The Signalling Channel of Central Bank Interventions: Modelling the Yen/US Dollar Exchange Rate

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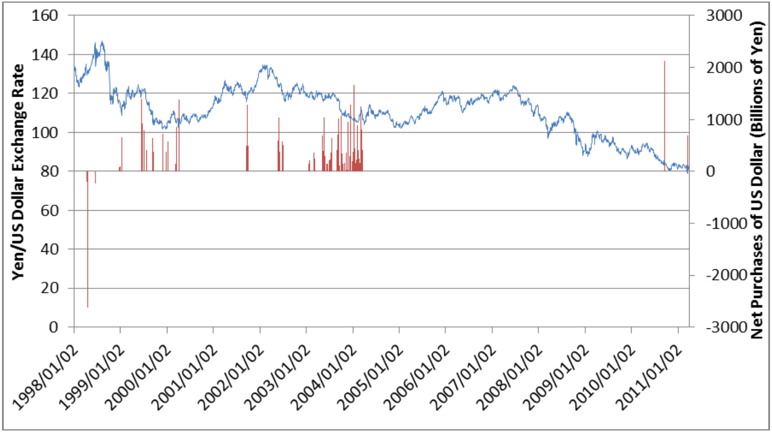
Outline

The Yen/US Dollar Exchange Rate from 1998 until March 2011



The Yen/US Dollar Exchange Rate from 1998 until March 2011

Some facts:

- Most of the interventions were undertaken to slow down the appreciation pressure.
- From January 2000 until December 2004 the Bank of Japan intervened on 148 days and sold more than 44 trillion yen.
- On 15 September 2010 the Bank of Japan spent the equivalent of 2.1249 trillion yen, which marks a record high intervention amount.
- In the aftermath of the earthquake in March 2011, the G7 countries carried out a large scale coordinated intervention.

The Yen/US Dollar Exchange Rate from 1998 until March 2011

The graph shows four noteworthy characteristics:

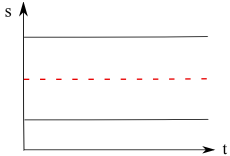
- Interventions have mainly been aimed at attempting to depreciate the yen.
- Intervention dates are separated by periods of random length.
- Repeated interventions are often carried out on several consecutive days. In other words, interventions tended to occur in clusters.
- One intervention regime is characterised by small-scale frequent interventions, while another regime is characterised by large-scale rare interventions.

Aim of the Paper

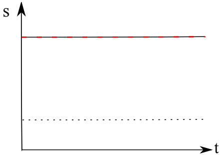
- The aim is to analyse the impact of Japanese FX interventions during the period 1999-2011 on the yen/US dollar dynamics.
- For this, we develop an implicit target zone framework with learning in order to model the signalling channel.

Exchange Rate Regimes

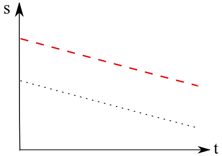
Krugman(1991)



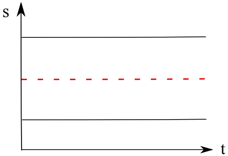
Hong Kong (1998 – May 2005)



Japan



Hong Kong (from May 2005 on)



References

Model:

- Krugman, P. (1991): *Target Zones and Exchange Rate Dynamics*, Quartely Journal of Economics 106, p. 669-682
- Klein, M.W. (1992): *Big Effects of Small Interventions: The Informational Role of Intervention in Exchange Rate Policy*, European Economic Review 36, p. 915-924
- Chen, Y.-F., Funke, M., Glanemann, N. (2012): *Off-the-Record Target Zones: Theory with an Application to Hong Kong's Currency Board*, Studies in Nonlinear Dynamics & Econometrics 16

Outline

Basic Model

Krugman's standard target zone model assumes fully credible preset exchange rate bands supported by infinitesimal interventions at the margins. The logarithm of the nominal exchange rate, $s(t)$, is given by

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

- $f(t) =$ logarithm of the fundamental
- $E[\cdot] =$ expectation operator
- $\tau =$ sensitivity to the expectations

Basic Model

Krugman's target zone model is 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.

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.

Basic Model

To make Krugman's model applicable we detrend the nominal Japanese exchange rate and then consider the dynamics of its logarithm:

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

where the fundamental is driven by fluctuations that lack any drift term but evolve according to

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

- $\mathbb{s}(t)$ = logarithm of the detrended exchange rate
- $\mathbb{f}(t)$ = logarithm of the detrended fundamental
- σ = standard deviation
- z = standard Brownian motion

The Strong-Side Band

The exchange rate equation becomes a second-order differential equation by means of Ito's Lemma.
Applying of the value-matching und smooth-pasting conditions provides:

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

where

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

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

- $\mathbb{F}^l$ = intervention triggering fundamental on the strong side

The Strong-Side Band

The exchange rate dynamics would be defined fully, if the central bank announced the exact value of $\mathbb{F}^I$.

Instead: intervention triggering values are assumed to be located in the "intervention zone" $[\mathbb{S}_1, \mathbb{S}_2]$ (corresponding to $[\mathbb{F}_1, \mathbb{F}_2]$).

The Outset

The situation at the outset in t_0:

- No a priori information about the next intervention is incorporated. Hence, 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 $[\mathbb{F}_1, \mathbb{F}_2]$.
- The exchange rate has not appreciated beyond $\mathbb{S}_2$, yet, and the intervention zone is framed by $\mathbb{S}_1$ and $\mathbb{S}_2$.

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

Applying the no-arbitrage condition, yields the value of the exchange rate at the outset:

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

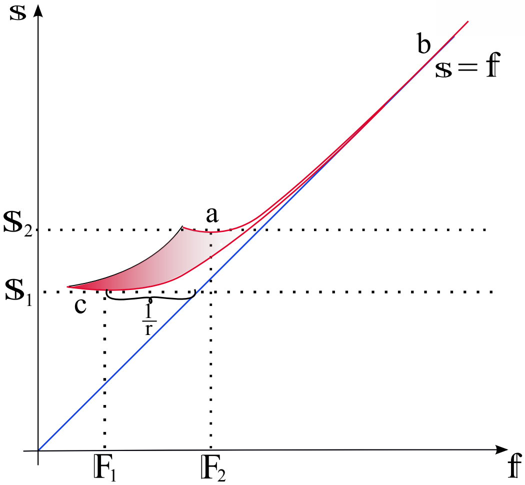
The Outset

Assume now that in $t = t^*$, $t^* > t_0$:

- The exchange rate appreciates beyond $\mathbb{S}_2$ by taking a value $\mathbb{S}^*$, $\mathbb{S}_1 \leq \mathbb{S}^* < \mathbb{S}_2$.
- The Bank of Japan does not respond by intervening, which is observed by the market participants and serves as information about the exchange rate values that are tolerable to the monetary authorities. The upper boundary $\mathbb{S}_2$ of the intervention zone is then updated by $\mathbb{S}^*$.

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

The Outset



The Exchange Rate after the First Intervention

Assume, in $t = T_1$ an intervention takes place.

- The post-intervention model also needs to account for the success of the intervention in $\mathbb{S}_{T_1}$: whether the exchange rate fluctuates above or beneath $\mathbb{S}_{T_1}$.
- 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 Exchange Rate after the First Intervention

Starting with the assumption that the last intervention in T_1 has been without success, we consider the conditional probability function $\mathscr{P}\left(\mathbb{f} = \mathbb{F}_{T_2} \mid \mathbb{F}_1 \leq \mathbb{f} \leq \mathbb{F}_{T_1}\right)$ with the associated density function:

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

- 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.

The Exchange Rate after the First Intervention

Hence, we obtain

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

where

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

When the exchange rate value moves beyond the upper boundary without an intervention response, the new information is incorporated in the same manner as before, i.e. technically $\mathbb{F}_{T_1}$ is replaced by $\mathbb{F}^*$:

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

The Information Content of Further Interventions

For further interventions we assume that market participants use a weighted average of past intervention triggering exchange rates as a predictor of future interventions.

After the Nth intervention, $N \in \mathbb{N}$, $N \geq 2$, in time t, $t \geq T_N$, the value of

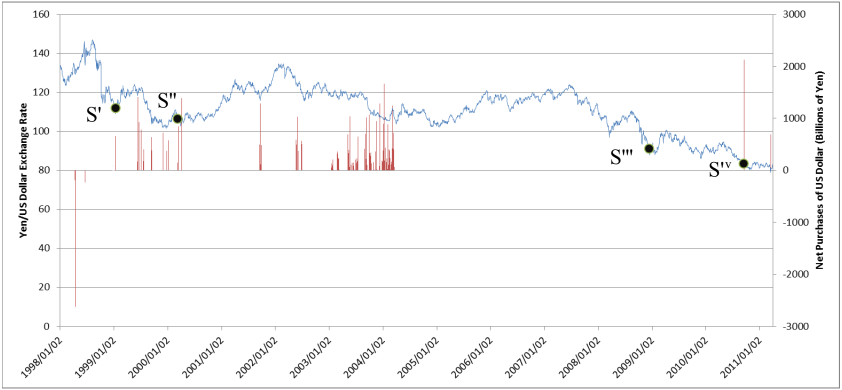
$$\frac{S_{\mathcal{T_N}}}{\zeta(t)} = \sum_{i=1}^{N} a(t - T_i, q_i) \frac{S_{T_i}}{\zeta(T_i)}$$

serves logarithmised as the upper boundary of the intervention zone.

- ζ = detrending function
- $a(t - T_i, q_i)$ = weighting function with $\frac{\partial a}{\partial t} < 0$ and $\frac{\partial a}{\partial q_i} > 0$
- q_i = amount of involved net purchases

Outline

Model Calibration and Simulation



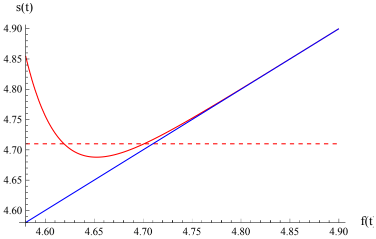
Model Calibration

- t covers the period from 4 January 1999 to 31 March 2011
- $\sigma = 0.1$ and $\tau = 0.25$
- $\zeta(t) = \exp(-9.845 \cdot 10^{-5} \cdot t)$ (exchange rate at the beginning of the period: 112.15 JPY/USD; and at the end: 82.87 JPY/USD; assumption of a continuous trend)
- $\mathbb{S}_1 = 100$

The simulations show the nominal exchange rate dynamics, which are reverse engineered from the detrended modelling framework.

Model Simulation

Perceived pre-intervention exchange rate dynamics for 8 January 1999 (S'):

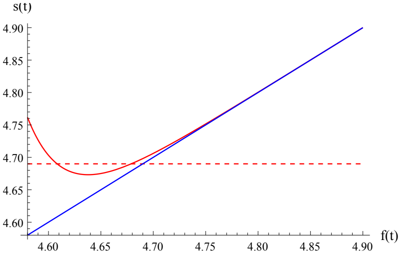


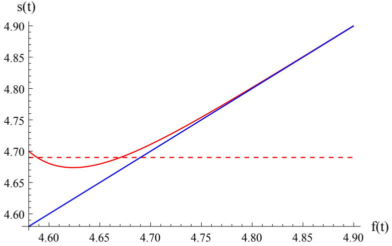
- simulation: market participants assumed the yen to appreciate further until it reaches a value of approximately 108.85 JPY/USD
- data: 3-month forward exchange rate = 110.05 JPY/USD, 1-year JPY/USD forward exchange rate = 106.25 JPY/USD

Two days later that forecast proved almost correct as the Bank of Japan intervened two days later at 108.88 JPY/USD.

Model Simulation

Perceived post-intervention exchange rate dynamics for 12 January 1999 (S') with $\tau = 0.25$ (left) and $\tau = 0.5$ (right):





- Both figures show that after the intervention, a further small appreciation beyond 108.88 JPY/USD was expected.
- The stabilising effect is slightly more pronounced for $\tau = 0.5$.

Model Simulation

Another question that can be raised is whether the intervention volumes matter. For the simulation of S'' we assume 3 different weighting functions:

- The elapsed time as well as the intervention amounts matter according to

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

- Only the time that has elapsed since the last intervention matters according to

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

Model Simulation

- The number of consecutive interventions alongside their frequencies is used as an indicator of the intensity of Bank of Japan interventions:

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

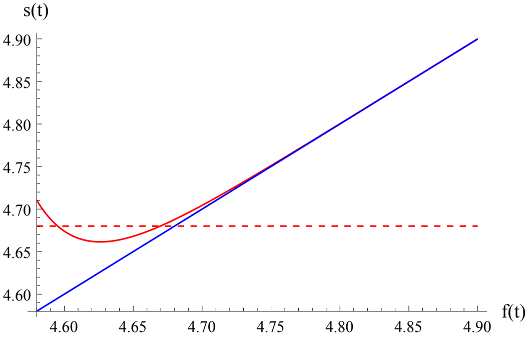
Thereby we assume that $T_1 - T_0 := T_2 - T_1$.

Model Simulation

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

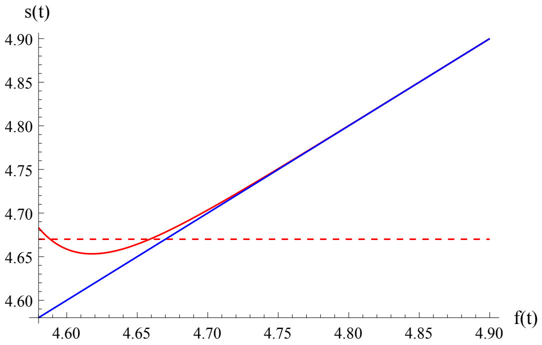
Model Simulation

Calibrated exchange rate dynamics for 9 March 2000 (S'') on the assumption that the elapsed time and the volume information played a role (a_1):



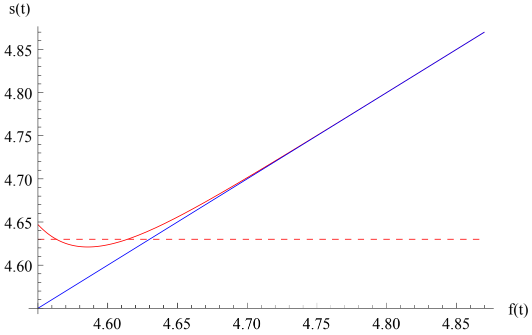
Model Simulation

Calibrated exchange rate dynamics for 9 March 2000 (S'') on the assumption that the solely the elapsed time since the last intervention played a role (a_2):



Model Simulation

Calibrated exchange rate dynamics for 9 March 2000 (S'') on the assumption that intervention campaigns matter (a_3):

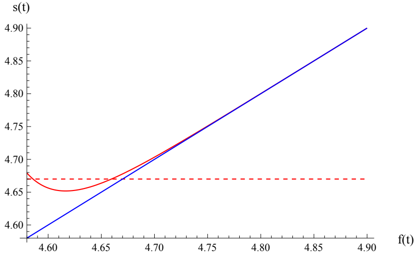


Model Simulation

- 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.
- 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.

Model Simulation

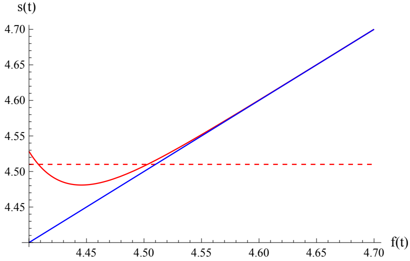
Counterfactual simulation on the assumption that the repeated interventions prior to S'' have not been carried out:



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.

Model Simulation

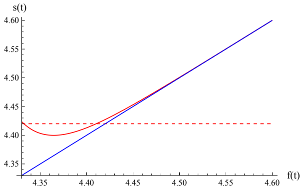
Perceived exchange rate dynamics for 12 December 2008, S''':

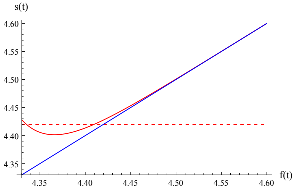


According to the model framework, market participants expected at that date no intervention for $S(t) > 88.23$ or $s(t) > 4.48$. Since the exchange rate still hovered above this threshold, no further intervention was expected. This is in accord with the absence of an intervention at that time.

Model Simulation

Comparison of the exchange rate dynamics shortly before (left) and after (right) the intervention on 15 September 2010, S'^{v}:

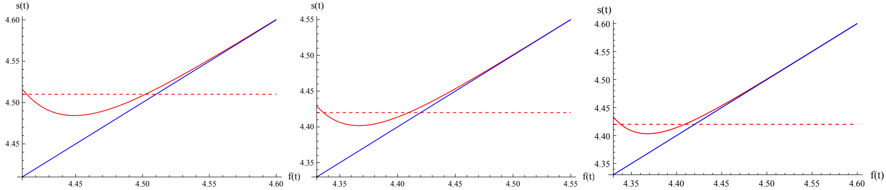




- According to the model calibration, a further appreciation to $S(t) = 81.44$ was expected at that time. The 1-year JPY/USD forward rate of 83.22 on 13 September also indicated a further appreciation.
- In view of this, the Bank of Japan undertook a huge 1-day intervention to prevent the yen from appreciating further.
- Despite the highest amount of US dollar ever bought by the Bank of Japan, market participants have abstained from adjusting their beliefs. This points to policy ineffectiveness.

Robustness with Respect to the Detrending Technique

Instead of using a mechanically determined linear trend we detrend the JPY/USD exchange rate using the Japan-US CPI inflation differential.



(a) 12 December 2008 (b) 13 September 2010 (c) 15 September 2010

Comparing the results, reveals that the choice of the detrending technique has very modest effects and thus our results are surprisingly robust.

Outline

Conclusions

- 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.
- 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.

Thank you