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**Working Paper**

## Foreign exchange market interventions as monetary policy

Working Paper, No. 2006:21

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*Suggested Citation:* Post, Erik (2006) : Foreign exchange market interventions as monetary policy, Working Paper, No. 2006:21, Uppsala University, Department of Economics, Uppsala, <https://nbn-resolving.de/urn:nbn:se:uu:diva-83096>

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Working Paper 2006:21

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# Foreign exchange market interventions as monetary policy

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Working paper 2006:21  
September 2006  
ISSN 1653-0975

## FOREIGN EXCHANGE MARKET INTERVENTIONS AS MONETARY POLICY

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# Foreign exchange market interventions as monetary policy

Erik Post<sup>\*†</sup>

September 26 2006

## Abstract

This paper sets up a simple model for interventions and interest rate setting assuming that the policy maker cares about deviations in inflation from a target level. Under a quadratic cost of interest rate adjustments and interventions the policy maker should use a combination of interest rate adjustment and interventions. According to the model interventions (purchases of foreign currency) will be negatively correlated with interest rate deviations from the steady state level but positively correlated with interest rate deviations pertaining to non-stabilizing motives or a binding zero lower bound. The model also predicts that interventions will be decreasing in inflation expectations and in the real exchange rate but increasing the expected interventions. Interventions are shown to be positively serially correlated if the policy maker cares about the future. Following the theoretical model closely two sets of regression results are presented using both Two Stage Least Squares and an Ordered Probit model. The empirical analysis uses daily intervention data for Australia, Japan and Sweden. Overall, the predictions of the model is supported in most dimensions indicating that interventions have been used in a way that is consistent with monetary policy considerations.

**Key words:** foreign exchange interventions; monetary policy; central banks

**JEL classification:** E52; E58; F31

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<sup>†</sup>The author gratefully acknowledges financial support from Handelsbankens forskningsstiftelser. Thanks to Nils Gottfries, Hans Dillén, Mikael Carlsson, Lars Svensson, David and Christina Romer, and seminar participants at Uppsala University, the Riksbank and the 10th Intl. Conference of Macroeconomic Analysis and International Finance (Crete) for valuable comments and suggestions. All remaining errors are my own.

# 1 Introduction

In a pure flexible exchange rate regime no interventions in the foreign exchange (forex) market will be carried out. The exchange rate will be allowed to dance as it wishes and the monetary authorities will stabilize the economy solely by the interest rate which in turn might affect exchange rate movements. Thus, the exchange rate is not seen as the instrument but is rather residually determined.

In reality, however, many countries that are characterized by having flexible exchange rates intervene or have intervened in the forex market.<sup>1</sup> These interventions are most commonly carried out in conjunction with domestic bond sales so that potential effects on the money supply are offset. In this sense interventions cannot be interpreted as regular monetary policy since they do not change the domestic money supply. Moreover, interventions have historically been carried out more or less secretly. Until recently, even data on historical interventions by central banks have not been made official. The secrecy involving interventions is somewhat of a puzzle given that signalling, or affecting expectations about future monetary policy, is considered as one of the main explanations of intervention (Mussa (1981)). The other explanation of intervention offered in the literature relies on the portfolio balance model. By altering the relative supplies of domestic and foreign bonds the central bank might be able to affect the exchange rate. See Sarno and Taylor (2002) for overview and Dominguez and Frankel (1993) for some evidence that it might actually work. Many questions remain regarding the possibility of moving the exchange rate by interventions. For recent surveys of the theory of interventions see Sarno and Taylor (2001) and Neely (2005).

No matter how plausible it is that the central bank can move the exchange rate, the simple observation remains that central banks at times intervene heavily. Why do central banks intervene? The central banks must clearly believe that interventions work since they keep doing them! Many studies have concentrated on modelling the intervention reaction function in terms of nominal exchange rate deviations from some target level (Almekinders and Eijffinger (1996) and Ito and Yabu (2004) *inter alia*). The argument is that the central bank will intervene to smooth deviations from some target level of the nominal exchange rate that the central bank deems optimal. From such studies evidence has emerged that central banks seem to "lean against the wind", i.e. the central bank attempt to smooth excessive fluctuations by interventions of the appropriate sign. Only a few have considered other determinants than nominal exchange rate deviations, most notably Kim et al. (2002, 2003, 2005)

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<sup>1</sup>E.g. Japan, Australia, Norway, Turkey, USA, Switzerland, Sweden and West Germany.

where prevention of exchange rate misalignment is considered as a possible, but peripheral, determinant.<sup>2</sup>

Is it possible that interventions could have been carried out partly to reinforce of counteract regular monetary policy, especially in periods where interest rate policy is restrained? Quoting the former Swedish Riksbank governor seem to indicate that this is an option for central banks. Borg and Heikensten (2002) state that:

*In addition to adjusting the interest rate, the Riksbank can resort to interventions in the foreign exchange market and a number of other measures for the purpose of maintaining price stability. The most obvious case for a central bank with an inflation target considering interventions is when the interest rate instrument no longer functions effectively. One such situation is when the steering interest rate is zero and the real interest rates are nevertheless unjustifiably high as a result of the economy being in a deflation process, with a general and persistent fall in prices. Interventions with the aim of achieving more expansionary monetary conditions through a weakening of the exchange rate would be a possible measure here. The fact that there is a possibility, which is not negligible, of getting into a situation where the interest rate is zero and thereby constitutes a restraint for monetary policy, is a strong reason for having interventions in the monetary policy arsenal. It is also a reason for establishing firm principles for how interventions should be used. p.31*

In Sweden, the Riksbank has intervened in the forex market on a number of times after the float of the krona in November 1992. The efficiency of moving the exchange rate by these interventions has been questioned, by e.g. Aguilar and Nydahl (2000) and Humpage and Ragnartz (2006). Nevertheless, after a series of interventions in June 2001 the governor at the time, Bäckström (6/14/2001), indicated that the Riksbank views interventions as a supplementary policy instrument:

*Currency market interventions are one of the instruments at the disposal of a central bank. For a central bank that targets inflation, the primary instrument is, however, the interest rate. But at a time when the exchange rate is a serious upside risk in the inflation forecast and deviates markedly from a reasonable value, a situation may arise where currency market interventions are motivated as an additional element in the work of continuously ensuring price stability.*

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<sup>2</sup>The papers cited are Kim and Sheen (2002), Kim (2003), and Kim and Sheen (March 2005).

In Japan, the official reason of the Bank of Japan to why they intervene in the forex market is to *stabilize the external value of the yen by taking necessary measures including foreign exchange transactions*.<sup>3</sup> In the introduction of the document the policy with regards to interventions is explained:

*Since the introduction of a floating exchange rate system in February 1973, the Japanese economy has experienced large fluctuations in foreign exchange rates, with the yen on a long rising trend. In order to mitigate the negative influence of such fluctuations on the Japanese economy, foreign exchange market interventions [ ] have been conducted from time to time.*

It should be clear however, that in fact it is not the Bank of Japan that decided on interventions, but the Ministry of Finance with the Bank of Japan acting solely as the agent of operations. This might lead to principal agent problems in that the Bank of Japan executes the order by the Ministry of Finance, but not necessarily deem interventions appropriate. The possible misalignment of objectives is not addressed in this paper implying that both interest rate policy and interventions are assumed to be decisions of the same policy maker. The interested reader can read more about this issue in Bernal (2006).

In Australia, the Reserve Bank of Australia has not described interventions as an explicit monetary concern. Deputy Governor Macfarlane (1993) explains:

*We would not wish to use intervention to correct a monetary policy imbalance, or to resist changing fundamentals. [ ] What then is the role of foreign exchange intervention? The answer is that it is a modest one – it is to make some contribution towards reducing the extent and duration of overshooting and to bring a little more short-term stability when markets threaten to overreact to news.*

This strong statement is somewhat softened in the conclusion where the Deputy Governor elaborates on the issue:

*[Being in a floating exchange rate system] does not mean that we can be indifferent to where the exchange rate ends up and sometimes monetary policy or foreign exchange intervention must be brought into play. We have been less inclined than most other countries to direct monetary policy at the exchange rate, but have used intervention quite often.*

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<sup>3</sup>Source: Bank of Japan home page at <http://www.boj.or.jp/en/about/basic/etc/faqkainy.htm>

The quotes above illustrate that the policy makers view interventions as a concern of monetary policy. Few papers have incorporated such monetary policy considerations when studying interventions. Kaminsky and Lewis (1996) and Kim (2003) study the signalling hypothesis. A few other papers have proposed interventions as a viable temporary monetary policy instrument, especially when short-term interest rates approach zero, e.g. McCallum (2000), Svensson (2001), and Nishimura and Saito (2003). Svensson (2001) argues that interventions are a crucial ingredient in a policy mix that is a "foolproof way" of getting out of a liquidity trap. McCallum (2000) appends a portfolio balance effect to the uncovered interest rate parity condition and argues that interventions can affect the exchange rate and help the economy out of a liquidity trap. Nishimura and Saito (2003) argue that intervention policy is a promising candidate to get out of the zero interest rate environment, but difficult to pursue for political reasons. Given the puzzle concerning motives of interventions and considering the secrecy and ambiguous effectiveness of interventions in actually moving the exchange rate it is relevant to revisit the determinants of interventions. The actual possibility of the central bank to alter the exchange rate level or volatility is left to other researchers.

To my knowledge no unifying model with an optimizing central bank has been proposed to derive theoretically what should be the most important determinants for interventions if the central bank cares about what it is said to care about: deviations in output and inflation from target levels. This paper attempts to do just that and finds that intervention should be negatively correlated with interest rates on average, but positively correlated with shocks to the interest rate, and be larger in magnitude in times of an overvalued exchange rate and low inflation. Also, the model predicts positively serially correlated interventions.

These predictions are taken to data for daily interventions by the Bank of Japan, the Reserve Bank of Australia 1991-2004 and the Swedish Riksbank 1993-2004. The results indicate that the Bank of Japan, the Reserve Bank of Australia and the Riksbank have used interventions in a way that is consistent with monetary policy since most predictions derived from the model are supported by the data.

The paper is organized as follows. Section 2 describes the theoretical model from which some empirical predictions are derived and Section 3 the data used in estimations. Section 4 presents the results from testing empirically the predictions derived from the model. Section 5 concludes.

## 2 Model

Consider a monetary authority that wishes to stabilize inflation,  $\pi_t$ , around a constant target level,  $\bar{\pi}$ . At its disposal the central bank has two instruments, the nominal interest rate,  $i_t$ , and sales of domestic bonds that alters the outstanding stock of bonds held by investors,  $z_t$ . Sterilized interventions,  $\Delta z_t$ , can be used to change the relative supplies of foreign and domestic bonds. Sterilization of the foreign bond purchases makes the money supply stay constant. Effectively, the central bank only changes the private sector's relative holdings of foreign to domestic bonds. Through the portfolio balance channel the central bank will hence be able to influence the level of the real exchange rate,  $q_t$ , since a premium must be given on domestic currency assets if investors are to hold a larger share.

The model economy is described by a Phillips curve, an aggregate demand function, a portfolio balance equation and a loss function that the authorities wish to minimize. The policy maker can stabilize the economy by interest rate policy and through sales of domestic bonds, i.e. interventions. The nominal interest rate is bounded by the zero lower bound. All parameters in the model are positive.

Inflation is determined by demand pressure and inflation expectations according to a forward-looking Phillips curve as in Clarida, Gali and Gertler (1999),

$$\pi_t = \beta_1 y_t + \pi_{t+1}^e, \quad (1)$$

where  $y_t$  is the output deviation from potential and  $\pi_{t+1}^e$  is expected inflation in the next period.<sup>4</sup> Output depends on the expected domestic real interest rate,  $r_t = i_t - \pi_{t+1}^e$ , and the real exchange rate according to

$$y_t = -\alpha_1 (i_t - \pi_{t+1}^e) + \alpha_2 q_t. \quad (2)$$

Variables are normalized so that output is equal to zero when the nominal interest rate equals expected inflation and the (log) real exchange rate is zero. The real exchange rate level is determined by a simple portfolio balance equation along the lines of Dominguez and Frankel (1993) and McCallum (2000),

$$q_t = u_t - \gamma_1 (i_t - i_t^f) + \gamma_2 (z_t - \bar{z}), \quad (3)$$

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<sup>4</sup>Inflation is home inflation only, but the model could easily be extended to allow for imported inflation. With imported inflation present, the implications of the model would only be strengthened in that a depreciation of the nominal exchange rate would not only boost exports, and via the Phillips curve induce inflation, but also make imported goods more expensive and increase inflation even more.

where  $i_t^f$  is the foreign interest rate and  $\bar{z}$  the "normal" level of outstanding domestic bonds at which no risk premium is required by risk averse investors.<sup>5</sup>  $q_t$  is defined as the relative price of domestic to foreign goods so that an increase in  $q$  is a depreciation. Consider a risk averse foreign investor who initially has an optimal risk/return portfolio that consists of a certain share of domestic bonds. Domestic and foreign bonds are imperfect substitutes and a larger share of any type must be compensated by a higher expected return. If more bonds are supplied to the market the representative investor will be willing to hold these only if the foreign currency is expected to appreciate with respect to the domestic. In other words, for the foreign investors to be willing to hold domestic bonds, the domestic currency must depreciate,  $q$  must increase. In steady state, with  $z_t = \bar{z}$  and a zero interest rate differential the real exchange rate level is pinned down by exogenous movements in the catch-all variable  $u_t$ .  $u_t$  is a stationary albeit persistent shock variable with an unconditional zero mean that captures expectations of the future evolution of the real exchange rate. These expectations include the relative price of foreign goods, foreign bond supplies, central bank credibility, productivity movements etc..

It is easily verified that the steady state of the model is characterized by  $y = q = 0$ ,  $\pi = \pi^e = i = i^f = \bar{\pi}$  and  $z = \bar{z}$ .  $\bar{\pi}$  is any arbitrary level of inflation but can be thought of as an inflation target with low but positive inflation.

Substitution of equations (2) and (3) into (1) yields that inflation is determined by

$$\begin{aligned}\pi_t &= (1 + \beta_1 \alpha_1) \pi_{t+1}^e - \beta_1 \alpha_1 i_t + \beta_1 \alpha_2 q_t \\ &= (1 + \beta_1 \alpha_1) \pi_{t+1}^e - \beta_1 \alpha_1 i_t + \beta_1 \alpha_2 \left[ u_t^{ex} - \gamma_1 (i_t - i_t^f) + \gamma_2 (z_t - \bar{z}) \right].\end{aligned}\quad (4)$$

The loss of the central bank is determined by

$$L_t = \frac{1}{2} (\pi_t - \bar{\pi})^2 + \frac{1}{2} \delta_1 (i_t - \bar{i} - x_t)^2 + \frac{1}{2} \delta_2 \Delta z_t^2. \quad (5)$$

The variable  $x_t$  captures other motives than those for stabilization purposes that affect interest rate setting.  $x_t$  includes the central bank's concerns about asset price bubbles, political pressures etc.  $\delta_1 > 0$  can be motivated by the unwillingness of the central bank to use the interest rate very aggressively which could induce excessive fluctuations in the financial market.<sup>6</sup> The motivation of  $\delta_2 > 0$  is that excessive

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<sup>5</sup>Equation (3) is the inverted form of demand for the portfolio share allocated to domestic bonds,  $z_t$ .

<sup>6</sup>In the usual lingo this is not interest rate smoothing since the authorities do not care about the change in interest rates from the previous period but the deviation from the long-run normal

interventions could make the central bank end up with such massive holdings of foreign bonds that in the long-run could be detrimental to the central bank's own risk composition of foreign versus domestic assets.<sup>7</sup>

The problem facing the central bank is to minimize an expected present value Lagrangian,  $\Lambda$ , with respect to the outstanding stock of bonds  $z_t$  and the interest rate  $i_t$  under the additional constraint that the interest rate cannot fall below zero

$$\min_{z_t, i_t} \Lambda = E_t \sum_{\tau=t}^{\infty} \rho^{\tau} \Lambda_{\tau}, \quad (6)$$

where  $\rho$  is a discount factor,  $0 \leq \rho \leq 1$ , and the time  $t$  Lagrangian is given by

$$\Lambda_{\tau} = L_{\tau} - \lambda (i_{\tau} - 0). \quad (7)$$

$\lambda$  is the shadow value of changes in the interest rate that will be zero if  $i_t > 0$  and positive otherwise.

The first order conditions are

$$\frac{\partial \Lambda}{\partial i_t} = -\rho^t [(\pi_t - \bar{\pi}) \beta_1 (\alpha_1 + \alpha_2 \gamma_1) + \delta_1 (i_t - \bar{i} - x_t) - \lambda] = 0 \quad (8)$$

$$\frac{\partial \Lambda}{\partial z_t} = \rho^t [(\pi_t - \bar{\pi}) \beta_1 \alpha_2 \gamma_2 + \delta_2 \Delta z_t] - \rho^{t+1} \delta_2 \Delta z_{t+1}^e = 0. \quad (9)$$

Substitute the Phillips curve, equation (1), into (8) and solve for  $i_t$  to get an augmented Taylor rule,

$$i_t = \bar{i} + \frac{\beta_1^2 (\alpha_1 + \alpha_2 \gamma_1)}{\delta_1} y_t + \frac{\beta_1^2 (\alpha_1 + \alpha_2 \gamma_1)}{\delta_1} (\pi_{t+1}^e - \bar{\pi}) + x_t + \frac{\lambda}{\delta_1}. \quad (10)$$

If  $x_t = 0$  so that the central bank has no other concerns than stabilization when setting the interest rate and  $\lambda = 0$  indicating that the zero lower bound is not binding then equation (10) reduces to the usual Taylor rule where the interest rate is increasing in the output gap and inflation expectations. Denote this interest rate by  $i_t^*$ . If, on the other hand, other concerns are present and the zero lower bound applies then equation (10) can be rewritten as

$$i_t = i_t^* + x_t + \frac{\lambda}{\delta_1}, \quad (11)$$

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interest rate level. The argument is similar, however, if the economy has been close to steady state for a long time and then suddenly experiences a shock that requires interest rate adjustments.

<sup>7</sup>Think China and Japan buying US assets, but eventually considering a reoptimization of their foreign asset portfolio. The assumptions of convex adjustment costs also assures, under reasonable parameterizations and future expectations, an inner solution of  $i_t$  and  $\Delta z_t$ .

and the actual interest rate is higher than would be recommended by stabilization concerns alone and in the absence of the zero lower bound constraint. Equation (11) indicates that as long as the central bank has no other motive than inflation targeting and it is unconstrained, then interest rates will follow the Taylor rule. If, however, other motives such as asset price stabilization exist, then interest rates will be higher or lower than what is suggested by the Taylor rule. The difference between the actual interest rate and the Taylor rule interest rate will be  $x_t$ . Moreover, if the macroeconomic situation really warrants a negative interest rate, as indicated by a negative  $i_t^*$ , this will show up as an even larger discrepancy between the actual interest rate and that implied by the Taylor rule,  $i_t^*$ .

Next, rearrange the first order conditions, divide one by the other and solve for  $\Delta z_t$  to get

$$\Delta z_t = -\frac{\alpha_2 \gamma_2 \delta_1}{\delta_2 (\alpha_1 + \alpha_2 \gamma_1)} \left( i_t - \bar{i} - x_t - \frac{\lambda}{\delta_1} \right) + \rho \Delta z_{t+1}^e. \quad (12)$$

Note that  $i_t - \bar{i} - x_t - \frac{\lambda}{\delta_1}$  can be rewritten as  $i_t - \bar{i} - (i_t - i_t^*)$  so that (12) becomes

$$\Delta z_t = -\frac{\alpha_2 \gamma_2 \delta_1}{\delta_2 (\alpha_1 + \alpha_2 \gamma_1)} (i_t - \bar{i}) + \frac{\alpha_2 \gamma_2 \delta_1}{\delta_2 (\alpha_1 + \alpha_2 \gamma_1)} (i_t - i_t^*) + \rho \Delta z_{t+1}^e. \quad (13)$$

Thus, it is not clear if the relation between interventions and the interest rate should be negative. From equation (13) we see that interventions will decrease with the actual interest rate deviation from the long-run level  $\bar{i}$  to support interest rate policy. But, on the other hand interventions will increase with deviations in the actual interest rate from the optimal level from a stabilization point of view,  $i_t^*$ . If stabilization motives dominate we expect a significant negative correlation between the interest rate and interventions, but in cases where the interest rate increase because of  $x$  we might have no significant correlation. The last term,  $\rho \Delta z_{t+1}^e$ , reflects that if interventions are expected tomorrow then interventions will begin today. This occurs since the policy maker cares about the future and balances the value of interventions today against the value of interventions tomorrow. In optimum, the marginal value of interventions today and in the future should be equal.

**Proposition 1** *If inflation stabilization concerns dominate other motives in interest rate setting, then we expect interventions to be negatively correlated with the interest rate. Decomposition of the interest rate yields that interventions are expected to be positively correlated with the misalignment of the actual interest rate from the interest rate suggested by the Taylor rule but negatively with the deviation from the long-run level. Interventions are expected to be positively serially correlated.*

Substituting the first order condition for the interest rate, equation (8), into the

Phillips curve we can solve for inflation,

$$\pi_t = \frac{1}{\chi} \left[ (1 + \beta_1 \alpha_1) \pi_{t+1}^e + \beta_1 \alpha_2 q_t - \beta_1 \alpha_1 \bar{i} + (\chi - 1) \bar{\pi} - \beta_1 \alpha_1 \left( x_t + \frac{\lambda}{\delta_1} \right) \right], \quad (14)$$

where  $\chi = \frac{\delta_1 + \beta_1^2 \alpha_1 (\alpha_1 + \alpha_2 \gamma_1)}{\delta_1}$ . Substitution of this expression of inflation into the first order condition for the domestic outstanding bonds yields an alternative expression of the determinants of interventions,

$$\Delta z_t = \frac{\beta_1 \alpha_2 \gamma_2}{\delta_2 \chi} \left[ \bar{\pi} + \beta_1 \alpha_1 \bar{i} - (1 + \beta_1 \alpha_1) \pi_{t+1}^e - \beta_1 \alpha_2 q_t + \beta_1 \alpha_1 (i_t - i_t^*) \right] + \rho \Delta z_{t+1}^e. \quad (15)$$

**Proposition 2** *We expect interventions to decrease in expected inflation and the real exchange rate. We also expect interventions to be positively correlated with the misalignment of the actual interest rate from the interest rate suggested by the Taylor rule. Interventions are expected to be positively serially correlated.*

The remainder of the paper is intended to test empirically the two propositions derived from equations (13) and (15) for interventions carried out by the Bank of Japan and the Reserve Bank of Australia during 1991-2004 and the Riksbank 1993-2001.

### 3 Data

For Japan, daily data on spot rates and interventions is provided by the authors of Ito and Yabu (2004) and identical to the data used in their paper.<sup>8</sup> This data covers the period 4/01/1991 to 3/31/2003. Daily spot rate and intervention data for Australia covers the same period and is provided directly by the Reserve Bank of Australia. Swedish data is provided directly by the Riksbank and covers 01/14/1993-6/25/2001. Time series intervention data is displayed in Figures 1-3. Monthly and quarterly data on prices, total production in industry and daily target rates are collected from the SOURCE OECD database, Ecwin and central bank sources. For Japan the daily overnight uncollateralized call rate, for Australia the target interest rate and for Sweden the repo rate is used as the monetary policy target interest rate. Descriptive statistics of interventions are supplied in the appendix, Table 2.

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<sup>8</sup>Data is also publicly available on the Japan Ministry of Finance home page: <http://www.mof.go.jp/english/e1c021.htm>

## 4 Empirical results

### 4.1 Correlations

Equation (13) implies that if interest rate movements are primarily driven by the stabilization motive, then we expect the correlation of interventions and interest rates to be negative. Table 3 shows negative but low correlations for all three countries. Although these negative correlations are low, they indicate that purchases of foreign exchange tend to occur in times when interest rates are low. This observation is consistent with the view that interventions occur in times when the interest rate is low in order to boost aggregate demand. Interventions reinforce monetary policy through their effects on the exchange rate.

Using the non-parametric Spearman rank correlation coefficient and computing the significance levels it is found that for Japan and Sweden all correlations of the level interest rate and interventions are significant at the one percent level whereas for Australia most are barely significant.<sup>9</sup>

The correlations of interventions and level interest rates thus point at the central banks having been more predisposed to intervening when interest rates have been low (with the possible exception of Australia). The first finding indicates that interventions have been used in times when the authorities have been concerned with the possibility of interest rates coming closer to the binding zero floor and have tried to stimulate the economy by other means.

Although correlations might give a hint as to how interventions may have been used they say nothing about how unanticipated changes in the interest rate are related to interventions. Also, further investigation is required to take a critical look at the timing of interest rate policy changes and interventions.

### 4.2 Some VAR evidence

Using a simple trivariate VAR with the target interest rate, interventions and the nominal exchange rate we further describe intervention behavior.<sup>10</sup> The results are reported in Figures 4-6.

For all countries a (depreciating) shock in the exchange rate makes the authorities inclined to intervene by buying domestic currency so as to lean against the wind.

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<sup>9</sup>At the magnitude of  $-0.03$  for Australia,  $-0.13$  for Japan and  $-0.26$  for Sweden.

<sup>10</sup>The VAR is kept very general including 20 lags. For Japan, only the time period 04/01/1991-01/02/1998 is used since after 1998 the target rate has been stuck at the zero lower bound with hardly no variation. For Sweden the TCW-weighted exchange rate is used, for Australia and Japan the bilateral USD exchange rate. For Sweden, joint stationarity of the VAR necessitated first differencing the interest rate.

This result corroborates the previous findings in the literature. (*See element 2,3 in the impulse response figures.*)

However, there is a difference when it comes to the response of the spot exchange rate to interest rate shocks. For Australia and Sweden a shock in the interest rate seems to appreciate the currency with a delay whereas for Japan no such effect is detected. (*See element 3,1 in the impulse response figures.*)

For Australia it appears as if interventions increase with the interest rate shock in the previous period. For Japan, the response of interventions to the interest rate shock is zero initially, but there appears to be a negative effect on interventions with a one week lag. For Sweden it appears as if the shock to interest rates are followed by interventions with a two week lag. (*See element 2,1 in the impulse response figures.*)

The results indicate that all countries have leaned against the wind, i.e. purchased domestic currency when the nominal exchange rate has depreciated. Further, Australia and Sweden seem to have intervened to offset interest rate policy whereas Japan has intervened to reinforce interest rate policy.<sup>11</sup>

### 4.3 Estimation of reaction functions with the interest rate

This section relies on the result in equation (13) as described by Proposition 1. To get at the possible link between interest rate policy and interventions we need to compute the difference between the actual and the "optimal" target rate from a stabilization point of view,  $x_t$ .

To get a value of the optimal interest rate policy from a stabilization point of view it is assumed that optimal policy can be described by the simplest possible estimated Taylor-rule. Although a simple description of optimal stabilization policy the Taylor rule has been found to conform with actual interest rate setting on the part of the central bank and is found to be close to optimal for a wide range of macro models. The Taylor rule in Taylor (1993) is formulated as:

$$\begin{aligned} i_t &= c + \alpha(Y_t - Y_t^*) + \beta(\pi_t - \bar{\pi}_t) \\ &= c + \alpha y_t + \beta(\pi_t - \bar{\pi}_t) \end{aligned} \tag{16}$$

where  $i_t = c$  if the output gap equals zero,  $y_t = 0$  and inflation is at target,  $\pi_t - \bar{\pi}_t = 0$ .<sup>12</sup> For the USA during 1987-1992 Taylor suggests a target inflation rate of two

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<sup>11</sup>All results are robust to ordering in the VAR and the inclusion of contemporaneous controls such as the output gap, inflation and the US federal funds rate.

<sup>12</sup>The real production trend in industrial production is measured by the HP-filter for Japan and

percent and  $c = 5$  consistent with a constant real neutral rate of three percent and estimated  $\alpha = 1.5$  and  $\beta = 0.5$ . Instead of taking these numbers as granted equation (16) is estimated for each country.

Equation (16) is the empirical counterpart to (10) with the exclusion of  $\frac{\lambda}{\delta_1}$  to get an estimate of  $i_t^*$  and  $x_t$ . The residuals which contain omitted variables in the policy rule of the central bank, are obtained from estimation of equation (16) and are interpreted as our variable  $x_t$ .<sup>13</sup> These residuals are in turn used to evaluate if the central bank have had too tight of a monetary policy, from a pure stabilization point of view, during the sample period and used as possible determinants of interventions.

From equations (13) and (15) we also know that the mean value of interventions should be higher in times when the zero lower bound on interest rates bind. The fitted values ( $i_t^*$ ) of the Taylor rule will define such periods. The dummy variable  $D_t$ , takes the value one if  $i_t^* < 0$  and zero otherwise. From mid 1998 and onward the zero lower bound binds for Japan according to  $i_t^*$ , which corresponds to the period when Japan has been said to have been caught in the "liquidity trap". For Australia and Sweden there are no such episodes. This variable is the proxy of  $\frac{\lambda}{\delta_1}$  in the theoretical model.

Estimation of (16) for Australia 1990-2004, Japan 1986-2001 and Sweden 1993-2004 yields the results in Table 4 and Figures 7-9.<sup>1415</sup>

Having a measure of  $x_t$  for all three countries equation (13) is estimated by regressing monthly aggregated interventions on the monthly Taylor rule residuals,  $x_t$ , and the deviation of the actual interest rate from its mean throughout the sample period,  $i_t - \bar{i}$ . By measuring  $\bar{i}$  by the sample mean it is assumed that the mean throughout the sample period is a sufficient characterization of the equilibrium nominal interest rate.<sup>16</sup> We have controlled for the endogeneity of the interest rate and  $x$  using instruments. The instruments are  $x_{t-1}$ , the foreign interest rate and a money supply indicator.<sup>17</sup>

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Australia, with a smoothing parameter of 126400 recommended for monthly data. For Sweden estimates the output gap is provided directly by the Riksbank.

<sup>13</sup>A discussion of inclusion of financial variables in the Tylor rule is discussed at length in Borio and Lowe (2004). For both Japan and Australia some evidence is found that financial variables have affected interest rate setting.

<sup>14</sup>The motivation of extending the sample backwards to 1986 for Japan is to avoid estimation in an economical downturn and instead capture a full cycle. Exclusion of the post 2001 period is warranted by the zero interest rate environment in Japan.

For Sweden we restrict the sample to 1993m1-2004m03 because of the early 1990's crises.

<sup>15</sup>Since the sign on the output gap for Sweden is perversely negative we exclude this variable. If included however, the final results are left unchanged.

<sup>16</sup>For Australia the mean of the nominal interest rate is 8.0, for Japan 4.2, and for Sweden 5.5 percent for their respective sample periods.

<sup>17</sup>Since interventions are sterilized, interventions should not be affected by the money supply.

Table 5 displays the estimation results using Two Stage Least Squares for different specifications, with and without the  $i - i^*$  term. Note that for Japan  $i - i^* = x_t + \frac{\lambda}{\delta_1}$  but for Australia and Sweden the zero lower bound never binds so that  $i - i^* = x_t$ . For Japan the two causes of deviations from the Taylor rule are separated in the estimations. The signs of the estimates are in most cases as expected. Australia, Japan and Sweden have intervened in significantly larger amounts when interest rates have been higher than suggested by the simple Taylor rule. Japan and Sweden have intervened more heavily when the interest rate has been below its mean over the period for most specifications; for Australia the result is of the same sign but insignificant. The identified zero lower bound for Japan has not made interventions larger after controlling for other factors as captured by the insignificant estimate of the parameter of the dummy variable  $D$ . We proxy the expected future interventions by the actual interventions,  $\Delta z_{t+1}^e = \Delta z_{t+1}$ . This assumes that when the authorities decide on intervention today they know the size of interventions tomorrow. Or, equivalently, the authorities set up a plan of interventions that span at least this and the next month. The estimated parameter for future interventions is positive and highly significant across all countries and specifications.

As can be seen in Figures 1-3, interventions are not normally distributed. Therefore, as an alternative an ordered probit model is estimated where the dependent indicator variable is defined as  $\Delta z_t^I = 1$  if  $\Delta z_t > 0$ ,  $\Delta z_t^I = 0$  if  $\Delta z_t = 0$ ,  $\Delta z_t^I = -1$  if  $\Delta z_t < 0$ . This ordered probit model estimation is more appropriate if one believes that the value of interventions is the same regardless of the size of intervention and if one assumes some fixed cost of intervention so that interventions only occur if a loss threshold is reached.

The results in Table 6 indicate that Australia has been more inclined to intervene by selling domestic currency when interest rate policy has been too contractionary according to the Taylor rule. The results for Japan and Sweden are of the same sign, but insignificant. Furthermore, both Sweden and Japan have intervened less frequently when interest rates have been higher than the mean throughout the period.

#### 4.4 Estimation of reaction functions with fundamentals

This section relies on the result in equation (15) as described by Proposition 2. Equation (15) suggests that intervention should be decreasing linearly in expected inflation and the real exchange rate. The real exchange rate is measured as the bilateral CPI based real exchange rate between Australia/Japan and the USA and the TCW-weighted exchange rate and CPI for Sweden. The expected inflation rate

in the next period is modelled by assuming that the central bank has a naive forecast of next day inflation so that  $\pi_{t+1}^e = \pi_t$ .

Regressing monthly aggregated intervention amounts on inflation, the real exchange rate,  $x$ , and the dummy capturing the zero lower bound period for which  $\lambda > 0$  yields the results in Table 7 for the same set of specification alterations as in estimation of equation (13). The Reserve Bank of Australia has intervened more heavily in times when the real exchange rate has been low, i.e. when it has been overvalued and when interest rate policy has been too restrictive, as captured by the positive coefficient on  $x$ . Japan and Sweden have intervened more heavily when inflation has been low.

Ordered probit models are also estimated. The results in Table 8 supports the findings that the Reserve Bank of Australia interventions have been carried out in times an overvalued exchange rate. The Bank of Japan and Riksbank interventions have occurred in times of low inflation. Japan also appears to have intervened when the exchange rate has been overvalued whereas Australia seems to have intervened more when inflation has been high(!). All results but the sign on inflation for Australia are of the predicted sign.<sup>18</sup>

As can be seen in all regression results we are unable to identify the effect of the zero lower bound on increased interventions for Japan when taking account of other factors implied by the model. Therefore we choose to drop these specifications and focus on the specifications with  $x$  only and without  $x$ . Doing so, we are left with the same two specifications for Japan as for Australia and Sweden. The results after dropping these two models is summarized in Table 1.

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<sup>18</sup>Because of the dummy variable,  $D_t$ , we cannot estimate an ordered probit model for Japan when this dummy is included and therefore estimate a probit model instead. The dependent variable is unity if interventions are positive and zero otherwise.

Table 1: Summary results

Results for test of Proposition 1	2SLS	OP
$\frac{\partial \Delta z}{\partial (i-i)}$	- (JPN,SWE)	- (JPN,SWE)
Results for test of Proposition 2	2SLS	OP
$\frac{\partial \Delta z}{\partial \pi}$	- (JPN,SWE)	- (JPN,SWE)
$\frac{\partial \Delta z}{\partial q}$	- (AUS)	- (AUS,JPN)
Results for test of effect of $x$	2SLS	OP
$\frac{\partial \Delta z}{\partial x}$	+ (AUS)	+ (AUS)

Table 1 reports the sign of the effect of the variable in question with respect to interventions. Only effects that are robust across both specifications, with and without the  $x$  term are reported. The effect of  $x$  is only reported if significant in both estimation of equation (13) and (15). All signs are as expected and reveal the following pattern across countries.

- Australia has intervened in larger amounts, according to the Two Stage Least Squares estimates, and more often, according to the Ordered Probit estimates, when the Australian dollar has been overvalued and when interest rate policy has been too contractionary.<sup>19</sup>
- Japan and Sweden have intervened in larger amounts and more often when interest rates have been low and when inflation has been low (or even negative in the Japanese case).<sup>20</sup>

<sup>19</sup> Japan has intervened more often when the Japanese yen has been overvalued, but not in larger amounts.

<sup>20</sup> Australia appears to have intervened more often when inflation has been high(!), but this result is not robust across specifications nor regression model.

## 5 Conclusions

This paper sets up a simple model for interventions and interest rate setting assuming that the policy maker cares about deviations in inflation from a target level. Under a quadratic cost of interest rate adjustments and interventions the policy maker should use a combination of interest rate adjustment and interventions. According to the model interventions (purchases of foreign currency) will be negatively correlated with interest rate deviations from the steady state level but positively correlated with interest rate deviations pertaining to non-stabilizing motives or a binding zero lower bound. The model also predicts that interventions will be decreasing in inflation expectations and in the real exchange rate but increasing the expected interventions. Interventions are shown to be positively serially correlated if the policy maker cares about the future.

Testing the model on intervention data for the Bank of Japan, the Reserve Bank of Australia and the Swedish Riksbank it is shown that interventions are negatively correlated with the interest rate. For Australia and Sweden it appears as if interest rate shocks have induced the Reserve Bank of Australia and the Riksbank to intervene to offset potential negative demand effects and exchange rate misalignment. For Japan it appears as if interest rate shocks have been further reinforced by interventions by the Bank of Japan and that interventions have preceded interest rate cuts. All countries show a leaning against the wind behavior in intervention policy.

Following the theoretical model closely two sets of regressions are presented using both Two Stage Least Squares and an Ordered Probit approach. Japan and Sweden have intervened more when interest rates and inflation have been low. Australia has intervened more when the exchange rate has been overvalued and when interest rate policy has been too contractionary. When controlling for other factors Japan does not seem to have intervened more in the zero lower bound environment. Interventions are shown to be strongly serially correlated across all countries and specifications.

Overall, the predictions of the model is supported in most dimensions indicating that interventions have been used in a way that is consistent with monetary policy considerations.

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## A Appendix

### A.1 Descriptive statistics

Table 2: Descriptive statistics, purchases of foreign currency by country

	Australia	Japan	Sweden
Mean	2.5	172.5	-3.5
Median	0	0	0
Maximum	376	16664	251
Minimum	-1256	-26201	-460
Std. Dev.	66.4	1141.0	27.2
No of interventions	907	343	180
Observations	3393	3393	2889

AUD millions, 100 million JPY and USD millions

Table 3: Cross correlation interventions and interest rates

Interest rate	Australia	Japan	Sweden
t-5	-0,01	-0,09	-0.02
t-4	-0,01	-0,09	-0.02
t-3	-0,01	-0,08	-0.02
t-2	-0,01	-0,09	-0.02
t-1	0	-0,08	-0.02
t	0	-0,09	-0.02
t+1	0	-0,08	-0.02
t+2	0	-0,09	-0.02
t+3	0	-0,09	-0.02
t+4	0	-0,08	-0.02
t+5	0	-0,09	-0.02
Obs.	3393	3344	2815

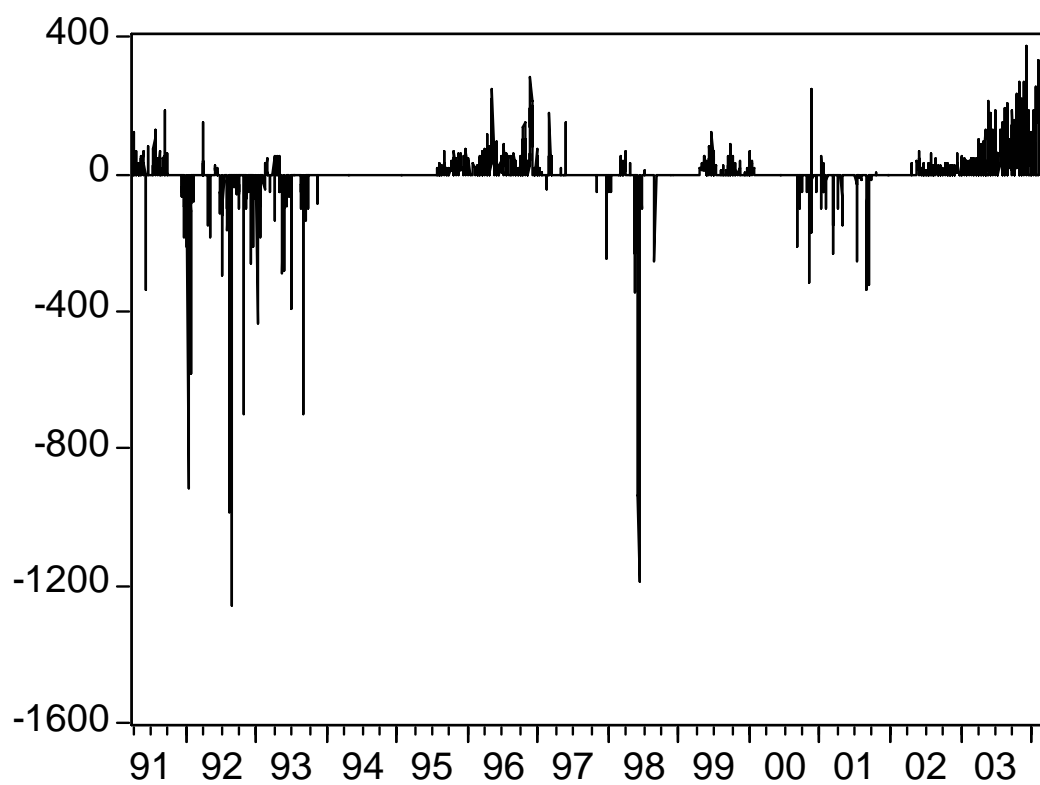


Figure 1: The Reserve Bank of Australia interventions (sales of AUD), AUD millions

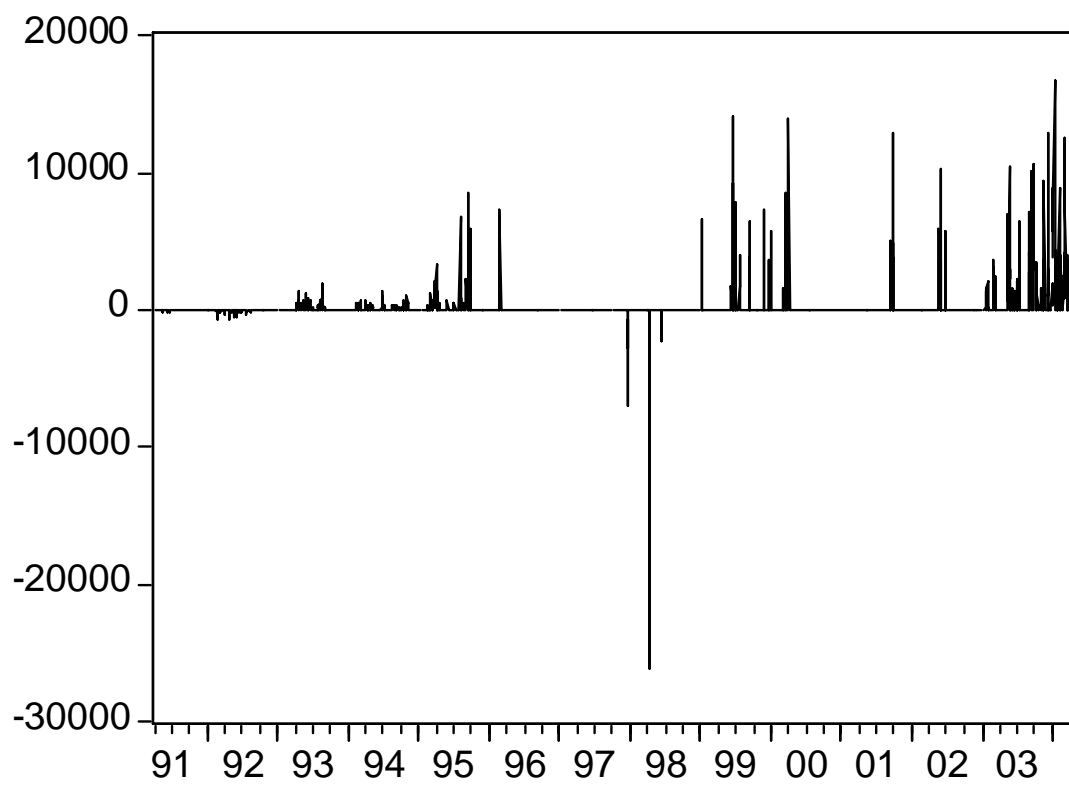


Figure 2: The Bank of Japan/Ministry of Finance interventions (sales of JPY), 100 million JPY

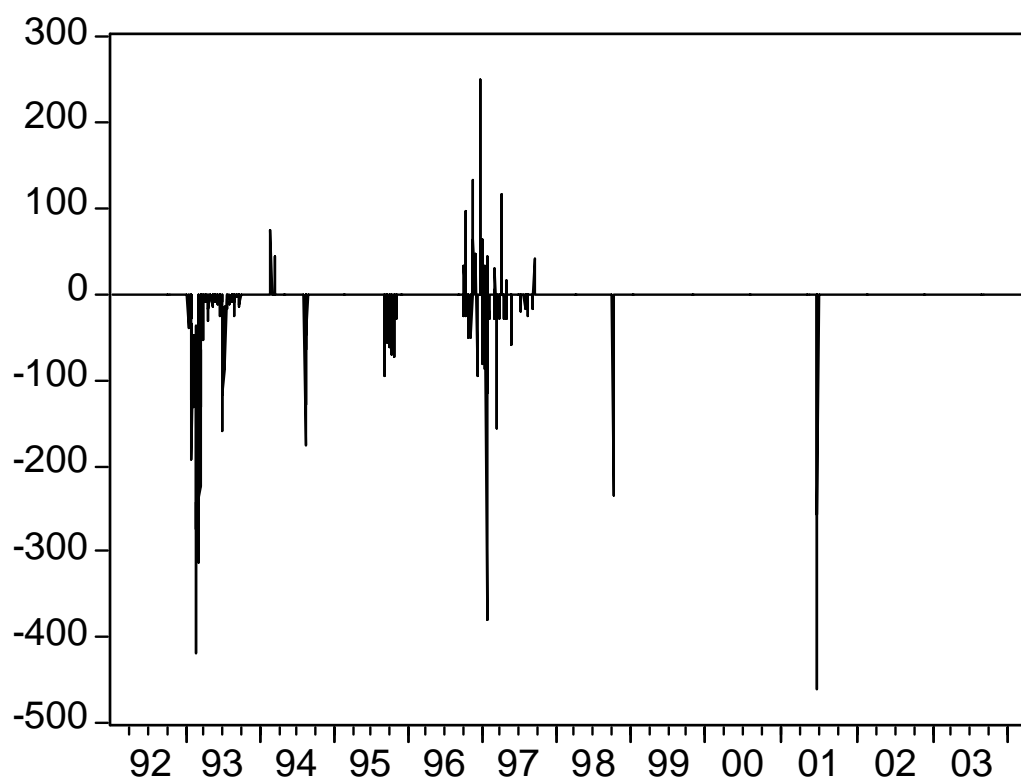


Figure 3: The Swedish Riksbank interventions (sales of SEK), USD millions

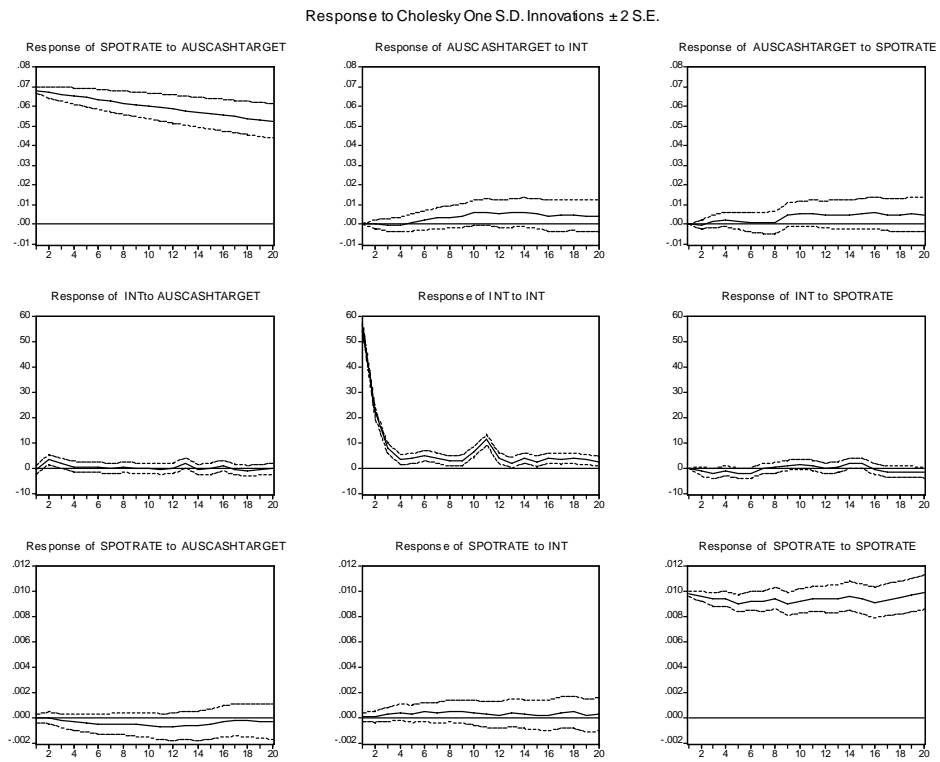


Figure 4: Australia: Impulse responses to interest rate and intervention shock, exchange rate added

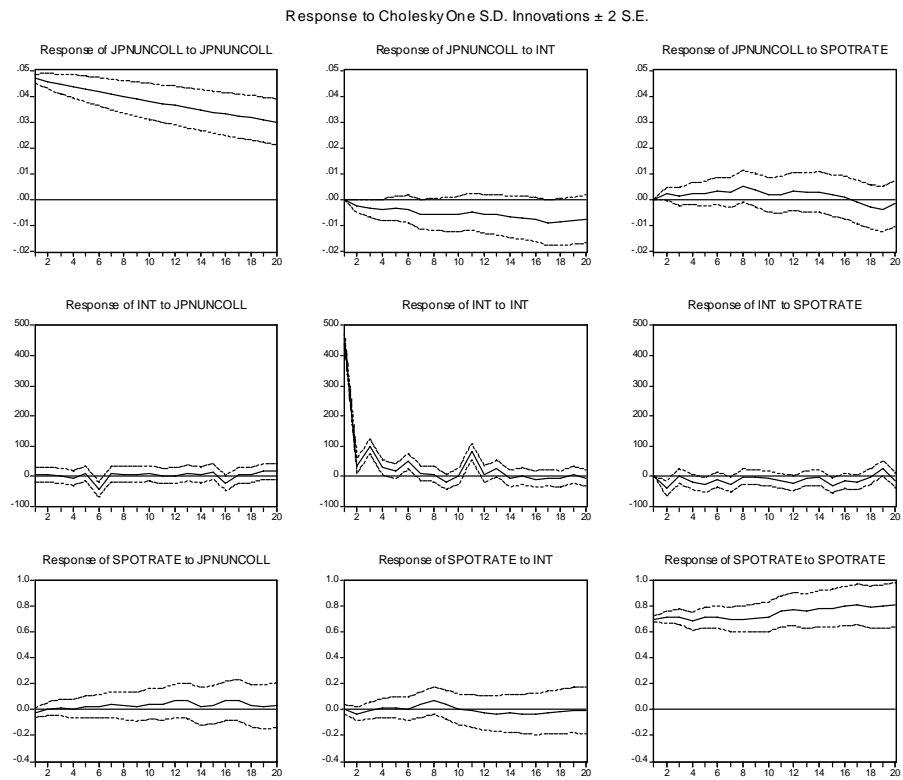


Figure 5: Japan: Impulse responses to interest rate and intervention shock, exchange rate added

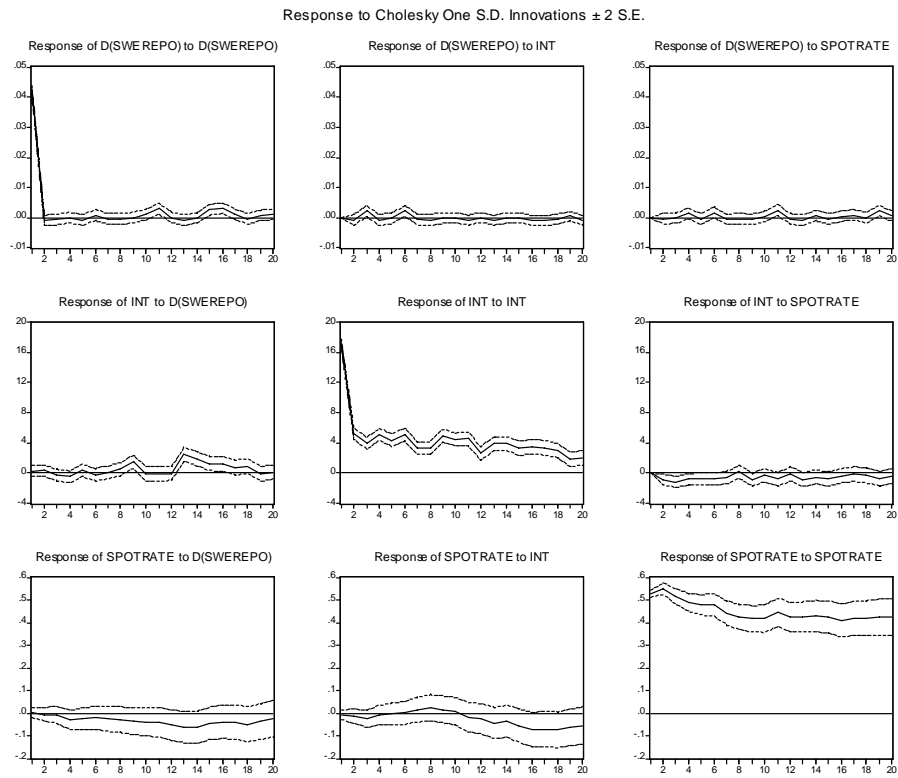


Figure 6: Sweden: Impulse responses to interest rate and intervention shock, exchange rate added

## A.2 Taylor rules

Table 4: Taylor rule estimates

Coefficient	Australia	Japan	Sweden	
$c$	8.03 (1.39)	4.24 (0.33)	5.21 (0.36)	5.48 (0.34)
$y$	0.31 (0.45)	0.07 (0.07)	-0.46 (0.13)	
$\pi - \bar{\pi}$	1.06 (0.71)	1.88 (0.19)	0.64 (0.18)	0.92 (0.16)
Adj R2	0.11	0.66	0.46	0.37
Obs	157	170	135	

\*NW standard errors below estimates in parentheses

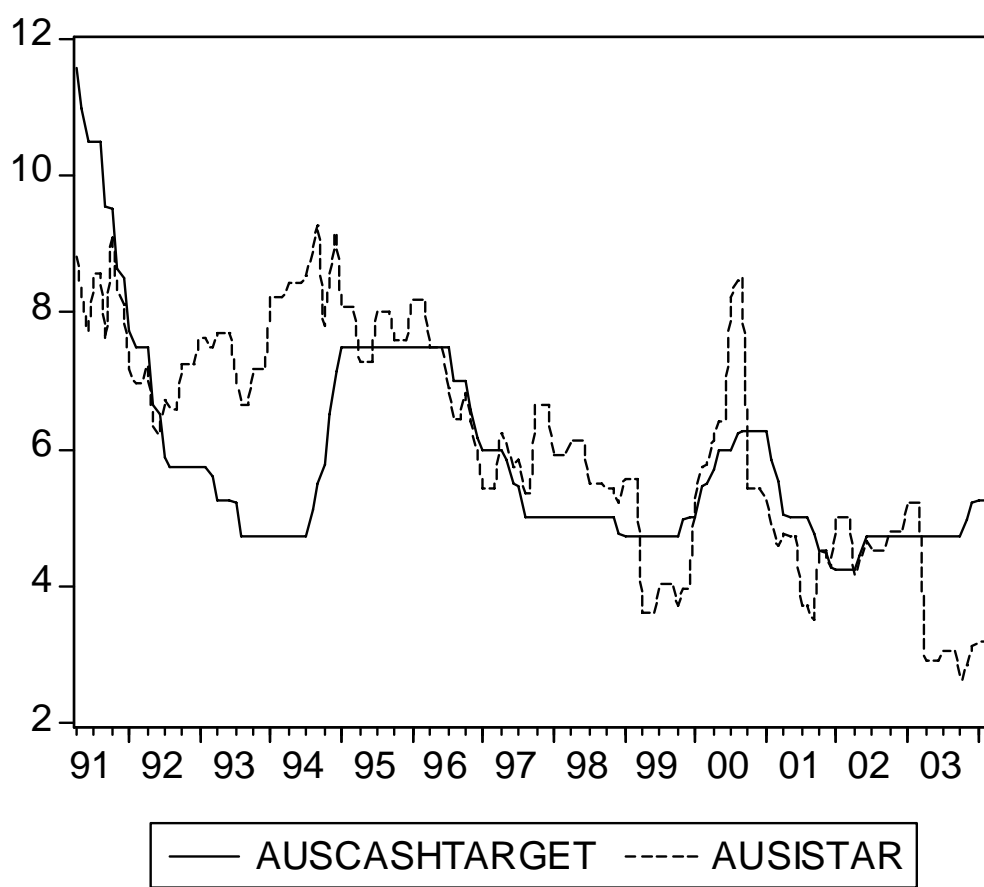


Figure 7: Australia: actual and Taylor rule interest rate

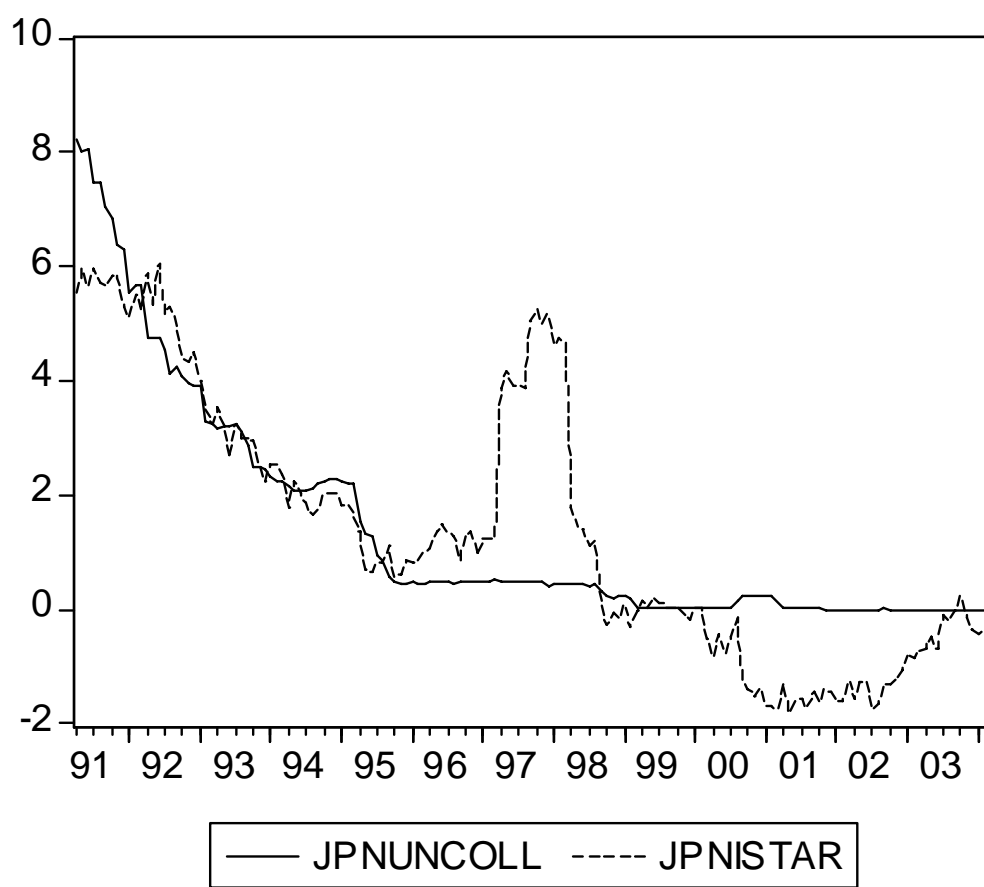


Figure 8: Japan: actual and Taylor rule interest rate

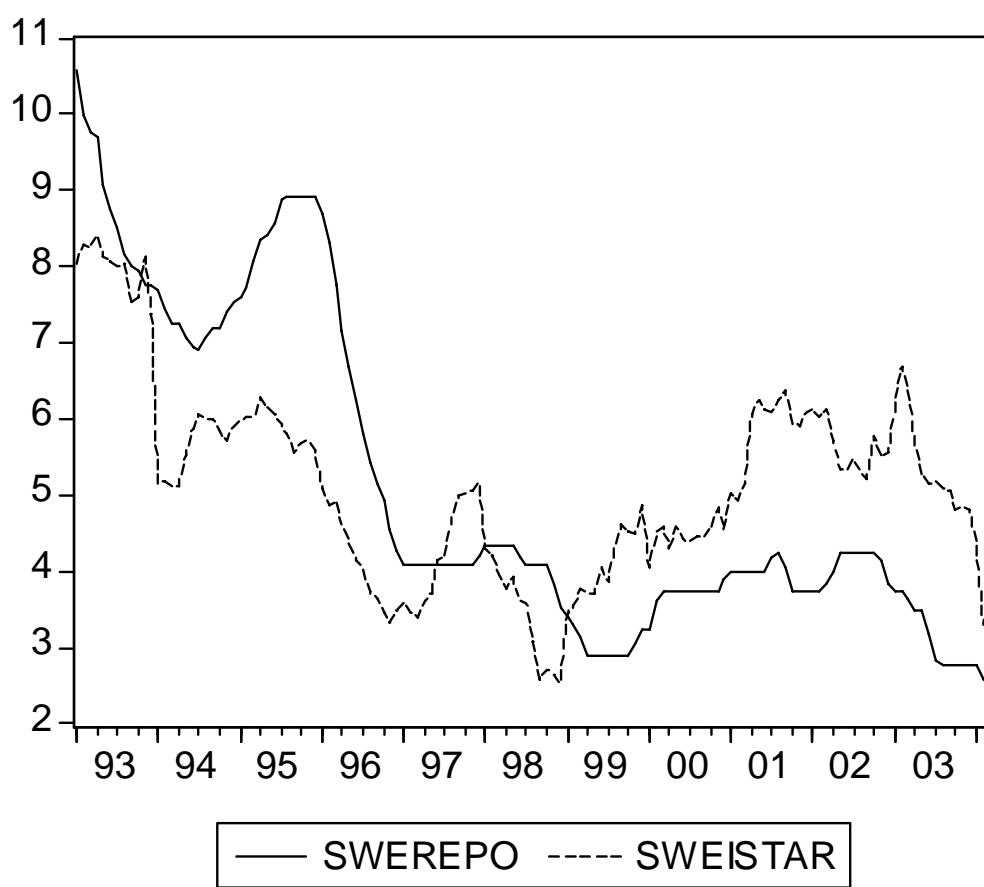


Figure 9: Sweden: actual and Taylor rule interest rate

### A.3 Regression results

Table 5: 2SLS estimation of equation (13) with and without  $i - i^*$

	Australia	Japan			Sweden	
$c$	68.9 (50.8)	2266.7** (944.5)	2095.3*** (745.7)	1504.9* (873.4)	-49.4* (29.2)	-50.1* (26.2)
$i - \bar{i}$	-67.9 (45.4)	-1168.0* (609.4)	-1120.0** (558.2)	-903.0 (583.7)	-115.4* (61.1)	-45.0* (26.7)
$x$	130.5** (51.2)	1120.8* (648.7)	1063.2** (541.4)	na na	92.8* (53.1)	na na
$D$	na na	na na	na na	1656.3 (1746.2)	na na	na na
$\Delta z_{t+1}$	0.42*** (0.09)	0.37** (0.15)	0.36** (0.15)	0.37*** (0.14)	0.48** (0.19)	0.33*** (0.12)
Adj R2	0.27	0.18	0.19	0.20	0.26	0.19
Obs	155	154	154	155	133	133

Note1: NW standard errors below estimates in parentheses

Note2: Instruments are lagged  $x$ , tcw-interest rate for SWE and FFR rate and real M1 for AUS and JPN

Table 6: Ordered probit estimation of equation (13) with and without  $i - i^*$

	Australia	Japan			Sweden	
$i - \bar{i}$	-0.00 (0.08)	-0.15 (0.09)	-0.11* (0.06)	-0.09 (0.09)	-0.09* (0.06)	-0.14** (0.06)
$x$	0.16** (0.08)	0.20 (0.15)	0.10 (0.08)	na na	na na	na na
$D$	na na	na na	na na	-0.14 (0.29)	na na	na na
$\Delta z_{t+1}$	1.11*** (0.14)	1.79*** (0.25)	1.71*** (0.22)	1.84*** (0.25)	1.75*** (0.21)	0.87*** (0.25)
Pseudo R2	0.26	0.34	0.35	0.33	0.34	0.15
Obs	155	155	155	155	155	134

Note1: Probit estimation for Japan in cases of  $D$  included

Note2: Threshold terms left unreported but available upon request

Table 7: 2SLS estimation of equation (15) with and without  $i - i^*$

	Australia	Japan			Sweden	
$c$	293.2* (153.9)	4707.6 (21544.3)	-9063.8 (20362.3)	6867.1 (21392.2)	-9913.7 (20339.9)	-3420.5 (2080.5)
$\pi$	93.3 (91.4)	-838.1 (516.5)	-1169.8*** (359.2)	-869.2 (573.1)	-1377.5*** (510.7)	-75.2* (45.2)
$q$	-736.3** (372.4)	-643.5 (4769.6)	2465.4 (4465.2)	-1129.8 (4717.3)	2659.8 (4455.8)	886.7 (539.9)
$x$	110.4*** (41.0)	na (469.3)	405.3 (412.7)	na	na	na
$D$	na (41.0)	na (469.3)	na (412.7)	na	na	na
	na (41.0)	2008.0 (2422.8)	na (2422.8)	2377.8 (2116.2)	na	na
$\Delta z_{t+1}$	0.41*** (0.07)	0.38*** (0.15)	0.38** (0.15)	0.38** (0.14)	0.39*** (0.15)	0.29*** (0.12)
Adj R2	0.30	0.20	0.19	0.21	0.20	0.21
Obs	155	154	154	154	154	134

Note1: NW standard errors below estimates in parentheses

Note2: Instruments are lagged  $x$ ,  $\pi$  and  $q$

Table 8: Ordered probit estimation of equation (15) with and without  $i - i^*$

	Australia	Japan			Sweden	
$\pi$	0.30* (0.17)	-0.24 (0.18)	-0.30** (0.12)	-0.24 (0.18)	-0.24*** (0.09)	-0.24*** (0.09)
$q$	-2.10*** (0.77)	-4.26*** (1.36)	-3.05*** (0.95)	-4.25*** (1.35)	0.24 (2.75)	1.65 (1.90)
$x$	0.21*** (0.08)	0.57 (0.47)	0.04 (0.08)	na (0.56)	-0.07 (0.10)	na (0.10)
$D$	na (0.15)	na (0.17)	na (0.17)	na (0.42)	na (0.10)	na (0.10)
$\Delta z_{t+1}$	1.03*** (0.15)	1.62*** (0.27)	1.59*** (0.22)	1.62*** (0.27)	0.81*** (0.26)	0.82*** (0.26)
Pseudo R2	0.29	0.39	0.38	0.39	0.16	0.16
Obs	155	155	155	155	134	134

Note1: Probit estimation for Japan in cases of  $D$  included

Note2: Threshold terms left unreported but available upon request

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