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The Effects of Sterilized Interventions through the Signalling Channel: Sweden 1986-1990

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Abstract

This paper examines the effects of sterilized interventions on both the level and the volatility of the Swedish krona exchange rate over a period when Sweden had an exchange rate band. The results show that sterilized interventions contained information about future monetary policy. This supports the idea that sterilized interventions may work through the signalling channel by conveying information — known to central banks, but not to market participants — about future fundamentals for the exchange rate. Sterilized interventions may thereby convey information that is crucial not only for the exchange rate level but also for the conditional variance of the exchange rate. This notion turns out to be fruitful within a GARCH framework. The results confirm that sterilized interventions reduced the volatility of the krona exchange rate. However, when the credibility of the exchange rate band deteriorated in the latter part of the sample period, so did the efficiency of sterilized interventions. This underscores that the signalling channel requires a credible link between interventions and future fundamentals. The main conclusion of the paper is therefore that sterilized interventions may work through the signalling channel, but that the channel is fragile.

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Contents

1 Introduction

It is widely accepted that *non-sterilized* interventions in the foreign exchange market affect exchange rates. Non-sterilized interventions alter the monetary base and thereby they involve the joint exercise of monetary policy and exchange rate policy. The effects of *sterilized* intervention are, however, more doubtful. Sterilized interventions are foreign exchange market operations by central banks whose effects on the monetary base are neutralized by offsetting domestic liquidity measures. Most empirical studies have been unable to produce any evidence of quantitatively significant effects from sterilized interventions on exchange rates (Edison (1993)). Nevertheless, central banks continue to use sterilized interventions in their exchange rate policy.

This paper examines the short run effects of sterilized intervention on both the level and the volatility of the Swedish krona exchange rate over the period June 1986 to December 1990. The main focus is on the effects that may work through the *signalling channel.* According to the signalling channel sterilized interventions may influence the exchange rate by conveying information – known to central banks, but not to market participants – about future fundamentals.

The outline of the paper is as follows. Section 2 discusses the theoretical channels for the impact of sterilized intervention on exchange rates and reviews some of the empirical approaches used in the previous literature. Section 3 describes Swedish exchange rate policy. Section 4 tests if sterilized interventions contain any information about future monetary policy. Section 5 tests for contemporaneous effects of sterilized intervention on the exchange rate level. Section 6 tests for the effects of intervention on future volatility. Section 7 concludes.

2 Channels of Influence for Sterilized Interventions

The *asset market view* of exchange rates emphasizes that exchange rates display many similarities with other asset prices determined in well-developed markets; they are strongly influenced not only by current events but also by market participants' expectations of future events. This gives expectations about future exchange rates a key role in determining current rates. A standard way of formalizing this notion is

$$s_t = f_t + \alpha(\mathrm{E}_t s_{t+1} - s_t), \tag{1}$$

where s_t is the logarithm of the exchange rate at time t, f_t a fundamental determinant of the currency, α a positive parameter and E_t the time t expectations operator. The saddle-path solution to (1) can be written as

$$s_t = \frac{1}{1+\alpha}\mathrm{E}_t \sum_{j=0}^{\infty}\left(\frac{\alpha}{1+\alpha}\right)^j f_{t+j}, \tag{2}$$

showing that s_t is the expected present value of future fundamentals. The saddle-path solution excludes the possibility of bubbles.

Sterilized interventions may affect the exchange rate through different channels. The most promising, in light of the results in the previous literature, is perhaps the *signalling (expectations) channel.*[1] The idea is that sterilized interventions convey information – known to central banks, but not to market participants – about future fundamentals for the exchange rate. The information a central bank can convey primarily concerns the future orientation of monetary policy, for instance, how a central bank interprets the character and persistence of a foreign exchange market shock and how the central bank will respond with its monetary instrument. If a sterilized intervention conveys that kind of information, market participants will revise their expectations of future fundamentals and thus their expectations about future exchange rates. This also brings about a change in the current exchange rate since the exchange rate is a forward looking price; cf. equation (2). However, for the signalling channel to work properly, market participants must be able to observe the interventions. The interventions must also on average send a true signal about future policy changes in order to establish a credible link between sterilized interventions and future fundamentals.

A direct way to assess the effects on the exchange rate, working through the signalling channel, is to look on the relationship between the exchange rate

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1 See, for example, Mussa (1981).

and interventions. However, econometric estimates of this relation will in most cases probably be plagued by *simultaneity bias*.[2] To illustrate the nature of this problem let us specify a simple signalling model on the basis of an ordinary flexible-price monetary model.

Let us we write the fundamental of the exchange rate as

$$f_t = m_t + v_t, \tag{3}$$

where m_t is the logarithm of base money and v_t can be thought of as the logarithm of velocity and a combination of other macro variables exogenous to the exchange rate, which for notational convenience will be referred to as just velocity.[3] Let us assume that velocity follows a random walk, that is,

$$v_t = v_{t-1} + e_t, \tag{4}$$

where e_t is an i.i.d. disturbance term. The central bank's policy rule for money supply is

$$m_{t+1} = m_t - \theta_{t+1} e_t + \mu_{t+1}, \tag{5}$$

where μ_{t+1} is an i.i.d. disturbance term. The second term on the right hand side of equation (5) represents interventions aimed at exchange rate smoothing, that is, interventions aimed at dampening the effects on s_t of e_t. The smoothing parameter, θ_{t+1} , is time varying; determined by the central bank at time t, but implemented at time t+1 .[4] Thus, there is some sluggishness in the implementation of monetary policy. This implies that the central bank must be able to communicate the value of time variable smoothing parameter, θ_{t+1}, when the disturbance occur at time t in order to smooth the exchange rate. Let us assume that this is accomplished by means of sterilized interventions.

The balance sheet of the central bank can be written as

$$R_t + D_t = M_t, \tag{6}$$

where R_t is foreign exchange reserves, D_t domestic credit (domestic currency bond holdings) and M_t base money held by the public. For simplicity, we then assume that the central bank behaves such that the

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2 See, for instance, the results reported by Dominguez and Frankel (1992b).

3 The monetary model consists of the monetary demand function, $m_t - p_t = \psi y_t - \alpha i_t$, the definition of the real exchange rate, $q_t = s_t + p_t^* - p_t$, and the equilibrium condition in asset markets $\rho_t = i_t - i_t^* - (\mathrm{E}_t s_{t+1} - s_t)$. Hence, $v_t \equiv q_t + \alpha\rho_t + \alpha i_t^* - \psi y_t$.

4 It is also assumed that $\mathrm{COV}(\theta_{t+1}, e_t) = 0$.

amount of sterilized interventions, $\Delta R_t = -\Delta D_t$, is proportional to the (expected) change in log money supply next period;

$$\Delta R_t = \gamma(\mathrm{E}_t m_{t+1} - m_t) = -\gamma\theta_{t+1} e_t, \tag{7}$$

where $\gamma > 0$. For instance, a sterilized purchase of foreign bonds, $\Delta R_t > 0$, will signal that the central bank will increase the (expected) money supply during the next period.

The assumptions made above, together with equation (2), enable us to express the exchange rate as

$$s_t = s_{t-1} + \left(\frac{1}{1+\alpha}\right)(\mathrm{E}_{t-1} m_t - m_{t-1}) + \left(\frac{\alpha}{1+\alpha}\right)(1/\gamma)\Delta R_t + \mu_t + e_t. \tag{8}$$

Hence, sterilized interventions will influence the current exchange rate through the signals they send about future money supplies. Sterilized interventions will thereby also be able to smooth the effects on s_t of e_t. However, the exchange rate smoothing will induce a negative autocorrelation in the first differences of the exchange rate since there will be an additional (expected) effect on the exchange rate when the monetary operations are conducted due to the discount factor; cf. the second term on the right hand side of equation (8).[5]

The exchange rate smoothing turns equations (7) and (8) into a simultaneous equation system. However, neither equation (7) nor (8) is identified since there are no data available on μ_{t+1} or e_t. Thus, if we would regress s_t on ΔR_t, the OLS estimate of the reduced form intervention coefficient would be biased downwards since $\mathrm{COV}(\Delta R_t, e_t) = -\gamma\theta\mathrm{VAR}(e_t)$. In worst case the OLS estimate of the intervention coefficient will be negative, only indicating that interventions are influenced by the exchange rate and hence not providing any information about the opposite relationship.

Another approach is to test whether sterilized interventions contain any information about future fundamentals for the exchange rate. Three studies on U.S. interventions by Kaminsky and Lewis (1992), Lewis (1993) and Dominguez (1992) support the idea that interventions signal future monetary policy. Moreover, empirical studies based on the signalling channel have had some success in establishing quantitatively significant effects of sterilized intervention on exchange rate expectations (Dominguez and Frankel (1993a)). However, if sterilized interventions only have an effect as a signal

5 It is worth noting that the negative correlation in the first differences of the exchange rate is in line with daily Swedish data for the period 1985 to 1990; cf. Lindberg and Söderlind (1994b).

of future monetary policy, sterilized intervention do not constitute an independent policy tool to manage the exchange rate. This is a corollary to the observation above that the central bank must send truthful signals to systematically affect the exchange rate.

Sterilized interventions may also effect the exchange rate through the *portfolio balance channel*.[6] The portfolio balance approach assumes that it makes a difference if a nation's assets are on the balance sheet of the government or the public. Thus, *Ricardian equivalence*, with the public fully anticipating and internalizing the fact that current government debt will be serviced by future taxation, does not prevail. The investors are also assumed to view domestic and foreign currency assets as *imperfect substitutes* and to diversify their holdings with the share of each asset determined by both expected returns and the covariance of returns.[7] Hence, the expected returns on domestic and foreign currency assets are not equal; the differ by the foreign exchange risk premium, which depends on the covariances of returns and on relative supplies.

A sterilized intervention implies a change in the relative supply of domestic and foreign bonds. The supply shift influences the risk premium on domestic currency assets and alters asset prices, including the exchange rate. For instance, a sterilized sale of foreign currency for domestic currency will raise the risk premium and appreciate the domestic currency. Sterilized intervention is thereby an independent policy tool that can be used as a complement to monetary policy.

However, most empirical studies based on the portfolio channel have been unable to produce any evidence of quantitatively significant effects from sterilized intervention on exchange rates (Edison (1993)). A direct way to assess the effects is to look on the relationship between the exchange rate level and the interventions (changes in asset supplies).[8] However, econometric estimates of this relation are often plagued by simultaneity bias, as noted above in the discussion of the signalling channel. A number of studies have instead approached the portfolio channel by estimating the effects of interventions on the risk premium in order to avoid the simultaneity problem. This is done by imposing rational expectations and regressing *ex post* excess returns on a cumulative intervention variable or some broader relative asset supply measure.[9] Another possibility is to use survey data on exchange rate expectations to get a measure of the risk premium. Regardless

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6 For an overview of portfolio balance models, see Branson and Henderson (1985).

7 More precisely, the covariance with the market portfolio (CAPM), consumption (consumption CAPM) or MRS (general AP-model).

8 See, for instance, Branson et al. (1977).

9 The ex post excess return is equal to $i_{t,k} - i^*_{t,k} - (s_{t+k} - s_t)$, where $i^*_{t,k}$ is the k-period-ahead foreign interest rate.

of how the tests are specified, studies using data from the 1970s find little evidence of portfolio balance effects. Some of the studies using data from the 1980s have been more successful in establishing statistically significant effects on excess returns, however. Dominguez (1990) finds that interventions (expressed as percent of wealth) had a significant effect on the one-month ahead dolllar/yen risk premium during the mid 1980s. Dominguez and Frankel (1993b) find significant effects on the one-month and the three-month ahead dollar/D-mark risk premia for the same period. Both of these two studies use survey data on exchange rate expectations.[10]

However, in the Swedish case it seems impossible to address the question whether interventions work through the portfolio balance channel or not for the period studied in this paper. The devaluation rumours that circulated frequently during the sample period had a simultaneous influence on exchange rates, interest rate differentials and intervention decisions. In these circumstances, there is no point in testing for the effects of interventions on the risk premium by imposing rational expectations and regressing ex post excess returns on relative asset supplies since the regressor would be contemporaneously correlated with the error term of the equation. The portfolio channel has in addition already been assessed on Swedish data by Vredin (1988) who estimates the private demand for foreign bonds of a portfolio balance model for the period March 1981 to November 1987. A notable result of this study is that excess returns and interest rate differentials did not have a significant influence on the demand of foreign bonds, which is interpreted in terms of an identification problem of the expected depreciation of the krona exchange rate. Inverting the asset demand equation and regressing ex post excess returns on relative asset supplies would not make much difference.

It has also been proposed that sterilized interventions work through a *noise trading channel* (Hung (1992)). The noise trading channel relies on two assumptions: First, on a minute-by-minute basis the exchange rate is determined by the marginal demand and supply for foreign exchange flowing through the currency market. That is, only flow equilibrium, not stock equilibrium is restored instantaneously in the currency market. In that case, a central bank can influence the exchange rate like any other big market participant, especially in situations when the market is relatively thin. Second, a sufficient number of market participants must be non-fundamentalists or "noise traders", most of them relying on feed-back trading rules like chartist analysis.[11] It is worth noting that both of these assumptions are in conflict with the exchange rate model outlined above.

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[10] Black (1993) and Loopesko (1984) find effects on ex post excess returns.

[11] For an essay on chartist analysis in financial markets, see Taylor (1992).

In a survey study of the London foreign exchange market by Taylor and Allen (1992), 90 percent of the respondents reported using some chartist input when forming their exchange rate expectations at time horizons from intra-day to one week. However, for noise traders to dominate the market, uncovered arbitrage by fundamentalists must be limited, either because of borrowing constraints or risk considerations if the number of rational investors trying to identify and exploit noise-driven exchange rate movements is small. In that case, it is clear that noise traders may push the exchange rate away from the fundamental equilibrium value if their actions are correlated. Thereby, the activity of noise traders may constitute a reason for intervention. But the presence of noise traders may also help to amplify and prolong the initial effect of a sterilized intervention. The results by Hung (1992), who studies the effects of U.S. intervention, strengthen the case for the noise trading channel. It is doubtful, however, if sterilized interventions working through the noise trading channel will have any permanent effects on exchange rates.

3 Swedish Exchange Rate Policy 1986 to 1990

This paper studies the effects of sterilized intervention using daily Swedish data from June 1986 to December 1990, a period when a fixed exchange rate was used as an intermediate target for Swedish monetary policy. However, the krona exchange rate was not completely fixed. Sweden had a unilateral exchange rate band to a trade weighted currency basket. The bandwidth was 1.5 percent around the benchmark value, the central parity.[12] *Figure 1* shows the exchange rate as the percentage deviation from central parity for the period June 1986 to December 1990. The exchange rate was most of the time kept in the lower (stronger) part of the band and ranged from -1.5 to 0.8 with the mean -0.6 (percentage points).

Sveriges Riksbank's monetary instrument is the marginal overnight rate on discount window lending. The key element of the institutional framework is a predetermined supply function for borrowed reserves (discount window lending); the so-called interest rate scale.[13] The marginal lending rate is increased, in a predetermined step-by-step fashion, when discount window lending rises.[14] In the short run, the demand for total reserves is almost fixed due to the practice of lagged reserve accounting for required reserves.[15] Thus, by adjusting the supply of non-borrowed reserves, using non-sterilized interventions in the foreign exchange market or other types of monetary operations, the Riksbank is able to force the banks to borrow at the preferred marginal rate. The most important monetary operations in the liquidity control process are repurchase and reversed repurchase agreements that the Riksbank makes with market makers in Swedish government bills.[16]

The central bank has almost complete control of the overnight rate quoted on the market, as no bank is willing to pay more for overnight funds than the marginal rate offered by the central bank. Via the control of the overnight rate the central bank is also able to influence interest rates on longer

12 In May 1991 Sveriges Riksbank abandoned the currency basket and pegged the Swedish krona unilaterally to the theoretical ecu. The krona came under pressure during the turmoil on the European currency markets in September 1992, and the fixed exchange rate regime was eventually abandoned on November 19, 1992.

13 In May 1994 the interest rate scale was replaced by an interest rate corridor with a ceiling, the lending rate, and a floor, the deposit rate. At the same time the marginal lending rate was replaced by the repo rate as the Riksbank's primary policy instrument.

14 The interest rate scale is also defined for overnight lending to the Riksbank, that is, when the commercial banks have excess reserves.

15 The accounting period is one month and required reserves are adjusted with a two month lag.

16 A repurchase agreement is a combination of a spot purchase of government bills and forward contract to resell the assets at some future date. The settlement for the spot leg takes place one day after the Riksbank announces the repurchase offer.

maturities and to control the exchange rate.[17] Thus, the marginal lending rate is an important determinant of the exchange rate. *Figure 2* shows the marginal lending rate for the period June 1986 to December 1990. The lending rate was adjusted by the Riksbank in one third of the business days. Most of the changes were soon reverted, however.

In the very short run (a few days), the Riksbank relied on foreign exchange market interventions for the control of the exchange rate. The Riksbank's transactions in the foreign exchange market can be classified into three categories; pure (outright) forward interventions, spot interventions and currency swaps.[18] A pure forward intervention is an agreement by the Riksbank to buy or sell foreign currency for Swedish kronor in the future, that is, the time to settlement is longer than two days. Thus, forward interventions alter the currency composition of the public's portfolios without affecting the liquidity. Forward interventions are therefore by definition sterilized. However, no pure forward interventions were recorded during the sample period.

The Riksbank instead relied on spot interventions. Spot interventions are outright purchases and sales for cash settlements two business days after the date of the actual spot deal. Most of the spot interventions were made intra-marginally, that is, inside the boundaries of the band (Lindberg and Söderlind (1994a)). The Riksbank acted as a seller in 19 % of the business days in the sample period and as a buyer in 30 % of the business days. The average daily intervention size was 230 million kronor for a purchase of foreign currency and 107 million for a sale. Thus, the interventions are fairly small compared to the daily turnover on the Swedish spot exchange market, which according to BIS (1990) was about 60 billion kronor (9.5 billion US-dollar) per day in April 1989.

In order to characterize the intervention policy of the Riksbank, I have estimated separate probit models for the decisions to buy and sell foreign currency in the spot market.[19] The estimation results are displayed in *table 1*. The selected explanatory variables belong to three categories. First, if the Riksbank has preferences for exchange rate smoothing, a simple way to capture this is to include lagged exchange rate changes, Δs_{t-i}. Second, in a target zone it is reasonable to assume that the central bank's willingness to

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17 For a discussion of institutions, targets and instruments in Swedish monetary policy during the period studied, see Hörngren and Westman-Mårtenson (1991). For an analysis of the operative characteristics of the system, see Englund et al. (1989).

18 The Riksbank is also involved in transactions with the government. However, these transactions are not included in the narrow, traditional definition of intervention; see Adams and Henderson (1983).

19 See, for instance, Maddala (1983) for an exposition of the probit model and discret regression models in general.

intervene depends on the exchange rate's position within the band, s_t. Third, the Riksbank had a tendency to intervene when the lending rate differed from the market interest rate level. The difference between the marginal lending rate and the 1-month deposit rate, $(i_{t,1} - i_{t,30})$, is therefore included in both equations. The reported likelihood ratio test statistics support the overall fit of both equations. In the selling equation the coefficient of the exchange rate is positive and strongly significant. In the buying equation the coefficient has a corresponding negative sign. This confirms that the decision to intervene was influenced by the exchange rate's position within the band. The idea of exchange rate smoothing is also supported by the significant impact of lagged changes in the exchange rate have on the decision to intervene in both the selling and buying equations. The coefficients of the variable $(i_{t,1} - i_{t,30})$ have the expected signs in both equations. For instance, in the buying equation the coefficient is positive, that is, it was more likely that the Riksbank bought foreign currency when the lending rate was above the 1-month rate.

The Riksbank also made a number of currency swaps (with spot legs) during the sample period. A currency swap with a spot leg is an agreement to sell (buy) foreign currency with settlement after two days and to buy (sell) it from the same counterpart at a future date. Thus, a currency swap with a spot leg is a combination of a spot deal and a forward deal. The spot legs of swaps can be used to sterilize liquidity effects of previous spot interventions. The Riksbank's use of currency swaps, with spot legs, was partly motivated by a desire to modify the weekly figure on foreign exchange reserves reported to the market. However, currency swaps do not alter the central bank's (true) net position in foreign currency (although they affect the balance sheet since forward positions are off balance). Hence, in the absence of forward interventions, the amount of spot interventions recorded over a period corresponds to the change in the Riksbank's net position in foreign currency to the private sector. Foreign exchange market interventions can therefore operationally be defined as spot interventions in this study.

The main focus later on in the paper will be on the effects of sterilized interventions at time horizons of intraday to a couple of days. It is therefore of importance to determine the degree of short-run sterilization. First, it must be recognized that the only difference between spot deals and forward deals is that spot deals have only two days to settlement. In that sense, one can regard spot deals as forward deals with two days to settlement and view all spot interventions as sterilized within a horizon of two days. Then, to what extent was spot interventions sterilized on cash settlement, or put differently, to what extent did the cash flows of spot interventions influence the marginal lending rate?[20] The correlation coefficient between spot interventions (net purchases) and the change in the marginal rate on cash settlement for the whole sample period was -0.08 with a 0.02 standard error, that is, significantly different from zero with a sign that indicates that spot interventions to some extent were non-sterilized.[21] Moreover, 19 % of the spot interventions were followed by a corresponding change of the marginal rate two days later on cash settlement, that is, spot purchases of foreign currency followed by decreases and spot sales followed by increases in the lending rate. To conclude, as long as the main focus is on the short run effects of sterilized intervention we may label all interventions as sterilized, but it should be acknowledged that this is an approximation.

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20 Spot interventions with cash settlement on day t+2 can be sterilized with a currency swap with a spot leg on day t or with an repurchase agreement in the domestic market on day t+1.

21 Newey-West standard error (10 lags).

4 Is There a Case for Signalling?

The main focus in the rest of the paper will be on the possibility that sterilized interventions may work through the signalling channel. According to the signalling channel sterilized interventions may influence the exchange rate by conveying information about future monetary policy or fundamentals in general to market participants. Here we will focus on the possibility that interventions contain information about future monetary policy. This is done by testing if the overnight rate, the monetary instrument of the Riksbank, was Granger-caused by spot interventions.

The first step in this procedure is to estimate the equation

$$i_t = \omega + \sum_{j=1}^{10} \theta_j i_{t-j} + \sum_{j=1}^{10} \beta_j SPOT_{t-j}, \tag{9}$$

by OLS for the period June 1986 to December 1990, where i_{t-j} is the overnight rate day t and $SPOT_{t-j}$ net spot purchases during day *t*-j. The next step is to make a F-test for the joint significance of the intervention coefficients.[22]

The idea is that spot interventions would improve the forecast of the overnight rate in the sense that spot purchases would signal a decline of the overnight rate and correspondingly that spot sales would signal a future increase of the overnight rate. This notion gains some support by the estimation results. The sum of the estimated β-coefficients is negative. Moreover, the restriction $\beta_1 = ... = \beta_{10} = 0$ yields the statistic F(10,1140-21) = 5.09, that is, the hypothesis of no information in spot interventions is rejected at the 1-percent level.[23]

It is also of interest to focus solely on the information value of interventions dated day *t*-4 and earlier. The cash flows from these interventions take place day *t*-2 at the latest. Thus, to the extent that these interventions improve the forecast of the overnight rate it can not be due to the liquidity effects from the interventions as such.[24] However, the picture does not change much when $\hat{\beta}_1$, $\hat{\beta}_2$ and $\hat{\beta}_3$ are ignored. The sum of $\hat{\beta}_4$ to $\hat{\beta}_{10}$ is also negative.

22 The Newey-West covariance matrix (10 lags) was used in the F-tests to allow for heteroskedastic and serially correlated error terms.

23 There were no signs of Granger-causality in the opposite direction, that is, from overnight rates to spot interventions.

24 The interventions on day *t*-3 with settlement on day *t*-1 are also excluded, since the overnight rate used in the test is quoted at 11.00 am.

Moreover, the restriction $\beta_4 = \ldots = \beta_{10} = 0$ yields F(7,1140-21) = 2.11. Thus, the restriction is rejected at the 5-percent level.

To conclude, spot interventions improved the forecast of the overnight rate during the period June 1986 to December 1990. It is therefore possible to argue that sterilized interventions contained information about future monetary policy. However, it is an open question whether market participants really perceived this information and to what extent this eventually influenced the exchange rate.

5 Effects on the Exchange Rate Level

The aim of this section is to test for the effects of sterilized interventions on the exchange rate level working through the signalling channel. The approach is to specify an exchange rate equation, corresponding to equation (8), in accordance with the target zone literature, include sterilized interventions among the regressors, and then estimate the equation with OLS and test for the significance of the intervention variable. This type of regression is often plagued by simultaneity bias (as noted in section 2). The regression is nevertheless of interest since the sign of the bias is known (negative). Thus, the estimate of the reduced form intervention coefficient may still be significant with the correct positive sign if the bias is fairly weak.

The target zone literature contains several suggestions for the specification of the exchange rate equation. In the Bertola-Svensson (1993) model the present exchange rate is a sufficient determinant of the expected future exchange rate. Svensson (1991) shows that this relationship is somewhat non-linear with a weak S-shape. However, Lindberg and Söderlind (1994a) do not find any strong evidence of non-linearity for the Swedish exchange rate band and suggest that this can be explained by the presence of intra-marginal non-sterilized interventions. Thus, theory and earlier empirical studies suggest that it would be sufficient to use a linear approximation. However, there is some support for including other variables than the present exchange rate in the conditional mean equation. For instance, the Svensson (1992) model of optimal intervention policy in a managed-float regime suggests that the expected exchange rate is function of current and lagged values of the exchange rate, the domestic interest rates and the foreign interest rates. Lindberg et al. (1993) find that the krona exchange rate displayed strong mean reversion inside the band and that lags of the exchange rate and lags of interest rates have some power in predicting the krona exchange rate on horizons from one to twelve months.

The equation for the exchange rate, s_{t+1}, was specified as follows: The autocorrelation and partial autocorrelation structure of the exchange rate indicated that s_t and s_{t-1} would be appropriate to include in the equation. In addition, changes in the marginal lending rate announced after closing day t were also included to capture the effects of non-sterilized interventions or monetary announcements.

The equation was estimated for the whole sample period and for two sub periods. The estimation results are presented in *table 2*. The point estimates of the exchange rate terms indicate that the krona displayed some mean reversion also on a daily horizon. The coefficient for the marginal lending rate is significant at the 5-percent level for the early sub-period, but not for the later. However, changes in the marginal lending rate had only a minor influence on the exchange rate; a one percent increase of the lending rate was followed by a 0.002 % appreciation of the krona exchange rate within the day. This might be explained by the fact that changes in the lending rate often were reverted within a couple of days.

What about sterilized interventions? The intervention variable $SPOT_{t+1}$ is net spot purchases of foreign currency during day t+1 measured in billion kronor. The coefficient of $SPOT_{t+1}$ should have a significant positive sign in order to confirm any effects of sterilized interventions on the exchange rate, for instance, that spot purchases of foreign currency would depreciate the krona exchange rate. However, the intervention coefficients are significant and incorrectly signed in the two sub-periods and over the full sample period. The same result was generated when the intervention variable was replaced with an intervention dummy (1,0,-1) and when the regressions were made on weekly data. Thus, the OLS estimates of the intervention coefficient only tell us that interventions were influenced by the exchange rate, but nothing about the opposite relationship.

This is an illustration of the identification problem (simultaneaty bias) that was discussed in section 2. The Riksbank has probably reacted immediately (intraday) on foreign exchange market disturbances. The decision to intervene is therefore contemporaneously correlated with the error term of the exchange rate equation in a way that biases the intervention coefficient downwards. Moreover, the nature of the intervention variable, basically that unexpected interventions at time t+1 by definition are uncorrelated with the information set at time t, makes it impossible to circumvent this problem by using instrument variables or related techniques such as 2SLS.

In summary, the estimation results presented in this section do not provide any evidence in favour of significant effects of sterilized interventions on the krona exchange rate. When it comes to the *level* of the exchange rate it seems impossible to disentangle the effect of interventions from that of other factors which may simultaneously influence interventions and the exchange rate. However, in the next section I will try to shed some light on the effects of interventions on the *volatility* of the exchange rate using a somewhat different approach.

6 Sterilized Intervention: A Determinant of Future Volatility?

This section draws on the possibility that sterilized interventions might be of importance for the volatility of the exchange rate. This is of interest since the use of sterilized interventions in general to some extent is motivated by an aim to reduce exchange rate volatility. For instance, the guiding principles for intervention policy by the IMF Executive Board explicitly state that the member countries should use sterilized interventions to decrease foreign exchange rate volatility.[25] It is also clear from policy statements that the intervention policy of the Riksbank to a large extent was focused on exchange rate smoothing during the sample period.[26] Thus, sterilized interventions should have decreased the volatility, the conditional variance, of the krona exchange rate if that policy was successful.

The idea that sterilized interventions influence the conditional variance of the exchange rate has already been explored empirically. Dominguez (1993) tests the proposition that interventions influence exchange rate volatility using a GARCH model of the dollar/D-mark rate. One of the results of this study is that publicly known Fed and Bundesbank interventions decreased daily volatility during the post-Louvre Accord period, that is, 1987 to 1991.[27] The route I follow in this section is closely related to the Dominguez study.

6.1 The Intuition

However, before assessing the effects empirically let me outline a mechanism for the influence of sterilized interventions on exchange rate volatility. The starting point for the reasoning is that the central bank's preferences for exchange rate stability are time-varying. One possibility is then that sterilized interventions work solely through the signalling channel by conveying information about future monetary policy aimed at bringing down the volatility of the exchange rate. However, this assumption implies that there must be some sluggishness in the decision making process of monetary policy or a time delay of the (formal) announcements of policy changes. Alternatively, we can assume that sterilized interventions ultimately work through the portfolio channel and that the central bank use them as a means to stabilize the exchange rate. If we then assume that interventions, and hence preferences for exchange rate stability, are serially correlated, it implies that

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25 IMF Executive Board Decision no. 5392-(77/63), adopted April 1977.

26 Hörngren and Lindberg (1993) discuss the Riksbank's smoothing ambitions.

27 Baillie and Humpage (1992) and Mundaca (1990) also use GARCH models to estimate the effects of interventions on the exchange rate.

they carry signals about future interventions. In either of these cases disturbances that hit fundamentals are bound to have a lower impact on the exchange rate since there would be expectations of counteracting actions by the central bank. Sterilized interventions would therefore contribute to a lower conditional variance of the exchange rate.

6.2 GARCH Models of Exchange Rate Volatility

The first step in testing for the effects of sterilized interventions on the volatility of exchange is to choose a model for volatility that is in line with stylized facts. It is well known that volatility of exchange rates changes through time. An important characteristic of this changing volatility, or heteroskedasticity, is that periods of turbulence seem to occur together and so do periods of calm. The krona exchange rate is no exception; cf. *figure 3* which shows the standard deviation of daily changes of the krona exchange rate for a rolling 10-day window. The ARCH (autoregressive conditional heteroskedasticity) model, by Engle (1982), and its successor the more general GARCH model, proposed by Bollerslev (1986), are well suited for variables exhibiting such behavior.[28]

A GARCH(p,q) model for the exchange rate with additional explanatory variables in the conditional variance equation can be written as

$$s_{t+1} = \beta X_t + \varepsilon_{t+1}, \tag{10}$$

$$\varepsilon_{t+1} \,|\, \Omega_t \sim N(0, h_{t+1}), \tag{11}$$

$$h_{t+1} = \omega + \sum_{i=0}^{p-1} \alpha_i \varepsilon_{t-i}^2 + \sum_{i=0}^{q-1} \delta_i h_{t-i} + \tau X_t. \tag{12}$$

In the conditional mean equation (10) s_{t+1} is the log of the exchange rate at time t+1, expressed as the log deviation from central parity, X_t is a vector of predetermined or weakly exogenous variables and $\beta X_t = \mathrm{E}_t\, s_{t+1}$. Equation (11) says that the error term is normally distributed conditional on information available at time t. The conditional variance equation (12) models the conditional variance, h_{t+1}, as a ARMA (p,q) process and as a function of predetermined or weakly exogenous variables at time t. If the lagged variances are excluded from the right-hand side of equation (12) the model transforms into an ordinary ARCH(p) model.

28 See Bollerslev et al. (1993) for an overview of GARCH models.

GARCH models are generally estimated by means of maximum likelihood. For the model defined in (10) to (12) the log likelihood function for the t^{th} observation can be written as

$$l_t = -\frac{1}{2}\left[\ln(2\pi) + \ln h_t + \varepsilon_t^2 h_t^{-1}\right].^{29} \qquad (13)$$

In many applications it is difficult to justify the assumption of normality. However, the ML-estimator based on the normal density may be given a quasi-maximum likelihood interpretation. The QML-estimator obtained by maximizing the likelihood (13) as if it was correct produces a consistent estimator despite the distributional misspecification. The correct asymptotic covariance matrix for the QML-estimator of a parameter vector θ is given by

$$\text{COV}(\hat{\theta}) = A^{-1}BA^{-1}, \qquad (14)$$

where $A = -\text{E}\left[\frac{\partial^2 \ln L}{\partial\theta\partial\theta'}\right]$, and $B = \text{E}\left[\frac{\partial \ln L}{\partial\theta}\left(\frac{\partial \ln L}{\partial\theta}\right)'\right]$.[30]

6.3 The Estimation Results

The conditional mean equation of the exchange rate (without intervention variables) was first estimated under the assumption of homoskedasticity. The estimation results are shown in the first column of *table 3*. The dependent variable is s_{t+1} (log percent deviation from central parity) with s_t, s_{t-1} and changes in the marginal lending rate as explanatory variables. Homoskedasticity is rejected by White's test (not reported). The Ljung-Box statistic with fifteen lags, Q(15), does not indicate any autoregression in the error terms, but the hypothesis of no autocorrelation in the squared errors is easily rejected.[31] This suggests that GARCH-effects might contribute to the heteroskedasticity.

The next step was to estimate a GARCH model for the exchange rate without any variables capturing sterilized intervention. The search for a suitable model was limited to the GARCH(p,q) family. After study of the autocorrelation structure as in Bollerslev (1988) an ARCH(1) model was

29 See Bollerslev et al. (1993) for a note on likelihood functions for GARCH models.

30 See White (1982) or Gourieroux et al. (1984).

31 There are fifteen degrees of freedom of Q(15) for ε_t and $\varepsilon_t h_t^{-0.5}$. The degrees of freedom of Q(15) for ε_t^2 and $\varepsilon_t^2 h_t^{-1}$ is equal to fifteen (the number of terms of autoregression) minus the number of parameters of the conditional variance.

chosen. However, there might be other explanations for the heteroskedasticity. For instance, Svensson (1991) shows that the basic (credible) target zone model implies that the conditional variance of the exchange rate should be lower towards the edges of the band. The absolute value of the exchange rate's deviation from the sample mean, $|s_t - \bar{s}|$, was therefore also included in the conditional variance equation.

The estimation results are presented in the second column of table 3.[32] The point estimates of the mean equation indicate that the exchange rate displays small mean reversion (as in section 5). The coefficient for changes in the marginal lending rate has a negative sign as expected (but is not significant). That is, an increase in the marginal rate appreciated the krona. I experimented somewhat with the specification of the conditional mean equation. For instance, more lags of the exchange rate were included as well as a cubic exchange rate term to check for non-linearity, but they could all easily be dropped on the basis of Wald tests. In the conditional variance equation the exchange rate term has a negative sign, but is not significant at any reasonable level. The ARCH coefficient, α_0, is strongly significant and is quite successful in capturing the autoregression since the Q(15) for squared standardized residuals does not indicate any remaining ARCH effects.

Those who have estimated GARCH models on flexible exchange rates have typically ended up with a GARCH(1,1) model with $(\alpha_0 + \delta_0)$ close to one, indicating great persistence in volatility. However, the volatility of the krona exchange rate exchange rate is much less persistent since an ARCH(1) with $\alpha_0 \approx 0.2$ is sufficient to take care of the autoregression. The question is if sterilized interventions, which occurred almost every other day during the sample period, contributed to this pattern.

The impact of sterilized interventions on the conditional variance of the exchange rate is modelled in two ways:

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32 The skewness and kurtosis measures of the standardized residuals (not reported) imply that the assumption of conditional normality is easily rejected. This induced me to look for a more appropriate distribution in order to improve efficiency. The model was reestimated with a Gram-Charlier type of distribution allowing both for skewness and leptokurtosis (Lee and Tse (1991)). However, the estimated skewness and kurtosis did not correspond well to their sample counterparts. The equations in table 3 and 4 were also estimated with the assumption of conditional t-distribution as suggested by Baillie and Bollerslev (1989). The results were similar to those obtained with the normality assumption.

$$h_{t+1} = \omega + \alpha_0 \varepsilon_t^2 + \tau_1 \left| s_t - \bar{s} \right| + \tau_2 I_t, \tag{15}$$

$$h_{t+1} = (\omega + \alpha_0 \varepsilon_t^2 + \tau_1 \left| s_t - \bar{s} \right|) \exp(\tau_2 |SPOT_t|). \tag{16}$$

In equation (15) purchases and sales of foreign currency are captured by two dummy variables, $I_t = \left[I_t^B, I_t^S\right]$, where for instance I_t^B takes the value of one in case of a purchase of foreign currency for Swedish kronor. Moreover, h_{t+1} is a linear function of $I_t = \left[I_t^B, I_t^S\right]$. In equation (16) $|SPOT_t|$ is the absolute value of the Riksbank's spot interventions made on day t, measured in billions of kronor. It is also worth noting that $|SPOT_t|$ enters the equation exponentially, which implies that the logarithm of h_{t+1} is a linear function of $|SPOT_t|$. This has the advantage that it excludes the possibility of negative variance estimates arising from $|SPOT_t|$. For the intervention models $I_t = \left[I_t^B, I_t^S\right]$ and $SPOT_t$ are also included in the mean equation for consistency.

The intervention models were estimated for the period June 1986 to December 1990 and for the sub-period June 1986 to September 1989, respectively. The latter period has two important characteristics: First, the fixed exchange rate was still fairly credible. This picture changed during the fall of 1989 when devaluation rumours started to circulate as a result of the general decline in the Swedish economy.[33] Second, the "hard core" of the exchange controls was in force until June 1989, which to some (unknown) extent reduced capital mobility. The Swedish exchange rate controls essentially prohibited foreign investors from taking positions in krona denominated bonds. In such a case, the supply of domestic currency assets is evaluated in relation to the net financial wealth of the private domestic sector instead of the total net financial wealth of the foreign and domestic private sector. Thus, relative asset supplies will be less sensitive to exchange rate movements, which would tend to strengthen the portfolio effects of interventions.

The estimation results for the period June 1986 to December 1990 are presented in columns (3) and (4) of *table 3*. The (mean) log likelihoods, l_t, for the models with the intervention variables do not indicate that they would fit data any better than the benchmark model. The parameter estimates for the intervention variables are far from significant. Moreover, a Wald test, using the robust covariance matrix, does not support the joint significance of the intervention parameters in the conditional variance of column (3) at any reasonable level. Note, however, that the parameter estimates and their

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33 See Lindberg et al. (1993) for a study of the devaluation expectations during the period 1985 to 1992.

standard errors imply that the converse null hypothesis of intervention having a negative impact on the conditional variance can not be rejected either. The results are in that sense inconclusive.

The estimation results for the sub-period June 1986 to September 1989 are presented in *table 4*. Let us focus on the impact of interventions and of the exchange rate term on the conditional variance of the exchange rate. The picture is now somewhat different. The exchange rate term, $|s_t - \bar{s}|$, is significant at the 5-percent level which confirms the prediction in the target zone literature of smooth pasting towards the edges of a credible exchange rate band. The coefficient for purchases of foreign currency at the bottom of column (2) is negative and significant at the 5-percent level, which confirms the ability of sterilized interventions to calm the exchange rate market. The sale dummy has also a negative impact on the volatility of the exchange rate, but is significant only at the 11 percent level. A Wald test, using the robust covariance matrix, reveals that the joint significance of purchases and sales is at the 9-percent level. The estimation results of the exponential specification in column (3) strengthen the case even further. The coefficient for spot intervention, $|SPOT_t|$, is about -0.38 and statistically significant at the 5-percent level. This implies that a spot intervention of one billion kronor for foreign currency brought down the conditional variance with 32 percent (38 log percent) the following day. There are also some persistence of the effects due to the autoregression of the conditional variance arising from the parameter α_0. The effects on the volatility are further illustrated in *figure 4*, which shows the estimated conditional standard deviation of the exchange rate for the exponential intervention model (the thick line) and the difference in volatility compared to the benchmark model without interventions (the thin line). The conditional standard deviation for the intervention model is lower compared to the benchmark model at instances when the Riksbank was fairly active in the foreign exchange market, but higher at instances when the Riksbank abstained from intervening. The difference in volatility is generally in the range ± 1 %. However, the effects are considerably larger during three episodes: March/April 1987, May 1988 and April 1989. A comparison with figure 1 reveals that the Riksbank at the former two events used sterilized interventions in a way that in the short run almost pegged the exchange rate at the lower boundary of the band.

In summary, the results show that sterilized interventions helped to stabilize the exchange rate during the period June 1986 to September 1989. However, the effects on the conditional variance of the exchange rate are not significant when the period October 1989 to December 1990 is included in the sample. One explanation to this is perhaps that the power of the portfolio balance channel was weakened by increasing capital mobility. Another explanation, and more convincing in my view, is that the signalling channel stopped working as the credibility of the fixed exchange rate regime deteriorated. Intuitively, it seems impossible that a credible link can exist between sterilized interventions and future fundamentals – a necessity for the signalling channel – when an exchange rate band has lost its overall credibility. In such a situation it seems more plausible that major sterilized sales of foreign currency signal that a collapse of the exchange rate band has become more likely, which would tend to destabilize the exchange rate.

7 Concluding Comments

According to the signalling channel sterilized interventions may influence the exchange rate by conveying information – known to central banks, but not to market participants – about future monetary policy or fundamentals in general. In the Swedish case, there are some evidence in favour of the signalling channel. The results show that spot interventions contained information about future monetary policy in the sense that they Granger-caused the overnight rate, that is, the monetary instrument of the Riksbank. Another question is if market participants really perceived this information and to what extent it eventually influenced the exchange rate. When it comes to the level of the exchange rate it is seems impossible to disentangle the effects of interventions from that of other factors which may simultaneously influence interventions and the exchange rate, since the Riksbank has reacted immediately (intraday) on foreign exchange market disturbances. However, sterilized interventions may convey information that is crucial not only for the exchange rate level but also for the conditional variance of the exchange rate.

This idea of interventions influencing future volatility of the exchange rate turned out to be fruitful within the GARCH-framework. The results confirm that sterilized interventions can influence exchange rates. The Riksbank's interventions lowered the volatility of the krona exchange rate. However, this result was only generated for the sub-period June 1986 to September 1989. This period has two important characteristics. First, some exchange controls were in effect until June 1989, which may have supported effects working through the portfolio channel. Second, the exchange rate band was still credible. The results indicate that sterilized interventions were inefficient during the following period that was turbulent with significant and fluctuating devaluation expectations. In such an environment it is unlikely that the signalling channel will work since it relies on a credible link between interventions and future fundamentals. The conclusion is therefore that sterilized interventions may work through the signalling channel, but that the channel is fragile.

Appendix 1. Data Description

The intervention data, made available by Sveriges Riksbank, are daily and cover the period June 1986 to December 1990. The data set contains spot interventions, forwards interventions, currency swaps and the cash flows of forward contracts and forwards legs of currency swaps. The figures on spot interventions, $SPOT_t$, are daily net purchases of foreign currency measured in billion Swedish kronor. The data were made available under certain conditions. For instance, I am not allowed to plot interventions against time.

The mid rate at market closing in units of kronor per unit currency basket, obtained from Sveriges Riksbank, is used to calculate the log percent deviation of the exchange rate from central parity, s_t.

The marginal lending rate (simple), $i_{t,1}$, announced at market closing was obtained from Sveriges Riksbank. The overnight rate (simple), i_t, obtained from Sveriges Riksbank, is an average of the overnight rates quoted on STIBOR at 11.00 am. The 1-month simple bid rate on Euro-deposits denominated in Swedish kronor, $i_{t,30}$, was obtained from the database of the Bank for International Settlements.

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Table 1. Probit estimation of the reaction functions for purchases and sales of foreign currency, June 1, 1986 to December 31, 1990; 1150 observations. Dependent variables: Binary realizations of purchases and sales of foreign currency at time t+1, respectively.[a]

Variables/parameters	Purchases	Sales
Constant	-0.6042 (0.0606)	-0.7672 (0.0661)
s_t	-0.1298 (0.0736)	0.6042 (0.0888)
Δs_t	-2.8656 (0.4704)	3.8690 (0.5200)
Δs_{t-1}	-2.5268 (0.4605)	3.4789 (0.5727)
Δs_{t-2}	-2.1883 (0.4596)	2.6421 (0.5713)
Δs_{t-3}	-1.5260 (0.4559)	2.2685 (0.5814)
Δs_{t-4}	-1.0100 (0.4538)	0.6322 (0.5462)
Δs_{t-5}	-1.0881 (0.4483)	1.2802 (0.5409)
Δs_{t-6}		1.6305 (0.5564)
$i_{t,1} - i_{t,30}$	0.0624 (0.0425)	-0.0933 (0.0427)
Diagnostics		
Log likelihood	-656.69	453.41
LR test for full model	98.32 (0.00)	195.38 (0.00)

[a] Standard errors within parentheses (p-values for LR tests).

Table 2. OLS estimation of
$s_{t+1} = \beta_0 + \beta_1 s_t + \beta_2 s_{t-1} + \beta_3 (i_{t+1,1} - i_{t,1}) + \beta_4 SPOT_{t+1} + \varepsilon_{t+1}$.[a]

Variables/parameters	June 1986 to September 1989	October 1989 to December 1990	June 1986 to December 1990
Constant	-0.017 (0.005)	0.009 (0.003)	-0.001 (0.005)
s_t	0.742 (0.039)	0.861 (0.054)	0.797 (0.023)
s_{t-1}	0.230 (0.038)	0.130 (0.056)	0.195 (0.023)
$i_{t+1,1} - i_{t,1}$	-0.002 (0.001)	-0.003 (0.003)	-0.002 (0.001)
$SPOT_{t+1}$ (billion kronor)	-0.050 (0.000)	-0.017 (0.006)	-0.022 (0.006)
Diagnostics			
N	832	318	1150
R-squared	0.96	0.98	0.97
σ	0.086	0.089	0.088

[a] Newey-West standard errors within parentheses ($N^{1/3}$ lags).

Table 3. The effects of sterilized interventions on volatility. ARCH models for s_{t+1}. June 1986 to December 1990; 1149 observations.[a]

Variables/parameters	(1)	(2)	(3)	(4)
Conditional mean				
Constant	-0.0039	-0.0023	-0.0007	-0.0015
	(0.0038)	(0.0034)	(0.0046)	(0.0033)
s_t	0.8265	0.8763	0.8847	0.8638
	(0.0663)	(0.0336)	(0.0351)	(0.0339)
s_{t-1}	0.1642	0.1173	0.1135	0.1294
	(0.6667)	(0.0340)	(0.0312)	(0.0342)
$i_{t+1,1} - i_{t,1}$	-0.0025	-0.0047	-0.0044	-0.0046
	(0.0026)	(0.0028)	(0.0027)	(0.0028)
Dummy for purchases (1,0)			-0.0075	
			(0.0057)	
Dummy for sales (1,0)			0.0018	
			(0.0065)	
$SPOT_t$ (billion kronor)				-0.0065
				(0.0033)
Conditional variance				
Omega	0.0082	0.0069	0.0074	0.0071
	(0.0008)	(0.0011)	(0.0013)	(0.0011)
Alpha		0.2034	0.2121	0.1895
		(0.0631)	(0.0594)	(0.0603)
$\|s_t - \bar{s}\|$		-0.0014	-0.0007	-0.0020
		(0.0019)	(0.0016)	(0.0022)
Dummy for purchases (1,0)			-0.0022	
			(0.0014)	
Dummy for sales (1,0)			-0.0013	
			(0.0016)	
$\|SPOT_t\|$ (billion kronor)				0.0588
				(0.1045)
Diagnostics				
l_t	0.98578	1.03493	1.04070	1.03775
Q(15) for $\varepsilon_t h_t^{-0.5}$	22.0	18.4	20.5	19.6
	(0.11)[b]	(0.24)	(0.15)	(0.19)
Q(15) for $\varepsilon_t^2 h_t^{-1}$	180.5	4.0	4.6	3.8
	(0.00)[b]	(0.98)	(0.92)	(0.98)

[a] Robust standard errors within parentheses, White (1982). P-values for diagnostics.

[b] For ε_t and ε_t^2, respectively.

Table 4. The effects of sterilized interventions on volatility. ARCH models for s_{t+1}. June 1986 to September 1989; 831 observations.[a]

Variables/parameters	(1)	(2)	(3)
Conditional mean			
Constant	-0.0089 (0.0051)	-0.0092 (0.0061)	-0.0117 (0.0051)
s_t	0.8551 (0.0360)	0.8254 (0.0406)	0.8372 (0.0424)
s_{t-1}	0.1348 (0.0406)	0.1583 (0.0398)	0.1476 (0.0430)
$i_{t+1,1} - i_{t,1}$	-0.0039 (0.0031)	-0.0026 (0.0027)	-0.0034 (0.0032)
Dummy for purhcases (1,0)		-0.0108 (0.0066)	
Dummy for sales (1,0)		-0.0005 (0.0081)	
$SPOT_t$ (billion kronor)			-0.0106 (0.0051)
Conditional variance			
Omega	0.0077 (0.0014)	0.0090 (0.0011)	0.0080 (0.0023)
Alpha	0.2027 (0.0825)	0.1875 (0.0573)	0.2485 (0.0921)
$\lvert s_t - \bar{s} \rvert$	-0.0045 (0.0020)	-0.0039 (0.0015)	-0.0046 (0.0021)
Dummy for purchases (1,0)		-0.0035 (0.0016)	
Dummy for sales (1,0)		-0.0028 (0.0018)	
$\lvert SPOT_t \rvert$ (billion kronor)			-0.3751 (0.1791)
Diagnostics			
l_t	1.06719	1.08596	1.07420
Q(15) for $\varepsilon_t h_t^{-0.5}$	21.9 (0.11)	24.5 (0.06)	24.5 (0.06)
Q(15) for $\varepsilon_t^2 h_t^{-1}$	3.1 (0.99)	4.8 (0.91)	3.7 (0.98)

a Robust standard errors within parentheses, White (1982). P-values for diagnostics.

Figure 1. Exchange rate

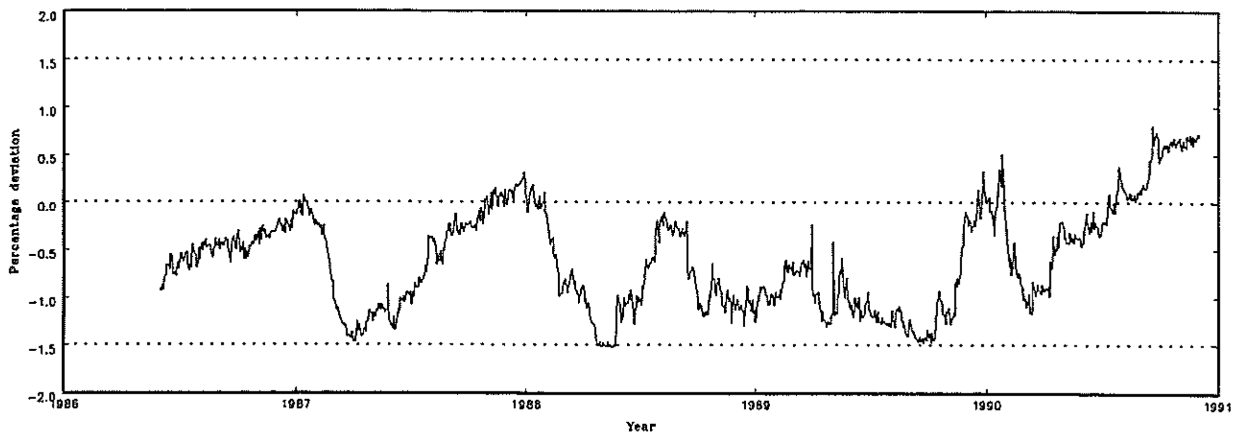

Figure 2. Marginal lending rate

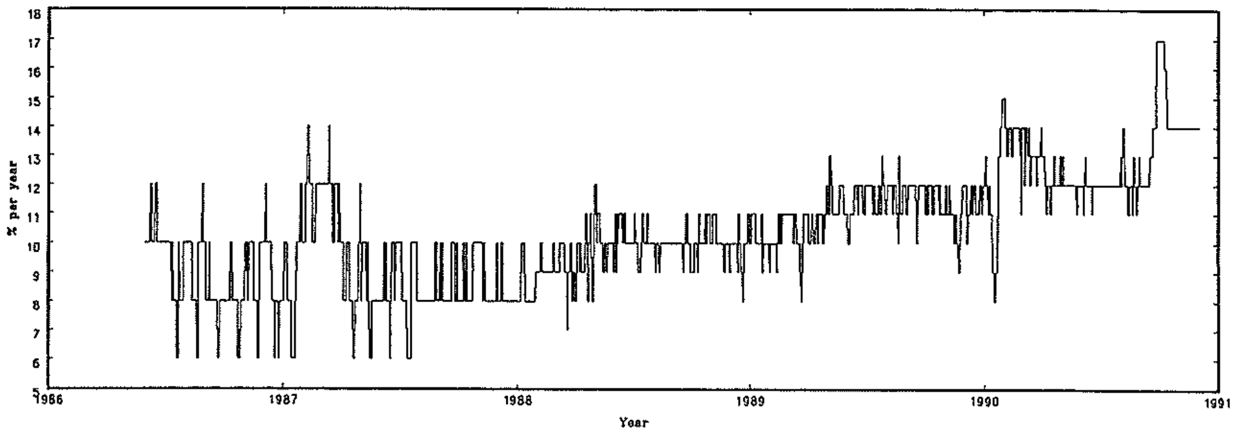

Figure 3. Rolling 10-day standard deviation
of exchange rate changes

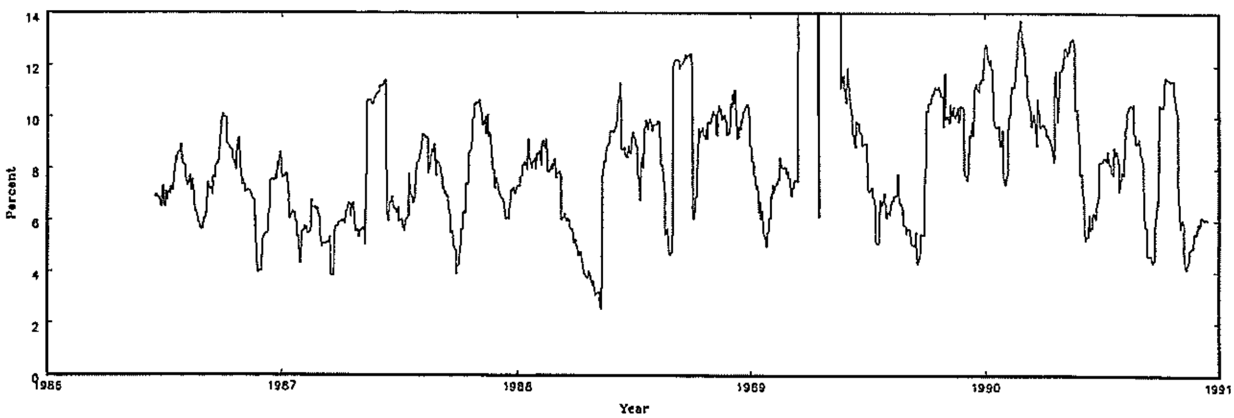

Figure 4. Conditional standard deviation