Central bank interventions and exchange rate band regimes

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Abstract

This paper presents an endogenous switching regression model for the exchange rate process where the switch is defined by the central bank criteria functions for intervening. We study the signal effect of interventions on the exchange rate using Norwegian daily data on official interventions. We first find that interventions seemed to have been more effective in moving the exchange rate in the expected (‘desired’) direction in the regime when the exchange rate was kept away from the edges of the band. This type of intervention regime also reduces significantly the conditional volatility of the exchange rate. Thus, when the exchange rate was near the weakest edge of the currency band, its conditional variance was significantly larger than when it was moving around its central parity. Finally, we show that in order to obtain consistent estimates, intervention variables cannot enter as exogenous variables in the conditional mean (or conditional variance) of the exchange rate. © 2001 Elsevier Science Ltd. All rights reserved.

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1. Introduction

There is still considerable scepticism among economists and policy-makers as to whether sterilized interventions can have any significant effect on the exchange rate. Moreover, the effect of sterilized interventions on the exchange rate has not yet been firmly established in the academic environment.
In the literature, one distinguishes between sterilized interventions, whose monetary effects are neutralized by offsetting domestic liquidity measures, and nonsterilized interventions, which alter money supplies and therefore involve the joint exercise of monetary policy and exchange-market policy. The issue of how the exchange rate is affected by sterilized interventions is controversial since these interventions are not supposed to alter the countries’ relative supplies of domestic and foreign currency in the same way as non-sterilized interventions. In theory, sterilized interventions may affect exchange rates through three hypothetical channels: the portfolio balance\(^1\), the noise trading\(^2\) and the signalling channels.

Here, we study the ‘signalling effect’ of sterilized intervention on an exchange rate in a currency band. The possibility of the ‘signalling effect’ has been suggested by Mussa (1981) who states that interventions (even sterilized) may signal monetary policy objectives. For instance, authorities may need to choose between two options, either to have relatively small variations of the exchange rate within its band, or to allow the exchange rate to move within the entire official band. By intervening frequently inside the band (intramarginally), the central bank may want to signal that it wishes to defend a narrower implicit band than the official one and reduce the volatility of the exchange rate. A different signal is given when interventions occur close to or at the edges of the currency band. The exchange rate is thus allowed to move within the entire band in order to gain some monetary independence (Svensson, 1994).\(^3\)

Interventions are modelled here as dichotomous choices. The effect of interventions on the exchange rate is measured through hazard functions (weighted probabilities of intervention). We find this approach useful when information about interventions is not (at least not immediately) made public to the market. Instead, one can observe the central bank’s participation in the foreign exchange market. In Norway, simultaneous intervention data are not available even in newspapers or similar sources.\(^4\)

On the other hand, we justify the assumption that the market knows when the central bank intervenes by noting that the Norwegian foreign exchange market is

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1 Sterilized interventions will affect the exchange rate through the ‘portfolio channel’ as long as foreign and domestic assets are imperfect substitutes. Sterilized interventions change the relative outstanding supply of domestic assets leading to a necessary change in the expected relative returns and eventually the exchange rate, in order to restore equilibrium. See Henderson (1984).

2 Hung (1997) studies the noise trading channel in order to explain why central banks need to intervene secretly. This author argues that through this channel secret intervention can lead chartists to believe that the prevailing exchange rate trend has been broken and that the trend is reversing. Noise traders may then alter their positions, betting on the intervention-inspired reversal.

3 In this context, monetary independence can be achieved when the exchange rate moves freely within its band and the monetary authorities can adjust, at least for a short time, interest rates to local conditions, for example, by lowering the domestic interest rate in a recession and increasing it during a boom.

4 This approach provides a methodology for the case where only qualitative rather than quantitative data are available to the econometrician and the market. The model can be applied not only to interventions but to other monetary policy variables which are known to be endogenous but are only observed as dichotomous decisions.
significantly smaller than the markets for larger currencies such as the US dollar, Japanese yen or British pound. It is reasonable to expect that it is harder for the Norwegian central bank to intervene without being noticed by market participants.

Hung (1997) introduces the noise trading channel hypothesis in an attempt to explain the negative or positive impact of a secret amount of sterilized intervention on exchange rate volatility. When noise trading is active, authorities may either use volatility-enhancing or volatility-decreasing intervention strategies, depending on how they wish to manage the exchange rate level. Thus, one may conclude secret interventions may undermine rather than strengthen the signalling effect hypothesis since secrecy by definition implies that there is no intention of revealing monetary policy objectives.

A couple of observations are in order here. First, in general, it may be easier for central banks to conceal the amount of intervention (especially if they deal with several private market participants) than it is to conceal their participation in the foreign exchange market. This is particularly the case in small foreign exchange markets such as the Norwegian one. Second, on certain occasions, a central bank may want to signal its intended monetary policy and not to go unnoticed by the market when it is active in the foreign exchange market. On other occasions, central banks cannot avoid being noticed by market participants even when they want to. It is difficult then to distinguish between secret and non-secret central bank participation as well as to know what type of participation economic agents believed was occurring.

Keeping in mind the above observations, we think that it makes little sense to test the noise trading channel hypothesis since central bank participation in the foreign exchange market, especially the Norwegian market, cannot easily be classified as secret. We can then safely argue that since the Norwegian authorities must have known that the central bank’s participation could hardly pass unnoticed, they must have intended to signal their monetary policy objectives when they intervened. Here, we are undoubtedly studying the signal effect of central bank participation on the exchange rate.

In this paper, the following issues are considered. First, interventions are modelled as dichotomous endogenous variables that both depend on and affect the exchange rate. Modelling (our qualitative) interventions as endogenous is of importance because under the hypothesis of signalling effects of interventions, exchange market participants actually revise their expectations when they believe that central bank interventions convey new, additional information. It is then necessary to show that there are certain objectives and criteria for intervening (i.e. to defend an implicit narrower band). If this is the case, interventions may possibly affect the exchange rate because they signal monetary policy objectives. Second, we present the differences in the stochastic process for the exchange rate when it depends on interventions occurring mostly close to or at the edges of the currency band (and the exchange rate is allowed to move within the entire official band) and when it depends on interventions occurring mostly inside the band (and the exchange rate moves within a more narrow band than the official one). Third, we investigate whether interventions close to or
at the edges of the exchange rate target zone affect the time-variant variance of the exchange rate differently than when there are intramarginal interventions.

Fourth, it is shown that the disturbances of the exchange rate mean equation are not only characterized by an autoregressive conditional heteroskedastic (ARCH) process, but also have another source of heteroskedasticity, namely their correlation with the intervention variables.  

Note that the conclusions drawn concerning the first two issues above (the objectives for intervening and the stochastic process for the exchange rate) should indicate whether or not there have been different regimes for Norwegian central bank interventions.

An econometric model that allows us to study the issues described above is presented here. The model is tested using daily data on sterilized spot interventions and the exchange rate for each of two different Norwegian exchange rate policy regimes followed by the Norwegian Central Bank (Norges Bank) between 1986 and 1990. The study covers the period from October 1986 to February 1990, while the regime shift, as announced by the authorities, occurred in mid-June of 1988.  

The first regime allowed the exchange rate to fluctuate between the upper and lower edges of the official currency band with interventions occurring mainly close to and at the edges. In the second regime, the exchange rate was only allowed to move within an unofficial implicit narrower band, within which there have been more frequent interventions by the central bank.

Note that we do not choose Hamilton’s (1989) regime-switching type of model to determine whether a regime switch has occurred as a result of changes in government policies and whether agents anticipated the switch. The introduction of uncertainty about the intervention policy is an interesting topic, but in this paper we would like to test whether the announced policy change did in fact take place and how it has affected the exchange rate. The effect of intervention decisions on the exchange rate variance using the regime-switching methodology is a more difficult task and for the moment is left for future research.

The study most closely related to this paper is that of Lewis (1995a). The main

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5 The literature provides ample empirical evidence that the conditional variance of the exchange rate varies over time, e.g. Cumby and Obstfeld (1984), Domowitz and Hakkio (1985), Hsieh (1989), Diebold and Nerlove (1989) and Mundaca (1991) and Bollerslev et al. (1992). This motivates the use of the ARCH class of models, introduced by Engle (1982), for studying exchange rates since the models take into account many of its important properties, such as its leptokurtic unconditional distribution.

6 The Norwegian target zone until 19 October 1990 had a band equal to ±2.25% around a par exchange rate specified in terms of a trade-weighted basket of foreign currencies. This exchange rate is called the Norwegian currency basket index. From 22 October 1990 until 11 December 1992, the Norwegian krone was pegged to the ECU with a band also equal to ±2.25%.

7 The period of study begins in October 1986 because the data on interventions are only available from that date.

8 The earlier version of this paper (Mundaca, 1989) covered the period between October 1986 and January 1989. There, no distinction was made between different regimes.

9 For this purpose, one would eventually implement the approach of Hamilton and Susmel (1994) where the time-varying variance in each regime would depend on intervention decisions.
difference is that she studies floating DM/$ and Yen/$ rates and that the variance is not parameterized to describe the volatility clustering of these exchange rates. It is, however, already very well established that such clustering or long-run persistence is an important feature of this type of financial times series (see Goodhart and O’Hara, 1997). The intervention series in Lewis are also compiled from daily newspaper accounts from the New York Times, the Wall Street Journal, and the London Financial Times. Other related studies include those presented by Baillie and Osterberg (1997a,b). In the first of these, they estimate the mean of the forward premium and generate its conditional variance. They then use a Probit analysis to test whether the generated conditional variance of the forward premium Granger caused intervention. They, therefore, do not estimate jointly the intervention decision and the mean (and variance) of the forward premium. In Baillie and Osterberg (1997b), they conduct a similar analysis, but in this case, they study the log-change of the spot exchange rate instead of using the forward premium. Hung (1997) studies the effect of a secret amount of intervention on both actual and implied exchange rate volatility. The actual volatility is the ex-post volatility realized at the end of period t, calculated as the annualized standard deviation of daily changes in the log of the exchange rate over 10 weekdays during the 2-week period. Interventions are also considered to be exogenous here. The implied (expected) volatility is constructed using currency option prices provided by the Philadelphia Stock Exchange.

Loopesko (1984), Dominguez (1989) and Dominguez and Frankel (1990) use data on interventions to study their effect on floating exchange rates using the portfolio choice approach. In these studies, interventions are considered exogenous. 10

The model in this paper makes some improvements on previous, related empirical studies of exchange rates. Methodologically, it provides a new model for the process of the exchange rate in a currency band. First, we model the conditional mean and variance of the exchange rate as functions of the intervention decisions. Second, we take into account important statistical properties of the exchange rate, e.g. its long-run volatility persistence and its leptokurtic unconditional distribution. This should improve, compared with previous approaches, the possibilities for studying the effect of the intervention objectives and exchange rate regime on the persistence in volatility. Finally, we model the exchange rate and interventions as determined simultaneously.

The paper is organized as follows: In Section 2, we present a model for the exchange rate conditional on two criteria functions for intervening. In Section 3, some methodological problems are explained. In Section 4, we present the estimates of the model for two different types of intervention regimes. Section 5 concludes.

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10 Edison (1990) has extensively reviewed the literature pertinent to studies on intervention and its effect on exchange rates, including those undertaken for the G-7 Working Group in Exchange Market Intervention (1982–1983), where the best known is the Jurgenson Report. The main conclusion in this report was that sterilized interventions are a relatively weak instrument of exchange rate policy, with little apparent effectiveness beyond the very short run, although this very short run was not defined.
2. A model for the exchange rate conditional on central bank interventions

The argument behind the ‘signalling channel’ is that by intervening, the central bank may want to transmit information about future developments in fundamentals, monetary policy or policy variable targets. If the central bank is successful in convincing market participants that its intervention policy is conveying useful and new information, these market participants may then find that they must revise their expectations about their own relevant fundamentals. Thus, as Lewis (1995b) argues, this hypothesis of the ‘signalling effect of interventions’ requires that interventions be related to monetary policy variables in a systematic way. If so, it is both interesting and important to analyze the motives for intervening. In the next section (Section 2.1), we show how interventions are related to monetary variables. In the next step (Section 2.2), we analyze whether or not interventions affect the exchange rate through the ‘signalling channel’. For reasons given above and in more detail below consistent estimation of the model requires that both interventions and the exchange rate are treated as endogenous variables.

2.1. Modelling the intervention decisions

Given the assumptions that the amounts of intervention are unobservable, at least contemporaneously, and that the market knows when there has been an intervention by the central bank (but not by how much), we find appropriate to model the sterilized interventions buying and selling foreign currency as qualitative variables (i.e. \( M_B^t \) or \( M_B^t = 0 \) and \( M_S^t \) or \( M_S^t = 0 \)). \( M_B \) and \( M_S \) indicate the central bank participation in the foreign exchange market, not the amount of intervention, buying or selling foreign currency respectively during day \( t \).

It follows that for studying the effect of the intervention decisions on the exchange rate, we need to define the dummy variables \( I_B^t \) and \( I_S^t \) that are related to \( M_B^t \) and \( M_S^t \), respectively, as follows:

\[
I_B^t = 1 \quad \text{iff} \quad M_B^t = Y_B^t d_B^t - m_1^t, \quad (1)
\]

\[
I_B^t = 0 \quad \text{iff} \quad M_B^t = Y_B^t d_B^t - m_1^t = 0,
\]

\[
I_S^t = 1 \quad \text{iff} \quad M_S^t = Y_S^t d_S^t - m_2^t, \quad (2)
\]

\[
I_S^t = 0 \quad \text{iff} \quad M_S^t = Y_S^t d_S^t - m_2^t = 0.
\]

Also, \( \delta_B = (\delta_{10}, \delta_{11}, \delta_{12}, \delta_{13}), \delta_S = (\delta_{20}, \delta_{21}, \delta_{22}, \delta_{23}) \), and \( Y_B \) and \( Y_S \) are matrices of explanatory variables (accompanying the \( \delta \)'s) of the decisions to intervene that are defined as:

\[
M_B^t = \delta_{10} + \delta_{11} \left( \frac{1}{Y_r - Y_t} \right) + \delta_{12} \left( \frac{Y_r - Y_{r-1}}{Y_{r-1}} \right) + \delta_{13} \left( \frac{Y_{r-1} - Y_{r-2}}{Y_{r-2}} \right) - \mu_{1r} = Y_B^t \delta_B - \mu_{1r}, \quad (3)
\]

\[
M_S^t = \delta_{20} + \delta_{21} \left( \frac{1}{Y_r - Y_t} \right) + \delta_{22} \left( \frac{Y_r - Y_{r-1}}{Y_{r-1}} \right) + \delta_{23} \left( \frac{Y_{r-1} - Y_{r-2}}{Y_{r-2}} \right) - \mu_{2r} = Y_S^t \delta_S - \mu_{2r}. \quad (4)
\]
Since $M^B$ and $M^S$ are qualitative variables, Eqs. (3) and (4) represent the selectivity criteria functions for intervening. Moreover, given Eqs. (1)–(4), $M^B$ and $M^S$ are defined as having dichotomous realizations $I^B$ and $I^S$, respectively. We can then use the probit ML to estimate the parameter vectors $\delta^B$ and $\delta^S$.

One should also note that $Y^B_t I^B_t$ (in Eq. (3)) is not $E[I^B_t \vert Y^B_t]$ but rather $E[M^B_t \vert Y^B_t]$ and similarly for $Y^S_t I^S_t$ (in Eq. (4)) is $E[M^S_t \vert Y^S_t]$.

$\mu_{jt} (j=1,2)$ are random disturbances which are assumed to be distributed as follows:

$$\mu_{jt} \sim N(0,1),$$
$$\mu_{jt} \sim N(0,1),$$
$$\text{COV}(\mu_{1t}, \mu_{2t}) = 0.$$

$Y^U$ and $Y^L$ represent the upper and lower edges of the currency band, $Y_t$ is the exchange rate at time $t$ (i.e. the Norwegian currency basket index).

The constant terms, $\delta_{10}$ and $\delta_{20}$, represent other factors besides the monetary policy variables that will make the central bank to be either more encouraged or discouraged to participate in the foreign exchange market. These factors can be opportunity costs of using international reserves and costs of labor used when intervening. International reserves may be used in other ways (such as portfolio investments). It can be noted that each intervention is a large operation involving several people (who can otherwise use their time on other activities) and hours in order to make the final decision about when to intervene and by how much. Given the other monetary objectives, if all these factors are of importance, it will result in negative $\delta_{10}$ and $\delta_{20}$. If this is the case, it would indicate that the central bank participates less than it would otherwise have done. The central bank will be more discouraged from intervening in the foreign exchange market. If such factors play a very small role, $\delta_{10}$ and $\delta_{20}$ may be zero or even positive. In this case, independent of the other motives for intervening, the central bank will participate even more frequently than it otherwise would.

The hyperbolic terms accompanying $\delta_{11}$ and $\delta_{21}$ embed assumptions that the central bank participation in the foreign exchange market may increase, and at a greater rate, the closer the exchange rate is to the edges of the band ($Y^U$ and $Y^L$, respectively). Such an effect is greater the larger positive $\delta_{11}$ and $\delta_{21}$ are, in which case the central bank signals its commitment to intervene when the exchange rate reaches its weakest

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11 $\mu_{jt}$ and $\mu_{jt}$ can safely be assumed independent since both selling and buying foreign currency have been observed positive on a given day $t$. This assumption is very well supported by the data, where one can see that on more than one day both selling and buying are different from zero. This should not be interpreted as both types of interventions occurring exactly at the same time, but rather both of them occurring during day $t$.

12 It is worthwhile to mention that we tried to ignore these costs and we obtained estimates that indicate that the central bank never intervened when the exchange rate reached the edges of its band. This is unreasonable since the data indicate that during our period of study, the central bank intervened at the edges of the band and by large amounts. Moreover, using the Schwarz (1978) information criteria (SIC), we find that the SIC selects the model with the constants $\delta_{10}$ and $\delta_{20}$ over the model without them.
or strongest levels. This hyperbolic representation, while arbitrary, is simple and suitable for capturing such effects.

The expressions assigned to the parameters $\delta_{12}$, $\delta_{13}$, $\delta_{22}$ and $\delta_{23}$ are designed to indicate expectations of central bank participation in the foreign exchange market when there have been large undesirable changes, in either direction, in the exchange rate level in the last two days (i.e. the central bank defends a narrower target zone than the official one). The signs of $\delta_{12}$ and $\delta_{13}$ should thus be negative, while $\delta_{22}$ and $\delta_{23}$ should be positive. If $\delta_{12}$ and $\delta_{22}$ (and $\delta_{13}$ and $\delta_{23}$) are statistically significant and relatively large, this indicates that interventions are expected to be intramarginal. If these coefficients differ (in absolute terms), then the central bank may have used an asymmetric intervention policy, indicating that it may dislike a depreciation more than an appreciation of the exchange rate within the band or vice versa. Similarly, if $\delta_{11}$ and $\delta_{21}$ are significantly different, it indicates that the intervention decisions are asymmetric when the exchange rate approaches, respectively, the strongest and weakest edges of the currency band.

Note also that if $\delta_{12}$, $\delta_{13}$, $\delta_{22}$ and $\delta_{23}$ are relatively small, both numerically and statistically, while $\delta_{11}$ and $\delta_{21}$ are larger and significant, this will indicate that interventions largely take place close to or at the edges of the exchange rate band. The central bank is then conveying information to the market that small variations in the exchange rate within its band had a low priority. Using the same argument, if $\delta_{12}$, $\delta_{13}$, and $\delta_{22}$ and $\delta_{23}$ are the only significant parameters, and $\delta_{11}$ and $\delta_{21}$ are small, it should indicate that the central bank objectives are to keep the exchange rate well inside its band and minimize daily variability, and is less committed to defending the band by intervening when the exchange rate gets close to its edges. A combination of these two motivations for intervening may of course be possible. The estimated values of the intervention decision rules will indicate whether or not there has actually been a regime shift in the Norwegian central bank intervention policy in June 1988 as the authorities announced.

The assumptions about the determinants of intervention decisions may be somewhat ad hoc but no more so than those of existing theoretical target zone models and those in empirical studies (e.g. Lewis, 1995a; Baillie and Osterberg, 1997b). In Lewis (1995a), for example, current intervention decisions are modelled to depend on the last-period exchange rate, while in Baillie and Osterberg (1997b), current interventions are determined by current deviations of the exchange rate from its target and current deviations of the conditional variance of the exchange rate.

13 Introducing $(Y_{t} - Y_{t-1})$ and $(Y_{t} - Y_{t-1})$ linearly will not capture the idea of greater expected participation of the central bank the closer the exchange rate gets to its boundaries. They rather indicate that, for given $\delta_{11}$ and $\delta_{21}$, the closer the exchange rate gets to its boundaries, the smaller expectations of central bank participation. This should mean that the only objective of the central bank is to defend an implicit narrower band (if $\delta_{12}$ and $\delta_{22}$ are, for example significant) and not to intervene much when the exchange rate reaches the edges of its band. To gain and maintain credibility, it is perhaps important to do so.

14 Since the decisions for intervening selling and buying are modelled separately, the squared of daily change in the exchange rate cannot enter as a motive for intervening, since squared depreciations and appreciations cannot be distinguished from each other.

15 Baillie and Osterberg (1997b) considered the target rates documented by Funabashi (1989).
(derived from an univariate GARCH model for the exchange rate) from the statistical average of that conditional variance.

Here, the criteria functions for intervening indicate the central bank’s motives for intervening and consequently the fashion in which the currency band will be managed. If the central bank wishes to have a credible exchange rate policy, it has to transmit to the market its willingness and commitment to defend the official band by intervening when the exchange rate approaches its boundary limits or to avoid a substantial depreciation/appreciation of the exchange rate by defending a narrower implicit band than the official one.

2.2. Specification of the model for the exchange rate

In order to illustrate the basic signalling hypothesis about the effect of central bank interventions on the exchange rate, the standard asset-pricing model for the exchange rate is considered here. The exchange rate is then assumed to be a forward-looking process that is expectationally efficient with respect to public information:

$$\log(Y_t) = (1-\theta) \sum_{j=0}^{\infty} \theta^j E_t[\log(f_{r,t+j})|\Omega_t]$$

Eq. (5) indicates that the log of the exchange rate ($\log(Y)$) is a function of the discounted value (with discount factor $\theta$) of current and expected future (log) fundamentals ($\log f$), which are normally thought of as the forcing variables including central bank interventions, while $\Omega_t$ is the public information set at time $t$. As mentioned above, for the signalling hypothesis to be valid, it is first necessary that interventions convey additional information so as to make the information set $\Omega_t$ larger. Given this, the market participants may find it worthwhile to revise their expectations about future movements in the fundamentals. It is then important that interventions reveal a certain policy rule that the central bank wished to follow. If $\delta_{12}$, $\delta_{13}$, and $\delta_{22}$ and $\delta_{23}$ are large, one would expect interventions to have a considerable effect on the exchange rate, particularly in reducing its volatility. In the next section we will first present the estimates of the criteria functions for intervening during the period for each of the two regimes.

With the econometric model presented below, the hypothesis of the signalling effect of the intervention policy on the exchange rate will be tested. The exchange rate is assumed to follow a truncated ARCH process where interventions (which are treated as endogenous) affect both the conditional mean and variance in each of the regimes mentioned above. While not founded strongly in economic theory, this takes into account several recognized statistical properties of the exchange rate. The estimates of the model for the exchange rate should provide empirical evidence about the signalling effect of central bank interventions on the exchange rate.

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16 One may argue that in fact we will be testing a joint hypothesis: The efficiency of the exchange rate market implied by Eq. (5) and the effectiveness of the intervention policy.
To arrive at the final econometric model of this paper, define first the following general empirical model for the one period change in the exchange rate, where $X_t$ is equal to log($Y_t/Y_{t-1}$):

$$X_t = W_t \beta + \epsilon_t,$$

(6)

where $\epsilon_t$ is the disturbance and $W_t$ may include lagged values of $X$ and explanatory exogenous variables. Note however that in Baillie and Osterberg (1997a,b), interventions are included in $W_t$ and considered exogenous but this is not the case here. Eq. (6), we claim, represents the exchange rate process only when it is not affected by endogenous central bank interventions or central bank decisions to intervene.

To underline the importance of considering central bank interventions as endogenous, we will now illustrate how biases may arise when this endogeneity is not taken into account. Econometrically, Eq. (6), independent of our assumptions about the distribution of the disturbances $\epsilon_t$, cannot represent the correct process for the exchange rate in a currency band regime nor be consistently estimated. This is because in reality central bank decisions to intervene affect the exchange rate and these decisions may depend on the exchange rate deviation itself. Our empirical model will not be Eq. (6) because the coefficient (vector) $\beta$ in Eq. (6) cannot be consistently estimated as $\epsilon_t$ is correlated with the intervention decision variables, as follows:

$$E[\epsilon_t | M_{t-1}^B > 0; \Omega_{t-1}] \neq 0,$$

$$E[\epsilon_t | M_{t-1}^S > 0; \Omega_{t-1}] \neq 0,$$

$$E[\epsilon_t | M_{t-1}^B = 0; \Omega_{t-1}] \neq 0,$$

$$E[\epsilon_t | M_{t-1}^S = 0; \Omega_{t-1}] \neq 0,$$

where $\Omega_{t-1}$ is the information set available at time $t-1$. It is essential to note that this correlation implies that intervention decisions, $M_t$, cannot simply be included in $W_t$ as one more exogenous explanatory variable, as is commonly done, but should be modelled as endogenous. One should then account for the correlation between the $\epsilon$’s and the $M$’s to measure correctly the effect of intervening on the exchange rate.

Therefore, due to the correlation between $\mu_t$ and $\epsilon_t$; $i = 1,2$, we have that Eqs. (1–4) and (6) constitute an endogenous switching regression model for the exchange rate, where the switch is defined by the criteria functions (1)–(4). Hence, following the work of Johnson and Kotz (1972) and Olsen (1980), we have that:

$$E[X_t | M_{t-1}^B > 0; M_{t-1}^S > 0; \Omega_{t-1}] = V_d \beta + E[\epsilon_t | M_{t-1}^B > 0; M_{t-1}^S > 0; \Omega_{t-1}] = V_d \beta$$

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17 For example, $\epsilon_t$ could be assumed to follow a ARCH process. This assumption is not actually crucial for the point to be made now.

18 Endogenous switching regression models have been applied to labor markets by Maddala and Nelson (1975), Heckman (1978) and Lee (1978) (see also Maddala, 1983 for other examples) but to our knowledge never to the exchange rate. Censored variable models (where the central parity is treated as a censored variable) have been used by Edin and Vredin (1993) to estimate devaluation risk in a target zone in the Nordic countries. The two-limit tobit model has been considered by Pesaran and Samiei (1992) to study the observable exchange rate truncated by the bounds of the currency band.
\[ E[\sigma_{\varepsilon_1}\mu_1|\mu_1^B<Y_1^B;\Omega_{t-1}]+E[\sigma_{\varepsilon_2}\mu_2|\mu_2^B<Y_2^B;\Omega_{t-1}]=V\beta \]  
\[ -\sigma_{\varepsilon_1}E[\mu_1|\mu_1^B<Y_1^B;\Omega_{t-1}]-\sigma_{\varepsilon_2}E[\mu_2|\mu_2^B<Y_2^B;\Omega_{t-1}]=V\beta \]  
\[ -\sigma_{\varepsilon_1}^{\mu_1}\phi(Y_1^B)/\Phi(Y_1^B)-\sigma_{\varepsilon_2}^{\mu_2}\phi(Y_2^B)/\Phi(Y_2^B) \]

or simplifying notation:

\[ X_t=F(V_t,\phi_B,\Phi_B,\phi_S,\Phi_S,\beta,\sigma_{\varepsilon_1,\sigma_{\varepsilon_2}})+\zeta_t \]

\(\zeta_t\) is the new disturbance of the mean equation for \(X_t\) with the following characteristics:

\[ \zeta_t|M_t^B>0;M_t^S>0;\Omega_{t-1}~N(0,h_t^B) \]

where:

\[ \zeta_t=e_t+\sigma_{\varepsilon_1}^{\mu_1}\phi(Y_1^B)/\Phi(Y_1^B)+\sigma_{\varepsilon_2}^{\mu_2}\phi(Y_2^B)/\Phi(Y_2^B) \]

\(\zeta_t\) here has a conditional mean equal to zero and a conditional variance equal to \(h_t^B\):

\[ h_t^B=\alpha_0+\sum_{i=1}^q\alpha_i\zeta_{t-i}+\sum_{j=1}^p\gamma_jh_{t-j}^{*}-\pi_1^*\left(\phi(Y_1^B)/\Phi(Y_1^B)^2\right)-\pi_2^*\left(\phi(Y_2^B)/\Phi(Y_2^B)^2\right) \]

where \(p\geq0, q>0; \alpha_0>0, \alpha_i\geq0\) for \(i=1,2,...,q;\) and \(\gamma_j\geq0\) for \(j=1,...,p.\) \(V_t\) in Eq. (7) is the matrix with all possible exogenous variables that explain the exchange rate and therefore it does not include the intervention variables. If we know the values of the parameter vectors \(\delta^B\) and \(\delta^S\), we can obtain the values of the random variables \(g_t^B=Y_t^B\delta^B\) and \(f_t^S=Y_t^S\delta^S\) and then the corresponding \(\phi\) and \(\Phi\), where \(\phi\) is the density function (pdf) and \(\Phi\) is the cumulative distribution function (cdf) of the random variables \(g^B\) and \(f^S\).

Note that \(\phi(g_t^B)/\Phi(g_t^B)\) and \(\phi(f_t^S)/\Phi(f_t^S)\) are the truncated means of \(E[\mu_1|\mu_1^B<\delta^B Y_t^B]\) and \(E[\mu_2|\mu_2^B<\delta^S Y_t^S]\), respectively, and represent the conditional distributions of \(M_t^B(\cdot)\) and \(M_t^S(\cdot).\) \(\sigma_{\varepsilon_1}^{\mu_1}\) and \(\sigma_{\varepsilon_2}^{\mu_2}\) are the covariances between the disturbances of the exchange rate mean Eq. (6) and the disturbances of the criteria functions for intervening Eqs. (3) and (4), respectively.

Therefore, consistent estimates of the signalling effect of central bank participation in the foreign exchange market on the exchange rate are obtained by estimating Eqs. (7) and (9) (and not Eq. (6)). Eq. (8) shows the nature of the heteroskedasticity of the disturbance \(\zeta_t:\) This is uncorrelated with the intervention decision variables and follows a GARCH process.\textsuperscript{19,20} One advantage of this class of time series model is

\textsuperscript{19} Note that the combination of Eqs. (7) and (8) yields Eq. (6).
\textsuperscript{20} We here generalized by defining a GARCH model although we estimate Eqs. (7) and (9) by testing first for simply ARCH. The GARCH model was introduced by Bollerslev (1986).
that the conditional variance is allowed to change over time. The conditional variance (9) is the GARCH measure of exchange rate uncertainty and long-run persistence of the exchange rate volatility.

Eqs. (7) and (9) describe the process for the exchange rate and may be viewed as a GARCH process for the exchange rate regulated by interventions. One could then call this model a ‘GARCH-Switching Regression Model with Endogenous Switching’.

The estimation strategy then consists of a two-stage method to estimate the parameters of interest. This procedure as suggested by Heckman (1978) and Lee (1978). In the first step we estimate Eqs. (1) and (2) with observations \( I^B \) and \( I^S \) as a typical probit model to obtain the estimates of the \( \delta \)'s and thereafter \( \phi(g^B)/\Phi(g^B) \) and \( \phi(f^S)/\Phi(f^S) \).

In the second step, we estimate Eqs. (7) and (9) by numerically maximizing the standard log likelihood function for GARCH models. This log likelihood function for a sample of \( T \) observations is:

\[
L_t = T^{-1} \sum_{t=1}^{T} \left( -\frac{1}{2} \log h_t - \frac{1}{2} \chi^2_t \right). \tag{10}
\]

3. The Norwegian exchange rate regimes and methodological considerations

As mentioned above, during the period studied, Norges Bank seemingly had two exchange rate policy regimes which also became publicly announced. In the first regime (October 1986–mid-June 1988), Norges Bank sold and bought foreign currency basically only when the currency basket index approached the upper and lower limits of its band (114.5 and 109.5, respectively), i.e., when the Norwegian krone was at its weakest and its strongest. This appears to be confirmed in Figs. 1 and 2.

In the second regime (mid-June 1988 until February 1990), interventions were much more frequent, apparently in order to reduce movements of the currency basket index within the band. Thus, Norges Bank was in effect defending a more narrow implicit currency band. Note that in November 1988 the bank also intervened at the edge of the band, obviously to prevent the currency basket index from moving outside the band, see Figs. 3 and 4.

We can therefore a priori distinguish between two regimes, based both on the authorities’ own declaration and on empirical observations of the intervention patterns during the period of study. This has prompted to an empirical test of whether there have been two intervention policy regimes.

In contrast to what the target zone models predicts, the Norwegian Central Bank would...
has sterilized all its interventions even when the exchange rate moved within the whole band. The main reason for this is that the Norwegian monetary authorities aimed to smooth the variability of the interest rate and have some control themselves over the short-run domestic interest rate. They sterilized the interventions because they wanted to have some monetary independence. For that, it was then necessary to leave money supply unchanged after an intervention. During our period of study the authorities wanted to lower the interest rates even when the Norwegian krone was in quite a few occasions in the weak side of its band and that there was large amount of interventions selling foreign currency. In fact, from our second regime, Norway experienced decreasing interest rates.
One important econometric problem needs to be faced, namely the high degree of simultaneous interaction between the exchange rate and interventions. It is difficult to identify the intra-day simultaneous effect between these two variables, since we do not know at what time interventions occur on a given day. This problem becomes more severe inasmuch as Norges Bank may intervene more than once on a given day and timing data are not available.

This problem is dealt with by first assuming that Norges Bank’s decision to intervene on day \( t \)\(^{22} \) depends on how close the currency basket index observed at 11.30 a.m.

\(^{22}\) Strictly speaking, interventions are assumed to have occurred at any time between 11.30 a.m. and 4:00 p.m. on day \( t \).
a.m. on day $t$ is to the lower and upper edges of the currency band (109.5 and 114.5, respectively); on the daily changes of the exchange rate from 11.30 a.m. on day $t-1$ to 11.30 on day $t$; and on the daily changes of the exchange rate from 11.30 a.m. on day $t-2$ to 11.30 on day $t-1$.

Second, we measure $X_t$ as $\log\left(\frac{Y_t^{4.00}}{Y_t^{11.30}}\right) \times 1000$, the change in the log of the currency basket index (*1000) between 11.30 a.m. and 4.00 p.m. on day $t$. $X$ is plotted in Figs. 5 and 6.23

Regarding the first assumption, if the Bank mostly intervenes before 11.30 a.m.,

$$X_t = \log\left(\frac{Y_t^{4.00}}{Y_t^{11.30}}\right) \times 1000$$

23 The Norwegian exchange market closes at 4.00 p.m.
this means that the reaction functions of Norges Bank are explained by endogenous variables (the currency basket index observed at 11.30 a.m.). This would imply a risk that the model may be misspecified. We will still claim that the chosen alternative makes the best use of the data available.

4. Empirical results

4.1. The intervention equations

We proceed to estimate Eqs. (3) and (4) with observations $I^B$ and $I^S$ as a standard probit model and to obtain the estimates of $\delta_{ij}$. It is important to avoid overparameterization when calculating the cumulative and probability distributions of $M^B$ and $M^S$, and we find that not all the $\delta_{ij}$ coefficients are significant at any reasonable level. We reestimate Eqs. (3) and (4) with only the variables that initially yield significant estimates.\(^{24}\)

The estimates of the intervention criteria functions are presented in Table 1. The probit-estimated parameters have the expected signs and are all significant at the 1% level. We find that there have been two different regimes but clearly not with only marginal interventions in one regime or only intramarginal interventions in the other. In the first regime there were high probabilities of intervening close to and at the

<table>
<thead>
<tr>
<th></th>
<th>First regime</th>
<th>Second regime</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\delta_{10}$</td>
<td>$-2.1046$</td>
<td>$-0.8055$</td>
</tr>
<tr>
<td></td>
<td>($-13.793$)</td>
<td>($-10.7152$)</td>
</tr>
<tr>
<td>$\delta_{11}$</td>
<td>$1.2875$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>($9.9543$)</td>
<td></td>
</tr>
<tr>
<td>$\delta_{12}$</td>
<td></td>
<td>$-0.5339$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>($-6.6604$)</td>
</tr>
<tr>
<td>$\delta_{13}$</td>
<td></td>
<td>$-0.2856$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>($-3.9427$)</td>
</tr>
<tr>
<td>$\delta_{20}$</td>
<td>$-1.7657$</td>
<td>$-1.2261$</td>
</tr>
<tr>
<td></td>
<td>($-13.2925$)</td>
<td>($5.260$)</td>
</tr>
<tr>
<td>$\delta_{21}$</td>
<td>$1.4488$</td>
<td>$1.7785$</td>
</tr>
<tr>
<td></td>
<td>($7.999$)</td>
<td>($3.0746$)</td>
</tr>
<tr>
<td>$\delta_{22}$</td>
<td>$0.176$</td>
<td>$0.5199$</td>
</tr>
<tr>
<td></td>
<td>($4.6288$)</td>
<td>($7.1425$)</td>
</tr>
<tr>
<td>$\delta_{23}$</td>
<td>$0.1664$</td>
<td>$0.2371$</td>
</tr>
<tr>
<td></td>
<td>($4.3629$)</td>
<td>($3.832$)</td>
</tr>
</tbody>
</table>

\(^{a}\) The $t$-values in parentheses.

\(^{24}\) The results of estimating the reaction functions (3) and (4) in their general form can be obtained from the author on request.
edges of the band. But there was also some probability of intervening intramarginally in response to daily depreciations/appreciations of the Norwegian krone.

The second regime is by contrast characterized by higher probabilities of frequent interventions in comparison to the first regime. We find there that $\delta_{22}$ and $\delta_{23}$ are significantly larger in the second regime than in the first regime, while $\delta_{12}$ and $\delta_{13}$ are significant only in the second regime. Basically, in the first regime, only depreciation and not appreciation within the band was avoided but less so than in the second regime where there was a high commitment to avoiding large deviations from the central parity.

We also observe that in the second regime, movements in the exchange rate towards the strongest edge of the band did not influence Norges Bank’s interventions. The estimated value of $\delta_{11}$ (for the second regime), which is not presented here, was small and statistically insignificant. This is in constrast to the parameter $\delta_{21}$, which is equally large numerically in the second regime as in the first regime, implying high probabilities of intervening when the exchange rate approached the weakest edge of its band in both regimes.

Another result is that in the first regime, the probability of intervening was equally large when the currency basket approached the upper ($Y_U$) and the lower ($Y_L$) bound of the currency band (i.e. $\delta_{11}$ is numerically and statistically similar to $\delta_{21}$). In the second regime, the probability of intervening was equally large when the Norwegian krone depreciated as when it appreciated between days (i.e. $\delta_{12}$ and $\delta_{13}$ are numerically and statistically similar to $\delta_{22}$ and $\delta_{23}$ respectively).

The factors other than the monetary policy objectives, that affect the intervention decisions and represented by $\delta_{10}$ and $\delta_{20}$, turn out to be negative and significant in both regimes but more so in our first regime. This indicates that for given other monetary objectives, the central bank participation in both regimes must have been less frequent than it would have been otherwise. Moreover, these results also explain why there were more interventions in our second regime. We pointed out above that in the second regime there were significantly more intramarginal interventions than in the first regime.

A main conclusion is then that only in the second regime did Norges Bank have the objective of minimizing the variance of the exchange rate, while in the first regime interventions took place mainly to prevent the exchange rate from moving outside the currency band. This result supports our prior hypothesis, and the authorities’ statements, that there actually was a regime shift during the period we study. It is also of interest with regard to investigating the signalling effect of interventions on the exchange rate. One main hypothesis that needs to be tested is that in the second regime, the Norwegian krone was more stable (inside its own band) because interventions aimed to reduce the exchange rate volatility in that regime.

4.2. The effect of interventions on the exchange rate

The effect on the conditional means as a result of interventions, is also obtained and presented. We here test in which regime interventions have been more effective in changing the exchange rate in the desired direction.
The use of daily data has some disadvantages: there are not many explanatory variables on the daily basis that can be included in the matrix $V$ in Eq. (6). For this reason we will be constrained to use the lagged values of $X$ as exogenous explanatory variables. The estimates presented in this section are the result of numerically maximizing Eq. (10).

4.2.1. First regime

The estimated model is here an ARCH model conditional on interventions, which was determined after performing the relevant tests for the inclusion of $h_{t-1}$ and the order of the ARCH process. The estimates with the $t$-statistics in parentheses, are:

$$X_t = \frac{0.0675}{(-1.3581)} X_{t-1} + \frac{0.0231}{(0.491)} X_{t-2} + \frac{0.0209}{(0.681)} \frac{\phi(M^B(Y^B_t \delta^B))}{\Phi(M^B(Y^B_t \delta^B))} + \frac{0.0194}{(0.977)} \frac{\phi(M^S(Y^S_t \delta^S))}{\Phi(M^S(Y^S_t \delta^S))} + \xi_t,$$

$$h_t = \frac{0.000068}{(1.54)} + \frac{0.0592}{(1.461)} \sigma^2_{t-1} - \frac{0.1067}{(-9.214)} \xi^2_{t-2} + \frac{0.0211}{(2.011)} \xi^2_{t-3} - \frac{0.0085}{(-0.478)} \left( \frac{\phi(M^S(Y^S_t \delta^S))}{\Phi(M^S(Y^S_t \delta^S))} \right)^2 + \frac{0.0354}{(1.636)} \left( \frac{\phi(M^S(Y^S_t \delta^S))}{\Phi(M^S(Y^S_t \delta^S))} \right)^2.$$

4.2.2. Second regime

The estimated model determined after performing the relevant tests is the following GARCH model with the $t$-ratios in parentheses:

$$X_t = \frac{0.0978}{(1.566)} X_{t-1} + \frac{0.0228}{(0.394)} X_{t-2} + \frac{0.0809}{(3.8)} \frac{\phi(M^B(Y^B_t \delta^B))}{\Phi(M^B(Y^B_t \delta^B))} - \frac{0.0883}{(-3.78)} \frac{\phi(M^S(Y^S_t \delta^S))}{\Phi(M^S(Y^S_t \delta^S))} + \xi_t,$$

$$h_t = \frac{0.00001}{(4.49)} + \frac{0.0585}{(2.139)} \sigma^2_{t-1} + \frac{0.7812}{(19.04)} h_{t-1} - \frac{0.0209}{(-6.533)} \left( \frac{\phi(M^B(Y^B_t \delta^B))}{\Phi(M^B(Y^B_t \delta^B))} \right)^2 - \frac{0.0159}{(-3.57)} \left( \frac{\phi(M^S(Y^S_t \delta^S))}{\Phi(M^S(Y^S_t \delta^S))} \right)^2.$$

In the first regime, we find that the parameters of the buying and selling indicator in the mean equation are statistically insignificant at any reasonable level. However, in the second regime, these parameters are significant and have the correct signs.

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25 Parameters corresponding to higher autoregressive order of $X$ in the mean equation were also found statistically and numerically insignificant at any reasonable level.

26 The specific results of the relevant hypothesis tests can be obtained from the author and are not presented here due to space limitations. It should also be mentioned that the estimation and the hypothesis testing for ARCH and GARCH models have been treated extensively by Engle (1982) and Bollerslev (1986).
This indicates that interventions in this regime may have accomplished their objectives, namely to avoid a large daily depreciation or appreciation of the exchange rate.

One way to interpret the above results for the first regime where interventions occur mostly close to or at the edges of its band, is that there were expectations that central bank participation depends heavily on the position of the exchange rate in its band. In this specific regime, interventions were not expected to aim at avoiding a large depreciation or appreciation of the exchange rate inside its band and this was signalled to the market. Because of this, it becomes difficult to measure the overall effect of central bank participation on daily changes in the exchange rate. In the middle of the band, the market may have expected for further appreciation or depreciation of the Norwegian krone. It is then reasonable that when the exchange rate is allowed to move inside the entire band, interventions are less effective away from the edges of the band and more effective at the edges (as central bank participation in the foreign exchange market is more certain). Strong evidence to support this argument is that during our period of study, the Norwegian exchange rate did not experience a realignment. This is perhaps the reason why the total effect (from a statistical point of view) of the decision to intervene appears to be weak in this first regime. 27

In the second regime, however, the market may have understood that the central bank aimed to keep the exchange rate stable (within a narrower implicit band). Then interventions could have been more effective since market expectations were ‘moving together’ with the central bank’s objective. By intervening to defend a narrower implicit band than the official one, the authorities were signalling that the large variation of the exchange rate within its band was not desirable and that they were committed to using whatever means necessary to keep the exchange rate away from the edges of its band.

A conclusion is that the type of intervention policy pursued in the second regime may have been responsible for the effectiveness of central bank participation in the foreign exchange market defending the exchange rate in any part of its band. Note for example in Figures Fig. 4 that even though the exchange rate has left the weakest edge of its band (around December 1998) and is well inside the band after that, the central bank continued intervening (or participating in the market). This is very much in contrast to the first regime, when the market was clearly less certain about the central bank’s goals on depreciation within the band.

Regarding the variance equation, in the first regime the coefficients corresponding to the selling indicator are statistically significant at the 10% level. They indicate that

27 One extension of this paper could be to consider the covariances and \( \sigma_{u_1} \) and \( \sigma_{u_2} \) of Eq. (6) for the first regime as changing continuously and endogenously. For this purpose the smooth transition regression model of Granger and Teräsvirta (1993) would be useful. This would imply that the covariances \((\sigma_{u_1} \text{ and } \sigma_{u_2})\) are modelled as changing continuously with, for example, the location of the exchange rate in the band. If the hypothesis that the effect of interventions depends on the location of the exchange rate in its band is valid, this would imply that \( \sigma_{u_1} \) and \( \sigma_{u_2} \) may take the right expected values the closer the exchange rate was at the edges of its band, but not necessarily in other parts of the currency band.
interventions may have increased the volatility of the exchange rate in this regime. In the second regime, we find that interventions by buying and selling foreign currency have both reduced the volatility of the exchange rate, and that the corresponding parameters are clearly significant statistically.

These results indicate that central bank participation in the foreign exchange market was more successful in reducing the volatility of the exchange rate in the second regime. When interventions only occur close to or at the edges as in the first regime, the volatility was greater. Our conclusion is that the type of intervention policy followed by the Norwegian central bank in the second regime signalled to the market that a large volatility of the exchange rate inside its band was not desirable. The market must have obtained such a signal, and therefore interventions accomplished their objectives.28

Figs. 7 and 8 display the conditional standard deviations of the exchange rate for the first and second regimes, with and without intervention effects. The figures refer to the scaled variable \( X_t = 1000 \times \log(Y_{4.00pm}^t/Y_{11.30am}^t) \). We believe it is important to compare the differences in these estimated conditional variances of \( X_t \). From Figs. 7 and 8, it is easy to see that we could obtain biased estimates of those conditional variances if interventions were not taken into account. We concentrate now on the dotted plots of the conditional variances. From them we can make two important observations. One is that in the first regime, where interventions primarily occur

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28 We cannot argue that we test the predictions of the target zone models since these models assumed nonsterilized intervention. It is however worthwhile to recall that Krugman (1991) found that the variability of the exchange rate is smallest at the edges of its band where the exchange rate must be locally predictable, and largest in the middle of its band. Low volatility, in turn, should keep the exchange rate in the neighbourhood of the edges for a relatively long time once it gets there. While Bertola and Caballero (1992) in an alternative target zone model with exogenous realignments find that when the currency band is not credible, the volatility of the exchange rate is larger at the edges of the band.
close to or at the edges of the currency band (see Fig. 1) and the exchange rate fluctuates rather freely within the band (see Fig. 2), the variance of the exchange rate is larger near the weakest edge of the band than when the exchange rate is well inside the band. The other is that in the second regime, when interventions take place to reduce the daily fluctuations of the exchange rate and they therefore occur quite often, the variance is smaller than in our first regime.

5. Conclusions

In this paper a particular process for the exchange rate is studied, namely an ARCH or GARCH process that depends on the intervention decisions and on the type of exchange rate policy regime. The conclusions are summarized as follows. First, we have found that only in the second of our two regimes did Norges Bank have the objective of minimizing the variance of the exchange rate, while in the first regime interventions took place mainly to prevent the exchange rate from moving outside the currency band. Second, interventions seem to have been more effective in moving the exchange rate in the expected ('desired') direction in any part of the currency band in the regime when the exchange rate was kept away from the edges of the band and a narrower currency band was defended (the second regime).

A third conclusion is that, in the second regime, the conditional variance of the exchange rate is significantly smaller than in the first regime. More specifically, central bank interventions in the form of buying and selling foreign currency have reduced the volatility of the exchange rate in the second regime, while interventions selling foreign currency seem to have increased the volatility of the exchange rate in the first regime. One main reason that central bank participation in the foreign exchange market was more successful in reducing the volatility of the exchange rate in the second regime must have been the signaling effect of the objectives of the
central bank. These were to keep the exchange rate as close as possible to the central parity or to defend a narrower implicit band.

A last conclusion is that if we do not include the intervention decisions as explanatory variables in the conditional mean and variance of the exchange rate, we may obtain biased estimators of the magnitude and persistence of the variance, as can be seen in Figs. 7 and 8. Moreover, the exclusion of this intervention variable as an endogenous explanatory variable in the ARCH or GARCH models can result in heteroskedastic disturbances in the autoregressive exchange rate equation. Disregarding this heteroskedasticity would result in inconsistent estimators.

One should also note that most of the studies modelling the exchange rate as an autoregressive (univariate or multivariate) conditional heteroskedastic process have been little concerned with finding the causes of exchange rate volatility. Here, we have tried to study the effects of interventions by the Central Bank of Norway (Norges Bank) not only on the mean but also on the volatility of the Norwegian currency basket.

The results strongly indicate the importance of modelling interventions and exchange rates as interdependent variables. Certainly, more detailed information on intervention activity (i.e. when it does take place) would make it possible to build and estimate more appropriately specified models of these relationships.

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