Japan's Currency Intervention Regimes: A Microstructural Analysis with Speculation and Sentiment

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Abstract

Abstract: This paper provides a unique examination of three separate regimes of Japanese currency interventions between 1991 and 2004. It is the first research to jointly test the coordination 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 'sentiment' and fundamental information.

There are several important findings based on the analysis of the paper. Firstly, the shocks to the bond yield differential are the key driving force of the dynamics of the JPY/USD exchange rate, and have a 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 sharp appreciations of the 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, speculation and sentiment had strong effects on the changes in the exchange rate, and the coordination channel worked when the changes in exchange rate volatility were slow.

JEL classification: E31; E43; F31; F32

Keywords: Cointegrated VAR, Currency Intervention, Forward Rate Bias, Microstructure, Sentiment Measures, Speculation, Transmission Channel, Reaction Function.

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1 Introduction

This paper 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 on the behaviour of the JPY/USD rate.

This paper is organized as follows. After providing background information about the regimes of Japanese interventions, we survey the related literature. Then we build a new theoretical framework and introduce the identified cointegrated VAR methodology. In the main sections of 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.

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.

Table 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			
Notes: The unit of the intervention data is billion JPY.			

The third regime started on 15th January 2003 and continued until 16th March 2004. This featured 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 a 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 and stimulate the economy. During the 2003-2004 period, interventions happened on 30.28% of total days, and the amount per 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.

3 Literature Review

Currency interventions are defined as purchases and sales of foreign currencies by the monetary authorities in order to influence the level or volatility of the exchange rate. 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). After the meetings at Plaza in 1985 and Louvre in 1987, sterilized interventions became regular and sometimes very heavy (Obstfeld, 1990). However, the U.S. and Japanese authorities stopped active currency interventions at 1997 and 2004 respectively (Ito, 2007). Before empirical analysis on the Japanese and U.S. interventions, we review literature related to transmission channels of currency intervention, methods of estimating intervention effectiveness, currency speculation and indirect sentiment measures.

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

3.1 The Signalling and Coordination Channels

Currency intervention can be classified either as unsterilised and sterilised. Although there were some exceptions in Japan between 2003 and 2004 when the exchange interventions and monetary expansions were parallel (Ito, 2007), most currency interventions in Japan and the USA are sterilised, which offset any changes in monetary base through immediate open market operations. Given the variables we choose for later empirical analysis, we focus on the intervention effects through two transmission channels, the signalling and coordination channels.

3.1.1 The Signalling Channel

The signalling channel has been proposed and adopted by Mussa (1981), Kenen (1988), Dominguez (1987), Almekinders (1995) and many others. The monetary authorities are assumed to have superior information to other market agents who can only learn of the superior information through the 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 the monetary authorities, and hence their expectations on exchange rates. As a means by which central banks convey their inside information to the market, a currency intervention is empirically examined to determine if it is a leading indicator for the changes in the monetary policies or the exchange rate expectations (Dominguez and Frankel, 1993).

Under the efficient market hypothesis, Eijffinger and Gruijters (1991) propose that currency interventions alter the expectations of foreign exchange market participants, and therefore have an 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 expectation hypothesis, Dominguez (1990) estimates an inverted portfolio balance equation of the risk premium with currency intervention as an explanatory variable. However, the empirical results of previous studies are mixed. While Dominguez (1987) and Dominguez and Frankel (1993) find sterilized interventions have very substantial effects on the exchange rates, Humpage (1989) and Eijffinger and Gruijters (1991) show that they are not effective.

3.1.2 The Coordination Channel

The coordination channel has been proposed by Taylor (1994) as an independent transmission channel related to the microstructure of the foreign exchange market. Unlike the signalling approach, the central bank is not assumed to be better informed than other participants. The fundamentals-based speculators are often able to coordinate with the central bank. However, amidst strong and persistent non-fundamental misalignments of exchange rates, they may loose confidence, credibility, and even liquidity. Therefore, the monetary authorities should use currency interventions as coordination signals to encourage them to re-enter the 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 reduce the size of deviation of the exchange rate from its equilibrium rate.

The new coordination approach has attracted some empirical studies over the past few years. Evans and Lyons (2002) use the net amounts of buyer-initiated and seller-initiated orders as an indirect measure of the order flows initiated by the central bank, i.e., interventions. They find that interdealer order flows have significant and substantial effects on exchange rates: a purchase of one billion USD increases the DEM/USD exchange rate by 0.5 percent.

Reitz and Taylor (2012) empirically test the coordination approach with daily data from the JPY and USD exchange rate markets using a smooth transition regression (STR)-GARCH procedure. The coordination channel was found to be effective in the USA: A purchase of one billion USD appreciated the currency by 0.04 percent. However, they found that the Japanese Ministry of Finance failed to provide a credible coordination signal to fundamental speculators, and hence the yen was not moving towards equilibrium.

Marsh (2011) examines the behaviour of end-user order flows in the JPY market between 2003 and 2004. He found that, while corporate customers were more likely to act with the monetary authorities, financial customers were net buyers of JPY on the same days when Japan's Ministry of Finance was selling the currency.

However, there are still some limits in the related studies on the coordination channel. Order flow data are often not publicly available, which restricts relevant research. In our research, contract positions in the currency futures markets are used as a proxy for order flows.

3.2 Estimation of Currency Intervention

Empirical studies on currency interventions are based on different econometric methods. Most of them can be classified into one of four groups, i.e., low-frequency time series, event study, high-frequency, and identified models. This section briefly reviews the four groups of empirical methods.

3.2.1 The Low-Frequency Time Series Method

The low frequency time series analysis measures the currency effects with low-frequency data, which has been widely used since the influential studies of Rogoff (1984)[2].

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

$$s_t = \alpha_1 + \beta_1 X_t + \gamma_1 CI_t + \varepsilon_t, \tag{1}$$

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

$$\triangle s_t = \alpha_2 + \beta_2 X_t + \gamma_2 I_t + \varepsilon_t, \tag{2}$$

where s_t is the exchange rate measured by units of domestic currency per foreign currency, normally in the logarithm form, I_t and CI_t measure actual and cumulative interventions respectively. X_t is a set of variables including interest rates, bond yields, inflation rates, macroeconomic news, etc.

Besides estimating the intervention effects on the level of the exchange rate, some researchers focus on the volatility of exchange rates[3]. Dominguez (1998) proposes two approaches to analyse intervention effects on exchange rate volatility. The first approach is based on a GARCH (1,1) model:

$$\triangle s_t = \alpha + \beta X_t + \gamma I_t + \delta \sqrt{h_t} \varepsilon_t, \tag{3}$$

$$h_t = \phi_0 + \phi_1 \varepsilon_{t-1}^2 + \phi_2 h_{t-1} + \phi_3 I_t + \varepsilon_t, \tag{4}$$

$$\varepsilon_t \mid \Omega_{t-1} \sim N(0, h_t, \kappa), \tag{5}$$

where $\triangle s_t$ is the change in spot exchange rates, h_t measures the conditional volatility of exchange rates, and ε_t is a t-distributed disturbance term with the variance h_t and the degree of freedom κ. The second approach to measure the intervention effects on the implied volatility of currency option prices:

$$\triangle IV_t = \alpha + \beta X_t + \gamma I_t + IV_{t-1}, \tag{6}$$

where $\triangle IV_t$ measures the changes in the implied volatility.

3.2.2 The Event Study Approach

The event study approach is introduced to analyse sporadic currency interventions which often happen in clusters. The key elements of the approach include defining events, windows around the events, and success criteria. The intervention effects are analysed by comparison of the exchange rate of pre- and post-event windows (Humpage, 2000).

Based on the direction criterion, Fatum and Hutchison (2003, 2006) find significant changes between pre- and post-intervention exchange rates. They also find that Japan's currency interventions systematically affect the exchange rate within one month, and large-scale (over one billion USD) and coordinated interventions tend to be more effective. Bordo et al. (2009, 2010) test the effectiveness of currency intervention based on the smoothing criterion, and find that the U.S. currency interventions might offer a means of calming market disorder in the Volcker-Greenspan era.

[3] The related studies include Almekinders and Eijffinger (1994), Baillie and Humpage (1992), Beine (2003), Bonser-Neal and Tanner (1996), Dominguez (1998), Frenkel, et al. (2005), Hillebrand and Schnabl (2008), and Ramaswamy and Samiei (2000).

3.2.3 The High-Frequency Time Series Approach

The high-frequency time series methods uses intraday data to analyse the intervention effects, which provides information difficult to grasp by low-frequency approaches (Vitale, 2007). Given the limited availability of official high-frequency data, the related studies are still sparse. Kim (2007) and Kim and Anh (2010) examine the Japanese and U.S. currency interventions by breaking down a trading day into three time zones. He finds that Japan's interventions significantly reduce the overnight volatility, and the impact of currency intervention on the exchange rate level is regime-dependent.

3.2.4 The Identified Models

The identified approach explicitly models structural economic relations to identify the intervention impact on exchange rate behaviour. Kim (2003) uses a structural VAR framework to jointly analyse the impact of the U.S. currency interventions and conventional monetary policies on the USD index of the post Brenton-Wood period:

$$\beta(L)\eta_t = u_t, \tag{7}$$

where structural parameters are contained in $\beta(L)$, and interventions, interest rates, exchange rates, monetary supply, inflation, industrial production, commodity prices are included in η_t. The following two equations of the reduced form VAR measure the effects of interventions and analyse the reactions of the central bank respectively:

$$s_t = \alpha_1 + \beta_1(L)s_{t-1} + \gamma_1(L)I_{t-1} + \delta_1(L)^{'}X_{t-1} + \varepsilon_{1,t}, \tag{8}$$

$$I_t = \alpha_2 + \beta_2(L)s_{t-1} + \gamma_2(L)I_{t-1} + \delta_2(L)^{'}X_{t-1} + \varepsilon_{2,t}, \tag{9}$$

where X_t includes a set of different macroeconomic variables. Kim found that currency interventions had significant effects on the exchange rate through the signalling channel.

Kearns and Rigobon (2005) adopt a simulated method of moments model, and find that the Japanese currency interventions have influential effects on the JPY/USD exchange rate: A sale of one billion USD appreciates JPY by two percent. Based on a friction model, Neely (2005b) estimates a system of equations to identify the cross-effects of interventions on the level and volatility of exchange rates.

3.3 Speculation versus Intervention

Currency intervention is a common occurrence in the foreign exchange market. Therefore, currency speculators may adjust their behaviour according to central banks' policies and objectives. Meanwhile, central banks may take account of the expected reactions of the speculators when formulating their intervention policies.

Based on the signalling approach, sales of the domestic currency signal future monetary easing, which is associated with the depreciation of the currency. In order to generate a credible signal, central banks are expected to earn profit from their interventions. However, as Dooley and Shafer (1983) note, '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) investigated the interventions of the Deutsche Bundesbank in the DEM/USD market over the period from 1974 to 1981. Neumann found that the central bank tried to compress the total risk premium of DEM to reduce the incentive for speculating DEM. Le Baron (1999) uses intervention data from the Federal Reserve to analyse the activities of DEM/USD and JPY/USD markets. His empirical results suggest that speculators make money at the expense of the central bank during the intervention period. Ito (2005) uses the net long futures positions in the Chicago Mercantile Exchange as indicators for currency speculation. He found that the net long yen positions and currency interventions had strong correlations between 2003 and 2004: The large net long yen positions occurred with heavy yen-selling interventions. It might suggest the Japanese central bank and currency speculators were at odds to control the direction of the yen.

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

3.4 The COT Indirect Sentiment Measures

Speculative sentiment indices can not only reflect the expectation of speculative traders but also present hints on the sentiment of overall investors in the markets. There are three groups of sentiment measures, i.e. direct, indirect and big data sentiment measures. While direct and big data measures are based on polling of investors and amalgam of vast financial information respectively, the indirect measures are derived from market prices, quantities or other objectively observable data.

The indirect sentiment measures include indices based on the Commitment of Traders (COT) reports, the put-call ratio, the long-short interest ratio, and the closed-end funds discount (Pan and Poteshman, 2006). The COT-related indices have been widely used for forecasting purposes in equity markets (Briese, 1994), energy markets, and recently in the foreign exchange market (Saettele, 2008). The COT reports are released weekly via the Commodity Futures Trading Commission (CFTC), reporting the futures positions in the regulated Chicago Mercantile Exchange (CME). There are three main groups in the reports, i.e., non-commercials (mainly speculators), commercials (mainly hedgers) and non-reportables (mainly small traders). The group of speculators refers mostly to large individual traders and hedge funds.

Wang (2004) transforms the weekly futures positions to a COT sentiment index, and formulates a baseline model:

$$R_{t+k} = \alpha_1 + \beta_1 COT_t + e_t, \tag{10}$$

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. Wang finds strong positive correlations between speculative sentiment and subsequent futures' returns on GBP, CAD, DEM, JPY, and CHF: A 1% increase in speculator sentiment is related to a 0.42% annualized return over the subsequent four weeks. The positive performance of speculators can be explained by the market risk premium. In other words, the speculators are compensated for the high risks they bear.

In summary, the COT indirect measures provide some interesting findings on the influential effects of sentiment in financial markets. However, financial theories are still needed to justify the construction of sentiment measures and interpret the related empirical findings.

3.5 Summary

In this section, we review the literature on the Japanese currency intervention, speculation and sentiment. Previous studies on the signalling and coordination channels, methods of estimating intervention effects, currency speculation and indirect sentiment measures have been presented to provide reference for related research.

4 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 term, 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 this section with empirical testing criteria.

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

In this sub-section we build a framework for the signalling channel. To this end we discuss the forward rate bias and the central bank credibility, which plays an important role in testing the effectiveness of the signalling channel.

4.1.1 Forward Rate Bias

Under the joint efficient markets hypothesis of risk neutrality and rational expectations, we can form a prediction equation for the change in spot exchange rates as:

$$(s_{t+k} - s_t) = (f_t^{t+k} - s_t) + \epsilon_{t+k}, \tag{11}$$

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

$$(s_{t+1} - s_t) = \alpha + \beta(f_t^{t+1} - s_t) + \epsilon_{t+1}. \tag{12}$$

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

For the JPY/USD, Frankel and Poonawala (2010) and Loring and Lucey (2013) find that the β estimates were negative for the period December 1996 to September 2010, which is adopted as a stylized fact for later tests on the effectiveness of the signalling channel.

4.1.2 Central Bank Credibility

If 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 a depreciating currency, which enforces the exchange rate misalignments and increases exchange rate volatility. Therefore, the signalling channel works if currency interventions change agents' expectations on 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, interventions without profits may fail to generate credible signals to change the expectations of market agents and result in the ineffectiveness of the signalling channel.

We use the Japanese interventions to illustrate the above mechanism. The aim of currency intervention is to depreciate the JPY. If 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 credable signal, the Bank of Japan should make profits from the interventions, at least in the long-term. Here, we propose using the following profit function to measure the central bank's profits:

$$\pi_K = \sum_{k=1}^{K} \left[I_k(s_t - s_k) - (i_k - i_k^\star) \sum_{j=1}^{K} I_j \right], \tag{13}$$

where π_K denotes the overall profits that the Japanese monetary authorities earn from 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 on the one-period-ahead expected profit $E_t(\pi_{t+1})$ after the intervention, the above profit equation can be simplified as

$$E_t(\pi_{t+1}) = I_t \left[(E_t(s_{t+1}) - s_t) - (i_t - i_t^\star) \right], \tag{14}$$

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).

4.1.3 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.

4.2 Market Microstructure Model of the Coordination Channel and Reaction Function

Using exchange rate volatility, speculation and sentiment, this 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.

4.2.1 Main Assumptions

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 a 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 conveys 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 changes 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. In contrast to Reitz and Taylor (2008, 2012), informed speculators do not have information on the long-term equilibrium exchange rate, e.g., real exchange rates.

6. Uninformed speculators are not informative with respect to the underlining economic fundamentals with respect to exchange rates. They base their trade on trend-following, extrapolative trading strategies, similar to Reitz and Taylor (2008, 2012).

4.2.2 Model Derivation

We use index i to represent the types of agents in the foreign exchange market: $i = M$ is for overall orders of the 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 factors, the net order flows from central bank interventions, and the overall trades of the informed and uninformed speculators (D_t^{In}+D_t^{Un}), as the market maker can not observe them individually. Therefore, the log-linear function of the exchange rate change can be expressed as

$$\triangle s_{t+1} = a_t^M (D_t^{In} + D_t^{Un}) + \epsilon_{t+1}, \tag{15}$$

where $a^M > 0$ denotes positive effects of speculation and intervention determined by the market maker, and the noise term, ϵ_{t+1}, captures the effects from direct public information.

We propose using a variant type of a standard mean-variance function (Engel, 1996) to express the order flows of informed speculators, D_t^{In}, with respect to risk-adjusted excess returns. We assume that informed speculators have direct information on short-term fundamentals and indirect information through the central bank activities, but not information on 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 $\triangle\sigma_t^{In}(s_{t+1})$, the rate of expected exchange rate volatility. The expectations on excess returns can be separated into the expected exchange rate variation, $E_t^{In}(s_{t+1}) - s_t$, and the foreign and domestic 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, we can express the initial speculation volume as

$$D_t^{In} = a_t^{In}\left[E_t^{In}(s_{t+1}) - s_t\right] + b_t^{In}(i_t^* - i_t) + c_t^{In}\left[\triangle\sigma_t^{In}(s_{t+1})\right], \qquad (16)$$

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. According to the assumptions, we expect $a_t^{In} > 0$, $b_t^{In} > 0$ and $c_t^{In} < 0$, so that informed speculators can maximize their risk-adjusted profits based on available information.

New fundamental information from the interventions I_t affects the informed speculators' expectations on the 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:

$$D_t^{In} = a_t^{In}\left[E_t^{In}(s_{t+1}|I_t) - s_t\right] + b_t^{In}(i_t^* - i_t) + c_t^{In}\left[\triangle\sigma_t^{In}(s_{t+1}|I_t)\right], \qquad (17)$$

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

In our framework, uninformed speculators lack fundamental information on both the long-term equilibrium exchange rate, and short-term exchange rate dynamics. They tend to rely on chartist or technical trading strategies, rather than the publicly available information and information related to interventions. Taylor and Allen (1992) observe that a large mount of uninformed or noise traders follow trend-following extrapolative strategies. Sager and Taylor (2006) also find that they tend to derive their orders from chartist or technical trading rules based on historical exchange rate behaviour. With consideration of interest rate differential, we express the order flows of uninformed speculators as:

$$D_t^{Un} = a^{Un}(\triangle s_t) + b^{Un}(i_t^* - i_t), \qquad (18)$$

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

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

We then model the central bank's orders, interventions I_t, with a reaction function. The dependent variable of the function is usually some measures for official interventions as an attempt to explain the behaviour of the central banks and to test certain theories related to currency interventions.

We assume that the central bank implements 'leaning against the wind' interventions, i.e., the central bank buys (sells) foreign currency when the domestic currency has appreciated (depreciated). The Japanese monetary authorities buy USD, i.e., $I_t > 0$, amid the yen's appreciation against USD, $\triangle s_t < 0$. The central bank may react if they expect the exchange rate volatility increases in the next period, $\triangle\sigma_t^A(s_{t+1}) > 0$. Furthermore, the central bank can bid together with speculators if their orders $(D_t^{In} + D_t^{Un})$ are in the direction the central bank expects. Therefore, the central bank's reaction function can be expressed as

$$I_t = \gamma_t(\triangle s_t) + \delta_t\left[\triangle\sigma_t^A(s_{t+1})\right] + \zeta_t(D_t^{In} + D_t^{Un}), \tag{19}$$

where I_t denotes the amount of intervention at time t, $\gamma_t < 0$ as the central bank implements 'leaning against the wind' interventions, $\delta_t > 0$ to reflect the central bank's reactions to the expected volatility change, and $\zeta_t > 0$ to present potential coordination between the central bank and speculators.

Based on the stylized facts that the β estimates of the function (11) were always negative. Accordingly, if we replace the explanatory variable of the expected change of exchange rate $\left[E_t^{In}(s_{t+1}|I_t) - s_t\right]$ with $\vartheta_t(f_t^{t+1} - s_t)$, 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 same expectations on the exchange rate volatility, i.e., $\sigma_t^A(s_{t+1}) = \triangle\sigma_t^{In}(s_{t+1}|I_t) = \sigma_t(s_{t+1})$. Then $\sigma_t(s_{t+1})$ can be represented by implied volatility IV_t, which measures the expected exchange rate volatility based on exchange rate option prices (Dominguez, 1998). When the options are efficiently priced, IV_t not only provides an unbiased estimate of the market's forecast of the exchange rate volatility but also measures long-term exchange volatility as it is calculated from options that expire in the future.

With the consideration of the forward rate bias and implied volatility, we can conclude our microstructure model with the following equations:

$$\triangle s_{t+1} = a_t^M(D_t^{In} + D_t^{Un}) + \epsilon_{t+1}, \tag{20}$$

$$D_t^{In} = a_t^{In}\vartheta_t(f_t^{t+1} - s_t) + b_t^{In}(i_t^* - i_t) + c_t^{In}\left[\triangle IV_t\right], \tag{21}$$

$$D_t^{Un} = a^{Un}(\triangle s_t) + b^{Un}(i_t^* - i_t), \tag{22}$$

$$I_t = \gamma_t(\triangle s_t) + \delta_t\left[\triangle IV_t\right] + \zeta_t(D_t^{In} + D_t^{Un}), \tag{23}$$

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 setup with forward rate bias and implied volatility, we can present empirical testing criteria for the effectiveness of the

Table 2: Test Criteria 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:	$\triangle s_t < 0, \triangle IV_t > 0, COT_t > 0$	

coordination channel. If the Japanese currency interventions with commitment of depreciating the domestic currency, i.e., $\triangle s_{t+1} > 0$, the main criteria is that $(\mathrm{D}_t^I + \mathrm{D}_t^U) > 0$[4]. The following 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, as discussed before, we expect to find $\triangle s_t < 0$, $\triangle IV_t > 0$, $(\mathrm{D}_t^{In} + \mathrm{D}_t^{Un}) < 0$.

In instances where actual speculation data is not available, related sentiment measures are needed as proxies. We can use the COT sentiment index, COT_t, defined by net long speculative futures positions on JPY[5] from the Commitments of Traders reports of the Chicago Mercantile Exchange, as a measure for the overall positions on the yen's appreciation, i.e., $-(\mathrm{D}_t^I + \mathrm{D}_t^U)$. Hence, equations (20) and (23) become

$$\triangle s_{t+1} = -a_t^M COT_t + \epsilon_{t+1}, \tag{24}$$

$$I_t = \gamma_t(\triangle s_t) + \delta_t [\triangle IV_t] - \zeta_t COT_t. \tag{25}$$

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

4.3 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 2 lists the testing criteria for the transmission channels and reaction function if the Japanese currency interventions are aimed at depreciating the 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 $(i_t - i_t^*) < 0$, increasing the possibility of excess returns for the speculators. Accordingly, they may be more willing to

[4] As it is only informed speculators that could coordinate with the information provided by the central bank, we should expect that $D_t^{In} > 0$. However, as the orders of the informed and uninformed speculators are indistinguishable, we can only find the overall volume of $(D_t^I + D_t^U)$.

[5] The long JPY positions benefits when JPY appreciates.

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 speculation and support the coordination of speculators and the central bank.

Table 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 analyses for separate intervention regimes.

5 Variable Description of the Three Regimes

The first issue for our 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-term 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 for the empirical analysis are as follows:

$\triangle s_t$ = the weekly percentage change of the spot JPY/USD rate[6],

$(f_t^{t+1} - s_t)$ = the weekly forward premium rate[7],

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

$(i_{l,t} - i^*_{l,t})$ = the difference of the Japanese and U.S. 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., $-(\mathrm{D}_t^I + \mathrm{D}_t^U)$, and the sentiment of the speculators[8].

[6] 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.

[7] 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

[8] COT_t is used to measure 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).

The main data source is Bloomberg as 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 U.S. Commodity Futures Trading Commission. All the data are based on the end-of-the-day values on Tuesdays in order to accommodate the Commitment of Traders reports which provide a breakdown of each Tuesday's net open interest on the JPY futures.

6 Analysis of the First Intervention Regime

6.1 Variable Description and Model Setup

As we noted in our literature review most empirical studies use single-equation regression methods to measure the effects of currency intervention. However, such methods have drawbacks of missing the whole structural picture of exchange rate movements and correlations of macroeconomic variables. To capture such structural aspects in this paper we use the cointegrated VAR methodology based on Juselius (2006) as it offers a coherent approach to test different hypothesis and provides both long- and short-run dynamics.

For the first regime between 1st April 1991 and 20th June 1995, our analysis covers the periods from 16th March 1993 to 20 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[9].

In Figure 1, the percentage change of the JPY/USD rate and the forward premium rate were relatively stationary around zero, except for the fluctuations in early 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 those in the U.S. Given that the Japanese interventions happened quite frequently, I_t is used instead of the cumulated interventions. The speculation and sentiment variable COT_t had big swings during 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 penalizing 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

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

From the standard errors of six variable residuals, there were two impulse dummies, namely dum930427 and dum950307, on 27th April 1993 and 7th

[9] 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.

Figure 1: Main Variables in the First Regime, 1993-1995

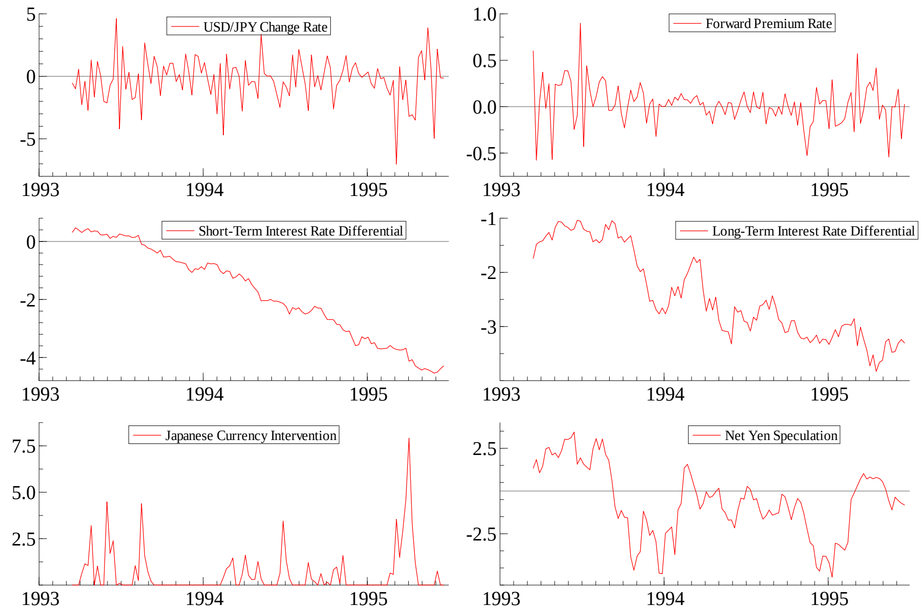

Table 3: Misspecification and Rank Tests, 1993-1995

Multivariate Misspecification Tests						
LM_2 Test on Autocorrelation: $\chi^2(36) = 28.45$ 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**
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

March 1995 respectively, which are ..., 0, 1, 0, ... dummies measuring permanent shocks on the forward premium and exchange rates.

Table 3 presents some important multivariate and univariate misspecification test statistics, with significant test statistics in bold face. Based on an LM test, 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 premium term showed some sign of ARCH effects. However, normality was rejected at the multivariate level with a p-value of 0. The non-normality was mainly due to excess kurtosis in the forward premium rate, currency intervention, and speculation and sentiment. Given a cointegrated VAR model is robust to moderate AR effects and excess kurtosis, the current model specification is kept for further analysis.

The cointegration rank divides the variables into r relations towards which the system is adjusting and $p-r$ relations which are pushing the system. Therefore, it indicates the effectiveness of adjustment. Table 3 also reports the trace test statistics which suggest accepting $r = 3$. 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.

6.2 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 the best hypothetical relations. We can find the main

Table 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-val
Tests on the Signalling Channel								
$H_{1.1.1}$		1	-0.04		-0.09			0.85
$H_{1.1.2}$		1	0.02		-0.08		0.003	0.86
$H_{1.1.3}$		1	-0.02	-0.04	-0.08			0.90
$H_{1.1.4}$		1	0.04	-0.04	-0.08		0.003	1
Tests on the Coordination Channel								
$H_{1.2.1}$					-4.35	1		0.53
$H_{1.2.2}$					-3.24	1	0.03	0.89
Tests on the Reaction Function								
$H_{1.3.1}$	2.38				1	0.12		0.99
$H_{1.3.2}$	5.28				1	0.68	0.01	0.98

results on the hypothesis tests in Table 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 premium rate $(f_t^{t+1} - s_t)$, 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, an increase in currency intervention was significantly correlated with an increase in the forward premium rate. Therefore, the results reject the long-run effectiveness of the signalling channel in the 1993-1995 period.

The tests on the effectiveness of the coordination channel were related to $H_{1.2.1}$ and $H_{1.2.2}$. With an increase in currency intervention, currency speculation COT_t also 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 reacted to the yen's appreciation, $\triangle s_t < 0$, or the increasing speculation and sentiment, $COT_t > 0$. We find that the interventions were reactions to the JPY appreciation. However, the central bank implemented more interventions when speculation and sentiment on JPY were low.

All of the above hypotheses are not be rejected with a p-value of larger than 0.05, and 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.

6.3 Identified Long-Run Structure

The search for a well-specified long-run structure is based on the Π matrix of the unrestricted model and the previous hypothesis tests. Facilitated by the data-mining procedures of Dennis, et al. (2005), we accept the cointegration structure listed in Table 5 with p-value of 0.77.

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

Table 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	-0.02	-0.05	-0.08		
$ecm_{2,t}$				-1.26	-2.84	1	
$ecm_{3,t}$	3.53				1	0.35	0.01

signalling channel:

$$(f_t^{t+1} - s_t) = 0.02(i_{s,t} - i^*_{s,t}) + 0.05(i_{l,t} - i^*_{l,t}) + 0.08I_t + error\ term. \quad (26)$$

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 2, the positive relationship between the forward premium rate and currency intervention meant the signalling channel was not effective between 1993 and 1995.

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

$$COT_t = 1.26(i_{l,t} - i^*_{l,t}) + 2.84I_t + error\ term. \quad (27)$$

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:

$$I_t = -3.53 \triangle s_t - 0.35COT_t - 0.01Trend + error\ term. \quad (28)$$

The Japanese interventions were negatively correlated with changes in the JPY/USD exchange rate, which supports 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 was no evidence that the central bank implemented interventions against the speculation and sentiment on JPY.

6.4 Short-Run Dynamics

After identification of the long-run structure, we analyse the short-run dynamics and summarise the key results in Table 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.

Table 6: Short-Run Dynamics 1993-1995

	$\triangle^2 s_t$	$\triangle(f_t^{t+1} - s_t)$	$\triangle I_t$	$\triangle COT_t$
$\triangle^2 s_{t-1}$				0.03
$\triangle(f_{t-1}^t - s_{t-1})$	-0.89	0.14	0.56	
$\triangle(i_{s,t-1} - i_{s,t-1}^*)$			-1.11	
$\triangle(i_{l,t-1} - i_{l,t-1}^*)$			-1.14	
$\triangle I_{t-1}$	0.23			
$ecm_{1,t-1}$		-1.24		1.31
$ecm_{2,t-1}$		0.02	0.20	
$ecm_{3,t-1}$	0.38			
$Constant$		0.17	-0.17	-0.21
$dum930427p$		-0.67	2.00	
$dum950307p$	-6.09	0.54	2.28	
Notes: The coefficients are significant with $p<0.05$.				
The ecm variables represent (26)-(28) respectively.				

The second column indicates 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 confirms the previous findings of the forward rate bias.

The fourth column reveals 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 the forward premium $(f_{t-1}^t - s_{t-1})$ 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 reveals the factors affecting speculation and sentiment and the effectiveness of the coordination channel. We find that speculation and sentiment are positively related to a JPY depreciation, which means 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

Table 7: Long-Run Impacts, 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.						

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.

6.5 Long-Run Impact of Shocks

This section illustrates the long-run impact of a permanent shock to the variables. Table 7 reports the estimates of the final impact matrix based on the MA representation equations.

Based on column-wise inspections, we note that 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 a strong impact on the exchange rate, currency intervention, speculation and sentiment, which implies that 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 was positive. This is not only supportive of 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 the 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 a JPY appreciation. Similarly, the speculation and sentiment on JPY had a 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 measures the long-term impact of shocks on currency speculation and sentiment. In accordance with equation (21), the shocks to the forward premium had a 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 (21) and (22): 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 appreciations 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.

6.6 Summary

The analysis of 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.

7 Analysis of the Second Intervention Regime

7.1 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 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.

Based on the standard errors of the residuals, there were impulse dummies, namely dum990914 and dum000307, on the 14th September and 7th March 2000, respectively. There was a transitory dummy, namely di000104, on 4th

Figure 2: Main Variables in the Second Regime, 1999-2000

Table 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: $\chi^2(14) =$ **28.82** with p-value of 0.01							
Univariate Misspecification Tests							
	$\triangle^2 s_t$	$\triangle(f_t^{t+1} - s_t)$	$\triangle(i_{s,t} - i^*_{s,t})$	$\triangle(i_{l,t} - i^*_{l,t})$	$\triangle IV_t$	$\triangle I_t$	$\triangle COT_t$
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**
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

January 2000, which was a .., 0, 1, -1, 0, ... dummy measuring transitory shocks on currency speculation and sentiment.

Table 8 presents some important misspecification test statistics. There was no serious residual autocorrelation: Only the speculation and sentiment terms showed some signs 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. We choose the rank condition $r = 4$ based on trace tests. 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.

7.2 Testing Transmission Channels and Reaction Function

We conduct hypothesis tests on the effectiveness of the transmission channels and the reaction function, and report our main results in Table 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 is a rejection of the long-term effectiveness of the signalling channel.

$H_{2.2.1}$ to $H_{2.2.4}$ test 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 intervention and changes in exchange rate volatility. The test results meant that, through the coordination channel, currency interventions were effective and reduced exchange rate volatility.

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

The hypothesis tests provide us with candidates for identified long-run coin-

Table 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-val*
Tests on the Signalling Channel									
$H_{2.1.1}$		1	-0.21			-0.18			0.06
$H_{2.1.2}$		1	-2.62			-0.12		-0.01	0.82
$H_{2.1.3}$		1	-0.13		0.02	-0.01			0.92
$H_{2.1.4}$		1		1		0.35			0.06
$H_{2.1.5}$		1	-0.12	-0.29		-0.07			0.09
Tests on the Coordination Channel									
$H_{2.2.1}$						2.814	1		0.609
$H_{2.2.2}$						2.901	1	0.309	0.501
$H_{2.2.3}$					0.307	2.820	1		0.548
$H_{2.2.4}$					0.275	2.784	1	0.018	0.410
Tests on the Reaction Function									
$H_{2.3.1}$	3.365					1	0.742		0.975
$H_{2.3.2}$	3.370				0.116	1	0.736		0.992

Table 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	$Trend$
$ecm_{1,t}$	4.26				0.15	1	0.80	-0.03
$ecm_{2,t}$	0.48			1	0.02	-0.03		
$ecm_{3,t}$		1	-0.12		0.02	-0.01		
$ecm_{4,t}$			77.16		0.89	5.00	1	

tegration 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.

7.3 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 10. Related to $H_{2.3.2}$, the first relation focuses on the reaction function of the central bank:

$$I_t = -4.26 \triangle s_t - 0.15 \triangle IV_t - 0.80 COT_t + 0.03 Trend + error\ term. \quad (29)$$

We find that interventions increased amidst times of 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 effectively depreciated the JPY by about 0.07% from the second relation:

$$(i_{l,t} - i^*_{l,t}) = -0.48 \triangle s_t - 0.02 \triangle IV_t + 0.03 I_t + error\ term. \quad (30)$$

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

$$(f_t^{t+1} - s_t) = 0.12(i_{s,t} - i^*_{s,t}) - 0.02 \triangle IV_t + 0.01 I_t + error\ term. \qquad (31)$$

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.

Correspondingly the hypothesis tests $H_{2.3}$, the fourth relation is mainly about the effectiveness of the coordination channel:

$$COT_t = -77.16(i_{s,t} - i^*_{s,t}) - 0.89 \triangle IV_t - 5.00 I_t + error\ term. \qquad (32)$$

The negative relation between the speculation and sentiment and the Japanese interventions means 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 supports 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 the JPY by about 0.07%. Meanwhile, the long-run effectiveness of the signalling channel was rejected.

7.4 Short-Run Dynamics

We analyse the short-run dynamics of the second regime and present the results in Table 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 means that the excess speculation increased the rate of JPY appreciation.

The fifth column offers findings related to the reaction function of the central bank: interventions happen in clusters. Meanwhile, the excess forward premium $ecm_{3,t-1}$ had positive impact on the rate of intervention change, which meant that the 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

Table 11: Short-Run Dynamics 1999-2000

	$\triangle^2 s_t$	$\triangle(f_t^{t+1} - s_t)$	$\triangle^2 IV_t$	$\triangle I_t$	$\triangle COT_t$
$\triangle^2 s_{t-1}$	0.28	0.05			-0.42
$\triangle(f_{t-1}^t - s_{t-1})$				-5.14	
$\triangle(i_{s,t-1} - i_{s,t-1}^*)$		-0.46		9.13	-4.58
$\triangle(i_{l,t-1} - i_{l,t-1}^*)$			3.49	-5.50	
$\triangle^2 IV_{t-1}$	-0.02	0.004	0.45		
$\triangle I_{t-1}$				0.67	
$\triangle COT_{t-1}$					0.15
$\triangle(i_{l,t} - i_{l,t}^*)$					3.22
$ecm_{1,t-1}$		-0.02			-0.27
$ecm_{2,t-1}$	-2.46				4.22
$ecm_{3,t-1}$	1.00	-0.92	-8.70	6.91	-1.88
$ecm_{4,t-1}$		0.01	-0.38	-0.16	0.05
$Constant$	-11.67	2.57	-11.80	-5.50	6.33
$dum990914$	-3.37			2.00	
$dum000307$	-3.45	0.44		-6.30	1.95
$di000104$	-1.13				2.16
Notes: The coefficients are significant with $p<0.05$.					
The ecm variables are based on (29)-(32) respectively.					

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.

7.5 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 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 a positive impact on itself. This was in line with the findings 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.

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.

Table 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.							

7.6 Summary

The second intervention regime was populated 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 shocks to the interest rate differentials that drove the change in the JPY/USD rate. Interventions were effective in both the short-term and long-term through the coordination channel. In the long-term, an intervention of one billion USD depreciated the JPY by about 0.07%.

8 Analysis of the Third Intervention Regime

8.1 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 on 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 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.

The following impulse dummies were used, namely dum030624, dum030923, and dum040224, for 24th June 2003, 23rd September 2003, and 24th February 2004. 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.

Figure 3: Main Variables in the Third Regime, 2003-2004

Table 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
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 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	$Trend$	$p\text{-}val$
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 13 lists some important misspecification test results. Residual autocorrelation at the multivariate level was rejected with a p-value of 0.09, and only the speculation and sentiment term showed some signs 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 chose the cointegration rank number to be 3. Meanwhile, the short- and long-term interest rate differentials, and the speculation and sentiment variables were weakly exogenous based on their χ^2 statistics.

8.2 Testing Transmission Channels and Reaction Function

Table 14 reports the results of the hypothesis tests on the reaction function and the effectiveness of the 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 and speculation and sentiment, which rejected the long-run effective-

Table 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	0.14		0.02	-0.02		0.001
$ecm_{2,t}$	-14.93			1	0.24	-0.14		
$ecm_{3,t}$	32.20				-1.13	1	-0.36	

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

8.3 Identified Long-Run Structure

We find a well-specified long-run structure with a p-value of 0.93 and list the identified cointegration relations in Table 15. The first relation is based on $H_{3.1.4}$ and about the effectiveness of the signalling channel:

$$(f_t^{t+1} - s_t) = -0.14(i_{s,t} - i^*_{s,t}) - 0.02 \triangle IV_t + 0.02 I_t - 0.001 Trend + error\ term, \tag{33}$$

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

$$(i_{l,t} - i^*_{l,t}) = 14.93 \triangle s_t - 0.24 \triangle IV_t + 0.14 I_t + error\ term. \tag{34}$$

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

$$I_t = -32.20 \triangle s_t + 1.13 \triangle IV_t + 0.36 COT_t + error\ term, \tag{35}$$

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 exchange rate volatility and currency speculation and sentiment, which indicates that the central bank aimed to reduce exchange rate volatility and fend off speculative attacks.

In summary, the Japanese central bank reacted to sharp JPY appreciations, 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 is not supported for this period.

Table 16: Short-Run Dynamics, 2003-2004

	$\triangle^2 s_t$	$\triangle(f_t^{t+1} - s_t)$	$\triangle^2 IV_t$	$\triangle I_t$
$\triangle^2 s_{t-1}$			-3.21	-1.16
$\triangle^2 IV_{t-1}$				-0.23
$\triangle I_{t-1}$				0.17
$\triangle COT_{t-1}$			1.24	
$\triangle COT_t$	-0.44			
$ecm_{1,t-1}$	0.50	-1.12		
$ecm_{2,t-1}$	0.10	-0.03	0.65	
$ecm_{3,t-1}$		-0.02	0.79	
$Constant$	0.40	-0.34		-2.20
dum030923	-3.84	-0.30	6.76	-6.00
dum040224		-0.35	7.60	1.81
Notes: The coefficients are significant with $p<0.05$.				
The ecm variables represent (33)-(35) respectively.				

8.4 Short-Run Dynamics

This section focuses on the short-run dynamics and we summarise our results in Table 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 implies that an increase in the speculative futures position of 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 that speculation and sentiment increased the volatility of the exchange rate, and the Japanese interventions failed to reduce exchange rate fluctuations.

The fifth column is related to the reaction function. Besides the finding that interventions happened in clusters, we note that currency intervention is 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 reacting 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

Table 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.							

rate fluctuations in the third regime.

8.5 The Long-Run Impact of Shocks

The results of the final impact of a permanent shock to the variables, are reported in Table 17. Noticeably, the intervention shocks had a 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 shocks had a negative impact on the forward premium, 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 term 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: $(i_{l,t} - i^*_{l,t}) \rightarrow COT_t \rightarrow I_t \rightarrow (\triangle s_t$, $(f_t^{t+1} - s_t)$, 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 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 $(f_t^{t+1} - s_t)$.

8.6 Summary

For the third intervention regime we found, as the main driving force, the cumulative shocks to the bond yield differential stimulated speculation and sentiment on the JPY, which, in turn, 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%.

9 Conclusion

This paper studies the JPY/USD rate in a new theoretical and empirical framework by separating the whole period into three regimes. Within an innovative microstructure framework, we structurally identify and analyse the relations between currency intervention, speculation and sentiment and exchange rate movements.

In all regimes, it was shocks to the bond yield differential that drove the whole system related to the JPY/USD rate. The Japanese currency interventions were reactions to the sharp JPY appreciation between 1991 and 2004. Similar to the findings of Ito (2005), the Japanese monetary authorities also reacted to the high exchange rate volatility and increasing speculation on JPY appreciation between 2003 and 2004.

The signalling channel, with the inclusion of the forward rate bias, was effective when the interventions were frequent: in the first regime, an intervention of one billion USD reduced the rate of JPY appreciation in the next week by as much as 0.61%. In the third regime, the interventions were effective in both the short- and long-run: an intervention of one billion USD increased the weekly rate of JPY depreciation by 0.01%.

The coordination channel was effective in the second regime when exchange rate volatility was low: an intervention of one billion USD increased weekly change in the exchange rate by about 0.07%. Similar to the findings of Ito (2005) and Marsh (2011), speculators in the foreign exchange market did not coordinate with the Japanese central bank amidst high exchange rate volatility in the third regime.

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

There are several policy implications we draw from the results presented here. The Japanese currency interventions were designed to control the changes in JPY/USD rate, although sometimes they were reactions to sharp changes in exchange rate volatility and high speculation and sentiment.

Therefore, the key elements in successful central bank interventions are as follows:

(1) If the central banks plans to send a clear signal to other agents in the foreign exchange market on future monetary or exchange rate policies, they should act frequently and constantly during the intervention period so that the signalling channel can be effective.

(2) To improve the effectiveness of currency intervention through the coordination channel, the central banks should intervene when they and other market agents expect there will be no sharp changes in exchange rate volatility.

(3) Before entering the market, central banks should consider specific market conditions, including the behaviour and sentiment of currency speculators. In the Japanese case, the monetary authorities should make sure the dynamics of the bond markets do not hurt the central banks' efforts since the bond yield differential proves to be the main driver of the JPY/USD market.

This paper closes with some suggestions for future research on currency intervention, speculation and sentiment. The relationship between actual and oral interventions should be examined further as the major central banks tend to influence the foreign exchange rate via oral interventions. For example, 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 the 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 counter-productive interventions in terms of the level and colatility of the exchange rate. Given the limited research progress, more research is needed to find the relations between oral and actual interventions.

More related research could be conducted for developing country currencies. In some developing countries, e.g., Czech Republic, Mexico and Turkey, currency interventions are quite active. However, as Menkhoff (2013) finds the literature on them is still sparse. Furthermore, there has been little investigation to compare the transmission channels and reaction functions across the developed and developing countries.

Another area for future research is to examine interventions in the option foreign exchange markets. Previously, most research on currency interventions examines interventions in the spot market, not the options markets. The research gap on the interventions through options needs to be filled to provide a better theoretical explanation and policy implication

Extra attention could also be paid to interactions between currency interventions and monetary policies. Although sterilised interventions offer a unique instrument, Kaminsky and Lewis (1996) question whether currency interventions signal future monetary policies. Watanabe and Yabu (2013) find the close relationship between the currency intervention and the quantitative easing policy of the Bank of Japan between January 2003 and March 2004. However, there is little research on the interactions between interventions and unconventional monetary policies during the last financial crisis. More research is needed to find their relationship and distinctive effects on the exchange rate.

Another potential research area is the profitability of central banks and speculators during the intervention period. Ito (2005) noted that the Japanese interventions between 1991 and 2002 generated profits for the monetary authorities.

While Le Baron (1999) finds 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 currency intervention and speculation should be the subject of further research.

Lastly, although this paper provides some analysis of currency intervention in interaction with speculation and sentiment and the effects of speculative sentiment on the exchange rate movements, there could be more research in this direction. Corrado et al. (2007) adopt a behavioural model of investor sentiment from Barberis et al. (1998). They demonstrate that currency interventions can coordinate beliefs of investors with those of policy-makers and hence reduce the excess exchange rate volatility. With recent advances in behavioural finance, this research direction seems quite promising.

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