators make money from the market inefficiencies generated from currency interventions, Neely

(2002) argues that currency interventions happen after speculators activate their positions and tend to reduce the profitability of speculations. In general, the profitability of interventions and speculations is subject to further research.

Lastly, there could be more research into the the interactions between interventions and the sentiment of foreign exchange market participants and the effects of market sentiment on the dynamics of exchange rates. Corrado et al. (2007) adopt the behavioural model of investor sentiment from Barberis et al. (1998), and demonstrate that currency interventions can coordinate investor beliefs with those of policy-makers and reduce the excess exchange rate volatility. The results of this thesis provides some analysis of interventions in interaction with speculation and sentiment and the effects of speculative sentiment on the exchange rate movements, more research is needed in this direction theoretical developments in behavioural finance.

In general this thesis contributes to the research related to the intervention, speculation and sentiment in the foreign exchange market in itself, provides feasible policy implication suggestions, and offers plenty of topics need to be addressed by future research.

Bibliography

[1] Adler, G. and C. E. Tovar (2011). Foreign exchange intervention: A shield against appreciation winds? IMF Working Paper WP/11/165.

[2] Almekinders, G. J. (1995). Foreign Exchange Intervention: Theory and Evidence, Edward Elgar Publishing Ltd, Cheltenham.

[3] Almekinders, G. J. and S. C. W., Eijffinger. (1994). Daily Bundesbank and Federal Reserve Interventions: Are They a Reaction to Changes in the Level and Volatility of the DM/$-Rate?, Empirical Economics, vol. 19(1), pp.111-130.

[4] Antweiler, W. and M. Z. Frank. (2004). Is All That Talk Just Noise? The Information Content of Internet Stock Message Boards, Journal of Finance, 59(3), pp. 1259-1294.

[5] Bacchetta, P. and E. Van Wincoop. (2006). Can Information Heterogeneity Explain the Exchange Rate Determination Puzzle?, American Economic Review, 96(3), pp. 552-576.

[6] Baillie, R. T. and O. F. Humpage (1992). Post-Louvre Intervention: Did Target Zones Stabilize the Dollar? Federal Reserve Bank of Cleveland, no. 9203.

[7] Barber, B. M., and T. Odean (2008). All That Glitters: The Effect of Attention and News on the Buying Behavior of Individual and Institutional Investors, Review of Financial Studies, 21(2), pp. 785-818.

[8] Barberis, N., Shleifer, A. and R. Vishny. (1998). A Model of Investor Sentiment, Journal of Financial Economics, 49(3), pp. 307-343.

[9] Beaumont R., van Daele, M., Frijns, B., Lehnert, T. and A. Muller. (2008). Investor Sentiment, Mutual Fund Flows and Its Impact on Returns and Volatility, Managerial Finance, Vol 34(11), pp.772-785.

[10] Beine, M. (2003) Volatility Expectations and Asymmetric Effects of Central Bank Interventions in the FX Market, Journal of the Japanese and International Economies, 2003, 17 (1), pp. 55-80.

[11] Beine, M., G. Janssen, and C. Lecourt. (2009). Should Central Bankers Talk to the FX Markets? Journal of International Money and Finance, 28(5), pp. 776-803.

[12] Berganza, J. C. and C. Broto (2012). Flexible inflation targets, forex interventions and exchange rate volatility in emerging countries, Journal of International Money and Finance, 31, pp. 428–444.

[13] Bonser-Neal, C. and G. Tanner. (1996). Central Bank Intervention and the Volatility of Foreign Exchange Rates: Evidence from the Options Market, Journal of International Money and Finance, Vol 15 (6), pp. 853-78.

[14] Bordo M., Humpage O. and A. Schwartz (2007). The historical origins of US exchange market intervention policy. International Journal of Finance and Economics, 12, pp.109-132.

[15] Bordo M., Humpage O. and A. Schwartz (2009). A brief empirical history of U.S. foreign-exchange intervention: 1973-1995. Federal Reserve Bank of Cleveland, Working Paper no. 09-03.

[16] Bordo M., Humpage O. and A. Schwartz (2010). U.S. foreign-exchange market intervention during the Volcker-Greenspan Era. NBER Working Paper No. 16345.

[17] Bordo M., Humpage O. and A. Schwartz (2012). Epilogue: Foreign-Exchange-Market Operations in the Twenty-First Century. NBER Working Paper No. 17984.

[18] Branson, W. H. (1984). A model of exchange rate determination with policy reaction: Evidence from monthly data. in P. Malgrange and P. A. Muet (eds.), Contemporary Macroeconomic Modelling, Blackwell, Oxford, UK, pp. 128-150.

[19] Briese, S. E. (1994) Illuminating Data: Commitments of Traders Report Can Disclose Promise, Perils in the Market, Barron's.

[20] Broto, C. (2013). The effectiveness of forex interventions in four Latin American countries, Emerging Markets Review, 17, pp. 224-240.

[21] Brown, G. W., and M. T. Cliff. (2004) Investor Sentiment and the Near-Term Stock Market. Journal of Empirical Finance, 11(1), pp. 1-27.

[22] Burnside, C., Eichenbaum, M., Kleshchelski, I., S. Rebelo (2006). The Returns to Currency Speculation. NBER Working Paper 12489.

[23] Campell, J. Y. (1995). Some lessons from the yield curve. Journal of Economic Perspectives, 9(3), pp.129-152.

[24] Campell, J. Y.and R. Shiller (1987). Cointegration and tests of present value models, Journal of Political Economy, 95, pp. 1062-1088.

[25] Canales-Kriljenko, J. I. (2006). Survey of Foreign Exchange Intervention in Developing Countries, in Ishii, S. et al. (eds.), Official foreign exchange intervention, International Monetary Fund Occasional paper, 249, Washington, D.C.

[26] Choi, H. and H. Varian (2012). Predicting the Present with Google Trends. Economic Record, 88, pp. 2-9.

[27] Clark, P. K. (1973). A Subordinated Stochastic Process Model with Finite Variance for Speculative Prices Econometrica, 41(1), pp. 135-155.

[28] Clinton, K. (1988). Transactions Costs and Covered Interest Arbitrage: Theory and Evidence. Journal of Political Economy, 96 (2), pp. 358–370.

[29] Corrado, L, Miller, M. and L. Zhang. (2007). Bulls, Bears and Excess Volatility: Can Currency Intervention Help? International Journal of Finance and Economics, 12(2), pp. 261-272.

[30] Cumby , R. and M. Obstfeld (1981). Exchange rate expectations and nominal interest rates: A test of Fisher hypothesis, Journal of Finance, 36, pp.697-703.

[31] Da, Z., Engelberg, J. and P. Gao (2011). In search of attention. Journal of Finance, 66 (5), pp. 1461–1499.

[32] Das, S. R. and Martinez-Jerez, F. and P. Tufano (2005). eInformation: A Clinical Study of Investor Discussion and Sentiment. Financial Management, 34(3), pp. 103-137.

[33] Das S. R. and M. Y. Chen (2007). Yahoo! for Amazon: Sentiment Extraction from Small Talk on the Web, Management Science, 53(9), pp. 1375-1388.

[34] Dennis, J., Johansen, S. and K. Juselius (2005). CATS for RATS: Manual to Cointegration Analysis of Time Series. Estima. Illinois, US.

[35] Disyatat, P. and G. Galati (2007). The effectiveness of foreign exchange intervention in emerging market countries: Evidence from the Czech koruna, Journal of International Money and Finance, 26, pp. 383-402.

[36] Domac, I. and A. Mendoza (2004). Is there room for foreign exchange interventions under an inflation targeting framework? World Bank Policy Research Working Paper 3288.

[37] Dominguez, K. M. (1987). Exchange rate efficiency and the behavior of international asset markets. Ph.D. thesis, Yale University, U.S.

[38] Dominguez, K. M. (1990). 'Market Responses to Coordinated Central Bank Intervention', Carnegie-Rochester Conference Series in Public Policy, 32, pp.121-163.

[39] Dominguez, K. M. (1998). Central Bank Intervention And Exchange Rate Volatility. Journal of International Money and Finance, vol. 17(1), pp. 161-190.

[40] Dominguez, K. M. (2003). The market microstructure of Central Bank intervention. Journal of International Economics, 59, pp. 25-45.

[41] Dominguez, K. M. (2006). When do central bank interventions influence intra-daily and longer-term exchange rate movements? Journal of International Money and Finance 25, pp.1051-1071.

[42] Dominguez, K. M. and J. A. Frankel (1993). Does foreign exchange intervention work? The portfolio effect. American Economic Review, 83, pp. 1356-1369.

[43] Dooley, M. P., and J. Shafer. (1983). Analysis of Short-Run Exchange Rate Behavior: March 1973 to November 1981. In Bigman, D. and T. Taya (eds.) Exchange Rate and Trade Instability: Causes, Consequences, and Remedies, pp. 43-72. Cambridge, MA: Ballinger.

[44] Edison, H. J. (1993). The Effectiveness of Central-Bank Intervention: A Survey of the Litterature after 1982. Princeton Studies in International Economics 18, International Economics Section, Departement of Economics Princeton University.

[45] Eijffinger, S. C. W. and N. P. D. Gruijters (1991). On the Short Term Objectives of Daily Intervention by the Deutsche Bundesbank and the Federal Reserve System in the US Dollar/Deutsche Mark Exchange Market. Kredit und Capital, 24, pp. 50-72.

[46] Engel, C. (1996). A Note on Cointegration and International Capital Market Efficiency. Journal of International Money and Finance, 15(4), pp. 661-664.

[47] Engle, R. F. and C. W. J. Granger (1987). Co-Integration and Error Correction: Representation, Estimation and Testing. Econometrica, 59, pp. 251-276.

[48] Epps, T. W., and M. L. Epps (1976). The Stochastic Dependence of Security Price Changes and Transaction Volumes: Implications for the Mixture-of-Distributions Hypothesis, Econometrica, 44, pp. 305-321.

[49] Evans, M. D. D. and R. K. Lyons (2002). Order Flow and Exchange Rate Dynamics. Journal of Political Economy, 110(1), pp. 170-180.

[50] Fama, E. F. (1970). Efficient Capital Markets: A Review of Theory and Empirical Work, 25(2), pp. 383-417.

[51] Fama, E. F. and R. Roll (1968). Some Properties of Symmetric Stable Distributions. Journal of the American Statistical Association, 1968, 63(323), pp. 817.

[52] Fama, E. F., Fisher, L., Jensen, M. C. and R. Roll (1969). The Adjustment of Stock Prices to New Information, International Economic Review, 10(1), pp. 1-21.

[53] Fatum, R. And M M. Hutchison (2003). Is sterilised foreign exchange intervention effective after all? An Event Study Approach. The Economic Journal, 113, pp. 390-411.

[54] Fatum, R. And M M. Hutchison (2006). Effectiveness of official daily foreign exchange market intervention operations in Japan. Journal of International Money and Finance, 25(2), pp. 199-219.

[55] Fatum, R. And M. King (2005). Rules versus discretion in foreign Exchange intervention: evidence from official Bank of Canada high-frequency data, SCCIE Working Paper No. 04-24, Copenhagen.

[56] Fischer, A M. (2006). On the inadequacy of newswire reports for empirical research on foreign exchange interventions, Journal of International Money and Finance, 25(8), pp. 1226-1240.

[57] Frankel, J. A. (1982). In Search of the Exchange Rate Premium:ASix-Currency Test Assuming Mean-Variance Optimization. Journal of International Money and Finance, 1, pp. 255-273.

[58] Frankel, J. and J. Poonawala (2010). The forward market in emerging currencies: Less biased than in major currencies. Journal of International Money and Finance, 29(3), pp. 585-598.

[59] Fratzscher, M. (2006). On the Long-term Effectiveness of Exchange Rate Communication and Interventions, Journal of International Money and Finance, 25, pp. 146-167.

[60] Frenkel, M., C. Pierdzioch and G. Statmann (2004) The accuracy of press reports regarding the foreign exchange interventions of the Bank of Japan. Journal of International Financial Markets, Institutions and Money 14, pp. 25-36.

[61] Frenkel, M., C. Pierdzioch and G. Statmann (2005). The effects of Japanese foreign exchange market interventions on the Yen/U.S: Dollar exchange rate volatility. International Review of Economics and Finance, 14, pp. 27-39.

[62] Friedman, M. (1953). Essays in Positive Economics. University of Chicago Press: Chicago.

[63] Frydman, R. and M. Goldberg (2007). Imperfect Knowledge Economics: Exchange Rates and Risk, Princeton University Press, Princeton and Oxford.

[64] Frydman, R., M. Goldberg, S. Johansen and K. Juselius (2008). A Resolution of the Purchasing Power Parity Puzzle: Imperfect Knowledge and Long Swings. Univ. of Copenhagen Dept. of Economics Discussion Paper No. 08-31.

[65] Galati, G., W. Melick and M. Micu (2005). Foreign exchange market intervention and expectations: the yen/dollar exchange rate. Journal of International Money and Finance, 24, pp. 982-1011.

[66] Girardin, E. and R. K. Lyons, (2007). Does intervention alter private behavior? Working Paper, GREQUAM Aix-Marseille.

[67] Goodhart, C.A.E. and T. Hesse, (1993) Central bank forex intervention assessed in continuous time. Journal of International Money and Finance, 12, pp. 368-389.

[68] de Grauwe, P. and M. Grimaldi (2006). The Exchange Rate in a Behavioral Finance Framework, Princeton University Press.

[69] Groves, R. M. (2004). Survey Errors and Survey Costs, John Wiley & Sons.

[70] Guimaraes, R. and C. Karacadag (2006). The Empirics of Foreign Exchange Intervention in Emerging Markets: Mexico and Turkey, in Ishii, S. et al. (eds.), Official foreign exchange intervention, International Monetary Fund Occasional paper (249), Washington, D.C.

[71] Hallwood, P. And MacDonald, R. (1999). International Money and Finance, 3rd Edition, Basil Blackwell, Oxford.

[72] Hillebrand, E. and G. Schnabl (2008). A structural break in the effects of Japanese foreign exchange intervention on yen/dollar exchange rate volatility. International Economics and Economic Policy, 5(4), pp. 389-401.

[73] Humpage, O. F. (1986). Exchange-Market Intervention: The Channels of Influence Federal Reserve Bank of Cleveland, Economic Review, 22(3).

[74] Humpage, O. F. (1989). On the Effectiveness of Exchange-Market Intervention. Federal Reserve Bank of Cleveland, mimeo.

[75] Humpage, O. F. (2000). The United States as An Informed Foreign-Exchange Speculator. Journal of International Financial Markets, Institutions, and Money,10(3-4), pp. 287-302.

[76] IMF [International Monetary Fund](2010), Annual report on exchange arrangements and exchange restrictions, Washington, D.C.

[77] Isard, P. (1980). Lessons From An Empirical Model of Exchange Rates, International Monetary Fund Staff Papers, 34, pp.1-28.

[78] Ito, T. (2002). Is foreign exchange intervention effective? The Japanese experiences in the 1990s. NBER Working Paper No. 8914.

[79] Ito, T. (2005). Interventions And Japanese Economic Recovery. International Economics and Economic Policy, 2(2), pp. 219-239.

[80] Ito, T. (2007). Myths and reality of foreign exchange interventions: An application to Japan. International Journal of Finance and Economics, 12, pp. 133-154.

[81] Ito, T. and T. Yabu. (2007). What promotes Japan to intervene in the forex market? A new approach to a reaction function. Journal of International Money and Finance, 26, pp.193–212.

[82] Johansen, S. (1988). Statistical Analysis of Cointegration Vectors. Journal of Economic Dynamics and Control, 12, pp. 231-254

[83] Johansen, S. (1991). Estimation and Hypothesis Testing of Cointegration Vectors in Gaussian Vector Autoregressive Models. Econometrica, 59, pp.1551-1580.

[84] Johansen, S. (1996). Likelihood Based Inference on Cointegration in the Vector Autoregressive Model. Oxford University Press, Oxford, 2nd ed.

[85] Johansen, S.; K. Juselius, R. Frydman and M. Goldberg. (2010). Testing hypotheses in an I(2) model with applications to the persistent long swings in the Dmk/$ rate. Journal of Econometrics, 158, pp.117-129.

[86] Johansen, S. and H. Luetkepohl. (2005). A note on testing restrictions for cointegration parameters of a VAR with I(2) variables. Econometric Theory, 21, pp.653-658.

[87] Juselius, K. (2006). The Cointegrated VAR model: Methodology and Applications, Oxford University Press, Oxford, UK.

[88] Juselius, K. and R. MacDonald. (2004). International Parity Relationships between Japan and the United States: A joint Modelling Approach. Japan and World Economy, 16(1), pp. 17-34.

[89] Kaminsky, G. and K. Lewis. (1996). Does Foreign Exchange Intervention Signal Future Monetary Policy? Journal of Monetary Economics, 37, pp. 285-312.

[90] Kearney, C. and R. MacDonald (1986). Intervention and Sterilisation Under Floating Exchange Rates: The UK 1973-1983, European Economic Review, 30, pp. 345-364.

[91] Kearns, J. and R. Roberton (2005). Identifying the efficacy of central bank interventions: The Australian case. Journal of International Economics, 66(1), pp. 31-48.

[92] Kenen, P. B. (1988). Managing Exchange Rates, Chatham House Papers, Routledge, London, UK.

[93] Kim, S. (2003). Monetary policy, foreign exchange intervention, and the exchange rate in a unifying framework. Journal of International Economics, 60(2), pp. 355-86.

[94] Kim, S.-J. (2007) Intraday evidence of efficacy of 1991–2004 yen interventions by the Bank of Japan. Journal of International Financial Markets, Institutions and Money ,17, pp.341-360.

[95] Kim, S.-J. and T. L. Anh (2010). Secrecy of Bank of Japan's Yen intervention Evidence of efficacy from intra-daily data. Journal of The Japanese and International Economies, 24, pp. 369-394.

[96] Kita, A. and Q. Wang (2012). Investor Attention and FX Market Volatility, Available at SSRN: http://dx.doi.org/10.2139/ssrn.2022100.

[97] Klibanoff , P. , Lamont, O. And T. A. Wizman (1998). Investor Reaction to Salient News in Closed-End Country Funds. Journal of Finance, 53(2), pp. 673-699.

[98] Klitgaard, T. and L. Weir (2004). Exchange Rate Changes and Net Positions of Speculators in the Futures Market, Economic Policy Review, Federal Reserve Bank of New York, issue May, pp. 17-28.

[99] Kumhof, M. (2010). On the theory of sterilised foreign exchange intervention. Journal of Economic Dynamics and Control, 34(8), pp.1403-1420.

[100] Kyle, A. S. (1985). Continuous Auctions and Insider Trading. Econometrica, 53 (6), pp. 1315-1336.

[101] Le Baron, B. (1999). Technical Trading Rule Profitability and Foreign Exchange. Interventions Journal of International Economics, 49(1), 126-143

[102] Lewis, K. K. (1988). Testing the portfolio balance model: A multi-lateral approach. Journal ofInternational Economics, 24, pp. 109–127.

[103] Loopesko, B. E. (1984) Relations among Exchange Rates, Intervention and Interest Rates: An Empirical Investigation. Journal of International Money and Finance, 3, pp. 257-277.

[104] Loring, G. and B. Lucey (2013). An Analysis of Forward Exchange Rate Biasedness cross Developed and Developing Country Currencies: Do Observed Patterns Persist out of Sample? Emerging Markets Review, 17, pp.14-28

[105] Lyons, R. K. (2001) The Microstructure Approach to Exchange Rates. MIT Press, Cambridge, MA, US.

[106] MacDonald, R. (2007). Exchange Rate Economics: Theory and Evidence, Routledge.

[107] MacDonald, R. and M. P. Taylor (1989). Interest Rate Parity: Some New Evidence, Bulletin of Economic Research, vol. 41(4), pp. 255-274.

[108] Mancini-Griffoli, T. and A. Ranaldo (2012). Limits to Arbitrage During the Crisis: Funding Liquidity Constraints and Covered Interest Parity. Working Papers on Finance, 1212, University of St. Gallen, School of Finance

[109] Marsh, I. W. (2011). Order flow and central bank intervention: An empirical analysis of recent Bank of Japan actions in the foreign exchange market, Journal of International Money and Finance, 30, pp. 377-392.

[110] Menkhoff, L. (2010). High-frequency analysis of foreign exchange interventions: What do we learn? Journal of Economic Surveys, 24(1), pp. 85-112

[111] Menkhoff, L. (2013). Foreign Exchange Intervention in Emerging Markets: A Survey of Empirical Studies. World Economy, 36, pp. 1187-1208.

[112] Mussa, M. (1981). The role of official intervention. Group of Thirty, New York, U.S.

[113] Neely, C. J. (2002). The Temporal Pattern of Trading Rule Returns: Intervention does not Generate Trading Rule Profits, Journal of International Economics, 58, pp. 211-232.

[114] Neely, C. J. (2005a). An analysis of recent studies of the effect of foreign exchange intervention. Federal Reserve Bank of St. Louis Review, Nov./Dec. 2005, 87(6), pp. 685-717.

[115] Neely, C. J. (2005b). Identification failure in a structural VAR with intervention: Alternative identification and estimation, mimeo, the Federal Reserve Bank of St. Louis.

[116] Neely, C. J. (2005c). Identifying the effects of central bank intervention. Working Paper 2005-031A, Federal Reserve Bank of St. Louis.

[117] Neumann, M. J. M. (1984). Intervention in the mark/ dollar market: the authorities' reaction function. Journal of International Money and Finance, 3, pp. 223-239.

[118] Nielsen, H. B. and A. Rahbek (2007).The likelihood ratio test for cointegration ranks in the I(2) model. Econometric Theory, 23(4), pp. 615-637.

[119] Obstfeld, M. (1983). Exchange Rates, Inflation and the Sterilization Problem. Germany 1975–81. European Economic Review, 21, pp. 161-189.

[120] Obstfeld, M. (1990). The effectiveness of foreign-exchange intervention: Recent experience: 1985-1988. in W. H. Branson, J. A. Frenkel and M. Goldstein (eds.), International Policy Coordination and Exchange rate Fluctuations, University of Chicago Press, Chicago, US, pp. 197-237.

[121] Obstfeld, M. and K. Rogoff (1995). Exchange rate dynamics redux, Journal of Political Economy, 103, pp. 624-660.

[122] Omtzigt, P. (2002). Automatic identification of simultaneous equations models, Economics and Quantitative Methods qf0201, Department of Economics, University of Insubria.

[123] Pan, J. and A. Poteshman (2006). The Information in Option Volume for Future Stock Prices, Review of Financial Studies, vol 19, pp. 871-908.

[124] Payne, R. and P. Vitale (2003). A transaction level study of the effects of Central Bank intervention on exchange rates. Journal of International Economics, 61, pp. 331-352.

[125] Pojarliev, M. and R. M. Levich. (2008). Do Professional Currency Managers Beat the Benchmark? Financial Analysts Journal, 64(5), pp. 18-32.

[126] Qiu, L. and I. Welch, (2004). Investor Sentiment Measures. NBER Working Papers No. 10794, National Bureau of Economic Research, Inc.

[127] Quintanilla, P., D. Delgado, D. Castillo, A. O'Farril and G. García. (2012). Foreign Exchange Intervention in Mexico: Evidence of the Signaling Channel. Downloadable from http://www.econ-jobs.com/research/33096-Foreign-Exchange-Intervention-in-Mexico-Evidence-for-the-Signalling-Channel.pdf

[128] Ramaswamy, R. and H. Samiei (2000). The Yen-Dollar rate - Have interventions mattered?, IMF Working Papers 00/95, International Monetary Fund.

[129] Reitz S and M. P. Taylor (2008). The coordination channel of foreign exchange intervention: a nonlinear microstructural analysis, Europen Economic Review, 52(1), pp. 55-76.

[130] Reitz S and M. P. Taylor (2012). FX intervention in the Yen-US dollar market: a coordination channel perspective, International Economics and Economic Policy, 9, pp.111-128.

[131] Rogoff, K. (1984). On the effects of sterilised intervention: An analysis of weekly data. Journal of Monetary Economics, 14, pp. 133-150.

[132] Saettele, J. (2008). Sentiment in the Forex Market: Indicators and Strategies to Profit from Crowd Behavior and Market Extremes. John Wiley & Sons.

[133] Sager, M. J. and Taylor, M. P. (2006). Under the Microscope: the Structure of the Foreign Exchange Market. International Journal of Finance and Economics, 11(1), pp. 81-95.

[134] Sakakibara, E. (2000). nihon to sekai ga furueta hi [The Day when Japan and the World Trembled], Tokyo Chuokoron-Shinsha.

[135] Sarno, L. and M. P. Taylor (2002). The Economics of Exchange rates. Cambridge University Press, Cambridge, UK.

[136] Shiller, R. J. (2000). Irrational Exuberance, Princeton University Press.

[137] Sidaoui, S. J. (2005). Central banking intervention under a floating exchange rate regime: ten years of Mexican experience, BIS Papers No. 24.

[138] Taylor, M. P. (1987). Covered Interest Parity: A High-Frequency, High-Quality Data Study, Economica, 54, pp. 429-438.

[139] Taylor, M. P. (1989). Covered Interest Arbitrage and Market Turbulence. Economic Journal, 99, pp. 376-391.

[140] Taylor, M. P. (1994) Exchange rate behavior under alternative exchange rate regimes. In: Kenen, P. (Ed.), Understanding Interdependence: The Macroeconomics of the Open Economy. Princeton University Press, Princeton, US.

[141] Taylor, M. P. (1995) The economics of exchange rates. Journal of Economic Literature, 33, pp. 13-47.

[142] Taylor, M. P. (2004). Is official exchange rate intervention effective, Economica, 71, pp. 1-11.

[143] Taylor, M. P. (2005). Official exchange rate intervention as a coordinating signal in the Dollar-Yen market, Pacific Economic Review, 10(1), pp. 73-82.

[144] Taylor, M. P. and H. Allen (1992). The Use of Technical Analysis in the Foreign Exchange Market. Journal of International Money and Finance, 11 (3), pp. 304-314.

[145] Taylor, J. (2006). Lessons from the Recovery from the 'Lost Decade' in Japan: The Case of the Great Intervention and Money Injection, Paper presented at the ESRI International Conference, Cabinet Office, Government of Japan, September 14, 2006. Available at http://www.stanford.edu/ johntayl/JapanCabinetOfficePresentation.pdf

[146] Tetlock, P. C. (2007) Giving Content to Investor Sentiment: The Role of Media in the Stock Market, Journal of Finance 62, pp. 1139-1168.

[147] Tetlock, P. C., Saar-Tsechansky, M. and S. Macskassy (2008). More Than Words: Quantifying Language to Measure Firms' Fundamentals, Journal of Finance, 63, 1437-1467.

[148] Uhl, M. (2011). Reuters Sentiment and Stock Returns, KOF Working papers 11-288, KOF Swiss Economic Institute, ETH Zurich.

[149] Vitale, P. (1999). sterilised Central Bank Intervention in the Foreign Exchange Market. Journal of International Economics, 49, pp. 245-267.

[150] Vitale P. (2007). An assessment of some open issues in the analysis of foreign exchange intervention. International Journal of Finance and Economics, 12, pp.155-170.

[151] Vlastakis, N. and R. N. Markellos (2012). Information Demand and Stock Market Volatility, Journal of Banking and Finance, 36(6), pp. 1808-1821.

[152] Wang, C. (2004). Futures Trading Activity and Predictable Foreign Exchange Market Movements, Journal of Banking and Finance, Vol.28 (5), pp.1023-1041.

[153] Watanabe, T. and T. Yabu (2013). The Great Intervention and Massive Money Injection: The Japanese Experience 2003-2004, Journal of International Money and Finance, 32, pp. 428-443.