Central Bank Intervention and Exchange Rates: The Case of Sweden[*]

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Abstract

This paper examines the effect of the Riksbank's currency market interventions on the level and the volatility of the USD/SEK and DEM/SEK exchange rates between 1993 and 1996. To model volatility both GARCH models and implied volatilities from currency options are used. Some support is found for the idea that interventions affect the exchange rate level during certain sub periods but overall the results are weak. Furthermore, in line with the findings for other countries, little empirical support is found for the hypothesis that central bank intervention systematically decreases exchange rate volatility.

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1. Introduction

During the last decades economists have changed their views regarding the effects of foreign exchange market interventions on the exchange rate. Under the Bretton Woods system of fixed exchange rates, interventions were used frequently to maintain the exchange rate within prescribed margins. After the breakdown of the Bretton Woods system in 1973 the magnitude of interventions initially increased.

In the early 1980s, the Reagan administration viewed interventions as both costly and inefficient and adopted more of a laissez-faire approach towards foreign-exchange markets. European central banks however continued to intervene to keep their currencies within the bands prescribed by the Exchange Rate Mechanism (ERM). The U.S. skepticism against interventions was partly based on the fact that research in the late 1970s seemed to show that exchange markets are efficient. Most empirical studies failed to find effects of interventions on the exchange rate. However even during this period some economists stressed that foreign exchange rate markets do not work as commodity markets. They claimed that in exchange rate markets without interventions or restrictions on asset holdings equilibrium exchange rates will not be determined (Wallace, 1978).

During the first half of the 1980s the dollar appreciated by approximately 50 percent in nominal terms. When the Congress threatened to adopt severe protectionistic measures the Federal Reserve began to intervene, but this time with the help from the G5 countries. Following the perceived success of these interventions economists began to reassess the effectiveness of interventions.

A majority of the new studies produced concluded, in line with the earlier results, that interventions effects on the exchange rate are minor at most. Still, most central banks continue to be active in the foreign exchange market. One explanation could be that countries with floating exchange rates usually try to decrease exchange rate volatility rather than move the level of the exchange rate. Indeed in the IMF Executive Board's 1977 guiding principles for intervention policy it is explicitly stated that countries should use interventions to decrease volatility in exchange rates (Dominguez, 1996).

A major part of the studies in this area of research is concerned with the effects of interventions on the DEM/USD and JPY/USD exchange rates. Very little has been done for other currencies. As pointed by Edison (1993) one main reason for the lack of empirical studies for other countries is that it is hard to get access to good data for interventions.

In this paper we study the effect of sterilized interventions on the Swedish krona from 1993 to 1996 using unique daily data on actual interventions made by the Riksbank. After a period of severe speculative attacks against the Swedish krona the Riksbank let the krona start to float in November 1992. This was the first time since the thirties that Sweden experienced a floating exchange rate regime. It is of interest to explore the effects of interventions conducted under a floating exchange rate regime in a small open economy.

The paper is organized as follows: Section 2 describes theory and different channels through which interventions could affect exchange rates. Section 3 presents empirical results. We test the effects of interventions both on the exchange rate level and on the exchange rate volatility. Section 4 concludes.

2. Theory of sterilized interventions

The Riksbank has during the period investigated in this paper neutralized the money stock effect of its interventions, i.e. used so called sterilized interventions. It is generally accepted among economists that nonsterilized interventions affect exchange rates in the same way domestic open-market operations. Nonsterilized interventions change the stock of base money and thus monetary aggregates and interest rates. The effects of sterilized interventions are however more controversial because the monetary base is not altered; the central bank make an offsetting transaction through an open market purchase or sale of domestic government securities or by granting more or less credit to the commercial banks. Thus a sterilized intervention simply alters the currency composition of domestic and foreign assets of the private sector portfolio investments but leaves the money supply unchanged. It is common practice among central banks to neutralize the money market effect of interventions in order to let exchange rate policy not interfere with domestic monetary policy.

There are many theories on the scope of foreign exchange market intervention. For a comprehensive survey we refer the interested to Almekinders (1995, Ch.2). Here we take the asset market view of exchange rates as a simple formal framework to discuss the different channels through which sterilized intervention may affect the exchange rate.

Following the standard asset pricing model approach to exchange rates the following process is considered for the exchange rate,

$$s_t = f_t + \alpha\left[E_t\left(s_{t+1}|\Omega_t\right) - s_t\right] \tag{1}$$

where s_t is the (log) exchange rate at time t, f_t represents the current period "fundamentals", E_t is the expectations operator and Ω_t is the information set in period t. Hence the exchange rate in period t is determined by the fundamentals in period t and the expected capital gain, $E_t\left(s_{t+1}|\Omega_t\right) - s_t$, of holding the currency until the next period. Equation (1) can be rewritten as,

$$s_t = \frac{1}{1+\alpha} f_t + \frac{\alpha}{1+\alpha} E_t\left(s_{t+1}|\Omega_t\right) \tag{2}$$

i.e. a stochastic difference equation. The general solution to equation (2) is given by a set of solutions that each may be expressed as,

$$s_t = s_t^* + b_t \tag{3}$$

where s_t^* is the fundamental value and b_t is a rational bubble satisfying, $E\left[b_{t+1}|\Omega_t\right] = \left(\frac{1+\alpha}{\alpha}\right) b_t$. s_t^* is the unique solution to (2) under the assumption of no bubbles. To see this we solve equation (2) recursively ,

$$s_t = \frac{1}{1+\alpha} \sum_j^T \left(\frac{\alpha}{1+\alpha}\right)^j E_t\left(f_{t+j}|\Omega_t\right) + \left(\frac{\alpha}{1+\alpha}\right)^{T+1} E_t\left(s_{t+T+1}|\Omega_t\right) \tag{4}$$

Under the assumption that $\lim_{T\to\infty}\left(\frac{\alpha}{1+\alpha}\right)^{T+1} E_t\left(s_{t+T+1}|\Omega_t\right) = 0$, the unique solution to (2) is,

$$s_t^* = \frac{1}{1+\alpha} \sum_{j=0}^{\infty} \left(\frac{\alpha}{1+\alpha}\right)^j E_t\left(f_{t+j}|\Omega_t\right) \tag{5}$$

Hence the solution for s_t can be written as,

$$s_t = \frac{1}{1+\alpha} \sum_{j=0}^{\infty} \left(\frac{\alpha}{1+\alpha}\right)^j E_t\left(f_{t+j}|\Omega_t\right) + \left(\frac{\alpha}{1+\alpha}\right) E\left[b_{t+1}|\Omega_t\right] \tag{6}$$

where the exchange rate is divided into two terms, the expected present value of future fundamentals and a bubble. Note the implication of the second term; for a bubble to survive it must reflect the expectation that it will continue to expand in the following period. We use the expression in (6) as a starting point to discuss how interventions can affect the exchange rate trough different channels. We start with the signalling channel.

The signalling channel

Studying the expression for the exchange rate in equation (6) the exchange rate is determined by expectations about future fundamentals (and a possible bubble). Sterilized intervention may affect the exchange rate by changing those expectations. This is called the signalling or expectations channel. For the signalling channel to be valid there must be asymmetric information between the market participants and the central bank. If so, the central bank is able to convey information by means of intervention. A central bank may have information about fundamentals of the exchange rate or of the future development of inflation that is not known to the market, e.g. because the central bank has access to data that is not available to the public (or available with a lag). In particular, sterilized interventions may provide information about future monetary policy. A central bank may signal a more contractionary policy by buying domestic currency in the foreign exchange market. The market participants will expect a tighter future monetary policy and will revise their expectations of the future exchange rate, and thus the exchange rate will appreciate (since it is a forward-looking price as shown in equation (6)), even if the immediate effects of the intervention on the monetary base are offset. One might ask oneself why the monetary authorities would prefer to use interventions instead of simple announcements to affect exchange-rate expectations. A potential explanation is that intervention provides credible information about future monetary policy since the monetary authorities stake their own capital in support of those policies.

Investigations of the signalling channel show a significant, but usually weak, impact of interventions on exchange rates. Lindberg (1994) tests if the overnight rate (a monetary instrument of the Riksbank) was Granger-caused by spot interventions on Swedish data. He concludes that sterilized interventions may have effects on exchange rates through the signalling channel but that the channel is fragile. Kaminsky and Lewis (1996) use a somewhat different approach and test the signalling theory by examining the information content of interventions, i.e. interventions' relationship with future monetary policy. They test the hypothesis that intervention provides no signal of future monetary policy and find significant signalling effects; but on average the effects are opposite to those expected on the basis of the theoretical arguments.

The noise-trading channel

In equation (6) the exchange rate is allowed to deviate from the fundamental value due to a rational bubble. There is a huge literature on how to model bubbles in different ways. Recently deviations from fundamentals have been modeled by introducing the concept of "noise traders" (for a survey see e.g. Kortian(1995)). Noise traders are said to be traders whose demand for currencies (or other assets) is affected by beliefs or sentiments that are not fully consistent with economic fundamentals. They base their expectations of future changes in the exchange rates on e.g. these rates' past behavior. The noise-trader hypothesis assumes that noise traders as a group can move asset prices away from their fundamental equilibrium.

A central bank can by entering a relatively thin market induce noise traders to buy or sell currency. The effect of the sterilized intervention is most likely to be transitory, but it may cause noise traders to perceive that the prevailing trend has been broken and that there is a trade reversal. For the noise trading channel to work the central bank must be familiar with noise traders' reactions function and be able to conduct covert intervention.

The portfolio-balance channel

Interventions may also work through the so called portfolio-balance channel. Sterilized intervention operations change the relative supplies of domestic and foreign assets. If asset holders are risk averse they are not indifferent to the composition of their portfolios, i.e., domestic and foreign assets are not perfect substitutes. Investors will allocate their portfolios to balance exchange-rate risk against expected rate of returns. Since sterilized intervention operations change the relative supply they will also alter the risk characteristics of foreign and domestic assets in the market portfolio, and thus the equilibrium exchange rate. A sterilized sale of domestic-currency-denominated bonds may increase their relative risk because investors will be more vulnerable to unexpected changes in the value of the domestic currency. Investors will thus require a higher expected return on domestic-currency-denominated bonds in order to be willingly hold the larger outstanding stock, leading to a depreciation of the domestic currency.

One way of testing the portfolio-balance approach is to estimate sterilized interventions effects on the risk premium of assets. An essential part of the studies of sterilized interventions based on the portfolio-balance approach show no statistically significant role of sterilized intervention, see e.g. Rogoff (1984) and Lewis (1988) who find insignificant coefficients of the wrong sign. Those researchers that find a statistically significant impact can only conclude that it is very weak or short-lived, as Gosh (1992). The reason for these somewhat negative results could be that in order to affect the relative supply of foreign and domestic assets the volume of sterilized interventions should be significant. Obstfeld (1989) points out that considering the tremendous daily volume in the foreign exchange market, central banks are unlikely to have the opportunity to intervene with large enough amounts to affect the exchange rate through the portfolio balance channel.

3. Empirical results

We investigate the impact of interventions on both the level of the exchange rate and exchange rate volatility. We do not explicitly test through which channel interventions work, but simply if they affect the exchange rate. The sample period runs from January 7, 1993 to December 30, 1996, basically covering the floating period after the currency peg was dropped (November 1992). We focus on two exchange rates, the dollar (SEK/USD) and German mark (SEK/DEM) vs. the Swedish krona. Daily spot prices for these exchange rates were obtained from the Riksbank's database and are the EU concertation rates collected at 2.15 pm every day. These are plotted in figure 1.

The implied volatility data (described below) were provided by a major commercial bank and are plotted in figure 2. Over-night interest rates were obtained from the Riksbank's database and actual intervention data available at the Riksbank were used to test the impact of intervention. We begin by jointly examining the relationship between interventions and the level and volatility of SEK/USD and SEK/DEM.

The effect of sterilized interventions on the exchange rate

We have described different mechanisms through which sterilized interventions can affect the exchange rate. To test empirically the effects of sterilized interventions by the Riksbank on the exchange rate we use a Multivariate extension of the Generalized AutoRegressive Conditional Heteroskedasticity (ARCH) model (Engle (1982), Bollerslev (1986)) model. In Figures 3 and 4 daily changes in the natural logarithm of the exchange rate (denoted "returns" henceforth) for the SEK/USD and SEK/DEM are shown for the whole period. Looking at the return series it is quite easy to spot volatility clustering, periods of turbulence are followed by periods of turbulence and calm periods by calm periods. These phenomena indicate the presence of ARCH/GARCH[1]. Using a GARCH framework it is possible to test the impact of interventions on both the level and volatility simultaneously. Earlier studies utilizing GARCH models have used univariate

[1] The presence of ARCH effects is also confirmed by a Ljung-Box test performed on the squared returns.

specifications. We find it natural to study the relations between sterilized interventions and the SEK/USD and SEK/DEM exchange rates as a system and therefore estimate a bivariate GARCH in MEAN model. The specification of the mean equations follows the standard setup for empirical studies using daily data (see e.g. Humpage (1989), Dominguez (1993), Baillie and Osterberg (1997a)) [2],

$$\begin{aligned} r_{SEK/USD,t} &= \beta_{0,USD} + \beta_{1,USD}\left(si_{d,t-1} - si_{f,t-1}\right) + \beta_{2,USD} Speech_t + \\ &\quad + \beta_{3,USD} Int_t + \beta_{4,USD} r_{SEK/DEM,t-1} + \beta_{5,USD} h_{USD,t} + \varepsilon_{USD,t} \end{aligned} \qquad (7)$$

$$\begin{aligned} r_{SEK/DEM,t} &= \beta_{0,DEM} + \beta_{1,DEM}\left(si_{d,t-1} - si_{f,t-1}\right) + \beta_{2,DEM} Speech_t + \\ &\quad + \beta_{3,DEM} Int_t + \beta_{4,DEM} r_{SEK/USD,t-1} + \beta_{5,DEM} h_{DEM,t} + \varepsilon_{DEM,t} \end{aligned} \qquad (8)$$

$$\varepsilon_t \big| \Omega_{t-1} \sim N(0, H_t), \quad \varepsilon_t = \begin{bmatrix} \varepsilon_{USD,t} \\ \varepsilon_{DEM,t} \end{bmatrix}$$

where $r_{it} = \ln(S_{it} / S_{it-1})$, i = $SEK/USD,\ SEK/DEM$, is the daily percentage change in the exchange rate from time t-1 to time t. The joint vector of residuals, ε_t, is specified to be a conditionally zero-mean normal process with time varying conditional covariance matrix, H_t. We also let the conditional variances, $h_{USD,t}$ and $h_{USD,t}$ affect the level equations. The specification of the covariance process is given below. $si_{d,t} - si_{f,t}$ is the over-night interest rate differential at time t ($si_{d,t}$ is the Swedish (domestic) interest rate and $si_{f,t}$ is the foreign interest rate) between Sweden and the foreign country at time t. The short term interest rate differential may affect the exchange rate by reflecting changes in the relative fundamentals between the domestic an the foreign economy. Speech is a dummy variable taking the value one for those days when the governor or the deputy governors held a speech which was aimed to signal a tightening of monetary policy, -1 if the aim was to signal a more expansive monetary policy and 0 in the case the speech was neutral. The classification of the Speech variable is adapted from Lindberg et al. (1996). Int_t is the intervention volume in US dollars on day t, a positive value means that the Riksbank bought foreign currency and sold domestic currency. We also allow for the returns of

[2] This system might be subject to simultaneity bias. This potential problem arises since we can not know if the exchange rate changed because the Riksbank was active in the foreign exchange market or if the Riksbank was induce to intervene because of movements in the exchange rate. Normally we could try to deal with this problem using an instrumental variables approach like two stage least squares. However, as pointed out by Lindberg (1994) finding instruments for interventions is very hard, since unexpected interventions in time t are, by definition, uncorrelated with the information set at t-1.

SEK/DEM, lagged one period, to affect the SEK/USD equation and vice versa. Finally $\varepsilon_{i,t}$ i = USD,DEM is an error term.

To test the impact of interventions on volatility we assume the following dynamics for the conditional variance/covariance matrix of the residuals in (7) and (8),

$$h_{USD,t} = \alpha_{0,USD} + \alpha_{1,USD}\varepsilon^2_{USD,t-1} + \alpha_{2,USD}h_{USD,t-1} + \delta_{1,USD}\left|Int_t\right| + \delta_{2,USD}\left|Speech_t\right| + \delta_{3,USD}\varepsilon^2_{DEM,t-1} \quad (9a)$$

$$h_{DEM,t} = \alpha_{0,DEM} + \alpha_{1,DEM}\varepsilon^2_{DEM,t-1} + \alpha_{2,DEM}h_{DEM,t-1} + \delta_{1,DEM}\left|Int_t\right| + \delta_{2,DEM}\left|Speech_t\right| + \delta_{3,DEM}\varepsilon^2_{US,t-1} \quad (9b)$$

$$h_{USD,DEM,t} = \alpha_{0,USD,DEM} + \alpha_{1,USD,DEM}\varepsilon_{USD,t-1}\varepsilon_{DEM,t-1} + \alpha_{2,USD,DEM}h_{USD,DEM,t-1} \quad (9c)$$

In (9a-9c) we allow the conditional variances for the SEK/USD and SEK/DEM, $h_{,t}$ and $h_{,t}$ and the conditional covariance between the two currencies, $h_{USD,DEM,t}$ to vary over time in an autoregressiv fashion. Shocks are also allowed to ”spillover” from one currency to another by including the lagged squared residuals from SEK/DEM in the variance equation for SEK/USD and vice versa. Including the absolute value of interventions in the variance equations tests the impact of intervention on the exchange rate volatility. The absolute value of the speech variable is also included to adjust for the impact of monetary policy on exchange rate.

The parameters of the system (7)-(8) and (9a-9c) are estimated using Maximum Likelihood. Under the assumption that residuals are conditionally multivariate normally distributed the likelihood to be estimated is,

$$L(\Theta) = \sum_{t=1}^{T} \ln f(\Theta)$$

where Θ is the parameters of the system above, T the number of observations and $f(\Theta)$ is the conditional multivariate normal distribution[3]. The log likelihood function is maximized using a

[3] We also estimated the model under the assumption that residuals are conditionally multivariate t-distributed. This did not alter the results in any significant way and the distribution parameter where generally very large, indicating that the disturbances are approximately normally distributed.

simplex algorithm for a few iterations to handle the influence of bad starting values and then switch to the BFGS algorithm. To account for potential non-normality in the residuals, $\varepsilon_{i,t}$, i = *USD, DEM* we adapt the Quasi Maximum Likelihood (QML) approach suggested by Bollerslev and Wooldridge (1992) which gives standard errors that are robust to a non-normal density function underlying the residuals.

The results of estimating the system (7) and (8) and (9a)-(9c) are presented in table 1. If we start with the mean equations the only parameter that is significant at the 5% level is the return ”spillover” from SEK/USD to SEK/DEM. The estimated coefficients for the intervention variable are both negative, i.e. indicating that interventions would depreciate the Krona, but are very small in magnitude and not anywhere close to being significant at normal levels. Turning to the estimated parameters of the conditional variance/covariance process we find strong support for time dependencies in the conditional variances and the covariance, all the ARCH/GARCH parameters are significant. Furthermore there is a positive and significant, at the 10% level, spillover effect from SEK/DEM to SEK/USD. This implies that an unexpected shock in the SEK/DEM exchange rate increase the conditional variance in the SEK/USD. It is also interesting to note that the speech variable has a negative impact on the conditional variance for both exchange rates and significantly so for SEK/USD. Similar to the results for the mean equations the effects of interventions on the exchange rates are not significant. As pointed out by Dominguez (1996) it might be the presence of a central bank in the market that influences the volatility and not the magnitude of the interventions. Therefore the intervention variable is re-specified as a (0,1) dummy variable indicating whether interventions were made at time t or not. This did not change the results.

For the estimated GARCH-M system we find no significant effects of interventions on the exchange rate level or volatility. We proceed by investigating whether interventions have had a more significant impact during shorter periods. The models are estimated in sub periods since official statements indicate that the Riksbank has changed its intervention policy during the sample period. Since we use somewhat different empirical specifications this analysis also provide a check of how robust the results above are to different estimation techniques and different volatility measures.

Subperiod analysis of interventions and the exchange rate level

Since the number of parameters in the GARCH system above is quite large, estimation is not feasible for one year subperiods. For the purpose of subperiod analysis we instead choose to study intervention's effect on the level and volatility separately. The level equations (7) and (8) with are estimated by ordinary least squares (with β_5=0). Standard errors that are robust to heteroscedasticity are calculate according to White (1980). The results of the estimation, for the whole period, 1993-1996, and four one year sub periods are presented in table 1 and table 2[4]. The robust standard errors are reported in parentheses. We also estimated equation (7) and (8) as a system of Seemingly Unrelated Regressions (SUR), this did not alter the results.

The estimated models give statistically significant effects of interventions on the SEK/DEM exchange rate for the 1995 and 1996 sub samples and during 1995 for the SEK/USD exchange rates. Interventions during 1995 made in order to depreciate/appreciate the krona, seem to have the desired effect, the intervention variable is positively related to changes in the Swedish krona[5]. The Riksbank's intention (as declared by the deputy governor at the time, Thomas Franzén, in an interview with Reuters in September 1995) during this period was indeed to reinforce an already existing appreciating trend of the krona. This is in line with the results in Baillie and Osterberg (1997a) who studied the effect of German and US interventions on the USD/DEM exchange rate and find significant effects almost exclusively of ”leaning with the wind” variety. For the 1996 sub sample the coefficient has a negative sign, which would mean that interventions to support the krona have in fact made it depreciate. This might be explained by the fact that during 1996 the intention of the Riksbank was to smooth exchange rate movements, (as was declared by the head

[4] The exchange rates used were obtained in connection with daily concertations at 2:15 p.m. European time. Since the currency market in Sweden does not close until 4:15 it is possible that interventions may occur after the concertation time. Hence we also tried lagged intervention as an explanatory variable but this did not alter the results.

[5] Recall that a positive value for the intervention variable means selling Swedish kronor and vice versa.

of the monetary and exchange rate department, Richard Gröttheim, in an interview with Direkt in September 1996). The Riksbank was selling or buying currency for this purpose. At the same time when interventions were performed the Swedish krona depreciated quite heavily. Hence it is plausible to believe that the depreciation of the krona was independent of the interventions performed during the same period of time.

The over-night interest rate differential is not significant for any sub samples for both exchange rates and the coefficient is positive. The speech variable is significant for the 1993 sub sample for the SEK/DEM exchange rates. One explanation could be that in 1993 shortly after the Riksbank let the krona float freely the market was extremely uncertain about the future policy of the Riksbank. This was the first time Sweden had a floating exchange rate since the thirties. It is possible that the market focused on speeches to find out what direction the Riksbank's policy was going to take. The speech variable is also significant 1996 sub sample for SEK/DEM exchange rate. The Riksbank lowered the repo rate by almost 5 percentage points during this year. This could be interpreted as an indication that the Riksbank was successful in conveying its monetary policy intentions.

The spillover coefficient is only significant for the 1994 SEK/DEM regression, during 1994 the exchange rate of the krona against the D-mark seems to depend on the development of the lagged SEK/USD exchange rate. A depreciation of the krona against the USD tends to depreciate the krona against the D-mark the following day.

Alternative volatility measures and sub period analysis of interventions and exchange rate volatility.

Above we used a GARCH model to get a measure of the volatility in the SEK/USD and SEK/DEM exchange rate. However when analyzing interventions effects on volatility for one-year sub periods estimating GARCH models might not be the best thing to do since. These models require a fair amount of observations, and for some sub periods the ARCH effects are quite weak.

An alternative method to get a measure of volatility is to use option prices. The Black and Scholes, (1973) model is probably the most well known option pricing model. For currency options the Black-Scholes model relates the price of a call option, C, to five variables (Garman and Kohlhagen (1983)),

$$C = f\left(S, X, \sigma^2, t, i_{dt} - i_{ft}\right) \tag{11}$$

where S is the price of the underlying currency, X is the strike price, σ^2 is the variance of the underlying currency, t is the time left to expiration and $i_{dt} - i_{ft}$ is the interest differential between the domestic and foreign interest rate. All the variables are known with certainty when the option is priced except σ^2, which has to be estimated. However we could also take the market price as given and back out σ^2 i.e calculate the *implied volatility* (IMV). If we believe that the options market is efficient and the option pricing model is correct the implied volatility should be the expected volatility for the underlying exchange rates. This approach has some advantages over GARCH based methods to estimate volatility (Lyons, 1997). First, we extract the market's current expectations about future volatility using the investor's information set as opposed to the econometrician's. Second, IMV's allow for sudden shifts in the conditional variance. Third, and quite important, we do not have to specify the mean. Hence we can analyze the impact of interventions on exchange rate volatility separately from the impact on the level. Empirical studies like Jorion (1995), indeed show that implied volatilities outperform time series based models in terms of forecasting future exchange rate volatility. In terms of the implied volatility data we follow Murray et al (1996) and use implied volatility quotes. We use daily quotes for at-the-money 1-month SEK/USD and SEK/DEM and DEM/USD currency call options. These quotes are used to price currency options in the OTC market. In figure 2 the implied volatilities are displayed.

To see how volatility for the SEK/USD and SEK/DEM rates are affected by interventions made by the Riksbank we run the following regressions using the IMV's,

$$\ln(\sigma^2_{SEK/USD,t} / \sigma^2_{SEK/USD,t-1}) = \mu_{USD} + \varphi_{1,USD}|Speech_t| + \varphi_{2,USD}|Int_t| + \varphi_{3,USD}\ln\left(\sigma^2_{SEK/USD,t-1}\right) + u_{USD,t} \quad (10a)$$

$$\ln(\sigma^2_{SEK/DEM,t} / \sigma^2_{SEK/DEM,t-1}) = \mu_{DEM} + \varphi_{1,DEM}|Speech_t| + \varphi_{2,DEM}|Int_t| + \varphi_{3,DEM}\ln\left(\sigma^2_{SEK/DEM,t-1}\right) + u_{DEM,t} \quad (10b)$$

where $\sigma^2_{SEK/USD,t}$ and $\sigma^2_{SEK/DEM,t}$ is the implied volatility of the Swedish Krona vs the US dollar and German mark respectively at time t. It might be the case that an increase in volatility from t to t-1 trigger central bank intervention in the market and therefore introduces a bias in the estimate. To reduce this bias we follow Murray et al (1996) and include $\ln\sigma^2_{i,t-1}$ as a right hand side variable. $u_{i,t}$, $i = USD,DEM$ is an error term. The intervention and speech variables are defined as above. 10a and 10b were estimated jointly by SUR for the whole sample period and four sub periods. The results are presented in table 4. We also estimated the system specifying the intervention variable as a (0,1) dummy variable indicating whether interventions were made at time t or not. These results can be found in table 5.

For the whole period we find a statistically significant, at the 10% level, positive effect of intervention for the SEK/DEM using the dummy specification. This regression implies that intervention increase the volatility in the SEK/DEM. In line with earlier studies using similar data, the R^2 for these models are rather low. In their study of the effects of interventions on the DEM/USD and JPY/USD implied volatility, Bonser-Neal and Tanner (1996) include over ten regressors to capture other news, but still have R^2:s around 5% for the whole period.

To investigate whether Riksbank interventions might have been more successful in reducing volatility during shorter periods of time we also estimated the implied volatility regressions for one year sub periods.

The subsample estimates suggest that interventions indeed have different effects during different periods. If we study the results for the dummy specification (table 5) we can see that in the year 1995 interventions seem to significantly reduce SEK/USD volatility while in 1993 they are associated with an increase in volatility. These results are similar to those of Hung (1997), who also find that interventions' effects on volatility differ over periods. Considering the intention to lower volatility in 1996 the results for this sub period are somewhat discouraging for policy makers. The coefficient on intervention is insignificant and has a positive sign. However this result should be interpreted cautiously since the sample is very small. The Riksbank was not active in the foreign exchange market until late in the fall.

The empirical results indicate that estimating the effect of interventions on exchange rate volatility is quite tricky since the effect might vary over time. For the whole period we found that the interventions made by the Riksbank have a small positive effect, if any, on exchange rate volatility. These results are in line with the findings by several earlier studies (e.g. Baillie and Osterberg (1997) and Bonser-Neal and Tanner (1996)) which mainly found interventions to be related to increases in exchange rate volatility. However analyzing subperiods we find that the influence of interventions change over time which has also been reported by Dominguez (1996) and Hung (1997). During the year of 1995 interventions significantly decreased SEK/USD volatility, while in 1993 the opposite occurs and for 1996 no significant effects can be found. Hung points out that this result, while puzzling from a traditional perspective on interventions, can be explained in a noise trading framework. However if interventions affect the exchange rate through the signalling channel this result might also be due to a shifting signal of future policy over the sample period. A comparison can also be made with Lindberg's (1994) study of Sweden during the currency peg period (1986-1990). In his study interventions are shown to lower volatility in the Swedish krona.

It is important to stress the drawbacks of any study trying to relate a variable like daily exchange rate volatility to a few explanatory variables. For example the low R^2-values from the IMV regressions give strong indications that much remains to be explained regarding the movements in this variable. To be sure it is hard to separate the impact of interventions from other news affecting volatility. A possible extension would be to expand our set of explanatory variables further to include other regressors that capture news, like the release of macroeconomic figures, as in Bonser-Neal and Tanner (1996). The potential gain however seems somewhat marginal since the R^2:s in Bonser-Neal and Tanner's regression, including over ten regressors, are still around 5% for the whole period.

5. Conclusions

This paper examines the Swedish experience with foreign exchange rate (sterilized) intervention over the period 1993-1996. This is the first study investigating interventions' effects on the Swedish Krona after the currency peg was dropped in 1992 and one of the first to study a small central bank's prospect of affecting the exchange rate by intervention.

We investigate the effect of actual Riksbank interventions on both the level and volatility of the Swedish Krona vs the US dollar and the German Mark. The results are somewhat mixed. For the level of the exchange rate no significant effect of interventions is found over the whole period. This is in line with earlier findings in the literature. However if interventions affect the exchange rate through the signalling channel these weak results might be due to a change in the relation between the signal and future monetary policy, a change which may in turn be the results of changes in monetary policy. Indeed when studying one year sub periods we found a significant effect for 1995. During this year the Riksbank's intention with the interventions was, according to official statements, to reinforce an existing trend.

We also investigate how interventions affect the volatility of the exchange rate. Using both GARCH models and measures of implied volatility from currency options for the period 1993-1996, we found only weak evidence that interventions affect the exchange rate volatility. In contrast, analyses of sub periods show a significantly negative effect of intervention on SEK/USD implied volatility for the years of 1994 and 1995 but a positive effect during 1993.

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Table 1. Maximum likelihood estimates of Multivariate GARCH-in-Mean model (7)-(9). Robust standard errors (Bollerslev and Wooldridge, 1992) are presented in parentheses. ***,** and * indicates significance at the 1%, 5% and 10% level. Ljung-Box statistics are reported for the standardized residuals (Q) and for the squared standardized residuals (QS). Bera-Jarque test for multivariate normality. Numbers within brackets are probability values.

Parameter	Estimated Value (Standard errors)
$\beta_{0,USD}$	-0.011151 (0.03675)
$\beta_{1,USD}$	0.936721 (3.97835)
$\beta_{2,USD}$	-0.000925 (0.09318)
$\beta_{3,USD}$	-0.000641 (0.00077)
$\beta_{4,USD}$	0.019337 (0.03157)
$\beta_{5,USD}$	-0.028989 (0.13319)
$\beta_{0,DEM}$	0.017169 (0.04142)
$\beta_{1,DEM}$	-5.132829 (4.57808)
$\beta_{2,DEM}$	-0.067784 (0.09384)
$\beta_{3,DEM}$	-0.000730 (0.00060)
$\beta_{4,DEM}$	0.067816*** (0.02392)
$\beta_{5,DEM}$	0.033582 (0.13490)
$\alpha_{0,USD}$	0.005365** (0.00272)
$\alpha_{0,USD,DEM}$	0.003039* (0.00180)
$\alpha_{0,DEM}$	0.009330* (0.00545)
$\alpha_{1,USD}$	0.040177*** (0.01044)
$\alpha_{1,USD,DEM}$	0.048892*** (0.01158)
$\alpha_{1,DEM}$	0.065143*** (0.01639)
$\alpha_{2,USD}$	0.933432*** (0.01424)
$\alpha_{2,USD,DEM}$	0.926163*** (0.01668)
$\alpha_{2,DEM}$	0.907126*** (0.02648)
$\delta_{1,USD}$	0.016522* (0.00866)
$\delta_{2,USD}$	0.000086 (0.00010)
$\delta_{3,USD}$	-0.043386** (0.01946)
$\delta_{1,DEM}$	-0.000911 (0.00533)
$\delta_{2,DEM}$	-0.000002 (0.00007)
$\delta_{3,DEM}$	-0.016596 (0.02304)
Log likelihood	177.17
LB Q (SEK/USD)	[0.139]
LB Q (SEK/DEM)	[0.748]
LB QS (SEK/USD)	[0.991]
LB QS (SEK/DEM)	[0.064]
Bera-Jarque	[0.000]

Table 2. OLS estimates of interventions effect on the daily percentage changes in the SEK/USD exchange rate. Robust standard errors (White, 1980) are presented in parentheses. ***,** and * indicates significance at the 1%, 5% and 10% level.

$$r_{SEK/USD,t} = \beta_0 + \beta_1\left(si_{d,t-1} - si_{f,t-1}\right) + \beta_2 Speech_t + \\ + \beta_3 Int_t + \beta_4 r_{SEK/DEM,t-1} + \varepsilon_t$$

	1993-1996	1993	1994	1995	1996
β_0	-0.02487 (0.036948)	0.36499 (0.40768)	0.08122 (0.14700)	-0.06860 (0.16419)	0.02231 (0.03260)
β_1	0.95578 (4.560816)	-20.45418 (26.35971)	-13.78463 (15.68573)	3.72888 (21.01895)	-0.62119 (9.00364)
β_2	-0.08735 (0.142182)	-0.52067 (0.56201)	-0.05552 (0.23706)	-0.04944 (0.13049)	0.22991 (0.18542)
β_3	-0.00067 (0.000941)	-0.00121 (0.00114)	0.00322 (0.00642)	0.00931*** (0.00320)	-0.00096 (0.00082)
β_4	0.00779 (0.041557)	0.05760 (0.10449)	0.05564 (0.08908)	-0.03877 (0.05579)	-0.04393 (0.07567)
R^2	0.0022	0.01939	0.0103	0.0337	0.0093

Table 3. OLS estimates of interventions effect on the daily percentage changes in the SEK/DEM exchange rate. Robust standard errors (White, 1980) are presented in parentheses. ***,** and * indicates significance at the 1%, 5% and 10% level.

$$r_{SEK/DEM,t} = \beta_0 + \beta_1\left(si_{d,t-1} - si_{f,t-1}\right) + \beta_2 Speech_t + \\ + \beta_3 Int_t + \beta_4 r_{SEK/USD,t-1} + \varepsilon_t$$

	1993-1996	1993	1994	1995	1996
β_0	0.05294 (0.04373)	0.17144 (0.16165)	0.13083 (0.14045)	0.10162 (0.21750)	0.03327 (0.070329)
β_1	-7.55827 (5.76823)	-33.10268 (35.87228)	-23.74460 (23.80433)	-7.39671 (18.44064)	-4.13946 (9.439434)
β_2	-0.07575 (0.11428)	-0.63187*** (0.22074)	0.19257 (0.26296)	-0.16310 (0.18356)	0.21208* (0.122629)
β_3	-0.00041 (0.00070)	-0.00063 (0.00083)	0.00070 (0.00398)	0.01367*** (0.00415)	-0.00304*** (0.001030)
β_4	0.04997 (0.03373)	0.01440 (0.05767)	0.13174** (0.05188)	0.02412 (0.08287)	-0.00214 (0.071698)
R^2	0.0069	0.0258	0.0391	0.0486	0.02906

Table 4. SUR parameter estimates of Implied volatility model for SEK/USD and SEK/DEM in (10a-b) for whole period and one-year sub periods. ***, **, * Indicates significance at the 1%, 5% and 10% level.

(a) SEK/USD

Parameters	1993-1996	1993	1994	1995	1996
Constant	0.04699*** (0.01326)	0.04699** (0.01326)	0.07608*** (0.03610)	0.14216*** (0.04164)	0.13007*** (0.04260)
SPEECH(t)	0.00032 (0.00526)	0.00032 (0.00526)	0.00253 (0.00773)	0.01234 (0.01157)	-0.00190 (0.01000)
INTERV(t)	0.00002 (0.00003)	0.00002 (0.00003)	0.00002 (0.00002)	-0.00061** (0.00029)	-0.00003 (0.00012)
ln(IMV(t-1))	-0.02017*** (0.00553)	-0.02017** (0.00553)	-0.02946*** (0.01365)	-0.05800*** (0.01690)	-0.06114*** (0.01992)
R^2	0.010	0.020	0.046	0.040	0.029

(b) SEK/DEM

Parameters	1993-1996	1993	1994	1995	1996
Constant	0.02110** (0.00947)	0.06544* (0.03485)	0.08819* (0.03174)	0.08120*** (0.02994)	0.01362 (0.01525)
SPEECH(t)	-0.00482 (0.00475)	-0.01022 (0.01050)	0.00277 (0.01041)	-0.00627 (0.01031)	-0.00334 (0.00724)
INTERV(t)	0.00002 (0.00003)	0.00000 (0.00003)	0.00018 (0.00012)	0.00008 (0.00026)	0.00004 (0.00009)
ln(IMV(t-1))	-0.01006** (0.00426)	-0.02793* (0.01483)	-0.04101* (0.01435)	-0.03417*** (0.01262)	-0.00856 (0.00789)
R^2	0.0058	0.0179	0.037	0.0176	0.0068

Table 5. SUR parameter estimates of Implied volatility model for SEK/USD and SEK/DEM, for whole period and one-year sub periods. ***, **, * Indicates significance at the 1%, 5% and 10% level. Intervention variable specified as dummy. Results for whole period and one-year sub periods. ***, **, * Indicates significance at the 1%, 5% and 10% level.

(a) SEK/USD

Parameters	1993-1996	1993	1994	1995	1996
Constant	0.04880*** (0.01348)	0.08493** (0.03550)	0.15317*** (0.04887)	0.14148*** (0.04157)	0.12618*** (0.04303)
SPEECH(t)	0.00029 (0.00525)	0.00385 (0.00767)	-0.01326 (0.01188)	0.01091 (0.01144)	-0.00205 (0.01001)
INTERV(t)	0.00455 (0.00390)	0.00836** (0.00333)	-0.00368 (0.01272)	-0.03155** (0.01408)	0.00517 (0.01127)
ln(IMV(t-1))	-0.02110*** (0.00566)	-0.03379** (0.01348)	-0.06616*** (0.02094)	-0.05756*** (0.01686)	-0.05954*** (0.02009)
R^2	0.011	0.0399	0.0461	0.0435	0.0300

(b) SEK/DEM

Parameters	1993-1996	1993	1994	1995	1996
Constant	0.02136** (0.00947)	0.06032* (0.03526)	0.09030*** (0.03179)	0.08021*** (0.029922)	0.01377 (0.01586)
SPEECH(t)	-0.00483 (0.00474)	-0.00971 (0.01049)	0.00174 (0.01043)	-0.00578 (0.010224)	-0.00360 (0.00725)
INTERV(t)	0.00556* (0.00336)	0.00429 (0.00447)	0.01917* (0.01113)	0.00095 (0.012585)	0.00408 (0.00868)
ln(IMV(t-1))	-0.01042** (0.00426)	-0.02637* (0.01491)	-0.04202*** (0.01438)	-0.03369*** (0.012615)	-0.00865 (0.00817)
R^2	0.0077	0.0214	0.0399	0.0173	0.0066

Figure 1. SEK/DEM and SEK/USD for the period January 7, 1993 through December 30, 1996

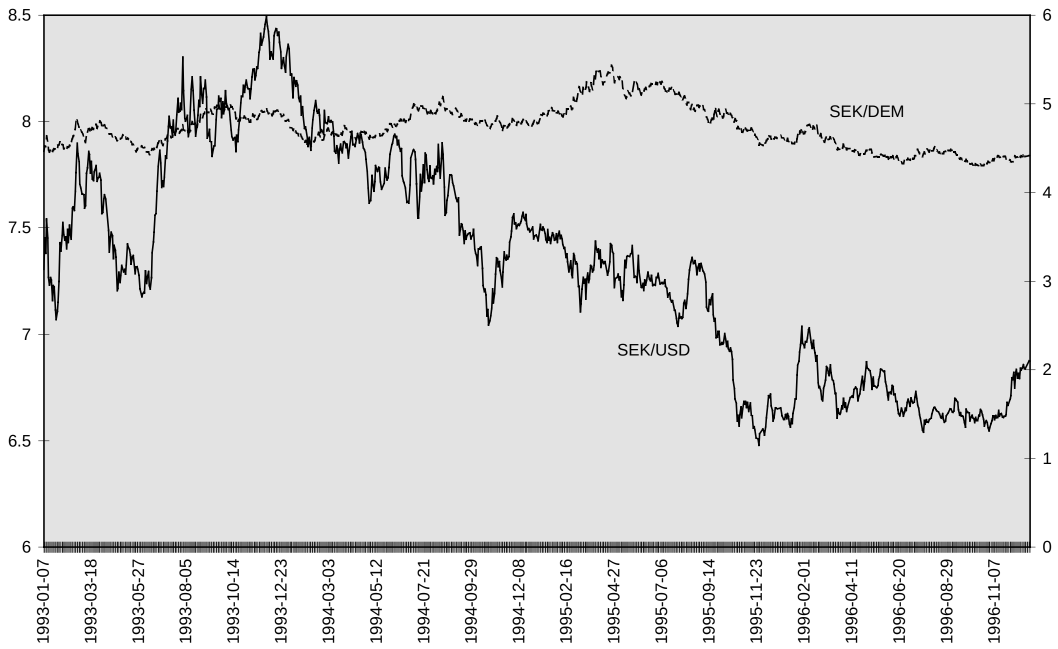

Figure 2. Implied Volatility for SEK/USD and SEK/DEM. January 7, 1993 - December 30, 1996

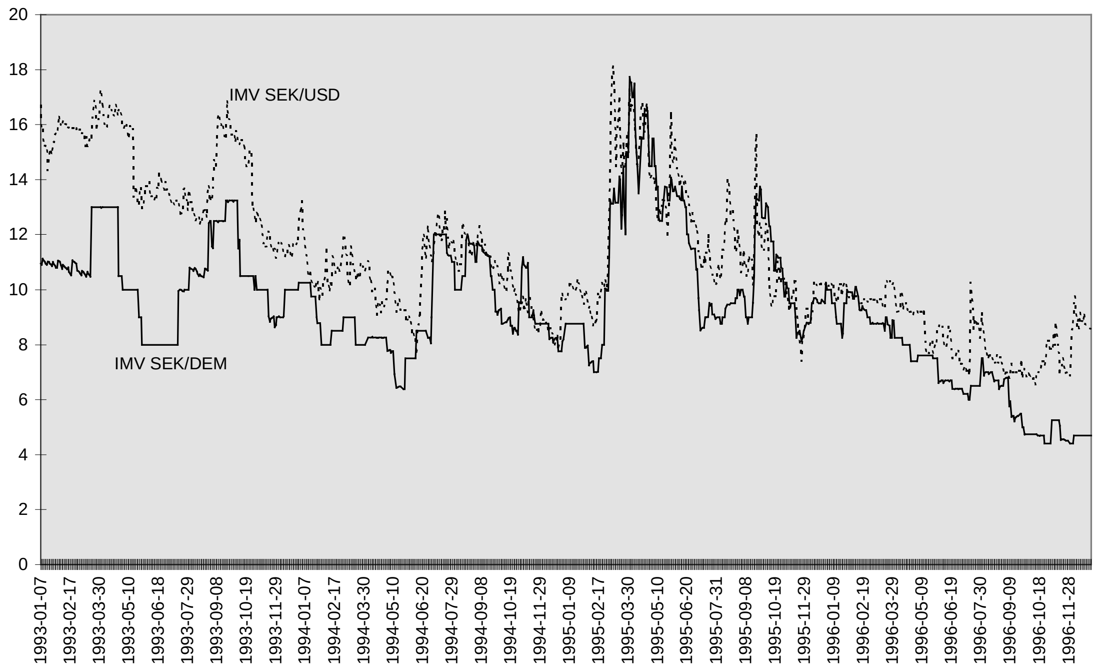

Figure 3. Daily percentage changes in SEK/USD, January 7, 1993 - December 30, 1996

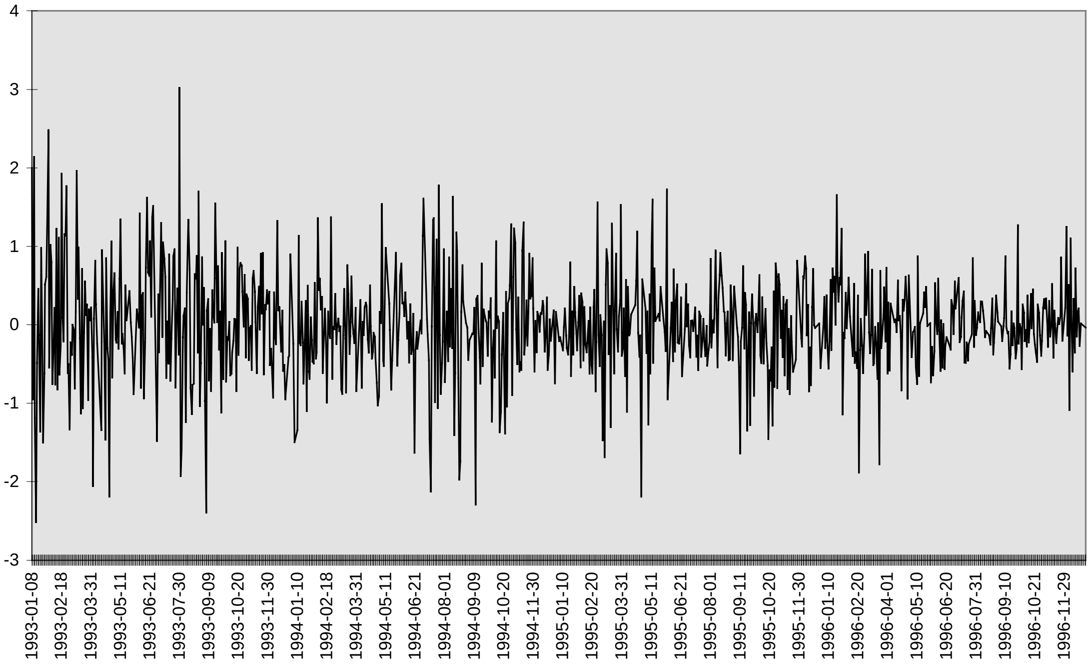

Figure 4. Daily percentage changes in SEK/DEM. January 7, 1993 - December 30, 1996