EXCHANGE RATE VOLATILITY AND HETEROGENEITY*

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Abstract

This study sheds light on the role played by heterogeneity in the relation between market activity and exchange rate volatility, through an investigation of the relation between the volatility in the Norwegian krone against the Euro and NOK/EUR spot transaction volume by banks in Norway. Whereas an increase in global interbank market activity as measured by an increase in quote frequency increases volatility, our results do not suggest that an increase in the currency transaction volume of banks in Norway has an effect on exchange rate volatility. Neither do the results suggest that the part of currency transaction volume that is with foreign traders has greater effect on volatility than the part that is with traders inside economy, nor that the currency transaction volume of bigger banks has a greater effect than that of smaller banks.

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1 Introduction

This study sheds light on the role played by heterogeneity in the relation between market activity and exchange rate volatility, through an investigation of the relationship between the volatility of the Norwegian Krone (NOK) against the Euro (EUR) and NOK/EUR spot trading volume in Norway. The relationship between volatility and volume is commonly analysed in terms of the joint hypothesis that the evolution of the exchange rate in question is compatible with a random walk model—this implies that volatility over a given period depends on the number of steps or speed of evolution within that period, and that volume reflects the number of steps. This joint hypothesis is often associated with Clark (1973), who suggested that variation in the trading volume of common stocks reflected variation in the rate at which information arrived to the market. However, since volume also reflect calendar effects (holidays, say) and institutional changes we will not restrict ourselves to Clark's explanation. Moreover, as proposed by Tauchen and Pitts (1983), a general increase in volume might have the opposite effect on volatility than that suggested by Clark (1973). In terms of the random walk metaphor, a general increase in volume might reflect increased liquidity which could lead to smaller steps. So the overall effect is not given.

Our spot trading volume data, which is of comparatively high quality internationally since they comprise all NOK/EUR trading during the week with banks in Norway, allow us to study the role played by heterogeneity in at least three ways. First, does Norwegian volume matter? On a global scale NOK/EUR trading is one of the smaller currency pairs in terms of volume, so if Norwegian banks and actors have an impact it is probably either due to their share of total trading volume being sizeable or due to their privileged proximity to Norwegian demanders and supplier of NOK. The second type of heterogeneity we investigate is whether who you are matters. Our data allow us to distinguish between three types of customers: 1) Norwegian non-bank customers, 2) Norwegian banks, and 3) foreign customers, both bank and non-bank. This means we can explore whether the volume of certain types of customers is more important or not. Finally, the third type of heterogeneity we investigate is whether size matters. Since the bigger banks are those that account for a bigger share of trading volume, one might expect that they have a greater impact on volatility than the small banks.

The rest of the essay consists of three sections. In the next we describe our data, section three contains the empirical results, whereas section four concludes.

2 Data and notation

This section proceeds in three steps. First we give an overview of exchange rate volatility in the Norwegian context and present our exchange rate data. The sample period is 15 January 1999 to 7 January 2005, which at the weekly frequency means 313 observations, and is determined by our weekly volume data. These and other measures of market activity based on quoted frequency data are detailed in the second subsection. Finally in the third subsection we present the other variables that play a part in our analyses.

2.1 Norwegian exchange rate volatility

Norway is a small and open economy with four and a half million inhabitants and has one of the highest ratios of export plus import to GDP in the world. Accordingly, with its own money and no formal peg or exchange rate arrangement against other currencies, the variability of Norwegian exchange rates is of major importance. Over the sample period 15 January 1999 - 7 January 2005 Norway experienced two types of exchange rate regimes. From the beginning of 1999 to 29 March 2001 policymaking was characterised by "partial" inflation targeting, whereas the period thereafter was characterised by "full" inflation targeting. In the beginning of 1999 the current central bank governor assumed the position and reinterpreted the guidelines, which in practice entailed a switch from exchange rate stabilisation to "partial" inflation targeting. The second type of exchange rate regime began in March 2001, when the Ministry of Finance instructed the Central Bank to fully pursue an inflation target of 2.5%.

We denote the NOK/EUR exchange rate at the end of week t for S_t, its log-counterpart for s_t and the log-return Δs_t for r_t. For the exact data transformations and data sources the reader is referred to the appendix. A useful distinction is that between observable volatility on the one hand, for example absolute or squared return, and latent volatility on the other hand, for example the conditional standard deviation or variance. Our focus is on observed exchange rate volatility which we define as squared return r_t^2 and denote V_t. Its log-counterpart $\log V_t$ we denote v_t. Graphs of S_t, r_t, V_t and v_t are contained in figures 1 to 4, respectively, and at least one attribute should be noted. Although a sustained shift upwards in volatility around or after the change to full inflation targeting 29 March 2001 is absent—or at least seemingly so, it is clear from figure 2 that the number of spikes outside $+/-2$ is visibly greater in the full inflation period.

2.2 Volume and quotes

We have access to two types of market activity data, quote (NOK/EUR) frequency in the international interbank market and spot NOK/EUR trading volume by banks within Norway's regulatory borders. The quote frequency series is from Olsen Financial Technologies and is denoted by Q_t (its log-counterpart is denoted q_t), see data appendix for details. The volume data are collected every week by Norges Bank (Central Bank of Norway) and are denoted Z_t with a superscript. More precisely, Z_t^{tot} denotes total volume and is equal to the sum of Z_t^{nor} (total trading with Norwegian non-bank customers), Z_t^{nib} (total Norwegian interbank trading) and Z_t^{for} (total trading with foreigner customers, bank or non-bank). We also disaggregate total volume according to size: Z_t^{big} denotes trading volume by big banks, Z_t^{med} by medium-seized banks and Z_t^{sma} by small banks. Descriptive statistics of the series and their log-counterparts (in small letters) are contained in table 1.

In an attempt to measure the two counteracting effects on volatility we employ two types of variables, relative changes and log-levels. The relative changes Δz_t and Δq_t are used as measures of the relative change in market activity from one week to another, which means they are hypothesised to be positively related to volatility. Relative week to week changes in quote frequency and volume are believed to constitute robust measures of increases and decreases in market activity compared to the previous week, since they are little affected by slow or structural changes in the level. The log-levels z_t and q_t are used as measures of liquidity, which means they are hypothesised to be negatively related to volatility. Descriptive statistics of these variables are also contained in table 1.

2.3 Other determinants of Norwegian exchange rate volatility

We also include various other variables in our statistical analyses. They are all described in detail in the appendix, here we only give an overview and introduce notation. To account for the possibility of skewness and asymmetries we use lagged return r_{t-1} for the latter, and an impulse dummy ia_t equal to 1 when returns are positive and 0 otherwise for the former. We also include variables intended to account for the impact of holidays and seasonal variation not fully captured by changes in quote frequency and volume. These are denoted h_i with $i = 1, 2, \ldots, 8$. As a measure of general currency market turbulence we use EUR/USD volatility. If $m_t = \log\ (\text{EUR/USD})_t$, then Δm_t denotes the weekly return of EUR/USD, M_t^w stands for weekly volatility and m_t^w is its log-counterpart. The petroleum sector plays a major role in the Norwegian economy, so it makes sense to also include a measure of oilprice volatility. If the log of the oilprice is denoted o_t, then the weekly return is Δo_t, weekly volatility is O_t^w with o_t^w as its log-counterpart. We proceed similarly with Norwegian and US stock market variables. If x_t denotes the log of the main index of the Oslo stock exchange, then the associated variables are Δx_t, X_t^w and x_t^w. In the US case u_t is the log of the New York stock exchange (NYSE) index and the associated variables are Δu_t, U_t^w and u_t^w. Finally, our interest-rate variables are constructed using the main policy interest rate variable of the Norwegian central bank. Let F_t denote the main policy interest rate in percentages and let ΔF_t denote the change from the end of one week to the end of the next. Furthermore, let I_a denote an indicator function equal to 1 in the period 1 January 1999 - Friday 30 March 2001 and 0 otherwise, and let I_b denote an indicator function equal to 1 after 30 March 2001 and 0 before. In the first period the Bank pursued a "partial" inflation targeting policy, whereas in the second it pursued a "full" inflation targeting policy. Now define $\Delta F_t^a = \Delta F_t \times I_a$ and $\Delta F_t^b = \Delta F_t \times I_b$, respectively, and f_t^a and f_t^b stand for $|\Delta F_t^a|$ and $|\Delta F_t^b|$, respectively.

3 Empirical results

The data allow us to study three types of heterogeneity. Whether Norwegian volume matters, whether stype of trade matters and whether size matters. In the following three subsections we address each question in turn.

3.1 Does Norwegian volume matter?

In this subsection we try to answer whether currency trading within Norway has an impact on NOK/EUR volatility. We report the estimation results of the four regressions

$$v_t = b_0 + b_2(v_{t-2} + v_{t-3}) + e_t \tag{1}$$

$$v_t = b_0 + b_2(v_{t-2} + v_{t-3}) + b_5 z_t^{tot} + b_6 \Delta z_t^{tot} + e_t \tag{2}$$

$$v_t = b_0 + b_2(v_{t-2} + v_{t-3}) + b_5 z_t^{tot} + b_6 \Delta z_t^{tot} + b_7 q_t + b_8 \Delta q_t + e_t \tag{3}$$

$$v_t = b_0 + b_2(v_{t-2} + v_{t-3}) + b_5 z_t^{tot} + b_8 \Delta q_t + b_9(x_t + u_t) + b_{10} f_t^b + b_{11} h_{2t} + b_{12} h_{4t} + e_t, \tag{4}$$

where e_t is the error term. The first specification is a parsimonious autoregression reflecting the estimated persistence in NOK/EUR volatility, the second is the parsimonious autoregression augmented by Norwegian volume variables z_t^{tot} and Δz_t^{tot}, the third adds quote variables to the second specification, whereas the last is a parsimonious specification obtained through single-path simplification of a general unrestricted model that nests the first three. The general unrestricted specification also contains terms intended to capture return skewness, return asymmetry, EUR/USD volatility, oilprice volatility, interest rate changes in the partial inflation period and other Norwegian holidays. The retained variables are Norwegian and US stock market volatility x_t and u_t, respectively, policy interest rate changes in the inflation targeting period f_t^b,[1] and the holiday variables h_{2t} and h_{4t}.

The estimation results are contained in table 3, and the short answer to the question of whether Norwegian volume matters is "no". The measure of Norwegian liquidity z_t^{tot} and the measure of relative change in market activity Δz_t^{tot} are both insignificant at conventional levels in the three specifications in which they appear. The measure of liquidity for the whole market q_t is not significant either, but the measure of global market activity Δq_t on the other hand is significant at the 10% level. The quote variables are partly overlapping with the volume variables, since they contain information regarding the market activity of Norwegian banks. However, leaving the quote variables out of the specifications do not change the results with respect to the volume variables.

[1] The policy interest rate is indeed a very concise summary of the impact absolute interest rates changes have on volatility in the full inflation period. We have tried to replace the policy interest-rate with a whole range of interest rate variables, including Norwegian short term market interest rates, Norwegian long term market interest rates and the short term interest rate differential with the EU. These exploratory analyses suggest that neither long term Norwegian interest rates nor the interest differential have an impact on volatility. Moreover, the analyses suggest that short term Norwegian market interest rate changes do not have an impact in between policy decisions by the Central Bank of Norway. Accordingly, the policy interest rate seems to be a very concise summary of the impact interest rates have on volatility.

3.2 Does who you are matter?

In this subsection we address the question of whether who trades NOK/EUR within Norway matters for NOK/EUR volatility. We report the estimation results of the three regressions

$$v_t = b_0 + b_2(v_{t-2} + v_{t-3}) + b_5 z_t^{nor} + b_6 \Delta z_t^{nor} + b_{11} q_t + b_{12} \Delta q_t + b_{13}(x_t + u_t) + b_{14} f_t^b + b_{15} h_{2t} + b_{16} h_{4t} + e_t \quad (5)$$

$$v_t = b_0 + b_2(v_{t-2} + v_{t-3}) + b_7 z_t^{nib} + b_8 \Delta z_t^{nib} + b_{11} q_t + b_{12} \Delta q_t + b_{13}(x_t + u_t) + b_{14} f_t^b + b_{15} h_{2t} + b_{16} h_{4t} + e_t \quad (6)$$

$$v_t = b_0 + b_2(v_{t-2} + v_{t-3}) + b_9 z_t^{for} + b_{10} \Delta z_t^{for} + b_{11} q_t + b_{12} \Delta q_t + b_{13}(x_t + u_t) + b_{14} f_t^b + b_{15} h_{2t} + b_{16} h_{4t} + e_t. \quad (7)$$

Each specification contains lags of volatility to account for time-varying volatility persistence, the volume and quote variables in question, the Norwegian and US stock market volatility variables x_t and u_t, respectively, the policy interest rate variable f_t^b, and the holiday variables h_{2t} and h_{4t}. The models are obtained through single-path simplification of a more general model containing the same additional variables as in the previous subsection. In the first specification (5) volume consists of trading between Norwegian banks and Norwegian non-bank customers, in the second specification (6) volume consists of Norwegian interbank trading, and in the third specification (7) volume consists of trading between Norwegian banks and foreign (bank or non-bank) customers.

The estimation results are contained in table 4 and suggest that neither Norwegian liquidity nor relative changes in Norwegian market activity matters at the 10% level. The estimated impacts of Norwegian liquidity are all negative, but the lowest p-value is only 0.52. This p-value is associated with trading with foreign customers. The liquidity variable for the whole NOK/EUR market q_t is also insignificant. The estimated impacts of relative changes in Norwegian volume are insignificant too, but the measure of relative change in market activity Δq_t is significant with very similar coefficient estimates as in table 3. The control variables are all significant and have very similar coefficient estimates across specifications, and also here is it the case that leaving the quote variables out of the specifications do not change the results of the volume variables.

3.3 Does size matter?

In this subsection we address the issue of whether size matters. Do bigger banks have greater impact on NOK/EUR volatility than intermediate and small banks? We report the estimation results of the three regressions

$$v_t = b_0 + b_2(v_{t-2} + v_{t-3}) + b_5 z_t^{nor} + b_6 \Delta z_t^{nor} + b_{11} q_t + b_{12} \Delta q_t + b_{13}(x_t + u_t) + b_{14} f_t^b + b_{15} h_{2t} + b_{16} h_{4t} + e_t \quad (8)$$

$$v_t = b_0 + b_2(v_{t-2} + v_{t-3}) + b_7 z_t^{nib} + b_8 \Delta z_t^{nib} + b_{11} q_t + b_{12} \Delta q_t + b_{13}(x_t + u_t) + b_{14} f_t^b + b_{15} h_{2t} + b_{16} h_{4t} + e_t \quad (9)$$

$$v_t = b_0 + b_2(v_{t-2} + v_{t-3}) + b_9 z_t^{for} + b_{10} \Delta z_t^{for} + b_{11} q_t + b_{12} \Delta q_t + b_{13}(x_t + u_t) + b_{14} f_t^b + b_{15} h_{2t} + b_{16} h_{4t} + e_t. \quad (10)$$

Each specifications contains lags of volatility to account for time-varying volatility persistence, the volume variables in question and the quote variables, and each specification is obtained through single-path simplification of a more general model as in the previous subsections. In the first specification (8) volume consists of trading by the largest Norwegian banks, in the second specification (9) volume consists of trading by medium-sized Norwegian banks, whereas in the third specification (10) volume consists of trading by small Norwegian banks.

The estimation results are contained in table 5 and confirms the previous results that Norwegian liquidity does not matter, just as is the case for the measure of liquidity for the whole market q_t. With respect to relative change in volume by Norwegian banks they too are insignificant at conventional significance levels. However, the relative change in volume by small bank is almost significant with a p-value of 11%. The measure of the relative change in activity for the whole market Δq_t is significant at the 10% level in two out of three equations, and at the 11% level in the specification with the volume variables of small Norwegian banks. Finally, again the coefficient estimates are relatively similar across the specifications both for Δq_t and for the control variables, and again is it the case that leaving the quote variables out of the specifications do not change the results of the volume variables.

4 Conclusions

This study has sought to shed light on the role played by heterogeneity in the relation between market activity and exchange rate volatility, through an investigation of the relation between NOK/EUR spot currency transaction volume in Norway and NOK/EUR volatility. Whereas an increase in global interbank market activity increases volatility, our results do not suggest that changes in currency transaction volume in Norway has an effect on exchange rate volatility. Neither do the results suggest that the part of Norway's currency transaction volume that is with foreign traders has greater effect on volatility than the part with traders inside Norway. Nor do our results suggest that bigger banks in terms of volume has a greater effect than smaller banks.

An increase in general or structural market activity, due to for example an increase in the number of participants, might lead to a general shift downwards or upwards in volatility, depending on whether the effect of increased liquidity is greater than the effect of increased speculation. The statistical analyses do not support the hypothesis that a change in the general level of currency transaction volume by banks in Norway affects the general level of volatility, nor that the general levels of some traders (foreign or Norwegian based trader, big or small bank) matter more than others'. Similarly, our results do not support the hypothesis that changes in the general level of global interbank market activity matters for the general level of volatility.

References

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Appendix: Data transformations and sources

The data transformations were undertaken in Ox 3.4 and EViews 5.1.

S_t	BID NOK/1EUR closing value (21:50 GMT) of the last trading day of week t. The source of the BID NOK/1EUR series is Reuters.
r_t	$(\log S_t - \log S_{t-1}) \times 100$.
V_t	$\{\{\log[S_t + I(S_t = S_{t-1}) \times 0.0009] - \log(S_{t-1})\} \times 100\}^2$. $I(S_t = S_{t-1})$ is an indicator function equal to 1 if $S_t = S_{t-1}$ and 0 otherwise, and $S_t = S_{t-1}$ occurs for $t = 17/2/2000$.
v_t	$\log V_t$.
Z_t^{tot}	Measure of total spot NOK/EUR trading by banks within Norwegian regulatory borders during week t. Source: Bank of Norway.
z_t^{tot}	$\log Z_t^{tot}$.
Z_t^{nor}	Measure of total spot NOK/EUR trading with Norwegian customers by banks within Norwegian regulatory borders during week t. Source: Bank of Norway.
z_t^{nor}	$\log Z_t^{nor}$.
Z_t^{nib}	Measure of total spot NOK/EUR Norwegian interbank trading by banks within Norwegian regulatory borders during week t. Source: Bank of Norway.
z_t^{nib}	$\log Z_t^{nib}$.
Z_t^{for}	Measure of total spot NOK/EUR trading with foreign customers by banks within Norwegian regulatory borders during week t. Source: Bank of Norway.
z_t^{for}	$\log Z_t^{for}$.
Z_t^{big}	Measure of total spot NOK/EUR trading by big banks during week t. Source: Bank of Norway.
z_t^{big}	$\log Z_t^{big}$.
Z_t^{med}	Measure of total spot NOK/EUR trading by medium-sized banks during week t. Source: Bank of Norway.
z_t^{med}	$\log Z_t^{med}$.
Z_t^{sma}	Measure of total spot NOK/EUR trading by small banks during week t. Source: Bank of Norway.
z_t^{sma}	$\log Z_t^{sma}$.

Q_t	Weekly number of NOK/EUR quotes. The underlying data is a daily series purchased from Olsen Financial Technologies, and the weekly values are obtained by summing over the days of the week.
q_t	$\log Q_t$. Note that this series is "synthetic" in that it has been adjusted for changes in the underlying quote-collection methodology at Olsen Financial Technologies. More precisely q_t has been generated under the assumption that Δq_t was equal to zero in the weeks containing Friday 17 August 2001 and Friday 5 September 2003, respectively. In the first week the underlying feed was changed from Reuters to Tenfore, and on the second a feed from Oanda was added.
Δq_t	$q_t - q_{t-1}$. Note that the values of this series has been set to zero in the weeks containing Friday 24 August 2001 and Friday 5 September 2003, respectively, due to the changes in the underlying data collection methodology described above.
M_t	BID USD/EUR closing value of the last trading day of week t. The source of the BID DEM/USD and BID USD/EUR series is Reuters.
m_t	$\log M_t$
O_t	Closing value of the Brent Blend spot oilprice in USD per barrel in the last trading day of week t. The untransformed series is Bank of Norway database series D2001712.
o_t	$\log O_t$
O_t	$\{\{\log[O_t + I(O_t = O_{t-1}) \times 0.009] - \log(O_{t-1})\} \times 100\}^2$. $I(O_t = O_{t-1})$ is an indicator function equal to 1 if $O_t = O_{t-1}$ and 0 otherwise.
o_t	$\log O_t$
X_t	Closing value of the main index of the Norwegian Stock Exchange (TOTX) in the last trading day of week t. The source of the daily untransformed series is EcoWin series ew:nor15565.
x_t	$\log X_t$
X_t	$\{[\log(X_t/X_{t-1})] \times 100\}^2$. $X_t = X_{t-1}$ does not occur for this series.
x_t	$\log X_t$
U_t	Closing value of the composite index of the New York Stock Exchange (the NYSE index) in the last trading day of week t. The source of the daily untransformed series is EcoWin series ew:usa15540.
U_t	$\{[\log(U_t/U_{t-1})] \times 100\}^2$. $U_t = U_{t-1}$ does not occur for this series.
u_t	$\log U_t$

F_t	The Norwegian central bank's main policy interest-rate, the socalled "folio", at the end of the last trading day of week t. The source of the untransformed daily series is Bank of Norway's web-pages.
f_t^a	$\|\Delta F_t\| \times I_a$, where I_a is an indicator function equal to 1 in the period 1 January 1999 - Friday 30 March 2001 and 0 elsewhere
f_t^b	$\|\Delta F_t\| \times I_b$, where I_b is an indicator function equal to 1 after Friday 30 March 2001 and 0 before
ia_t	Skewness term, equal to 1 when $r_t > 0$ and 0 otherwise.
h_{lt}	$l = 1, 2, \ldots, 8$. Holiday variables with values equal to the number of official Norwegian holidays that fall on weekdays. For example, if 1 January falls on a Saturday then h_{1t} is equal to 0, whereas if 1 January falls on a Monday, then h_{1t} is equal to 1. h_{2t} is associated with Maundy Thursday and Good Friday and thus always equal to 2, h_{3t} with Easter Monday and thus always equal to 1, h_{4t} with Labour Day (1 May), h_{5t} with the Norwegian national day (17 May), h_{6t} with Ascension Day, h_{7t} with Whit Monday and h_{8t} with Christmas (Christmas Day and Boxing Day). Source: Http://www.timeanddate.com.

Table 1: Descriptive statistics of volume and quote data

	Average	*Median*	*Max.*	*Min.*	*S.e.*
Z_t^{nor}	73778	73113	129827	24366	18589
Z_t^{nib}	10164	9059	37878	1429	5003
Z_t^{for}	235157	231095	452912	73531	61494
Z_t^{tot}	319099	314101	600343	105508	80411
Z_t^{big}	232254	230478	494937	65264	73890
Z_t^{med}	78037	77664	182651	3530	37634
Z_t^{sma}	8808	7993	25345	896	5037
Δz_t^{nor}	0.0005	0.023	0.969	-1.033	0.27
Δz_t^{nib}	-0.0010	-0.008	2.170	-1.211	0.38
Δz_t^{for}	0.0017	0.029	0.966	-0.975	0.26
Δz_t^{tot}	0.0014	0.033	0.973	-0.994	0.26
Δq_t	-0.0008	-0.003	1.792	-1.127	0.30
Δz_t^{big}	0.0032	0.033	0.836	-1.112	0.30
Δz_t^{med}	-0.0039	0.002	2.485	-2.014	0.48
Δz_t^{sma}	-0.0025	-0.003	2.002	-2.226	0.55

Note: Sample 15 January 1999 - 7 January 2005 (313 observations).

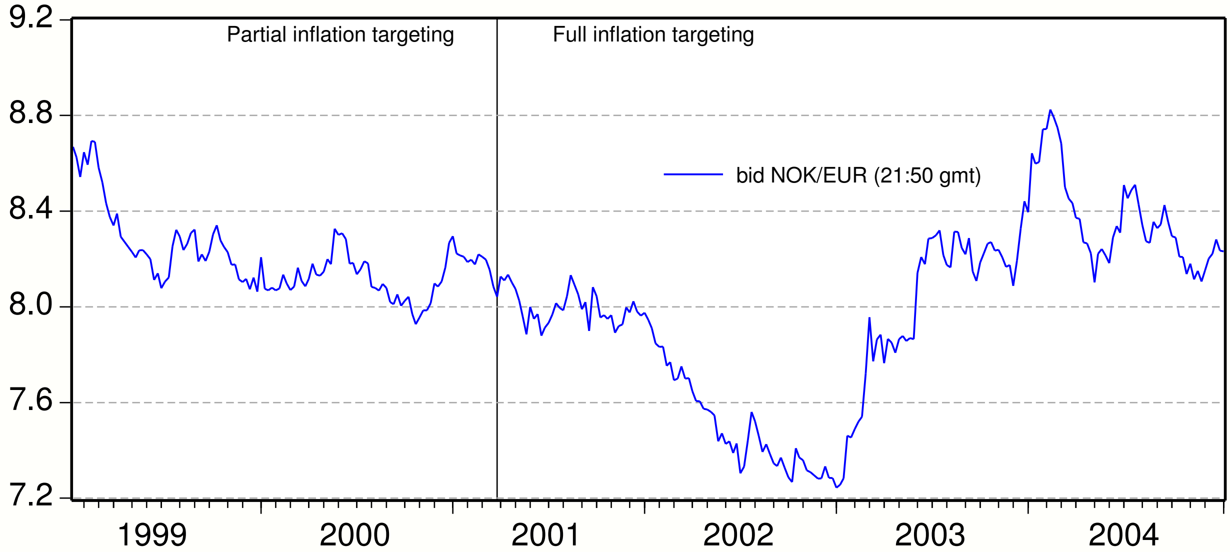

Figure 1: Bid NOK/EUR at 21:50 GMT in the last trading day of the week 15 January 1999 - 7 January 2005

Table 2: Sample correlations between volume and quote data

	Z_t^{nor}	Z_t^{nib}	Z_t^{for}	Z_t^{tot}	Z_t^{big}	Z_t^{med}	Z_t^{sma}
Z_t^{nor}	1.00						
Z_t^{nib}	0.46	1.00					
Z_t^{for}	0.85	0.47	1.00				
Z_t^{tot}	0.91	0.53	0.99	1.00			
Z_t^{big}	0.73	0.30	0.91	0.88	1.00		
Z_t^{med}	0.50	0.55	0.36	0.42	-0.05	1.00	
Z_t^{sma}	0.07	-0.11	-0.16	-0.12	-0.23	0.06	1.00

	z_t^{nor}	z_t^{nib}	z_t^{for}	z_t^{tot}	q_t	z_t^{big}	z_t^{med}	z_t^{sma}
z_t^{nor}	1.00							
z_t^{nib}	0.54	1.00						
z_t^{for}	0.86	0.50	1.00					
z_t^{tot}	0.91	0.57	0.99	1.00				
q_t	0.04	0.17	0.36	0.30	1.00			
z_t^{big}	0.74	0.28	0.90	0.87	0.40	1.00		
z_t^{med}	0.48	0.57	0.28	0.35	-0.27	-0.10	1.00	
z_t^{sma}	0.09	-0.06	-0.13	-0.08	-0.50	-0.21	0.21	1.00

	Δz_t^{nor}	Δz_t^{nib}	Δz_t^{for}	Δz_t^{tot}	Δq_t	Δz_t^{big}	Δz_t^{med}	Δz_t^{sma}
Δz_t^{nor}	1.00							
Δz_t^{nib}	0.66	1.00						
Δz_t^{for}	0.96	0.63	1.00					
Δz_t^{tot}	0.98	0.67	1.00	1.00				
Δq_t	0.10	0.07	0.10	0.10	1.00			
Δz_t^{big}	0.92	0.61	0.92	0.93	0.04	1.00		
Δz_t^{med}	0.45	0.36	0.50	0.50	0.13	0.23	1.00	
Δz_t^{sma}	0.49	0.32	0.47	0.48	0.20	0.32	0.44	1.00

Note: Sample 15 January 1999 - 7 January 2005 (313 observations).

Table 3: Regressions of NOK/EUR volatility on total volume and quote data

	(1)		(2)		(3)		(4)	
	Est.	*Pval.*	*Est.*	*Pval.*	*Est.*	*Pval.*	*Est.*	*Pval.*
const.	-1.480	0.00	-2.849	0.67	-1.334	0.84	1.150	0.86
$v_{t-2} + v_{t-3}$	0.113	0.01	0.113	0.01	0.111	0.01	0.093	0.03
z_t^{tot}			0.108	0.84	-0.135	0.80	-0.301	0.58
Δz_t^{tot}			0.211	0.69	0.248	0.62	0.194	0.70
q_t					0.194	0.35	0.122	0.55
Δq_t					0.788	0.06	0.760	0.07
$x_t + u_t$							0.113	0.00
f_t^b							4.073	0.00
h_{2t}							-0.657	0.09
h_{4t}							-1.385	0.10
R^2	0.02		0.02		0.04		0.12	
AR_{1-10}	9.73	0.46	9.66	0.47	8.81	0.55	4.82	0.90
$ARCH_{1-10}$	5.74	0.84	5.60	0.85	5.10	0.88	7.47	0.68
Het.	4.17	0.12	8.28	0.22	9.72	0.47	12.68	0.70
Hetero.	4.17	0.12	11.11	0.27	25.37	0.19	29.48	0.96
JB	75.50	0.00	75.78	0.00	71.83	0.00	86.51	0.00
Obs.	310		310		310		310	

Note: Computations are in EViews 5.1 with OLS estimation. All specifications use standard errors of the White (1980) type, *Pval* stands for p-value and corresponds to a two-sided test with zero as null, AR_{1-10} is the χ^2 version of the Lagrange-multiplier test for serially correlated residuals up to lag 10, $ARCH_{1-10}$ is the χ^2 version of the Lagrange-multiplier test for serially correlated squared residuals up to lag 10, *Het.* and *Hetero.* are White's (1980) heteroscedasticity tests without and with cross products, respectively, and *JB* is the Jarque and Bera (1980) test for non-normality.

Table 4: Regressions of NOK/EUR volatility on disaggregated volume data according to investor type and quote data

	(5)		(6)		(7)	
	Est.	*Pval.*	*Est.*	*Pval.*	*Est.*	*Pval.*
const.	1.323	0.83	-1.636	0.59	0.767	0.90
$v_{t-2} + v_{t-3}$	0.092	0.03	0.095	0.03	0.093	0.03
z_t^{nor}	-0.332	0.52				
Δz_t^{nor}	0.193	0.69				
z_t^{nib}			-0.086	0.78		
Δz_t^{nib}			0.016	0.97		
z_t^{for}					-0.282	0.59
Δz_t^{for}					0.192	0.70
q_t	0.088	0.66	0.093	0.65	0.129	0.54
Δq_t	0.783	0.06	0.768	0.07	0.755	0.07
$x_t + u_t$	0.114	0.00	0.114	0.00	0.113	0.00
f_t^b	4.092	0.00	4.047	0.00	4.062	0.00
h_{2t}	-0.659	0.08	-0.679	0.08	-0.657	0.09
h_{4t}	-1.389	0.10	-1.422	0.09	-1.385	0.10
R^2	0.12		0.12		0.12	
AR_{1-10}	4.76	0.91	4.47	0.92	4.86	0.90
$ARCH_{1-10}$	7.53	0.67	7.53	0.67	7.43	0.68
Het.	11.43	0.78	11.18	0.80	12.75	0.69
Hetero.	29.44	0.96	30.03	0.96	29.67	0.96
JB	87.07	0.00	87.65	0.00	86.54	0.00
Obs.	310		310		310	

Note: See table 3.

Table 5: Regressions of NOK/EUR volatility on disaggregated volume according to bank size and quote data

	(8)		(9)		(10)	
	Est.	*Pval.*	*Est.*	*Pval.*	*Est.*	*Pval.*
const.	-1.110	0.81	0.418	0.90	-1.619	0.67
$v_{t-2} + v_{t-3}$	0.094	0.03	0.091	0.03	0.094	0.03
z_t^{big}	-0.118	0.77				
Δz_t^{big}	0.035	0.94				
z_t^{med}			-0.207	0.30		
Δz_t^{med}			0.270	0.28		
z_t^{sma}					-0.059	0.83
Δz_t^{sma}					0.385	0.11
q_t	0.110	0.61	0.024	0.91	0.060	0.81
Δq_t	0.762	0.07	0.779	0.06	0.644	0.11
$x_t + u_t$	0.113	0.00	0.116	0.00	0.111	0.00
f_t^b	4.013	0.00	4.177	0.00	3.731	0.00
h_{2t}	-0.671	0.08	-0.657	0.09	-0.688	0.07
h_{4t}	-1.411	0.09	-1.414	0.09	-1.397	0.10
R^2	0.12		0.12		0.13	
AR_{1-10}	4.65	0.91	4.20	0.94	3.72	0.96
$ARCH_{1-10}$	7.25	0.70	7.56	0.67	6.24	0.79
Het.	11.08	0.80	12.84	0.68	9.28	0.90
Hetero.	28.83	0.97	29.71	0.96	27.00	0.98
JB	88.40	0.00	83.82	0.00	90.45	0.00
Obs.	310		310		310	

Note: See table 3.

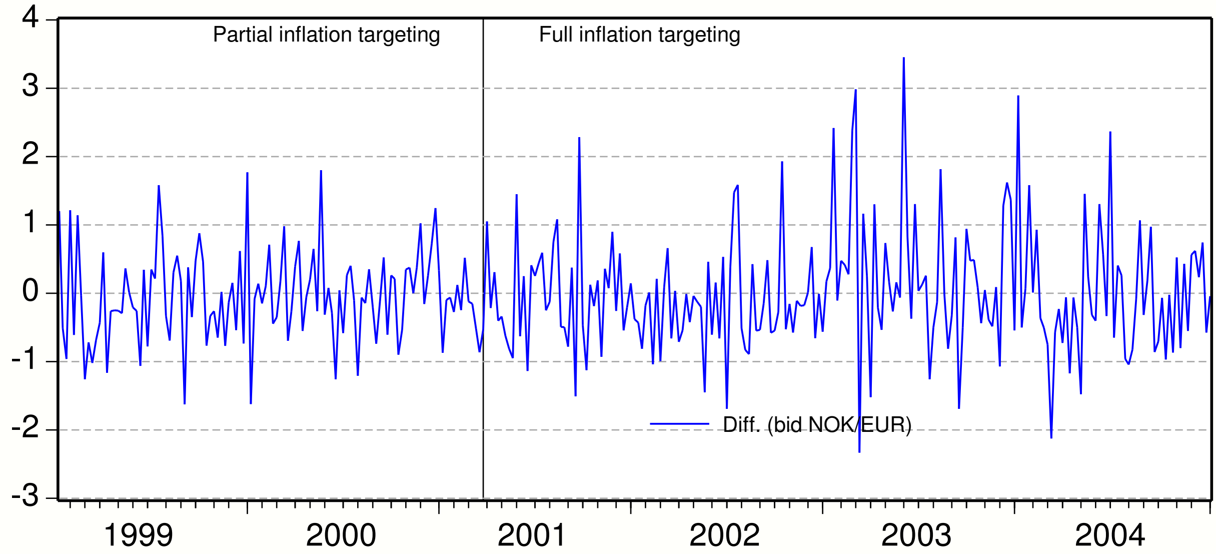

Figure 2: Weekly bid NOK/EUR log-returns in percent 15 January 1999 - 7 January 2005

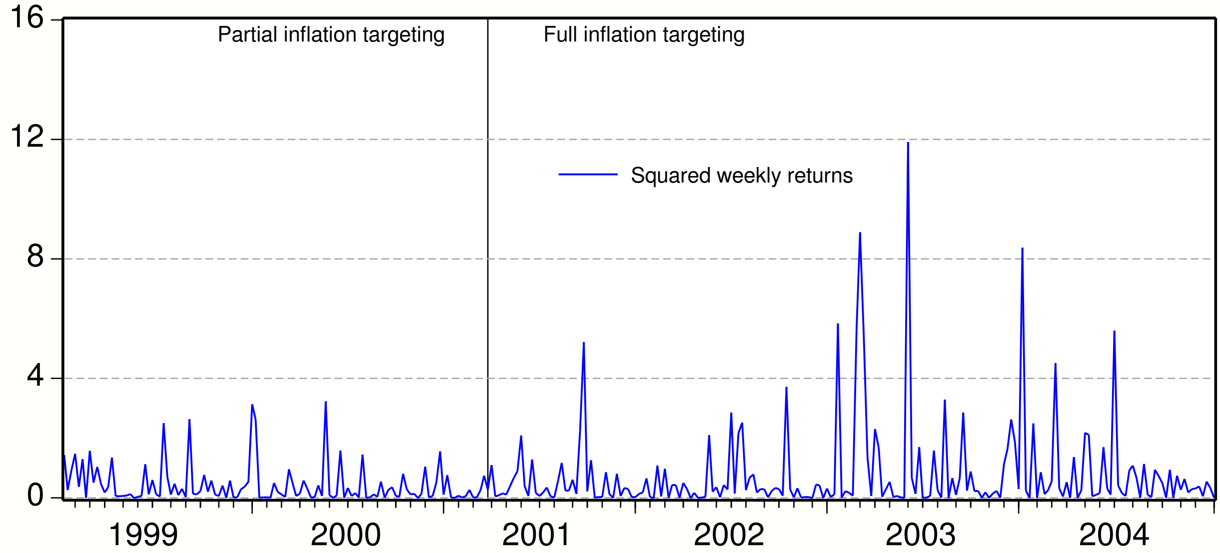

Figure 3: Weekly squared NOK/EUR returns 15 January 1999 - 7 January 2005

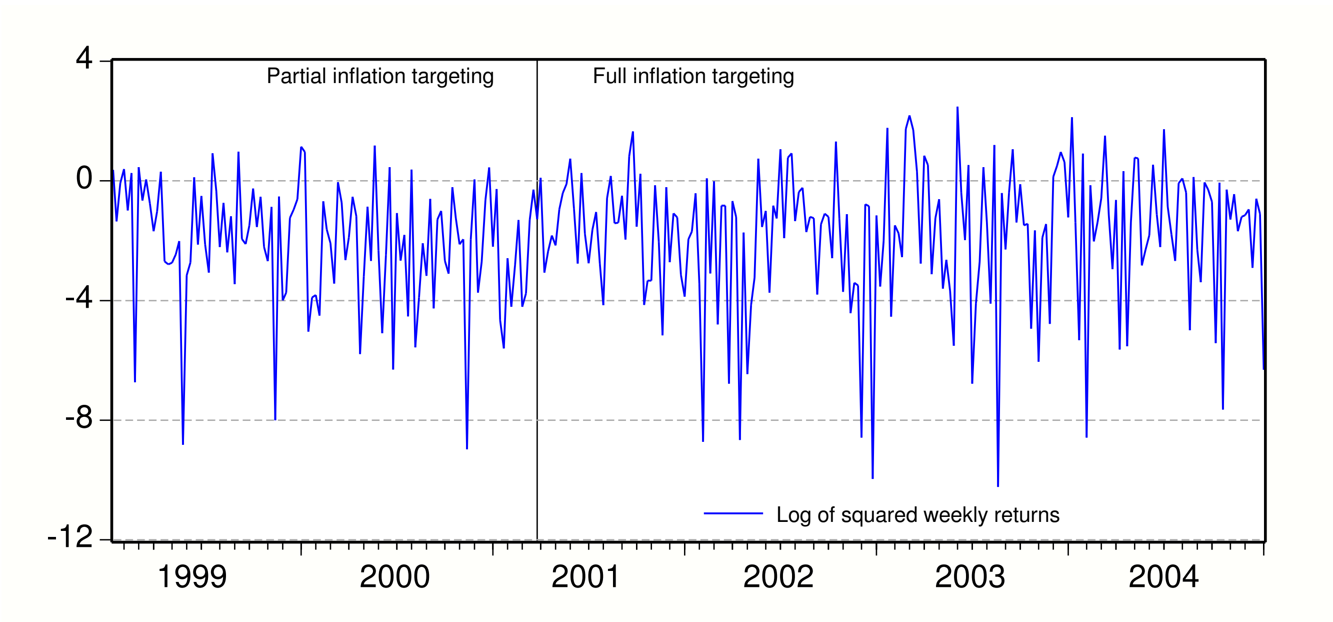

Figure 4: Log of weekly squared NOK/EUR returns 15 January 1999 - 7 January 2005