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No. 1765| April 2012

Web: www.ifw-kiel.de

Kiel Working Paper No. 1765 | March 2012

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Keywords: foreign exchange intervention; coordination channel; STR-GARCH model

JEL classification: C10; F31, F41

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Japanese and Federal Reserve Intervention in the Yen-US Dollar Market: A Coordination Channel Perspective

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APRIL 2012

ABSTRACT

The coordination channel has recently been established as an additional means by which foreign exchange market intervention may be effective. In Sarno and Taylor (2001) it is conjectured that strong and persistent misalignments of the exchange rate are caused by a coordination failure among fundamentals-based traders. In such situations official intervention may act as a coordinating signal, encouraging traders to engage in stabilizing speculation. We apply the framework developed in Reitz and Taylor (2008) to daily data on the yen-US dollar exchange rate and on Federal Reserve and Japanese Ministry of Finance intervention operations. The results provide further support for the coordination channel of intervention effectiveness.

JEL classification: C10; F31, F41
Keywords: foreign exchange intervention; coordination channel; market microstructure; nonlinear mean reversion

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1 Introduction

The recent appreciation of the yen particularly vis-à-vis the US-dollar, but also vis-à-vis other major currencies, heavily deteriorated the competitiveness of Japanese exporters and prompted the Japanese Ministry of Finance (MoF) to intervene in the foreign exchange market for the first time since March 2004. Thereby, policy makers reveal some confidence in the ability of official intervention to move exchange rates, though economists still doubt their effectiveness, especially when it comes to sterilized operations. Of course, the official release of intervention data in the mid 2000s already started a growing literature studying the motives and effectiveness of Japanese foreign exchange interventions. Contributions such as Fatum and Hutchison (2005, 2006), Frenkel et al. (2005), Galati et al. (2005), and Ito (2003, 2005, 2006) reveal that the Ministry of Finance aimed to 'calm disorderly markets' and supported some target level thereby systematically affected the exchange rate, at least in the short run. While these authors generally assess a the linear impact of central bank operations on exchange rates this paper is concerned with the so-called coordination channel as introduced by Sarno and Taylor (2001) and developed further by Taylor (2004, 2005) and Reitz and Taylor (2008). Within this new route of nonlinear effectiveness, central bank intervention may be seen as resolving a coordination failure in the foreign exchange market. Given the prevalence of non-fundamental influences in the foreign exchange market, as well as the general heterogeneity and diversity of opinion even among traders basing their analysis on economic fundamentals (Allen and Taylor, 1990; Taylor and Allen, 1992; Cheung and Chinn, 2001), there may be periods in which the exchange rate moves strongly and persistently away from the fundamental equilibrium level. At this point, however, since fundamentalists' trades based on their own forecasts would have been extremely unprofitable in the immediate past, during which time the non-fundamentalist traders held sway, the fundamentalists will have lost confidence in their trading strategy (Shleifer and Vishny, 1997). This therefore deters fundamentalist traders from entering the market and trading on a fundamentals-based forecast, even though they know that if they were all to enter the market together, they would force a return of the exchange rate to a level consistent with fundamentals. In other words, the market suffers from a coordination failure (Howitt, 2003). In this situation central bank intervention may effectively act as a coordinating signal to the fundamentalists, who re-enter the market, thereby providing the otherwise lacking stabilizing speculation.

Using a Markov regime-switching model of the real exchange rate and intervention data from the Federal Reserve, the Bundesbank and the Japanese Ministry of Finance, Taylor

(2004, 2005) reports some supporting evidence for the coordination channel of intervention effectiveness, showing that intervention operations increased the switching probability from the unstable to the stable state in the 1980s for dollar-mark and dollar-yen, and that the probability of an intervention switching the exchange rate into the stable state increased with the size of the deviation of the exchange rate from the fundamentals-based equilibrium (based on purchasing power parity). Reitz and Taylor (2008) use a more direct testing strategy applying a STR GARCH framework to model the (smooth) transition between stable and unstable regimes. Consistent with the coordination channel of intervention the speed of mean reversion of the exchange rate does indeed slow as the exchange rate deviates from its equilibrium value and speed up when the Federal Reserve intervened in the foreign exchange market. Using a unique dataset of end-user order flow from 1995 to 2004 Girardin and Lyons (2008) find evidence in favor of the coordination channel of FX intervention. The authors show that over the period of aggressive Japanese intervention in 2003 – 2004 the trades of Citibank's customers shifted significantly in the intervention direction.

In this paper we apply the Reitz and Taylor (2008) framework to yen-US dollar exchange rates, Federal Reserve and Japanese Ministry of Finance (MoF) operations to further investigate the nonlinear effectiveness of intervention. Statistically significant parameter estimates of meaningful magnitude provide support for the coordination channel. It is shown that in the period between 1980 and 1998 the Federal Reserve increase traders' confidence in fundamentals thereby helped to bring back the exchange rate to its PPP level. In contrast, the strong accumulation of US dollar reserves by the Japanese Ministry of Finance quite often point to exchange rate targets other than PPP. As argued by Ito (2003, 2006) the MoF tended to buy (sell) yen when the US dollar was high (low), whereby the threshold of changing the direction was 124-125 yen/US dollar. In terms of PPP, however, this implied purchases of an overvalued US dollar thereby hindering the mean reversion of the real exchange rate.

The remainder of the paper is organised as follows. In Section 2, we briefly review our microstructural model of the foreign exchange market and of the coordination channel of intervention effectiveness. In Section 3 the STR GARCH framework is introduced by which the propositions of the theoretical model are tested. In the following section, we describe our daily data set on yen-US dollar exchange rates, intervention and fundamentals, while in Section 5 we present our main empirical results concerning intervention effectiveness. The final section concludes.

2 A Microstructural Model of the Coordination Channel

To study the effectiveness of central bank intervention in the conceptual framework of the coordination channel, we assume that exchange rates are determined in an order-driven market populated by heterogeneous agents (Bacchetta and van Wincoop, 2006; De Grauwe and Grimaldi, 2005, 2006). Demand for currency is expressed in terms of market orders, i.e. traders ask for an immediate transaction at the best available price. All orders are filled by the market maker at an exchange rate that is shifted from the previous exchange rate by an amount that depends on the excess demand of traders (Kyle, 1985; Evans and Lyons, 2002). At first glance, the Kyle structure of the model may appear inappropriate because it posits a batched and centralised trading structure, whereas real-world foreign exchange markets are decentralised dealer markets (Sarno and Taylor, 2002). However, as Vitale (1999) points out, the batch structure may serve as a proxy for the prevailing lack of transparency.

Assuming a log-linear price-impact function, the change in the exchange rate at time *t*+1 may be expressed as a function of net order flow from informed and uninformed trades, plus a noise term:

$$s_{t+1} = s_t + a^M \left(D_t^I + D_t^U\right) + \varepsilon_{t+1}, \qquad (1)$$

where s_t is the logarithm of the spot exchange rate at time *t*, defined as the price of home currency in units of foreign currency, and a^M is a positive reaction coefficient determined by the market maker. D_t^I and D_t^U denote the net order flow from informed and uninformed speculators, respectively. The exchange rate depends on the *net* order flow from informed and uninformed speculators because the market maker does not observe them individually. Due to this trading protocol we may distinguish three sources of exchange rate variation. Firstly, the noise term ε_{t+1} captures publicly available information that directly affects the market maker´s price-setting decision. Secondly, public news may operate via induced order flow and thirdly, exchange rate variation may be caused by order flow that is unrelated to publicly available news. Evans and Lyons (2003) find that all three sources significantly account for observed exchange rate changes; in particular, they find at the daily frequency one third of the price variation from publicly available macro news seems to be directly and immediately incorporated, while two thirds are transmitted via order flow.[1]

Orders are submitted by risk-neutral speculators and depend on expected excess returns.

[1] Dominguez and Panthaki (2005) provide further supporting evidence on the relevance of all three sources of exchange rate changes.

Expected excess returns on foreign exchange markets consist of the expected change in the exchange rate and on the interest differential. When calculating expected exchange rate changes, however, speculators differ with respect to the information set upon which their expectations are conditioned.

Orders from uninformed traders D_t^U are not derived from a mathematically well-defined econometric or economic model and are perceived to be largely uninformative regarding the equilibrium value of the exchange rate that is consistent with the underlying economic fundamentals. Since such traders' investment strategies are perceived to be a major source of systematic forecasting errors, the term "noise trader" has become a familiar description in the analysis of financial markets literature over the past two decades (Black, 1986). In the Kyle model, uninformed traders complicate the market maker's inference of the equilibrium value from the order flow, which, in contrast, allows informed traders to camouflage their information-revealing orders. In real-world financial markets, uninformed traders may correspond to chartists or technical traders (Allen and Taylor, 1990; Sager and Taylor, 2006). Although there exists a remarkable number of different chartist or technical trading rules, these forecasting devices generally rely on historical exchange rates (Menkhoff and Taylor, 2008). Their practical importance is confirmed by the market survey studies of Allen and Taylor (1990), Taylor and Allen (1992) and Cheung and Chinn (2001), which reveal that up to 30% of traders are best characterised as technical traders. In addition, there is some evidence that technical traders may generate persistent risk-adjusted profits (Levich and Thomas, 1993; LeBaron, 1999; Qi and Wu, 2006). Given that an important element of technical trading relies on trend-following, extrapolative methods (Taylor and Allen, 1992), we model uninformed traders' orders as a positive function of the recent return, plus a term in the interest differential:

$$D_t^U = a^U\left(s_t - s_{t-1}\right) + b^U\,(i_t^* - i_t)\,, \qquad (2)$$

where i_t^* and i_t represent the interest rates of foreign and home currency deposits, respectively. The parameter a^U is expected to be positive. The expected sign of b^U, however, is not immediately clear. According to uncovered interest rate parity (UIP), the interest differential $(i_t^* - i_t)$ should be an unbiased predictor of the percentage change in the exchange rate, $\left(s_{t+1} - s_t\right)$. Equivalently, given that covered interest rate parity (the condition that the interest differential is just equal to the forward premium) is known to hold closely, at least among eurodeposit interest rates (Taylor, 1987, 1989), UIP implies that the forward exchange rate should be an unbiased predictor of the spot rate. If uninformed traders believed in UIP, therefore, one would expect b^U to be positive. However, the failure of UIP (equivalently, the failure of forward rate unbiasedness) is so well documented as to have established itself as a stylised fact (Froot and Thaler, 1990; Taylor, 1995), and it seems that, if anything, there is a tendency among traders to bet against UIP using various 'forward-rate bias' trading strategies (Fabozzi, 2001; Rosenberg, 2003), which would suggest a negative sign for b^U.[2] Overall, therefore, the sign of this coefficient is ambiguous.

Informed traders base their expectations about future exchange rate changes on an analysis of exchange rate fundamentals. In general, this boils down to the calculation of a time-varying long-run equilibrium value, f_t say, towards which the exchange rate is expected to revert over time, although the weight attached to the deviation from fundamentals in determining orders may vary over time. Thus, informed traders' orders may be expressed as

$$D_t^I = a^I w_t\left(f_t - s_t\right) + b^I (i_t^* - i_t), \qquad (3)$$

where a^I is a positive reaction coefficient and w_t determines the weight attached by informed speculators to deviations of the exchange rate from its fundamental equilibrium level, $0<w_t<1$. As before, the sign of the coefficient on the interest differential, b^I, is ambiguous.

According to equation (3), so long as $w_t>0$, the actions of informed traders amount to stabilising speculation in the sense that it will tend to drive the exchange rate towards its equilibrium value. The finite speed of adjustment a^I (for given w_t) may be rationalised by the fact that informed traders are aware of the uniformed traders' destabilising influence on exchange rates (DeLong et al., 1990). Alternatively, informed traders may recognise that closing their open positions moves the exchange rate in the opposite direction and so the adjustment has to be gradual (Osler, 1998).

Since the basis for the coordination channel of intervention effectiveness is the time-varying influence of stabilising speculation on exchange rates through its effect on informed traders' confidence, the informed traders' reaction coefficient a^I has to be adjusted by a variable w_t ranging between zero and unity. In the following, we construct w_t as a measure of speculators' confidence in fundamental analysis as basis for their trades.

The precise notion of confidence that w_t is designed to capture is worthy of further comment. Firstly, if the distance between the exchange rate and its equilibrium value increases, fundamental analysis wrongly predicts the sign of the exchange rate change. The

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[2] The act of buying high-interest rate currencies is also referred to in the markets as a 'carry trade'—see e.g. Galati and Melvin (2004).

gap $\left(f_t - s_t\right)$ may thus represent a temporary deviation exploitable for speculative purposes. However, if the exchange rate is trending away from the fundamental equilibrium, then traders face a fundamental risk (Figlewski, 1979) and betting against the trend may be associated with substantial losses. Informed traders thus become increasingly reluctant to submit orders (Shleifer and Vishny, 1997). Conversely, if misalignments decrease, fundamental analysis delivers correct predictions and regains its popularity. The ability of current misalignments to signal shifts in the equilibrium value is diminished by noise. Misalignments from high-volatility (high signal-to-noise ratio) periods are less informative than those from low-volatility (low signal-to-noise ratio) periods (De Grauwe and Grimaldi, 2006). It therefore seems reasonable to postulate that standardised absolute misalignment influences traders' confidence. Secondly—and crucially from the point of view of the coordination channel—we allow the trading activity of central banks in the foreign exchange market to influence informed traders' confidence in fundamental analysis. If a central bank sells a currency that is widely perceived to be overvalued, it reveals its commitment to a lower exchange rate. In the market microstructure literature, central banks are perceived to have superior information about the exchange rate's fundamental value, because they observe innovations in fundamental data series in advance and are able to assess their impact on future exchange rate returns (Sager and Taylor, 2006). Informed traders then become more confident that the exchange rate will revert to its fundamental value and engage in trading. The market increasingly focuses on fundamentals, so interventions may be viewed as a device with which to coordinate traders' expectations.

As argued by Taylor (2004, 2005), the influence of intervention operations on traders' confidence through the coordination channel should depend on the level of current misalignment. In the neighborhood of the fundamental value, the potential stabilising gains of interventions should be negligible because informed traders will interpret small misalignments as temporary phenomena exploitable for speculative purposes and will trade intensively in the market. If the misalignment is large, however, intervention will tend to be more effective, because informed traders who have reduced their orders because of a loss in confidence in the fundamentals may by encouraged by the central bank intervention. Finally, it must be noted that buying an overvalued currency would puzzle informed traders and perhaps drive them out of the market. To capture these misleading signals, we set an indicator variable equal to –1 if the exchange rate is overvalued and equal to +1 if it is undervalued according to the measure of the fundamental equilibrium. Multiplying the indicator variable by the current sale or purchase provides us with an intervention measure (int_t) that is positive only if the central bank operates in the appropriate direction.

Following the above line of argument, informed traders' confidence in the fundamentals can be expressed as a function of the standardised absolute misalignment and the intervention of the central bank:

$$w_t = \frac{2\,exp(c_t)}{1+exp(c_t)}, \tag{4}$$

where

$$c_t = -(\varphi - \psi\, int_t)\frac{|\, f_t - s_t \,|}{\sigma_t^S}, \tag{5}$$

and where σ_t^S denotes the conditional standard deviation of exchange rate movements. As central banks' intervention operations will not be able completely to eliminate informed traders' lack of confidence, we assume $\varphi > \psi\, int_t$, which means the value of c_t lies on the interval (–∞, 0). A logistic normalisation transforms the value c_t into a confidence measure w_t ranging between 0 and 1.[3]

Combining equations (1)–(5), the solution for the exchange rate emerges as

$$s_{t+1} = s_t + \alpha(s_t - s_{t-1}) + \delta\, w_t(f_t - s_t) + \gamma(i_t^* - i_t) + \varepsilon_{t+1}, \tag{6}$$

where

$$\alpha = a^M a^U > 0, \delta = a^M a^I > 0, \text{ and } \gamma = a^M(b^U + b^I),$$

the sign of γ being ambiguous.

From equation (6) we can see that, for a given value of δ, informed traders' stabilising impact on the exchange rate increases nonlinearly with their confidence in fundamental analysis. If, for instance, the exchange rate is near its fundamental equilibrium value, informed traders provide maximum mean reversion, since w_t will be close to unity. However, as the exchange rate becomes increasingly misaligned, informed traders reduce their orders and mean reversion weakens. This creates a role for central bank intervention which, though its coordinating influence on informed traders, effectively raises their confidence in the fundamentals and generates an increase in the degree of mean reversion of the nominal exchange rate towards the fundamental equilibrium.

[3] The logistic form of (4) was suggested by the switching mechanism of Brock and Hommes (1997) and Lux (1998) and is in the spirit of recent work by De Grauwe and Grimaldi (2005, 2006), who develop a similar switching function in their model of chartist-fundamentalist interaction.

3 The Empirical Model

Our empirical model belongs to the STR (smooth transition regression) family of models originally proposed by Ozaki (1985) and further developed and analysed by Teräsvirta and Anderson (1992), Granger and Teräsvirta (1993) and Teräsvirta (1994). STR models allow an economic variable to follow a given number of regimes, with switches between regimes achieved in a smooth and continuous fashion and governed by the value of a particular variable or group of variables. The STR framework has previously proved successful in applications to exchange rate behaviour (Taylor and Peel, 2000; Taylor et al., 2001; Kilian and Taylor, 2003).[4]

In order to examine the empirical evidence of the market microstructure model we shall use daily data, implying that the conditional variance of exchange rate returns cannot be treated as constant over time and may be better modeled as a generalised autoregressive (GARCH) process (Bollerslev, 1986). To cope with the heteroscedastic properties of daily exchange rate returns, we therefore apply the STR-GARCH procedure originally developed by Lundbergh and Teräsvirta (1998) and applied by Gallagher and Taylor (2001) and Reitz and Westerhoff (2003) and Reitz and Taylor (2008). The STR-GARCH model consists of a mean equation containing a smooth transition function and a standard GARCH(1,1) volatility equation:

$$\Delta s_t = \alpha \Delta s_{t-1} + \delta\, w_t\, \left(f_{t-1} - s_{t-1} \right) + \gamma (i^*_{t-1} - i_{t-1}) + \xi\, INT_t + \varepsilon_t \tag{7}$$

$$w_t(\varphi; \psi_i ; f_{t-d} - s_{t-d} ; int_{t-i} ; h_{t-d}) = \frac{2\, exp\left(-\left(\varphi - \sum_{i=1}^{3} \psi_i\, int_{t-i} \right) \frac{| f_{t-d} - s_{t-d} |}{\sqrt{h_{t-d}}} \right)}{1 + exp\left(-\left(\varphi - \sum_{i=1}^{3} \psi_i\, int_{t-i} \right) \frac{| f_{t-d} - s_{t-d} |}{\sqrt{h_{t-d}}} \right)} \tag{8}$$

$$h_t = \beta_0 + \beta_1 \varepsilon^2_{t-1} + \beta_2 h_{t-1}, \tag{9}$$

where Δ is the first-difference operator, INT_t denotes net purchases of US dollars against yen, $\varepsilon_t = \nu_t \cdot \sqrt{h_t}$ and $\nu_t \overset{iid}{\sim}$ N(0,1). The major differences between the empirical model (7)-

[4] Many of these studies in fact apply a special case of the STR specification, namely the smooth transition autoregressive (STAR) model, where the sum of the autoregressive coefficients of an autoregressive process depends nonlinearly on lagged values of the process. De Grauwe and Grimaldi (2001) apply a quadratic specification to model deviations of the exchange rate from fundamental equilibrium, which can be interpreted as an approximation to a smooth transition specification.

(9) and the theoretical model set out in the previous section are threefold. The first difference lies in our introduction of a GARCH model to capture the conditional standard variance of the error term.

The second difference is concerned with the suggested influence of intervention on exchange rates. Though our focus is on the coordination channel, interventions may have a linear impact on exchange rates via the traditional signaling or portfolio balance channels. In order to distinguish between these two routes of effectiveness, and as a robustness check, we introduce the intervention variable as an explanatory variable into the mean equation. Moreover, we allow for additional lags in the transition function to model the influence of intervention on traders' confidence in fundamentals. As pointed out by Neely (2005b), there is good reason to assume that the entire effect of intervention on exchange rates "takes at least a few days". In case of the coordination channel the estimation routine reveals that three trading days seem to be sufficient.

Third, we allow in our empirical model for a value of the delay parameter, *d,* different from one since the importance of searching for an appropriate value of the delay parameter in empirical applications of STR models has been stressed by Teräsvirta and others (e.g. Teräsvirta and Anderson, 1992; Granger and Teräsvirta, 1993; Teräsvirta, 1994). In our empirical implementation, it turns out, however, that a value of the delay parameter of unity was in fact selected.

4 Data

We use daily spot US dollar exchange rates against the yen to calculate percentage exchange rate returns as $100 \cdot \Delta s_t$. The price of one US dollar is expressed in yen. In terms of the preceding discussion, therefore, the US is taken as the home economy and Japan as the foreign economy. The home interest rate is thus i_t^{US}, the overnight US dollar eurodeposit interest rate, and the foreign interest rate is i_t^{Yen}, the overnight eurodeposit yen interest rate.

We assume that the fundamental equilibrium value of the exchange rate, f_t, can be adequately described by a measure of the purchasing power parity (PPP) level, based on relative consumer prices. PPP as a measure of the fundamental exchange rate f_t seems to be suited to investigate central bank intervention, because monetary authorities in the US have used it as a target level (Dominguez and Frankel, 1993; Neely, 2002, 2005a). Ito (2003, 2006) suggests that Japanese monetary authorities at times maintained a long-run average of the exchange rate around 125 yen/US$ as an implicit target value. Since preferences for a particular value of the exchange rate have not been communicated to the public, however, we do not expect the coordination channel to work in favor of the target rate. In fact, estimating the STR GARCH model using the above target value instead of PPP results in statistically insignificant parameter estimates. Furthermore, Takagi (1991) provides evidence from survey data that foreign exchange market participants accept PPP as a valid relationship in the long run and that estimates of the PPP level are frequently taken as an indication of "fair value" (Rosenberg, 2003). This view is also supported by recent research that suggests that the exchange rate reverts to the PPP level, but only in the long run (Rogoff, 1996).[5]

Monthly observations of consumer price indices (CPIs) for the US and Japan were taken from the International Monetary Fund's International Financial Statistics database to construct a measure of the PPP fundamental as $log\left(CPI_t^J\right) - log\left(CPI_t^{US}\right)$. Since observations on the consumer price indices are only available at the monthly frequency, we transformed the PPP fundamental series to daily frequency by taking the latest published value of the CPI indices as valid for the entire following month, which seems to be compatible with the information environment of a market participant in a daily trading context.[6] The PPP fundamental was normalised to be equal to the nominal exchange rate at the beginning of January 1990, although we effectively relaxed this normalisation by allowing a shift parameter θ in our estimations, such that $f_t = ppp_t + \theta$. In fact, a statistically significant parameter value of –0.25 implies that the US dollar would have been slightly overvalued at the beginning of 1990.

Daily log exchange rates and our measure of the PPP fundamental are represented in the upper panel of Figure 1.

[Figure 1]

We use Ministry of Finance and Federal Reserve intervention data in order empirically to investigate the coordination channel. As discussed in detail in Reitz and Taylor (2006) the coordination channel may work only if interventions are perceived by market participants. However, data on intervention operations is generally disclosed only with considerable lags so that official announcements of current foreign exchange interventions are practically unavailable. However, intervention information may be quickly disseminated via interdealer trades (Peiers, 1997;

[5] There is strong evidence, moreover, that this mean reversion may be nonlinear (Taylor and Peel, 2000; Taylor et al., 2001; Kilian and Taylor, 2003).

[6] To check whether or not the estimation results are driven by this simplifying assumption we experimented with linearly interpolated data (Neely, 2005b). Again, the estimation results do not change significantly.

Dominguez, 2003). To what extent central banks operations were public information is thus an empirical issue. Regarding Federal Reserve intervention Bonser-Neal and Tanner (1996) estimate the probability that Federal Reserve intervention actually occurred given that it was reported in the *Wall Street Journal* was 0.76, while the probability that Federal Reserve intervention was reported given that it actually occurred was 0.69. Galati et al. (2005) finds that Reuters reports are a relatively accurate indicator of actual Ministry of Finance interventions. The probability that an intervention was reported and perceived by traders, given that it actually occurred, was 0.77. Conversely, the probability of an intervention conditional on a Reuters report was 0.84. These numbers suggest there were few false reports of Federal Reserve and Ministry of Finance intervention leading us to the conclusion that market participants should have been largely aware of concurrent operations.

As can be seen in the lower panels of Figure 1, interventions by both the Federal Reserve and the Ministry of Finance were sporadic and clustered. Since the Federal Reserve stopped intervening in the yen-dollar market in June 1998 while data on Japanese intervention is available only from April 1991 to March 2004 we decided to investigate the influence of intervention on exchange rates using two sub-samples. In the first sub-sample from January 1980 to June 1998 the effectiveness of Federal Reserve intervention is analysed ignoring any intervention activity of the Japanese Ministry of Finance. The percentage of trading days in which Federal Reserve intervention occurred in this sample is 0.44 %. The average intervention was 71,329 dollars, indicating a small amount (US$ 343.95 mill.) of net buying home currency. Conditional on the occurrence of intervention, the mean absolute value of purchases or sales is US$ 151.3 million.[7]

In the second sub-sample from April 1991 to March 2004 tests are performed for Ministry of Finance intervention. Regarding the latter time period, the percentage of trading days in which intervention occurred is 10.26%. In contrast to the Federal Reserve, the Ministry of Finance strongly accumulated dollars in this period (US$ 539.6 bill.), the average intervention being US$ 159.07 million. Conditional on the occurrence of intervention, the mean absolute value of purchases or sales is US$ 1.769 billion. A detailed discussion of the Japanese intervention record is provided by Ito (2003, 2006).

5 Estimation Results

The modeling procedure for building STR models was carried out as suggested by Granger and Teräsvirta (1993) and Teräsvirta (1994). First, linear autoregressive models were estimated in order to choose the lag order of the autoregressive term on the basis of the Bayes Information Criterion criterion. We found that first-order autocorrelation seemed to be appropriate for exchange rate returns in our data. Second, we tested linearity against the STR model for different values of the

[7] See Neely (2005b) for more details.

delay parameter d, using the linear model (w_t = 1, for all t) as the null hypothesis and choosing the value of d that gives the smallest marginal significance level (Granger and Teräsvirta, 1993).[8] The transition parameters φ and ψ_i are slope parameters that determine the speed of transition between the two extreme regimes, with lower absolute values resulting in slower transition. Since (8) is a linear transformation of the standard logistic transition function as proposed by Teräsvirta and Anderson (1992), robust standard errors may be derived. This is important because conditional normality cannot be maintained. Under fairly weak regularity conditions, however, the resulting robust estimates are consistent even when the conditional distribution of the residuals is non-normal (Bollerslev and Wooldridge, 1992).

5.1 Federal Reserve Intervention

Table 1 contains the estimation results of Federal Reserve intervention and reveals that the point estimates of the important coefficients are significantly different from zero and appropriately signed and the estimated model passes a number of diagnostic checks for remaining serial correlation, nonlinearity or conditional heteroscedasticity in the standardised residuals.

[Table 1]

We also tested the model against a restricted model in which $\alpha = \delta = \varphi = \psi_i = 0$, so that the constrained model became an intervention augmented model of uncovered interest parity. The resulting test statistic, *LRT*, is reported in Table 1, and reveals that the simpler model is rejected against our STR-GARCH model at the one percent significance level.

While the positive signs of the point estimates of the trader coefficients, i.e. α and δ respectively, accord with our theoretical priors, only the informed trader coefficient is statistically significant. The fact that the uninformed trader coefficient is statistically insignificant reveals that assuming a simple trend-following trading strategy may not be sufficient in order to model the average influence of chartist behavior. Moreover, negative point estimate of the interest rate differential coefficient implies – on average – an appreciation of the dollar if US interest rates are higher than Japanese interest rates. Given our discussion of the likely sign of the coefficients b^U and b^I in Section 2, however, this is not

[8] Checking the standardized residuals of the model reveals that setting d = 1 passes the test for no remaining nonlinearity up to ten lags using the specification test of Eitrheim and Teräsvirta (1996).

surprising. Statistically significant point estimate of φ indicate moderate transition between regimes with respect to the standardised misalignment. The interpretation in terms of our model is straightforward. If the exchange rate converges towards the PPP value—as predicted by fundamental analysis—informed traders gain confidence in fundamental analysis and trade more heavily in the market. But, the more the exchange rate deviates from PPP, the more reluctant are informed traders to submit speculative orders.

Regarding the direct impact of intervention on exchange rates the estimation of the model reveals a statistically significant coefficient but of the wrong sign. The negative sign of ξ might be due to a simultaneity problem, quite common in central bank intervention studies (Dominguez and Frankel, 1993). Against this background, we interpret this result as a consequence of the Federal Reserve's leaning-against-the-wind-strategy implying US dollar purchases if returns were negative and vice versa (Neely, 2005b). Given that the parameter ξ seemingly measures central banks' reaction to exchange rate returns, a linear impact of intervention on exchange rate may or may not exist. In contrast, the lags in the nonlinear part of our model allows us to derive more clear cut conclusions about the impact of intervention on exchange rates via the coordination channel. In line with the coordination channel the statistically significant parameters ψ_1 and ψ_2 indicate the potential that an intervention operation can compensate for the lack of traders' confidence. Obviously, it takes two trading days to develop the total influence of intervention on exchange rates via the coordination channel. This corresponds to Neely's (2005b) conjecture that that the entire effect of intervention on exchange rates "takes at least a few days".

Although the point estimate of δ may seem small (0.01), when combined with the estimates of φ and ψ_i, together with typical values of volatility and the intervention variable, the implied behaviour of the exchange rate is in fact quite plausible. For example, the point estimates of the parameters imply that, at the average level of exchange rate volatility, a 20% misalignment results in a daily mean reversion towards fundamentals of 0.4%, or 2% on a weekly basis. Under these circumstances an intervention operation of US$ 200 million increases the mean reversion parameter to 0.76%. The nearly doubling of mean reversion by a slightly more than average intervention operation indicates an economically significant contribution by the Federal Reserve. From the model's perspective, Federal Reserve intervention has been able to encourage agents to engage in fundamental speculation, thereby helping to bring the exchange rate back to the PPP level. This is in line with the analysis of

Reitz and Taylor (2008) where comparable numbers are reported for Federal Reserve intervention in the mark-US dollar market.

5.2 Japanese Ministry of Finance Intervention

As outlined in section 4, empirical research suggests that mean reversion of real exchange rates is weak if not absent particularly when it comes to a combination of high frequency data and relatively short samples. This phenomenon applies here as well, because our sample from April 1991 to March 2004, for which we have intervention data of the Japanese Ministry of Finance, results in statistically insignificant transition and mean reversion parameters. To circumvent this problem we first estimated the exchange rate model without intervention using the entire sample from January 1980 to March 2004. In a second step the statistically significant transition parameter is used to restrict the intervention augmented model applied to the shorter sample. Table 2 reports the estimation results.

[Table 2]

Interestingly, the parameter estimates as well as the significance levels of the mean equation generally remain in the same range as before, except for the direct impact of foreign exchange intervention. A properly signed and statistically significant estimate of the parameter ξ confirms recent studies such as Beine and Szafarz (2002) and Fatum and Hutchison (2005, 2006) that Ministry of Finance interventions had a linear impact on exchange rates. The parameter value indicates that – on average – a purchase of US$ 1 billion raises the US dollar by 0.04 %. Assuming that the estimate constitutes a permanent effect on exchange rates the total buying of US$ 540 billion since early 1991 would account for an US dollar increase of more than 20 %.

Regarding the influence of intervention on exchange rates via the coordination channel Table 2 reports statistically significant parameters of – in aggregation – correct sign. Of course, this does not mean that interventions always increased traders' confidence in fundamentals. Figure 1 reveals that the Ministry of Finance heavily accumulated US dollar reserves, which might be due to the course of Japanese expansionary monetary policy or – as suggested by Ito (2003, 2006) – an implicit exchange rate target of around 125 yen/$.[9] In

[9] We re-estimated the model using a target rate of 125 yen/$ instead of the PPP level. Though intervention operations were properly signed, we do not find statistically significant parameter estimates.

either case the intervention operations since early 2000 represent purchases of an overvalued US dollar (in terms of our PPP measure) thereby decreasing traders' confidence in fundamentals. From this point of view the intervention policy of the Ministry of Finance clearly prevented the exchange rate from moving closer in line with PPP.

Moreover, the parameter values indicate lower elasticities with which traders' confidence reacts to Ministry of Finance intervention compared to Federal Reserve intervention. In contrast to an US$ 200 million intervention of the Federal Reserve in order to increase the daily mean reversion parameter of a 20 % undervalued US dollar from 0.4% to 0.76% the Japanese authorities must have bought an amount of US$ 2.27 billion to produce a similar effect. Again, this might be due to the Ministry of Finance policy of piling up foreign reserves pursuing an undervaluation of the yen relative to the PPP measure. As buying an undervalued US dollar is consistent with the coordination channel, but buying an overvalued foreign currency is definitely not, the estimated elasticities may suffer from a downward bias. In order to investigate this asymmetry we set two indicator variables, one equal to –1 if the exchange rate is overvalued (and zero if it is not) and another equal to +1 if it is undervalued (and zero if it is not). Re-estimation of the model reveals statistically significant coefficient $\psi_1 = 0.29$ if the US dollar is currently undervalued vis-à-vis the yen and $\psi_1 = 0.04$ if it is overvalued.[10] As the former is clearly in the range of Federal Reserve impact coefficients we may confine low elasticities to situations when Japanese monetary policy goals conflict with the idea of the coordination channel.

7 Conclusion

Complementary to standard linear time-series approaches applied by a number of previous contributions on Japanese intervention effectiveness, this paper focuses on central banks' potential to influence exchange rates in a nonlinear fashion. We applied the STR GARCH developed in Reitz and Taylor (2008) in order to study the relevance of the coordination channel of intervention in the yen-US dollar foreign exchange market. Parameter estimates reveal that the further removed the exchange rate is from its PPP fundamental, the weaker becomes informed traders' trading activity. This nonlinearity may account for the observed strong and persistent misalignments of the yen-US dollar exchange rate and

[10] Higher order lags of ψ turned out to be statistically insignificant in case of undervaluation and remain in the range of the symmetric estimators in case of overvaluation.

provides the basis for the coordinating role of Federal Reserve and Japanese Ministry of Finance interventions. In line with the results of Taylor (2004, 2005) and Reitz and Taylor (2008), our empirical analysis provides evidence in favor of this route of intervention effectiveness. In particular, it was shown that the Federal Reserve's intervention policy tended to reduce misalignments of the yen-US dollar exchange rate in a manner consistent with the coordination channel. However, this is not the case for Japanese Ministry of Finance interventions. Though parameter estimates are statistically significant and of correct sign, intervention operations quite often seem to have deterred fundamentals based speculation and prevented the exchange rate from moving closer in line with PPP. The reason might be that the Japanese intervention policy was driven by monetary policy strategies and/or implicit target rates other than purchasing power parity. In general, however, the nonlinear dynamics of foreign exchange markets obviously allow for intervention effectiveness via a coordination of stabilising speculation.

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Table 1: Federal Reserve Intervention

Parameter estimates of the STR model (in percent) 1980.01.02 – 1998.06.30

γ	– 2.57 (3.32)***
α	0.02 (1.39)
δ	0.01 (7.13)***
ξ	– 0.97 (2.97)***
φ	0.02 (4.25)***
ψ_1	0.18 (2.00)**
ψ_2	0.50 (2.01)**
ψ_3	– 0.36 (1.37)
β_0	0.01 (2.59)***
β_1	0.04 (4.38)***
β_2	0.93 (53.05)***
LLh	– 164.33
LRT	20.74***
AR(1)	0.51
AR(5)	0.42
ARCH(1)	0.27
ARCH(5)	0.11
NRNL	0.28

Notes: The sample contains daily observations of the dollar spot exchange rate against the yen from January 1980 to June 1998. α, δ, γ, ξ, φ, and ψ_i indicate the estimated parameters of the mean equations, β_0, β_1, and β_2 are the estimated GARCH(1,1) parameters, LLh is the log likelihood value and LRT the likelihood ratio test statistic with restrictions $\alpha = \delta = \varphi = \psi_i = 0$. AR(p) denotes the p-value for the Ljung-Box statistic for serial correlation of the residuals up to p lags. ARCH(q) denotes the p-value for the Ljung-Box statistic for serial correlation of the standardised squared residuals up to q lags. NRNL is the lowest p-value of the test for no remaining nonlinearity with up to ten lags (Eitrheim and Teräsvirta, 1996). t-statistics in parentheses are based on robust estimates of the covariance matrices of the parameter estimates. * (**, ***) denotes significance at the 10% (5%, 1%) level.

Table 2: Japanese Ministry of Finance Intervention

Parameter estimates of the STR model
(in percent) 1991.04.01 – 2004.03.30

γ	– 3.60 (3.16)***
α	0.01 (0.89)
δ	0.01 (5.76)***
ξ	0.04 (3.46)***
φ	0.02
ψ_1	0.04 (3.05)***
ψ_2	– 0.02 (2.53)**
ψ_3	0.04 (2.08)**
β_0	0.01 (4.48)***
β_1	0.04 (9.99)***
β_2	0.94 (363.37)***
LLh	– 248.90
LRT	11.62**
AR(1)	0.65
AR(5)	0.57
ARCH(1)	0.22
ARCH(5)	0.58
NRNL	0.48

Notes: The sample contains daily observations of the dollar spot exchange rate against the yen from April 1991 to March 2004. α, δ, γ, ξ, φ, and ψ_i indicate the estimated parameters of the mean equations, β_0, β_1, and β_2 are the estimated GARCH(1,1) parameters. φ is restricted to be equal to the estimated value using the entire sample from January 1980 to March 2004. LLh is the log likelihood value and LRT the likelihood ratio test statistic with restrictions $\alpha = \delta = \psi_i = 0$. AR(p) denotes the p-value for the Ljung-Box statistic for serial correlation of the residuals up to p lags. ARCH(q) denotes the p-value for the Ljung-Box statistic for serial correlation of the standardised squared residuals up to q lags. NRNL is the lowest p-value of the test for no remaining nonlinearity with up to ten lags (Eitrheim and Teräsvirta, 1996). t-statistics in parentheses are based on robust estimates of the covariance matrices of the parameter estimates. * (**, ***) denotes significance at the 10% (5%, 1%) level.

Fig. 1. *Log US dollar spot rate, PPP fundamental, and central bank intervention*