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Abstract

This paper presents a theoretical framework analysing the signalling channel of exchange rate interventions as an informational trigger. We develop an implicit target zone framework with learning in order to model the signalling channel. The theoretical premise of the model is that interventions convey signals that communicate information about the exchange rate objectives of central bank. The model is used to analyse the impact of Japanese FX interventions during the period 1999 -2011 on the yen/US dollar dynamics.

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1 Introduction

Since the introduction of a flexible exchange rate regime in Spring 1973, the Japanese yen has experienced large fluctuations, with the yen on a rising trajectory. In order to mitigate the impact of such fluctuations on the Japanese economy and in order to help push economic growth into positive territory, foreign exchange market interventions with the aim of influencing exchange rates have been conducted from time to time. These interventions are executed by the Bank of Japan on behalf of the Japanese Minister of Finance.[1]

Between April 1991 and 2010, the Bank of Japan intervened on 350 days against the US dollar, often on a massive scale and in a unilateral manner. More than 90 percent of the transactions involved purchases of US dollar, as the Bank of Japan attempted to slow down the appreciation of the bilateral yen/US dollar ("JPY/USD" hereinafter) exchange rate.

After the deadly earthquake in the city of Kobe on 17 January 1995 the JPY/USD exchange rate experienced a remarkable surge. Initially, the Japanese currency weakened to 100.23 JPY/USD before appreciating to a 79.75 JPY/USD in April 1996. This triggered a series of interventions by the Bank of Japan at that time.

In the opposite direction, an unprecedented level of yen purchasing took place on 10 April 1998 leading to a rebound of the exchange rate. On the 18th of June, 1998 a time-shifted parallel US intervention occurred. Subsequently, the yen began to appreciate against the US dollar intermittently. That finally led the Bank of Japan to intervene in the foreign exchange markets. From January 2000 to December 2004 the Bank of Japan intervened on 148 different days and sold more than 44 trillion yen, in the hope of propping up the US dollar and reversing the "unwelcome" and "disorderly" yen appreciation. However, a precise target zone band was never established.[2]

After April 2004, Japan experienced a record duration without an exchange rate interven-

[1] Since the Bank of Japan is acting as an agent, the term "Bank of Japan intervention" is only superficially correct. In July 2001 the Japanese Ministry of Finance started to release daily intervention amounts and the direction of the intervention going back to 1991. Since then the Japanese Ministry of Finance reports the track record of its interventions (dates, currencies involved and amounts) 30 days after the end of each financial quarter. See `http://www.mof.go.jp/english/international_policy/reference/feio/index.htm`.

[2] The underlying problem is that the Bank of Japan has never released a categorical breakdown of when, why and how they intervene. Nor have they ever published any definition of "disorderliness". Ito and Yabu (2007) and Hall and Kim (2009) have tried to determine empirically the Japanese "leaning against the wind" intervention philosophy. They have found that interventions were more likely after large exchange rate movements on the previous day, and that deviations from a long-term moving average have also led to decisions to intervene. On the other hand, Japan's government repeatedly announced that intervention was aimed exclusively at curbing excessive foreign exchange movements, not meant to weaken the yen to gain a competitive advantage.

tion. However, on 15 September 2010 Japan made its first foreign yen selling exchange rate intervention in six years and spent the equivalent of 2.1249 trillion yen on currency intervention. This represented an attempt to stem the yen's strength, which had been pushed to its highest rate against the US dollar since 1995. By doing this, the Bank of Japan demonstrated that they were willing to intervene to prevent the US dollar from moving below 83 JPY/USD. The intervention topped the previous record of 1.666 trillion yen for Japanese yen-selling intervention on a single day, set on 9 January 2004. The intervention was triggered by speculation that the Federal Reserve would implement further quantitative easing measures in order to shore up the US economy. This speculation had driven the yen higher, which had raised concerns in Japan that it could derail the fragile Japanese economic recovery and aggravate the long-standing liquidity trap.[3] Another explanation behind the yen's strength was that increasing Chinese purchase of Japanese government bonds and other yen denominated assets had contributed to the yen's appreciation. Taking all these things together, the yen headed towards the upper 80 JPY/USD level against the US dollar and the intervention reversed the yen's appreciation trend only briefly.

On 11 March 2011, a destructive earthquake and tsunami hit North East Japan and killed thousands of people and left tens of thousands injured and homeless. The nuclear crisis brought on by the natural disaster made the situation even worse. After the disastrous earthquake, a sudden surge in the value of the yen to a new post-war high against the US dollar occurred at 76.25 JPY/USD. The expected large-scale repatriation of foreign assets to pay for earthquake reconstruction may have been a factor. In this instance, history appears to have repeated itself: In the aftermath of the Kobe earthquake in 1995, the yen temporarily surged by almost 20 per cent against the US dollar. In any case, a further rise in the yen would be at odds with the needs of an economy still mired in a deflationary trap, and add to the economic pain of rebuilding the country after the contractionary shock from the earthquake and the nuclear disaster. In response to the yen surge, the G7 countries carried out a large scale coordinated intervention on 18 March. A large proportion of the intervention funds were spent by the Bank of Japan. The coordinated G7 action sent the yen tumbling to 81.11 JPY/USD. Lastly, in August 2011, the Japanese government took further action to tackle the strong yen without intervening directly in the FX market.

[3] The Bank of Japan appeared to have bought US dollars after the JPY/USD exchange rate had declined to certain (time-varying) levels. On the other hand, Japan's government repeatedly announced that intervention was aimed exclusively at curbing excessive foreign exchange movements, and not meant to weaken the yen to gain a competitive advantage.

The government set up a fund of 100 billion US dollars available for Japanese acquisitions abroad in a bid to encourage capital outflows. The action, however, did little to stop the yen from rising.[4]

The article proceeds as follows. In the next section, we revisit the impact of central bank interventions in a theoretical modelling framework. Section 3 outlines the calibration methodology and discusses the results from the numerical exercise. Finally, Section 4 concludes our study.

2 Modelling Framework

In this section we propose a theory of exchange rate interventions that is consistent with the salient descriptive empirical facts documented in the introduction.[5] As emphasised in the thorough literature survey by Sarno and Taylor (2001), interventions may have an impact via various transmission channels. In their appraisal of the academic literature they attach particular importance to the signalling (or expectations) channel and the means by which it works. The signalling channel indicates that, through transparent exchange rate interventions, the Bank of Japan conveys inside information to market participants and hence alters their expectations about the future dynamics of the nominal JPY/USD exchange rate. Interventions may also indicate the Bank of Japan's commitment to a specific value of the JPY/USD exchange rate.[6] The informational gain arises because central banks have at least inside information about their own future actions and policies that other market participants do not have. Central bank interventions are therefore "big

[4]However, the Bank of Japan was unwilling to commit itself to a preset "minimum" exchange rate as Switzerland did on 6 September 2011. The Swiss National Bank (SNB) announced it would buy "unlimited quantities" of foreign currency in exchange for Swiss francs (SFr) to defend the ceiling of SFr 1.20 per euro. Ultimately, the SNB is using quantitative easing with the aim of driving down its exchange rate to the preset ceiling. The SFr has become a haven for investors fleeing the euro zone's debt crisis. The SNB decided to take this step after having attempted to drive down the SFr by intervening in the FX markets, to little lasting effect.

[5]It should be noted that our presentation of the model leaves aside the normative discussion on the desirability of influencing the exchange rate, as well as its merits relative to other policy instruments. While the focus of our paper is on Japan, our model can also cast light on the experience of other emerging market countries. For example, attracted by high growth rates and exceptionally low interest rates in rich countries, capital flows into Latin America have surged once more in 2010. Many Latin American countries have tried to prevent their currencies from rising in nominal terms and governments have launched a battery of measures in an attempt to restrain the appreciation of their currencies.

[6] Baillie et al. (2000) have surveyed the role of interventions in terms of their effects on the flow of information and the formation of expectations. Reeves (1998) has analysed the working of the signalling channel in a theoretical model which allows for nonrational expectations and partial credibility. Bhattacharya and Weller (1997) have constructed a theoretical, asymmetric information model of the FX market that explicitly incorporates interventions. In their model, the central bank makes accurate inferences about the private agentsť information, and agents get better but incomplete information from observing the interventions of the central bank.

news" on the market and convey a signal to market participants about future fundamentals. The novelty of our approach is to combine this signalling channel with recent advances of the exchange rate literature in modelling implicit exchange rate targets.[7]
Thereby we begin with the Krugman (1991) target zone model typifying many intermediate regimes, and extend the model incorporating ideas by Klein (1992) and Chen et al. (2010). A particular characteristic of the JPY/USD exchange rate is the long-term appreciation. This crawling of the exchange rate over time and the standard target zone modelling approach with horizontal bands mutually exclude one another. Therefore, unlike Krugman's original approach, we detrend the exchange rate in order to obtain an implicit horizontal band that allows the application of the target zone modelling approach. For the simulations in section 3, the detrended exchange rate is then reverse engineered. This methodological fix allows one to determine how the signalling channel has altered the dynamics of the exchange rate at various points of time.

2.1 Basic Model

Exchange rate dynamics in a target zone are typically modelled as in the seminal paper by Krugman (1991). The standard target zone model assumes a fully credible preset exchange rate bands supported by infinitesimal interventions at the margins. Krugman highlights the stabilising effect of such a target zone on the exchange rate, due to market expectations of interventions if the exchange rate hits the bands. These market expectations generate a nonlinear S-shaped relationship between the exchange rate and economic fundamentals. The following equations are expressed in continuous time and solved by applying stochastic calculus. Displaying the idea that the forward-looking nature of rational expectations exerts an influence on the dynamics of the exchange rate, the model starts with the log-linear asset pricing equation that expresses the logarithm of the nominal exchange rate, $\ln(S(t)) =: s(t)$, as the sum of the logarithm of the fundamental, $\ln(F(t)) =: f(t)$, and the expected rate of change in the exchange rate:

$$s(t) = f(t) + \tau \frac{E(ds(t))}{dt}, \tag{1}$$

[7] Given the presence of a signalling channel, it is a puzzle why some central banks maintain secrecy of their intervention operations. One possible explanation for this behaviour is given in Bhattacharya and Weller (1997). According to their model, interventions under asymmetric information may lead to perverse responses and therefore the model provides a rationale for hiding interventions. But this constitutes a special case which is ill-suited to explain the frequent incidence of secret interventions.

where $E[\cdot]$ denotes the rational expectations operator and $\tau \geq 0$ captures the sensitivity to the expectations. For a pure free float arrangement the nominal exchange rate moves according to the developments of the fundamentals, meaning $s(t) = f(t)$ which is displayed by a 45 degree line when plotting the fundamentals against the exchange rate. On the contrary, for a credible target zone arrangement the exchange rate curve is non-linear where its upper and lower part is bounded by the bands. If the exchange rate approaches either of the boundaries, the public's expectations of appreciation or depreciation cannot be zero any longer, since the central bank is believed to prevent the exchange rate from transgressing the band. Expressed in technical terms, the expectation operator $\frac{E(ds(t))}{dt}$ in equation (1) assumes a negative value in the upper part of the zone and positive one in the lower part. Ruling out arbitrage opportunities, the exchange rate is supposed to approach the boundaries smoothly until it touches them tangentially. Due to the increasing probability of an intervention and as the exchange rate depends also on its expected future development, the exchange rate is drawn more closely to the centre of the target zone than a free floating exchange rate.[8] Hence, the influence of the expectations makes the exchange rate curve evolve in an S-shaped pattern. However, it must be noted that equation (1) and the above described features are based on the assumption of a steady state, where the target zone is framed by fixed horizontals. Time-dependently moving bands exclude an analytically derived closed-form solution for the exchange rate dynamics.[9] In the case of Japan, where the prevailing relatively low inflation rate has been forcing the exchange rate to appreciate for many years, the assumption of a constant strong-side band would be far-fetched. To make Krugman's model applicable we detrend the nominal Japanese exchange rate and then consider the dynamics of its logarithm:

$$\mathbb{s}(t) = \mathbb{f}(t) + \tau \frac{E(d\mathbb{s}(t))}{dt} \tag{2}$$

where $\mathbb{s}$ denotes the detrended exchange rate. Which detrending technique to apply without introducing a source of bias is discussed in section 3. For now, we leave this question aside and choose a symbolical notation for the relationship between the nominal exchange

[8] The empirical relevance of this effect - referred to as the honeymoon effect - is examined for an estimated target zone model for the ERM system by Iannizzotto and Taylor (1999). They find that although the target zone arrangement is assumed as fully credible, the honeymoon effect could be of a small magnitude only. In fact, aside from the dynamics close to the boundaries, their estimates disclose no significant deviation from the linear relationship between the fundamentals and a free float.

[9] An upward moving real exchange rate band is examined by Weller (1992), where interventions occur as soon as the price level excesses certain thresholds. Due to the non-availability of an analytical solution the model is discussed qualitatively by considering it transferred to a constant nominal band.

rate and its detrended version by $\mathbb{s}(t) = \frac{s(t)}{\zeta(t)}$. Being a detrended value the fundamental $\mathbb{f}$ is driven by fluctuations that lack any drift term but evolve according to

$$d\mathbb{f} = \sigma dz. \tag{3}$$

This equation states that infinitesimal changes in $\mathbb{f}$ are given by changes in the Brownian motion dz that are scaled with its own standard deviation σ. To handle this process, we introduce a function g with $g(\mathbb{f}) := \mathbb{s}$. Given the process for the fundamental as described in equation (2), applying Itô's lemma yields the following differential equation:

$$\frac{E(d\mathbb{s})}{dt} = \frac{\sigma^2}{2} g''. \tag{4}$$

Equation (4) implies that the logarithm of the detrended exchange rate is subject to the second-order differential equation

$$\mathbb{s} = \mathbb{f} + \tau \frac{\sigma^2}{2} g''. \tag{5}$$

The innovation is that we solve the second-order ordinary differential equation (5) for the special case of a free-float on the weak side and an implicit target on the strong side.[10] This provides a sound modelling framework with considerable rigour to facilitate an understanding of yen dynamics. In particular, we seek to answer two questions. First, how do exchange rate interventions orientate expectations towards future exchange rate dynamics? Second, how sensitive is the dynamics of the exchange rate to prior beliefs? To answer these questions, we extend the implicit band model to include learning about the intervention triggers.[11]

2.2 The Strong-Side Band

To solve equation (5) we incorporate information about the Japanese exchange rate system. Officially, the JPY/USD exchange rate is operated as a free-float. Indeed, the central bank has not been forced to intervene on the weak side for more than 12 years.[12] However, the

[10] Frenkel and Goldstein (1987) have labelled a target zone regime allowing for domestic policy discretion without precommitting defending the exchange rate at any price a "quiet target zone".

[11] This focus on informational issues is in contrast to the view that interventions work via changing demand and supply condition of the FX market.

[12] More precisely, the last intervention against depreciation pressure was operated on the 17th of July 1998.

yen also faces constant appreciation pressure and a certain appreciation trend is expected by the public and accepted by the Bank of Japan. Intensified pressure on the strong side has prompted interventions to avoid negative exchange rate impacts that would be particularly harmful to foreign trade. An overly strong yen could hurt Japan's economy, as it is an economy that depends heavily on foreign trade. This observation justifies the assumption of a free-float on the weak side and an implicit strong-side band for solving equation (5).

Denote the intervention triggering fundamental on the strong side by $\mathbb{F}^l$. Then by applying the value-matching and smooth-pasting conditions and substituting the fundamental value, we obtain

$$\mathbb{s}(t) = \mathbb{f}(t) + A(\mathbb{F}^l)\exp(-r\mathbb{f}(t)), \tag{6}$$

where

$$r = \sqrt{\frac{2}{\tau\sigma^2}}, \tag{7}$$

and

$$A(\mathbb{F}^l) = \frac{1}{r}\,\exp(r\mathbb{F}^l). \tag{8}$$

Equation (6) would define the exchange rate dynamics fully, if the central bank announced the exact value of $\mathbb{F}^l$. It should be noted that $\frac{1}{r}$ captures the difference between $\mathbb{s}$ and $\mathbb{f}$ at the announced and fully credible strong side band. The stronger the uncertainty σ, and the higher the sensitivity to expectations, the bigger is the deviation of the exchange rate to the fundamentals along the 45 degree line due to more frequent/stronger interventions. In the next section we describe how intervention policies via the disclosure of information serve as a focal point for market participants in an asymmetric "quiet target zone".

2.3 The Outset

This section provides an outline of the initial situation. Market participants' expectations are assumed to depend on their perception of the present central bank behaviour and not on past interventions. A possible justification of this assumption is that the public has observed a very long period without any intervention, or that economic and politic circumstances have changed in a way that past experiences and observations do not provide any anchoring for their expectations.

In this situation, the idea of how to include the expectation formation by market participants into the model is based on Klein (1992). In this paper the nominal exchange rate that triggers intervention against appreciation pressure is expected to be somewhere in the horizontal interval $[\ln(S_1), \ln(S_2)]$. Specified for the nominal JPY/USD exchange rate the intervention zone slopes downward over time. Enclosing all possible values for the implicit strong-side band, this zone is thus to be detrended in the same manner as equation (1). From now on let the intervals $[\mathbb{S}_1, \mathbb{S}_2]$ and the corresponding fundamentals $[\mathbb{F}_1, \mathbb{F}_2]$ always refer to the normalised values forming the intervention zone in the detrended exchange rate model.

As past interventions are excluded from market participants' expectations and thus no a priori information about the next intervention is incorporated, it is reasonable to postulate that people act on the assumption of a uniform distribution of possible (unknown) trigger values of fundamentals in the range $[\mathbb{F}_1, \mathbb{F}_2]$. In other words, any fundamental in the range $[\mathbb{F}_1, \mathbb{F}_2]$ has an equal chance of being the trigger for an intervention.[13]

Consider the situation at the outset in t_0, where the exchange rate has not appreciated beyond $\mathbb{S}_2$, yet, and the intervention zone is framed by $\mathbb{S}_1$ and $\mathbb{S}_2$. To obtain the closed form solution for equation (5) that takes the market participants' expectations into account, Klein (1992) proposes to make use of a no-arbitrage condition. Thus the actual exchange rate value must equal the expected one, i.e. $\mathbb{s}(t_0) = E(\mathbb{s}(t_0))$. Using $E(\mathbb{s}(t_0))$ requires the computation of the expected value of A that evolves as

$$E(A) = \int_{\mathbb{F}_1}^{\mathbb{F}_2} \frac{\exp(rv)}{r\,(\mathbb{F}_2 - \mathbb{F}_1)}\,dv = \frac{\exp(r\mathbb{F}_2) - \exp(r\mathbb{F}_1)}{r^2(\mathbb{F}_2 - \mathbb{F}_1)}, \tag{9}$$

where we use the uniform distribution to weigh the parameter A in (8). Now applying the no-arbitrage condition by calculating $E(\mathbb{s}(t_0))$ and then equalising it with $\mathbb{s}(t_0)$, the value of the exchange rate at the outset in t_0 is derived:

$$\mathbb{s}(t_0) = \mathbb{f}(t_0) + \frac{\exp(r\mathbb{F}_2) - \exp(r\mathbb{F}_1)}{r^2(\mathbb{F}_2 - \mathbb{F}_1)} \exp(-r\mathbb{f}(t_0)). \tag{10}$$

Assume now that in $t = t^*$, $t^* > t_0$, the exchange rate appreciates beyond $\mathbb{S}_2$ by taking a

[13] The uniform distribution assumption also economises on the model's complexity.

value $\mathbb{S}^*$, $\mathbb{S}_1 \leq \mathbb{S}^* < \mathbb{S}_2$, and the Bank of Japan does not respond by intervening. This is observed by the market participants and serves as information about the exchange rate values that are tolerable to the monetary authorities. Speaking technically, the upper boundary $\mathbb{S}_2$ of the intervention zone is then updated by $\mathbb{S}^*$. Graphically, the upper boundary shifts downward into $\mathbb{S}^*$. Therefore the intervention zone narrows and every exchange rate in this new zone becomes a more likely candidate to be the intervention triggering one. Implementing this, we obtain the new closed form solution for the exchange rate for time $t > t^*$ by using the corresponding fundamental value $\mathbb{F}^*$ instead of $\mathbb{F}_2$ in equation (10):

$$\mathbb{s}(t) = \mathbb{f}(t) + \frac{\exp(r\mathbb{F}^*) - \exp(r\mathbb{F}_1)}{r^2(\mathbb{F}^* - \mathbb{F}_1)} \exp(-r\mathbb{f}(t)). \tag{11}$$

In the limit case, where the exchange rate appreciates so far that $\mathbb{F}^*$ approaches $\mathbb{F}_1$, equation (11) evolves as[14]

$$\mathbb{s}(t) \longrightarrow \mathbb{f}(t) + \frac{\exp(r\mathbb{F}_1)}{r} \exp(-r\mathbb{f}(t)) \quad \text{for } \mathbb{F}^* \searrow \mathbb{F}_1. \tag{12}$$

For $\mathbb{f} \to \mathbb{F}_1$, L'Hospital's Rule provides the lowest point of the curve being

$$\mathbb{S}_1 = \mathbb{F}_1 + \frac{1}{r}. \tag{13}$$

It should be noted, that the second summand in equation (11) grows with declining $\mathbb{F}^*$ until it reaches the limit $\frac{1}{r}$. The economic interpretation of the term $\frac{1}{r}$ is straightforward. The wedge $\frac{1}{r}$ represents the deviation from the 45 degree line and thus captures the difference between $\mathbb{S}_1$ and $\mathbb{F}_1$ at the implicit strong-side band. Comparing equation (12) with equation (8), it is obvious that the exchange rate dynamics match, in the limit, those of a fully credible target zone at the lower edge. Another intuitive explanation is that this is like the honeymoon effect in the fully credible target zone model, but here it is driven by expectations of future interventions aimed at discouraging the JPY/USD exchange rate from appreciating too much.

As a thumbnail sketch, Figure 1 illustrates the modelling framework. It describes the

[14] Lowering only the upper boundary of the intervention zone, while leaving the lower boundary unchanged, may raise the question, whether the market participants would not rather update their expectations by shifting the whole intervention zone downwards. This approach assigns to every exchange rate the same probability to be the intervention triggering one regardless of the exchange rate movements. However, by following Klein (1992) we emphazise that the market participants think an intervention more likely the more the currency appreciates.

intervention zone $[\mathbb{S}_1, \mathbb{S}_2]$ and the corresponding interval $[\mathbb{F}_1, \mathbb{F}_2]$ of the fundamentals by the dashed lines. The 45 degree line depicts the dynamics of the free-float, $\mathbb{s} = \mathbb{f}$. At the outset, where the exchange rate has not moved beyond $\mathbb{S}_2$, the actual curve is outlined by the segment *ab*. Resembling the curve progression in a fully credible target zone model, it pastes smoothly to $\mathbb{S}_2$ at the lower edge. At the upper edge, however, it takes the shape of the free-float. When appreciating over time, the curve lowers until it pastes smoothly to the lower boundary of the intervention zone, $\mathbb{S}_1$. We can even tell the exact locations of the minima. Equation (11) reveals that this point of the curve and the 45 degree line are kept separate by the second term in the sum. This distance is thus growing with declining $\mathbb{F}^*$ until it amounts $\frac{1}{r}$ for the limit case represented by curve *bc*. Put differently, the more the exchange rate appreciates the more it deviates from the free-float and the more expectations matter. Hence, all possible exchange rate curves that may evolve over time are located in the sickle-shaped red area, *abc*.

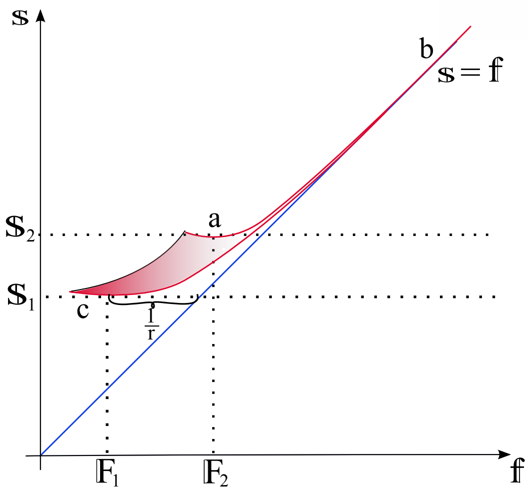


Figure 1: Relationship between Fundamentals and Exchange Rate with a Continuum of Possible Intervention Triggering Exchange Rates on the Strong Side

The framework described above works on the assumption that the non-occurence of an intervention signals the unknown edge of the strong-side band. It reveals the central bank's true preferences and alters market participants' expectations. In addition, the more the exchange rate appreciates, the higher the expected intervention probability, as the intervention zone narrows. In the next subsection, we offer a sophisticated modelling framework that describes the exchange rate in the aftermath of the first intervention.

2.4 The Exchange Rate after the First Intervention

As time passes, an intervention takes place at $t = T_1$. Numerous survey studies confirm that speculators in foreign exchange rate markets prefer to pursue simple backward-looking trading rules than strategies derived from mathematically well-defined econometric and economic models, see Cheung and Chinn (2001) and Menkhoff (1998). Thus it is reasonable to assume that the market participants make use of the information of $\mathbb{S}_{T_1}$, which is tantamount to replacing the uniform distribution of possible intervention triggering fundamentals with a density function that puts more weight on the corresponding fundamental value $\mathbb{F}_{T_1}$.

The post-intervention model also needs to account for the success of the intervention in $\mathbb{S}_{T_1}$. An effective operation leads to exchange rate values that are larger than $\mathbb{S}_{T_1}$. In this case, the exchange rate $\mathbb{S}_{T_1}$ may serve as the new strong-side band in the public's expectations. On the contrary, if the fundamentals make the exchange rate appreciate further regardless of the central bank's efforts, $\mathbb{S}_{T_1}$ is not regarded as an anchor to forecast exchange rate movements.

A model that meets these considerations has been developed by Chen et al. (2010). The approach, which is applied to the nominal HKD/US dollar exchange rate, can be transferred to this detrended exchange rate model. Hence, we postulate that the market participants' expectations of the intervention triggering exchange rate in $t = T_2$ are assumed to be conditioned on the actual detrended exchange rate value being located above $\mathbb{S}_{T_1}$ or beneath, that is in the intervention zone $[\mathbb{S}_1, \mathbb{S}_{T_1}]$.

Starting with the assumption that the last intervention in T_1 has been without success, we consider the conditional probability function $\mathscr{P}\left(\mathbb{f} = \mathbb{F}_{T_2} \mid \mathbb{F}_1 \leq \mathbb{f} \leq \mathbb{F}_{T_1}\right)$. This probability function incorporates the information about the last intervention and - in particular - about $\mathbb{F}_{T_1}$. To simplify the problem, we assume here that the density is convex and defined by

$$\varphi(v) = \frac{2\exp(2v)}{\exp(2\mathbb{F}_{T_1}) - \exp(2\mathbb{F}_1)} \, \mathbb{1}_{\{v \in [\mathbb{F}_1, \mathbb{F}_{T_1}]\}}, \tag{14}$$

This density puts the most weight on the fundamental $\mathbb{F}_{T_1}$ and all values that are close to but smaller than $\mathbb{F}_{T_1}$. The smaller the intervention zone becomes, the more weight is assigned to its largest value and thus the higher is the probability of an intervention. Implementing the density in equation (14), the closed form expression for the exchange rate in the lower range evolves as

$$\mathbb{s}(t) = \mathbb{f}(t) + E(A)\exp(-r\mathbb{f}(t)) \tag{15}$$

where

$$\begin{aligned} E(A) &= \int_{-\infty}^{\infty} \frac{1}{r}\exp(rv)\, d\varphi(v) \\ &= \int_{\mathbb{F}_1}^{\mathbb{F}_{T_1}} \frac{1}{r}\exp(rv)\frac{2\exp(2v)}{\exp(2\mathbb{F}_{T_1}) - \exp(2\mathbb{F}_{\mathbb{1}})}\, dv \\ &= \frac{2\left(\exp(\mathbb{F}_1(2+r)) - \exp(\mathbb{F}_{T_1}(2+r))\right)}{r(2+r)\left(\exp(2\mathbb{F}_1) - \exp(2\mathbb{F}_{T_1})\right)} \end{aligned} \tag{16}$$

When the exchange rate value moves beyond the upper boundary without an intervention response, this observation serves as feedback to market participants and provides the basis for updating prior expectations. The new information is incorporated in the same manner as in section 2.3, i.e. technically $\mathbb{F}_{T_1}$ is replaced by $\mathbb{F}^*$:

$$\mathbb{s}(t) = \mathbb{f}(t) + \frac{2\left(\exp(\mathbb{F}_1(2+r)) - \exp(\mathbb{F}^*(2+r))\right)}{r(2+r)\left(\exp(2\mathbb{F}_1) - \exp(2\mathbb{F}^*)\right)}\exp(-r\mathbb{f}(t)) \tag{17}$$

Considering the limit case for the function in equation (17), we obtain the same results as displayed by equation (12) and (13) for the exchange rate dynamics at the outset. The second term in equation (17) is also growing with declining fundamental $\mathbb{F}^*$. Therefore Figure 1 also sketches the post-intervention dynamics appropriately. However, expectations play a more dominant role for this framework. The minimum of the curve is more distant from the 45 degree line for the post-intervention model for all values except for $\mathbb{F}_1$. This information unfolds when comparing the second summand in the equations describing the exchange rate dynamics.

On the contrary, if it is the case that the central bank succeeds with the last intervention, then the boundary $\mathbb{S}_{T_1}$ appears to be a good candidate as a current off-the-record strong-side band. This can be modelled by means of equation (6).

However, including an expectation updating process is reasonable when the current fundamentals do not approach the implicit band for a prolonged period of time. This might be rationalised by changing economic developments. In this situation the market participants update by taking into account their observations after the first intervention. After some fixed period of time t^*, the public updates its expectations if the exchange rate has departed from the implicit strong-side band. On the contrary, if the fundamentals have come close to this value, no updating occurs and the basic model as in section 2.2 holds.

2.5 Information Content of Further Interventions

In the last subsection, we analyse the exchange rate dynamics assuming that an intervention only occurs once. This setup may be unrealistic for economies for which (a) the structure of the economy is constantly evolving in ways that are imperfectly understood by both the public and policymakers and (b) the policymakers' objective function may change over time and is not fully known by private agents. For further interventions we assume that market participants use a weighted average of past intervention triggering exchange rates as a predictor of future interventions. Apart from simplicity, its advantage is that the weighting may be used to specify the relevance and size of the past interventions. Hence, we introduce a function $a(t-T_i, q_i)$ that encapsulates the information about the time that has elapsed since intervention i and the amount of involved net purchases q_i, involved. Therewith we assume that a more recent intervention plays a more important role for anchoring the expectations, i.e. $\frac{\partial a}{\partial t} < 0$. Likewise, an intervention going along with higher net purchases is supposed to be of more significance for the market participants, $\frac{\partial a}{\partial q_i} > 0$. Consequently for the second intervention onwards, the upper boundary of the intervention zone that is implemented directly after the Nth intervention, $N \in \mathbb{N}$, $N \geq 2$, in time t, $t \geq T_N$, is calculated by means of the weighted average of the detrended exchange rates that marked the past monetary operations. Thus we conjecture

$$\text{(18)} \qquad \frac{S_{\mathcal{T}_N}}{\zeta(t)} = \sum_{i=1}^{N} a(t-T_i, q_i) \frac{S_{T_i}}{\zeta(T_i)},$$

where the values of a are normalised in a fashion that its co-domain ranges from 0 to 1, $a(t-T_i, q_i) \mapsto [0,1]$, and sum up to 1, $\sum_{i=1}^{N} a(t-T_i, q_i) = 1$. The detrended exchange rate $\frac{S_{\mathcal{T}_N}}{\zeta(t)}$ is then used to compute the upper boundary $\mathbb{S}_{\mathcal{T}_N} := \ln\left(\frac{S_{\mathcal{T}_N}(t)}{\zeta(t)}\right)$. The weighted average exchange rate value $\mathbb{S}_{\mathcal{T}_N}$ yields together with $\mathbb{S}_1$ the intervention zone for the mechanism in section 2.4. Equation (18) implies that the anchor for expectations can change, depending on the current and past conduct of monetary policy.

In summary, the modelling approach allows one to determine how exchange rate interventions orientate expectations towards future exchange rate dynamics.

3 Model Calibration and Simulation

As the well-known proverb says "The proof of the pudding is in the eating". In this section, we therefore test whether a calibrated version of the model can account quantitatively for Japan's experiences. In the event study, we select interventions and intervention phases and model the associated exchange rate dynamics. In the calibrations below we focus on "positive" interventions, i.e. FX purchases or derivative operations with similar effect. Purchases have been by far the overriding tendency of Japanese intervention, and it is of considerable policy interest to know whether such operations could mitigate appreciation pressures. Figure 2 shows the nominal JPY/USD exchange rate dynamics from the year 1998 until the end of March 2011 on a day-by-day basis, where the red bars indicate the net purchases of US dollar involved in the monetary operations by the Bank of Japan.[15] The upward facing vertical bars indicate interventions against appreciation pressure, whereas the negative bars stand for operations against depreciation pressure. Figure 2 shows four noteworthy characteristics. First, interventions have mainly been aimed at attempting to depreciate the yen.[16] Second, intervention dates are separated by periods of random length. Third, repeated interventions are often carried out on several consecutive days. In other words, interventions tended to occur in clusters.[17] Fourth, one intervention regime is characterised by small-scale frequent interventions, while another regime is characterised by large-scale rare interventions.

In the following we focus on the exchange rate dynamics from 1999 onwards, as from that year onwards the bank's efforts against the pressure began to strengthen – and the US dollar was bought and the yen was sold in every instance. Furthermore, 1999 appears to be a good starting point for applying the model in section 2.3, as the last intervention on the strong side was undertaken 3 years previously. Hence, we may assume that the information of the past interventions is of no significance for the expectation formation in 1999 anymore. Below we analyse the situation at various points of time, which are marked in Figure 2 as S'-S'^{v}. The four highlighted dates indicate that the effects of interventions tend not to be robust across time periods and/or modes of interventions. S' represents a 1-day intervention type that successfully prevented a further appreciation at that time.

[15] Other monetary policy instruments not discussed here (for example, interest rate changes) may also influence the JPY/USD exchange rate, but in a less direct manner, and are normally not used with this objective in mind.

[16] The sole exception is 1998 when Japan was facing contagion effects from the Asian currency crisis.

[17] Sequential interventions could possibly be seen as a single event as they may correspond to the same political decision in a particular economic situation.

On the contrary, the appreciation pressure was not stopped by the 1-day and record-high purchase of US dollars at S'^{v}. A sequential strategy was pursued at S'', when repeated interventions were conducted over a short period of time. Simulating the dynamics in S''' may clarify why no interference by the central bank was needed. Analysing these points in time will both demonstrate the working of the model and the implications of different intervention modes.[18]

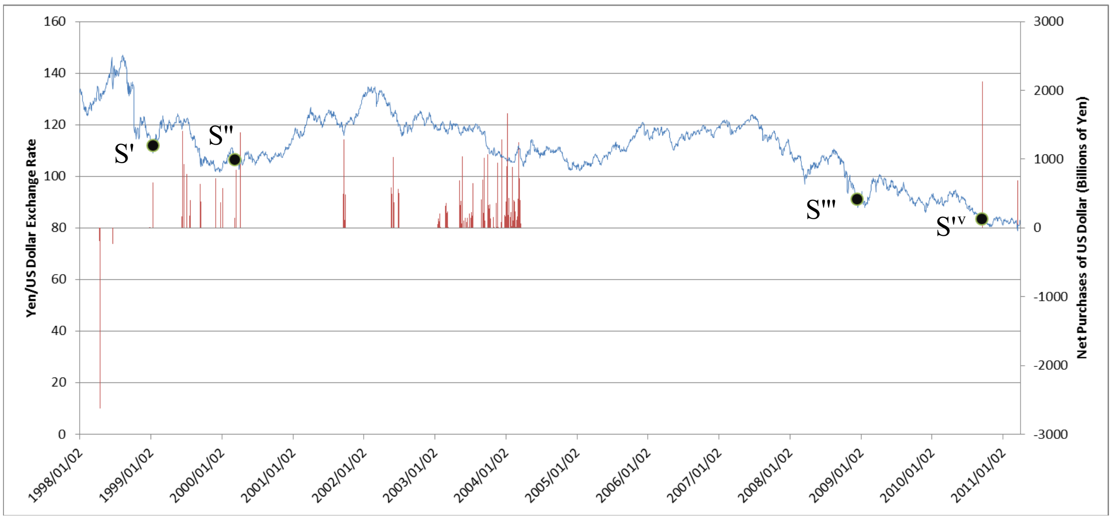


Figure 2: Nominal Daily JPY/USD Exchange Rate (Blue Line) and Intervention Amounts (Red Lines), January 1999 -March 2011

As usual, several problems related to the parameter calibration occur when applying a theoretical framework to a real-world case. The determination of some parameters requires the use of personal judgement or back-of-the-envelope calculations. The parameter values that have a major impact are explained in detail. To start with, we assume $\sigma = 0.1$ and $\tau = 0.25$. By calibrating τ, it can be determined to what extent the expectations have a stabilising effect onto the exchange rate. For $\tau = 0$ equation (1) and equation (2) shrink to $s = f$ and $\mathbb{s} = \mathbb{f}$, respectively. Thus $\tau = 0$ typifies the dynamics of a pure free float, where no intervention against undesired developments is expected. The higher the value of τ is, the more the exchange rate is stabilised by the market participants' expectations of a band at which the central bank intervenes. Because the choice of τ is a critical issue, we shall conduct a sensitivity analysis for alternative values for τ.

At the beginning of our sample period the nominal exchange rate was 112.15 JPY/USD. The exchange rate at the end of the sample period was 82.87 JPY/USD. If one assumes a

[18] Naturally, we acknowledge the problem that intervention data from other central banks are not available. This problem is mitigated somewhat by the fact that central banks always seem to have intervened in the same direction.

continuous trend and no fluctuations, then $\zeta(t)$ is computed as $\zeta(t) \approx \exp(-9.845 \cdot 10^{-5} \cdot t)$, where t is a time trend covering the period from 4 January 1999 to 31 March 2011. It should be noted that we choose a simple specification for the trend being the same continuous function for the period 1999-2011 under consideration. While this is mathematically convenient, a possible criticism to this approach is that the specification does not allow for time-varying trend expectations. Because this could potentially introduce a source of bias into the analysis, we also evaluate the sensitivity of our results with respect to the detrending technique.

Finally, the lower boundary $\mathbb{S}_1$ should be distant enough from the minimum exchange rate experienced so far. Hence, we consider a calibration of $\mathbb{S}_1 = 100$ JPY/USD to be reasonable at the base point in 1999.

First we show how the modelling approach helps us to reveal the perceived dynamics of the exchange rate on 8 January 1999, which is shortly before the intervention on 12 January in 1999 took place. This point in time is marked by S' in Figure 2, where the corresponding upward facing vertical line illustrates the involved positive net purchase of 656.3 billion US dollar involved in the intervention.. As no intervention on the strong side had been undertaken for 3 years at that time, we assume that market participants did not take into account any pre-event intervention when forming expectations. Thus, we apply the model of section 2.3. Figure 3 shows the associated nominal exchange rate dynamics for this benchmark case, which is reverse engineered from the detrended modelling framework. Two business days before the intervention, the nominal exchange rate $S(t)$ was observed to be 111.53 JPY/USD, which approximately equals logarithmised $s(t) = 4.71$. In Figure 3 this is available as the dashed red line. The perceived exchange rate dynamics on this day is given by the solid red line. The upper section of the curve pastes smoothly towards the 45 degree line. Thus our simulations are in line with the free float policy on the weak side. In contrast, the lower section of the curve pastes smoothly at $s(t) = 4.69$ and therefore $S(t) = 108.85$. In other words, according to the model the market participants assumed the yen to appreciate further until it reaches a value of approximately 108.85 JPY/USD, ($\approx \exp(4.69)$). The 3-month forward exchange rate at that date was 110.05 JPY/USD. The 1-year JPY/USD forward exchange rate was 106.25. This means that the perceived maximum appreciation of the JPY/USD exchange rate according to the model is positioned in the centre of both forward rates.[19] Two days later that forecast proved almost correct

[19]Alternatively, one may derive the market's perception of the implicit target zone from forward-looking options. This literature is now very large. See Söderlind and Svensson (1997) for an introductory text.

as the Bank of Japan intervened two days later at 108.88 JPY/USD. As a consequence, the exchange rate jumped to 112.1 JPY/USD.

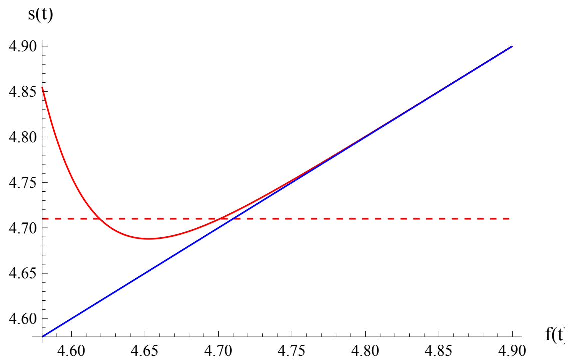


Figure 3: Perceived Pre-Intervention Exchange Rate Dynamics for 8 January 1999

Being based on the post-intervention modelling framework of section 2.4, Figures 4 and 5 display the calibrated signalling effect of this intervention. As stated above, the calibrations depend upon the parameterisation of τ . To investigate the robustness of our results to alternative τ measures, we evaluate the perceived exchange rate dynamics for $\tau = 0.25$ and $\tau = 0.50$. The upper boundary of the intervention zone $[S_1, S_2]$ is now assumed to be in conformity with the exchange rate that has triggered the intervention. This exchange rate is again marked by the red dashed line. Both figures show that after the intervention, a further small appreciation beyond 108.88 JPY/USD was expected. The signalling effect of the last intervention is revealed by the size of the lense that forms between the dashed red line and the minimum of the solid red curve. The smaller lens in Figure 4 compared to Figure 3 reveals that the next intervention was expected to take place in the immediate vicinity of the previous intervention point. Another indication of the stabilising effect of the intervention is the counter-clockwise rotation of the red curve away from the blue curve in the lower curve segment. Put differently, the perceived exchange rate dynamics at the strong side is stabilised, as the market participants recall the past intervention and incorporate it into their expectations. As expected, this effect is slightly more pronounced for $\tau = 0.50$.[20]

Another question that can be raised is whether the intervention volumes matter. As an extension, we therefore further refine our analysis to see whether the magnitude of an intervention operation affects its outcome. To this end, the model in section 2.4 along with section 2.5 is applied to the situation on 9 March 2000 - being the point S'' in Figure 2.

[20]This result is mirrored by the marginal appreciation of the 3-month and 1-year JPY/USD forward exchange rate immediately after the intervention to 110.71 and 106.84, respectively.

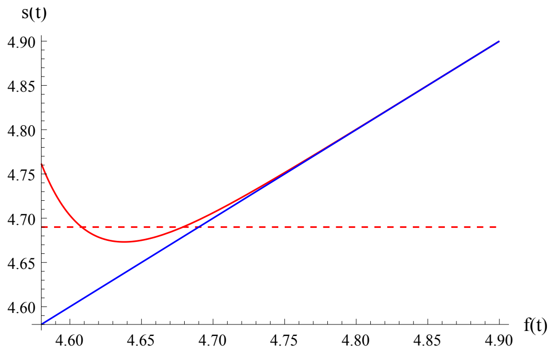


Figure 4: Perceived Post-Intervention Exchange Rate Dynamics for 12 January 1999 with $\tau = 0.25$

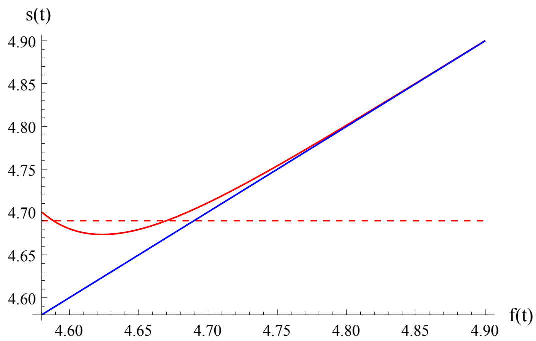


Figure 5: Perceived Post-Intervention Exchange Rate Dynamics for 12 January 1999 with $\tau = 0.5$

One possibility is that higher volumes and/or cumulative interventions convey a stronger or more credible signal, than small volumes and/or 1-day interventions. Section 2.5 explains how the upper boundary in the wake of past interventions is derived. In order to account for different modes of Bank of Japan interventions while at the same time economising on the number of parameters in the model, we specify three different functions for a: a_1, a_2 and a_3. All three versions of the model have one thing in common: different ways of implementing interventions may yield different information.

First, we assume that a depends upon the normalised volume and the no-intervention business days until 9 March 2000:

$$a_1(t - T_i, q_i) = \frac{\frac{q_i}{t-T_i}}{\sum_{j=1}^{N} \frac{q_j}{t-T_j}}. \tag{19}$$

In other words, the specification of $a1$ allows the intensity with which the Bank of Japan defends their exchange rate target to play a role for the effectiveness of interventions. Second, we assume a weighting function in which the intervention intensity does not play a role. Instead, only the time that has elapsed since the last intervention matters according to

$$a_2(t - T_i) = \frac{\frac{1}{t-T_i}}{\sum_{j=1}^{N} \frac{1}{t-T_j}}. \tag{20}$$

Third, the number of consecutive interventions alongside their frequencies is used as an indicator of the intensity of Bank of Japan interventions. With every consecutive intervention, market participants take the intentions of the central bank more seriously. If interventions are being conducted in quick succession, they gain more weight.

$$a_3(t - T_i) = \frac{\frac{\exp(i)}{T_i - T_{i-1}}}{\sum_{j=1}^{N} \frac{\exp(j)}{T_j - T_{j-1}}} \tag{21}$$

Thereby we assume that $T_1 - T_0 := T_2 - T_1$. The simulations may clarify whether the mere presence of the Bank of Japan matters more or less than the strength of the signal.[21] Table 1 describes the components for the computation of a_1, a_2 and a_3 .

Date (T_i)	S_{T_i}	$t - T_i$	Net Purchase q_i (in Bn US dollar)	Value of a_1	Value of a_2	Value of a_3
1999/01/12	112,1	292	656,3	0,010295392	0,003046727	$1{,}22465 \times 10^{-7}$
1999/06/10	118,81	187	166,5	0,004078458	0,004757457	$3{,}32895 \times 10^{-7}$
1999/06/14	120,35	185	1405,9	0,034810163	0,004808889	$4{,}75073 \times 10^{-5}$
1999/06/21	122,3	180	927,2	0,023595233	0,004942469	$5{,}16553 \times 10^{-5}$
1999/07/05	122,38	171	783,7	0,020993125	0,005202599	$7{,}80076 \times 10^{-5}$
1999/07/20	118,93	160	179,2	0,005130284	0,005560278	0,000173493
1999/07/21	118,28	159	405,2	0,011673354	0,005595248	0,005187623
1999/09/10	109	124	640,1	0,023645554	0,007174552	0,000402898
1999/09/14	105,34	122	379,4	0,014244947	0,007292167	0,019165819
1999/11/29	102,42	70	724,4	0,047402774	0,012709206	0,002003773
1999/11/30	101,78	69	410,4	0,027244674	0,012893397	0,28323462
1999/12/24	102,96	51	370,4	0,033267806	0,017444008	0,042772862
2000/01/04	103,05	47	575,3	0,05606862	0,018928604	0,523209125
2000/03/08	106,88	1	150,1	0,687549617	0,8896444	0,123672161

Table 1: Computation of the Weighting Coefficients a_1, a_2 and a_3 in (19), (20) and (21).

The first column gives the date of the past intervention, the second the nominal exchange rate, the third the number of business days until the simulated day in time t, the fourth the amount of net purchases in billions of US dollar, and finally the last three columns comprise the weighing coefficient computed with equation (19), (20) and (21), respectively. With

[21] In the standard microstructure mechanism, only price signals matter (see, for example, Glosten and Milgrom (1985)). Easley and O'Hara (1987) have subsequently introduced volume signals helping to improve the learning process.

the coefficients computed by a_1, equation (18) yields the detrended exchange rate $\frac{S_{T_{\mathcal{N}}}}{\zeta(t)}$ of approximately 110.65 JPY/USD and the nominal exchange rate of 107.45 JPY/USD. The upper boundary of the intervention zone is thus assumed to be 4.68 in the simulation. The other weighting procedure gives the detrended exchange rate of approximately 110.18 JPY/USD, which equals 107.01 JPY/USD in nominal terms. Hence, we obtain an upper boundary of 4.67. The intervention campaign version of the model in equation (21) is straightforward to implement. The upper boundary of the intervention zone is computed to be 102.84 and hence 4.63. The calibration results for the three model variants are given in Figure 6-8. The alternative sets of model runs allows one to analysing interventions from different angles.

Next we discuss what difference all this makes. The comparison of Figure 6 with Figure 7 indicates that incorporating the intervention amounts means that the expectations are anchored to a slightly higher exchange rate. In other words: A larger intervention amount improves the quality of the signal and therefore it may be concluded that larger-scale operations should be favoured by the Bank of Japan.[22] The calibrated exchange rate dynamics for a_3 in Figure 8 reveals that intervention campaigns exert a virtuous impact on the dynamics of the exchange rate. To the extent that influencing the JPY/USD exchange rate is by far the most important objective of the Japanese authorities, it might be concluded that repeated operations should be favoured by the Bank of Japan. In short, allowing for heterogeneous intervention patterns sharpens our understanding of the effects of interventions.

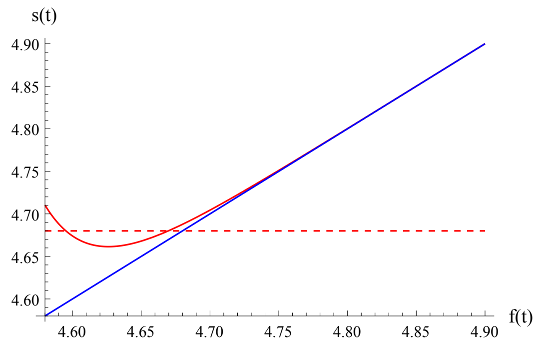


Figure 6: Calibrated Exchange Rate Dynamics for 9 March 2000 on the Assumption that the Elapsed Time and the Volume Information Played a Role

On the surface, one may simply think that a criterion for evaluating the success of an intervention means to check the direction of the exchange rate: if the yen depreciates as a

[22]This is an important result since part of the literature argues that the incidence of central bank intervention matters, but not the size of the intervention as such.

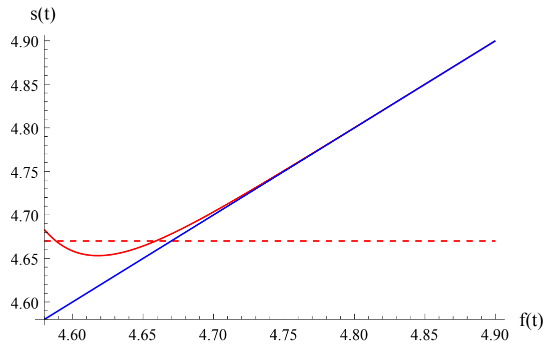


Figure 7: Calibrated Exchange Rate Dynamics for 9 March 2000 on the Assumption that Solely the Elapsed Time Since the Last Intervention Played a Role

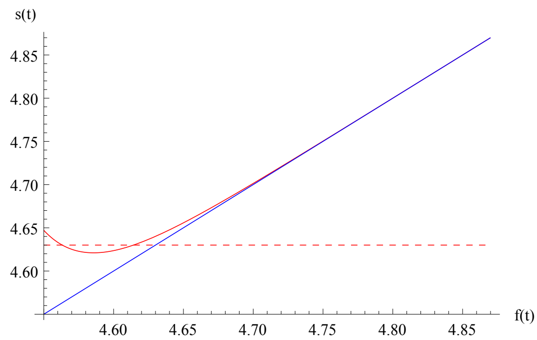


Figure 8: Calibrated Exchange Rate Dynamics for 9 March 2000 on the Assumption that Intervention Campaigns Matter

result of the intervention, then it is a success, and vice versa. However, this is ultimately too simplistic. Even if an intervention does not reverse the trend, the policy may not be a failure as the simplistic assessment supposes. When the appreciation trend is strong, the yen would have appreciated had there not been an intervention. Appreciation by the magnitude less than otherwise (counterfactual) may be hailed as a success by the central bank. The obvious problem is the counterfactual. Where would the exchange rate have been if there had not been an intervention? In other words, the counterfactuals should provide genuine answers to "what if...?" questions. When we consider whether to implement a new exchange rate policy or try to evaluate whether an intervention has been successful, we consider the counterfactual question: "What if the FX intervention had not been undertaken?".[23] We start from the assumption that the sole difference in both scenarios is that the intervention cluster has either occurred of has never taken place. All else being equal, how does the exposure to past interventions in turn determine the

[23]"What if...?"' questions play a central role throughout economics. Of course, our degree of certainty about our counterfactual judgments can be no higher than our degree of certainty that our modelling framework is correct. Furthermore, when the counterfactual posed is too far from the data at hand, conclusions drawn from the analyses become based largely on speculation that few would be willing to defend.

perceived exchange rate dynamics? With the proviso of these underlying difficulties, we calibrate in Figure 9 the exchange rate dynamics for S" on the (counterfactual) assumption that the repeated interventions prior to S" have not been carried out. So what has happened at S"?

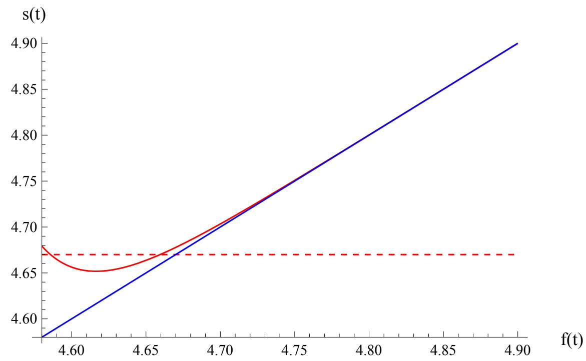


Figure 9: Counterfactual Simulation on the Assumption that the Repeated Interventions Prior to S" have not Been Carried Out

There are some notable findings here. The perceived boundary of the intervention zone is now represented by $S(t) = 109.61$ and therefore $s(t) = 4.67$. The comparison with the baseline calibration results reveals that the occurence of interventions does affect the perceived exchange rate dynamics to a noteworthy extent. Ultimately, this implies that market participants have altered their exchange rate expectations.

Next, we apply the model in section 2.3 to the 'eventless' time from 2006-2010. Since the last intervention took place on the 16 March 2004, we may safely assume that past interventions did not play a role anymore at that time. This in fact means that the model variant of section 2.3 can be applied. On 12 December 2008 the JPY/USD exchange rate was $S(t) = 91.29$ or $s \approx 4.51$ in logarithmic terms (dashed red line). This point is marked by S''' in Figure 2. Given the elapsed time and the assumed gradual appreciation of the JPY/USD exchange rate over time, the expected intervention trigger-point has shifted down. According to the model framework, market participants expected at that date no intervention for $S(t) > 88.23$ or $s(t) > 4.48$. Since the exchange rate still hovered above this threshold, no further intervention was expected. This is in accord with the absence of an intervention at that date in Figure 10.

The perceived dynamics of the exchange rate around the 1-day intervention at S'^{v} is displayed in Figure 11 and 12, respectively. More precisely, we investigate the exchange rate dynamics shortly before and after the intervention on 15 September 2010, where the Bank of Japan vigorously attempted to prevent a further appreciation of the JPY/USD

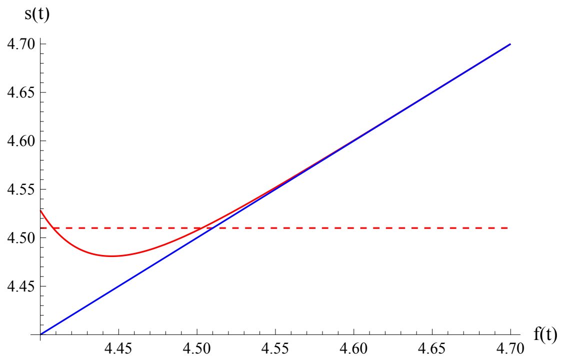


Figure 10: Perceived Exchange Rate Dynamics for 12 December 2008

exchange rate. The single vertical red bar represents the net purchase of 2124.9 billion of US dollar, which is indeed the highest amount of US dollar ever bought in an intervention during the period under consideration. On 13 September 2010 the JPY/USD exchange rate was $S(t) = 83.5$ which corresponds to $s(t) = 4.42$ (dashed red line). According to the model calibration in Figure 11, a further appreciation to a value of $s(t) = 4.4$ corresponding to $S(t) = 81.44$ was expected at that time. The 1-year JPY/USD forward rate of 83.22 on 13 September also indicated a further appreciation. In view of this, the Bank of Japan undertook a huge 1-day intervention to prevent the yen from appreciating further. The impact of the intervention upon the perceived exchange rate dynamics is displayed in Figure 12. Clearly, both curves look almost alike. Thus, despite the strong signal, market participants have abstained from adjusting their beliefs. This points to policy ineffectiveness. In other words, S'^{v} is an example that a large intervention amount is not necessarily a guarantee of success. We attribute this finding to the firmness of agents' beliefs.

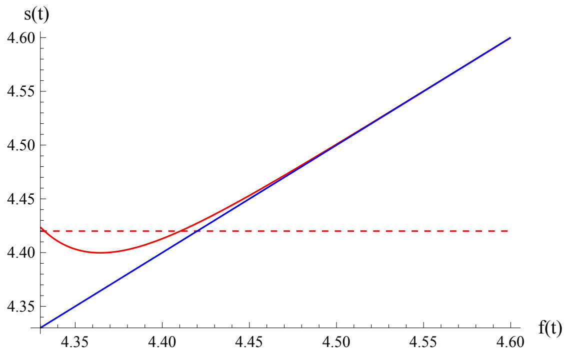


Figure 11: Perceived Pre-Intervention Exchange Rate Dynamics for 13 September 2010

Last but not least, we investigate the robustness of our calibration results with respect to an alternative detrending technique. To inform the selection of an alternative detrending

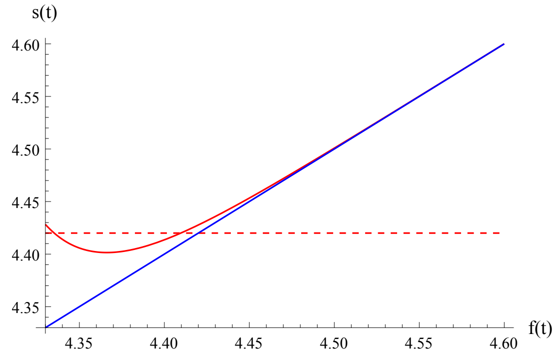
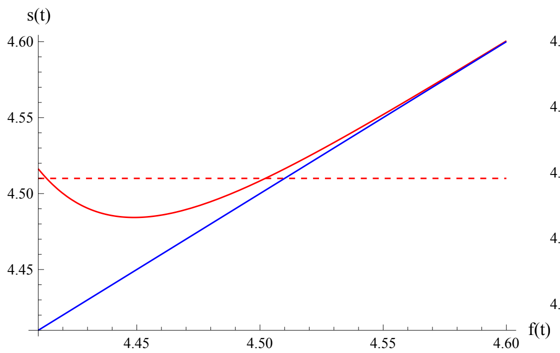
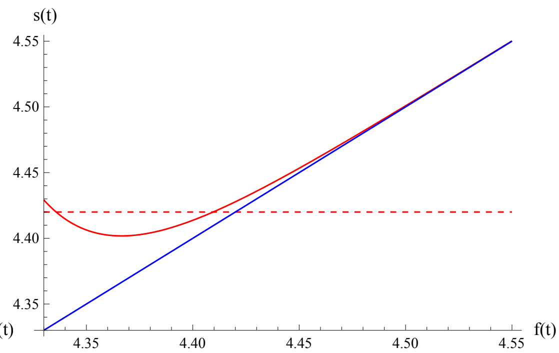


Figure 12: Perceived Post-Intervention Dynamics for 15 September 2010

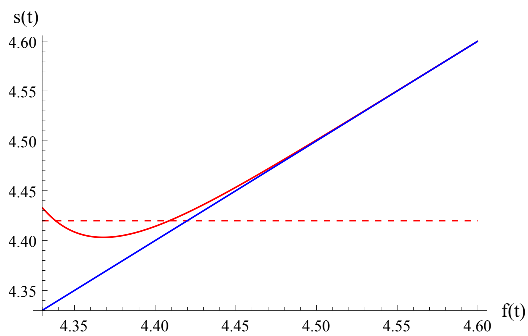
method, we draw on the PPP literature. Instead of using a mechanically determined linear trend we detrend the JPY/USD exchange rate using the Japan-US CPI inflation differential. The replicated calibration results under the assumption of a PPP detrended exchange rate are given in Figure 13. Comparing the results in Figure 13 with those in Figure 10-12 reveals that the choice of the detrending technique has very modest effects and thus our results are surprisingly robust.



(a) 12 December 2008



(b) 13 September 2010



(c) 15 September 2010

Figure 13: Calibrated Exchange Rate Dynamics Under the Assumption of a PPP Detrended Exchange Rate

What do all these results suggest? All in all, it appears that there are different ways and detours in which signals can be transmitted. The signal can forcefully influence market expectations as in the Figure 4 and 5, where a relative small intervention amount sufficed to stop the appreciating trend. This holds also true for multiple interventions as shown by Figure 6 and 7. In contrast, huge 1-day interventions such as those in Figure 12 may also prove ineffective as measured by the subsequent further appreciation of the JYP/USD exchange rate.

4 Conclusions

Exchange market developments and their associated economic effects constitute a defining challenge of our time. Although exchange rate interventions seemingly went out of fashion with the advent of inflation targeting, the recent financial crisis has put them firmly back on centre stage. Massive interventions have been employed by emerging market countries to dampen currency appreciation. Not least for that reason, the effectiveness of Japanese FX interventions has given rise to an important debate. The situation is further aggravated by the lack of an official stance on the determinants of intervention. This has been a major impetus for researchers to uncover the effects of time-varying interventions upon the exchange rate dynamics.[24] Our "learning by intervention" model examines the mechanism through which central bank intervention signals are transmitted to market participants and ultimately impact the exchange rate dynamics. Using an asymmetric and implicit target zone framework with learning, we model the time-varying impact of interventions upon mean JPY/USD exchange rate expectations during the period 1999 -2011.[25] The model calibrations at various points in time clarify the workings of the model and illustrate how Japanese exchange rate interventions have shaped expectations towards future exchange rate dynamics. All in all, then, this provides an important layer of understanding in relation to exchange market developments. It is important to emphasise that the possibility described above, namely that interventions shape exchange rate expectations, is just that: a possibility. We choose to emphasise it because a general perception is that policy signalling is the most effective transmission channel of FX interventions.[26] In this sense, the

[24] One should note that the framework proposed here could be adapted to other countries when authors attempt to analyse other implicit target zone regimes.

[25] We do not model heterogeneity among FX forecasters although recent literature to the intervention literature highlights the vital interest in this transmission channel (see, for example, Fratzscher (2008)). The reason for this course of action is that we do not analyse the so-called coordination channel of interventions.

[26] The results in our paper should not be used to answer normative policy questions such as "Should the Bank of Japan intervene?". These questions need to be addressed within the framework of DSGE models, i.e. within the context of a theoretical macro model rather than on a calibrated reduced form exchange

modelling framework adds significantly to the literature on hybrid exchange rate regimes and represents a fruitful avenue for future research into the modelling of undisclosed exchange rate corridors.

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