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Exchange Rate Variability, Market Activity and Heterogeneity*

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Abstract

We study the role played by geographic and bank-size heterogeneity in the relation between exchange rate variability and market activity. We find some support for the hypothesis that increases in short-term global interbank market activity, which can be interpreted as due to variation in information arrival, increase variability. However, our results do not suggest that local short-term activity increases variability. With respect to long-term market activity, which can be interpreted as a measure of liquidity, we find that large and small banks have opposite effects. Specifically, our results suggest that the local group of large banks' liquidity increases variability, whereas the local group of small banks' liquidity reduces variability.

Keywords: Exchange Rate Variability, Heterogeneity, Volume-Volatility Relation, Liquidity

JEL Classification: C53, F31

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1 Introduction

It is well-known that increased trading in a currency pair tends to be accompanied by increased exchange rate variability, see amongst others Grammatikos and Saunders (1986), Galati (2003) and Bjønnes et al. (2005). The most common explanation cited for this relationship is that information arrival induces both price changes trading, a hypothesis which at least goes back to Clark (1973).[1] However, what is less well understood is from which parts of the market that the impact comes from, and to what extent they differ. The study by Bjønnes et al. (2005) sheds light on this issue by studying the role played by bank size and type of instrument. They find that spot trading is the most important instrument and that large banks are more important than small banks—in particular in periods of high variability.

Using Norwegian spot volume data our study sheds additional light on heterogeneity by seeking to address two questions. First, how important is local trading activity compared with global activity? If local 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 local demanders and suppliers of the currency. We find that an increase in short-term global interbank activity, which can be interpreted as due to information arrival, increases range variability. But our results do not support the hypothesis that increases in local short-term trading has an impact. With respect to long-term market activity, which can be interpreted as liquidity, we find some support of the hypothesis that increased local liquidity increases range variability.

The second question we investigate is whether similarly sized groups of local banks—big, medium-sized and large—differ in their impact on variability. In particular, since bigger banks account for a bigger share of trading volume one might expect that their impact on variability is greater than that of small banks, for example because the information contained in the bigger banks' volume is more important. We do not find support for this hypothesis nor that any of the other groups of local banks has an impact on variability through their short-term market activity. However, we do find that small local banks' long-term liquidity has a negative impact on period variability, whereas the group of large local banks' liquidity has a positive impact on range variability.

Our study also sheds light on the relation between exchange rate regime and exchange rate variability. A large body of literature studies the effect of exchange rate regime on exchange rate variability, see amongst others Baxter and Stockman (1989), Flood and Rose (1995), and Killeen et al. (2006). The main conclusion from this literature is that the variability in macro data are unable to account for the shift in exchange rate variability often associated with regime changes, a finding typically is referred to as the "excess volatility puzzle". Our data covers two different exchange rate regimes, one in which exchange rate stabilisation constituted the central bank's main objective and one in which inflation targeting was the main objective, and our results suggest that the effect of changes

[1] Bauwens et al. (2006, table 1) provides a recent overview of empirical studies on the relation between exchange rate variability and information intensity, whereas Karpoff (1987) provides an early survey of financial markets more generally.

in the central bank's main policy interest rate on variability is greater in the inflation targeting regime.

Another contribution of our study concerns Bank for International Settlements (BIS) data on the foreign exchange markets, see for example BIS (1999, 2002, 2005). Numerous studies either use BIS data directly or indirectly, in particular in the estimation of market shares. Our data suggest there may be substantial imprecisions in the BIS data, so that great care should be taken if used.

The rest of the essay consists of four sections. In the next we give a brief description of the economic context, motivate and explain our definitions of exchange rate variability, and describe and motive our econometric model. Section three explains the data and introduces notation, whereas section four contains our empirical investigation. The final section concludes.

2 Economic context, definitions of exchange rate variability and models

This section describes the economic context of the data, and describes and motivates the definitions and models of exchange rate variability that we employ. We proceed in three steps. The first subsection describes the Norwegian economy over the sample period in question, paying particular attention to characteristics of relevance for the study and modelling of exchange rate variability. Then, in the second subsection, a distinction is made between period and within-period variability. This distinction is of particular usefulness when studying variability across different exchange rate regimes as in the case of Norway over the period studied here. The third and final subsection presents and describes the exponential model of variability (EMOV), a model that is especially useful and flexible in explanatory exchange rate variability modelling, and relates the model to the more common autoregressive conditional heteroscedasticity (ARCH) and stochastic volatility (SV) families of models.

2.1 The Norwegian economy

Norway is a small and open economy with only four and a half million inhabitants, and has one of the highest ratios of export plus import to GDP in the world.[2] Accordingly, with its own money and no formal peg or exchange rate arrangement against other currencies, the variability of Norwegian exchange rates is of great importance. Over our sample period 15 January 1999 - 7 January 2005 one may distinguish between two different exchange rate management regimes. The first can be labelled a “partial” inflation targeting regime and originated in a formal letter exchange between Norges Bank—the Central Bank—and the Ministry of Finance in May 1998. In that exchange the Ministry affirmed that the best way

[2] See Sucarrat (2006, subsection 1.1) for a more detailed description of the Norwegian economy over the period in question.

to achieve exchange rate stability, the then main objective of Norges Bank, was to pursue an inflation policy that did not differ substantially from the European Monetary Union (EMU) countries. This implied a change, since previously it was comparable inflation level to Norway's main trading partners—which comprises more countries than EMU—that had been specified as the main means of achieving exchange rate stability. With a new Governor taking office in the beginning of January 1999, this combination proved to entail a *de facto* change in exchange rate regime.

The second exchange rate regime started 29 March 2001 when Norges Bank was instructed by the Ministry of Finance to fully pursue an inflation target of 2.5%. In other words, the main objective of Norges Bank changed from stabilising the exchange rate to inflation targeting. The period after March 2001 may thus be termed a "full" inflation targeting regime. Although analysts agree that a formal change took place on this date, they disagree to what extent there were learning effects present before and/or after March 2001.

The most important exchange rate for the actors that regularly trade the Norwegian krone (NOK) in the spot market is the krone against the Euro (NOK/EUR).[3] Figure 1 contains a graph of the level of the Bid NOK/EUR at the end of the last trading day of the week over the study period.[4] An increase in the exchange rate means a depreciation in the value of the NOK, and a decrease the opposite.

2.2 Definitions of exchange rate variability

Conceptually we may distinguish between period variability on the one hand and within or intra-period variability on the other. If $\{s_t\} = \{s_{0(t)}, s_{1(t)}, \ldots, s_{n(t)}, \ldots, s_{N-1(t)}, s_{N(t)}\}$ denotes a sequence of the log of an exchange rate at times $0, 1, \ldots, N$ in period t, then the squared log-return $(s_{N(t)} - s_{0(t)})^2$ is an example of a period definition of variability. Range variability at t, defined as $(\max\{s_t\} - \min\{s_t\})^2$ where $\max\{s_t\} - \min\{s_t\}$ is the range log-return, and realised volatility at t, defined as $\sum_{n(t)=1}^{N(t)}(s_{n(t)} - s_{n(t)-1})^2$, are examples of within-period definitions of variability.[5] The main difference between period and within-period definitions of variability is that the latter is also capable of capturing variation between 0 and N. For example, if s_n fluctuates considerably between 0 and N but ends up close to s_0 at N, then the two types may produce substantially different results. Under certain continuous time assumptions the three definitions essentially provide estimates of the same thing but with varying precision, see amongst other Parkinson (1980), Garman and Klass (1980), Andersen and Bollerslev (1998), Andersen et al. (2001), Andersen et al. (2005) and Aït-Sahalia (2006). However, the reader should be aware that

[3]According to a recent estimate (Meyer and Skjelvik 2006, p. 36) spot NOK/EUR trading accounts for 71% of total spot NOK-volume during the period October 2005 to January 2006, whereas spot NOK/USD trading accounts for only 14% of total spot volume. The estimate is based on daily data collected by Norges Bank, and comprises all NOK-trading in Norway and, it is believed, a substantial part of NOK-trading outside Norwegian regulatory borders.

[4]This series is denoted $S_{t_2}^C$ in the data appendix.

[5]When $n(t) = 1$, then $n(t) - 1 = 0$ and $s_{0(t)} = s_{N(t-1)}$.

nowhere do we rely upon such restrictive continuous time models, say, a continuous time semi-martingale. Indeed, in explanatory variability and volatility modelling starting from a theoretical continuous time model as if it were more fundamental than the empirical discrete time counterpart can lead to erroneous conclusions, see Bauwens and Sucarrat (2007, section 2) for a discussion. To fully appreciate the distinction between period and within-period variability, recall that Norway experienced two different exchange rate regimes over the sample studied here, and that in one of the regimes the main objective was exchange rate stabilisation. So it is not at all clear at the outset that period and within-period definitions of exchange rate variability behave and react similarly across the regimes, even though they should population-wise according to some statistical models.

2.3 Models of exchange rate variability

If r_t denotes the period or range log-return of an exchange rate in period t, then the (linear) EMOV is given by

$$r_t^2 = \exp(\mathbf{b}'\mathbf{x}_t + \nu_t), \tag{1}$$

where $\mathbf{b}$ is a parameter vector, $\mathbf{x}_t$ is a vector of conditioning variables that can contain variables prior to t, and $\{\nu_t\}$ is a sequence of mutually uncorrelated errors each with conditional mean equal to zero.[6] The exponential specification is motivated by several reasons. The most straightforward is that it results in simpler estimation compared with the more common ARCH and SV models, in particular when many explanatory variables are involved. Under the assumption that $\{r_t = 0\}$ is an event with probability zero, then consistent and asymptotically normal estimates of $\mathbf{b}$ can be obtained almost surely with OLS under standard assumptions, since

$$\log r_t^2 = \mathbf{b}'\mathbf{x}_t + \nu_t \qquad \text{with probability 1.} \tag{2}$$

Other advantages of the exponential specification is that it renders large values of r_t^2 less influential, ensures positivity of the fitted values of variability, and presumably leads to faster convergence of the OLS estimator of $\mathbf{b}$. Applying the conditional expectation operator in (1) gives

$$E(r_t^2|\mathcal{I}_t) = \exp(\mathbf{b}'\mathbf{x}_t) \cdot E[\exp(\nu_t)|\mathcal{I}_t], \tag{3}$$

where $\mathcal{I}_t$ denotes the information set in question. Estimates of $E(r_t^2|\mathcal{I}_t)$ are then readily obtained if either $\{\nu_t\}$ is IID or if $\{\exp(\nu_t)\}$ is a mean innovation, that is, if $E[\exp(\nu_t)|\mathcal{I}_t] = E[\exp(\nu_t)]$ for $t = 1, \ldots, T$, since the formula $\frac{1}{T}\sum_{t=1}^{T}\exp(\hat{\nu}_t)$ then provides a consistent estimate of the proportionality factor $E[\exp(\nu_t)|\mathcal{I}_t]$.

To see the relation between the EMOV and the ARCH and SV families of models, recall that the latter two decompose returns into a conditional mean μ_t and a remainder e_t

$$r_t = \mu_t + e_t, \tag{4}$$

[6] Epps and Epps (1976, p. 311), and Tauchen and Pitts (1983, p. 494) can be interpreted as making early use of the EMOV. More recent applications are found in Bauwens et al. (2006), and in Bauwens and Sucarrat (2007). See the latter for a fuller discussion of the EMOV and its relation to continuous time counterparts of discrete time volatility.

where e_t is equal to $e_t = \sigma_t z_t$. The better μ_t is specified the smaller e_t is in absolute value, and the better σ_t is specified the smaller z_t is in absolute value. If σ_t^2 follows a non-stochastic autoregressive process and if $Var(r_t^2|\mathcal{I}_t) = \sigma_t^2$, then (4) belongs to the ARCH family.[7] A common example is the GARCH(1,1) of Bollerslev (1986)

$$\sigma_t^2 = \omega + \alpha e_{t-1}^2 + \beta \sigma_{t-1}^2, \tag{5}$$

with $z_t \sim \text{IN}(0, 1)$. Explanatory terms, say, $\mathbf{c}'\mathbf{y}_t$, would typically enter additively in (5). If σ_t^2 in (4) on the other hand follows a stochastic autoregressive process, then (4) belongs to the SV family of models, and in the special case where σ_t and z_t are independent the conditional variance equals $E(\sigma_t^2|\mathcal{I}_t)$.

The EMOV can bee seen both as an approximation to the ARCH and SV families of models of volatility, and as a direct model of variability. To see this consider the specification

$$r_t = \sigma_t z_t, \tag{6}$$

which implies that $r_t^2 = \sigma_t^2 z_t^2$. Now, recall that expected variability within the ARCH family[8] is

$$E(r_t^2|\mathcal{I}_t) = \mu_t^2 + \sigma_t^2. \tag{7}$$

In words, the total expected exchange rate variation consists of two components, the squared conditional mean μ_t^2 and the conditional variance σ_t^2. Because information with considerable explanatory power typically is not readily available for the conditional mean μ_t—or at least not *ex ante*, the factor σ_t^2 typically dwarfs μ_t^2 with a factor of several hundreds to one. Hence, the "de-meaned" approximation

$$\mu_t^2 + \sigma_t^2 \approx \sigma_t^2 \tag{8}$$

is often reasonably good in practice. Accordingly, the expression $\exp(\mathbf{b}'\mathbf{x}_t) \cdot E[\exp(u_t)|\mathcal{I}_t]$ can be interpreted both as a model of variability r_t^2 *and* as a model of volatility σ_t^2.

3 Data and notation

In order to make efficient use of our spot NOK/EUR volume data we need to make use of an unusual frequency. To be more precise, we make a distinction between the first part of the week on the one hand and the second part of the week on the other, and it should be noted that we only employ volume data for the second part of the week, typically Thursday and Friday, in our empirical investigations.[9]

In addition to providing details of the currency transaction volume data, the purpose of this section is thus to explain the needed data-transformations (further details are provided

[7] It should be noted that since conditioning occurs within a different statistical setup the $\{\mathcal{I}_t\}$ may differ from above in the EMOV.

[8] No generality is lost by only considering the ARCH family since the same type of argument applies with respect to the SV family under common assumptions. In particular, that $\{\sigma_t\}$ and $\{z_t\}$ are independent.

[9] This is due to weaknesses in the data, see the appendix for details.

in the data-appendices), and to introduce the associated notation. We proceed in three steps. The first subsection contains the definitions of variability. Then, in the second subsection we detail the currency transaction volume data and explain how we use them and the quote frequency data to construct measures of market activity at a bi-weekly frequency. Finally, the third subsection explains the transformations associated with the other variables that we include in our empirical investigations.

3.1 Period and range variability

Let $r_{t_2}^{se}$ denote the period log-return of the NOK/EUR exchange rate from 07:00 GMT on Thursday to 21:50 GMT on Friday. The superscript "se" is intended to evoke the association "start-end". The time index t_2 stands for the period that comprises the last two trading days in week t, and due to holidays Thursday and Friday are not always the last two trading days of the week. When they are not then returns are adjusted accordingly, see data appendix for further details. Similarly, the time index t_1 is used to denote the period that comprise the trading days that precedes t_2 in week t. The trading days of week t that precedes the last two are typically Monday, Tuesday and Wednesday. When they are not they are adjusted accordingly too.

Period variability in the second part of week t is thus defined as $(r_{t_2}^{se})^2$ and is denoted $V_{t_2}^{se}$, whereas range variability in t_2 is defined as $(\max\{s_{t_2}\} - \min\{s_{t_2}\})^2$ and is denoted $V_{t_2}^{hl}$. Their corresponding log-transformations are denoted in small letters, $v_{t_2}^{se} = \log V_{t_2}^{se}$ and $v_{t_2}^{hl} = \log V_{t_2}^{hl}$. Their main characteristics are contained in tables 1 and 2, and in figures 3 - 6. For comparison purposes the evolution of $r_{t_2}^{se}$ is contained in figure 2.

There are at least four characteristics worth noting. First, at times period and range variabilities differ notably. For instance, the average of $V_{t_2}^{se}$ over the whole period is 0.27, whereas the average of $V_{t_2}^{hl}$ over the same period is more than double. Moreover, the averages of $V_{t_2}^{se}$ and $V_{t_2}^{hl}$ are higher in the full inflation targeting period than in the partial inflation targeting regime. Second, the log-transformation matters also for the correlation between period and range variabilities. For instance, the sample correlation between $V_{t_2}^{se}$ and $V_{t_2}^{hl}$ is 0.90 over the whole sample, whereas the sample correlation between $v_{t_2}^{se}$ and $v_{t_2}^{hl}$ is only 0.58 over the same sample. The drop in correlation is similar when the two subsamples are compared. Third, the two definitions are less correlated than one might have expected, particularly between $v_{t_2}^{se}$ and $v_{t_2}^{hl}$, with a minimum of 0.47 attained in the partial inflation targeting period. Fourth, although figures 3 and 4 suggest that there are more large values of variability in the second policy period, a general increase or shift upward in variability around 29 March 2001 is absent—or at least seemingly so by just looking at the graphs.

3.2 Measuring market activity

In order to shed light on the role played by heterogeneity we use two types of market activity data, quote frequency of the NOK/EUR rate in the international interbank market and a measure of spot NOK/EUR trading volume by banks within Norway's regulatory borders. The number of quotes in t_2 is denoted Q_{t_2}, its log-counterpart q_{t_2}, and the source of the rawdata is Olsen Financial Technologies. Spot NOK/EUR volume is based on data collected every week by Norges Bank and goes back to the beginning of the 1990s. However, due to substantial changes in the underlying data-collection methodology and definitions we opt to only use the part after 1999, which corresponds to 313 observations at the weekly frequency from 15 January 1999 to 7 January 2005. For more details regarding these data the reader is referred to the data appendix.[10] The spot volume variables in the second part of week t are denoted $Z^i_{t_2}$, where $i \in \{tot, big, med, sma\}$ denotes total volume or volume by big, medium or small banks. By definition we have that $Z^{tot}_{t_2} = Z^{big}_{t_2} + Z^{med}_{t_2} + Z^{sma}_{t_2}$, and their log-counterparts are denoted in small letters, that is, $z^{tot}_{t_2}$, $z^{big}_{t_2}$, $z^{med}_{t_2}$ and $z^{sma}_{t_2}$.

The three categories of banks are "naturally" formed in the sense that the volume of each "large" bank is substantially higher than that of the other banks, and in the sense that the volume of each "small" bank is substantially lower than that of the others. For confidentiality reasons we cannot disclose the identities of the banks that make up which category nor the volume associated with each bank, and for further details of the data the reader is referred to the data appendix.[11] Descriptive statistics of the Z_{t_2} variables and their log-counterparts are contained in table 3, and in data appendix 2 we undertake a comparison with BIS data which suggests that BIS substantially underestimate spot NOK/EUR volume at times. On average total spot NOK/EUR transaction volume in t_2 amounts to almost 323 million NOK, and about 234 million NOK of this, more that 2/3 of the total amount, is due to the group of large banks. The group of small banks account for less than 5%. These shares are relatively stable over the sample and mean the group of large banks account for a substantive part of volume.

In order to distinguish between the different effects market activity can have on exchange rate variability, we make a distinction between "short-term" and "long-term" variation in market activity. In a highly opaque market, like the foreign exchange market, it may be that market participants only perceive persistent variation to represent information. Let the symbolism $t_2 - 1$ stand for the second part of week $t - 1$, $t_2 - 2$ for the second part of week $t - 2$, and so on. If z_{t_2} denotes the log of a measure of volume in the second part of week t, then a straightforward decomposition is to define short-term variation as $\Delta z_{t_2} = z_{t_2} - z_{t_2-1}$ and z_{t_2-1} as a measure of long-term variation, since by definition $z_{t_2} = \Delta z_{t_2} + z_{t_2-1}$. The short-term component Δz_{t_2} has a straightforward and intuitive economic interpretation, namely the relative increase or decrease in volume compared with the previous period. Similarly, z_{t_2-1} is a (noisy) time-varying measure of the the general or long-term level of market activity.[12]

The drawback of using z_{t_2-1} as a measure of long-term variation in market activity is that it might be a noisy measure. One solution is therefore to replace z_{t_2-1} with a

[10] The underlying data collection methodology and definitions were changed again in January 2005. For this reason we do not use the data after 7 January 2005, see appendix 2 for more details.

[11] Also, we are not permitted to investigate the impact of order flow as defined as Evans and Lyons (2002).

[12] The more serially correlated z_{t_2-1} is with previous lags, that is, with z_{t_2-2}, with z_{t_2-3} and so on, then the less noisy as estimator of the (slowly) time-varying level.

smoothed expression, for example a simple moving average. The average of log of total volume $z_{t_2}^{tot}$ using two past values is denoted $\bar{z}_{t_2-1}^{tot/2}$, the average using three values is denoted $\bar{z}_{t_2-1}^{tot/3}$, and so on. Similarly, the average of log quote frequency using two past values is denoted $\bar{q}_{t_2-1}^{2}$, the average of log quote frequency using three past values is denoted $\bar{q}_{t_2-1}^{3}$, and so on. Table 4 contains selected sample correlations of the various measures of long and short-term variation in market activity. The $\hat{q}_{t_2}$ and $\hat{z}_{t_2}$ variables denote measures of long-term variation obtained through a two-step ARMA method used by (among others) Bessembinder and Seguin (1992), Jorion (1996) and Bjønnes et al. (2005). Generally the sample correlations between the measures is relatively strong (typically more than 0.8), so one might ask whether using one instead of another actually matters. Our exploratory analyses suggest it does.

3.3 Other determinants of exchange rate variability

To account for the possibility of skewness and asymmetries in r_{t_2} we use the lagged return r_{t_1}—that is, the log-return of NOK/EUR in the first part of week t—for the latter, and an impulse dummy ia_{t_2} equal to 1 when returns are positive and 0 otherwise for the former.

The Norwegian interest-rate variables reflect the fact that Norway changed inflation policy on 29 March 2001, when the Ministry of Finance instructed Norges Bank to replace exchange rate stabilisation as its main policy objective with inflation targeting. If $\Delta ir_{t_2}^{no}$ denotes the change in the 3-month Norwegian market interest rate in the second part of week t, then $ir_{t_2}^{no,b}$ is equal to $(\Delta ir_{t_2}^{no})^2$ before the regime change took place and zero thereafter, whereas $ir_{t_2}^{no,c}$ is defined as $(\Delta ir_{t_2}^{no})^2$ after the regime change took place and zero before. To further distinguish between the impact of Norwegian interest rates between changes in the policy interest rate by Norges Bank and the impact when Norges Bank changes the policy interest rate, we further decompose $ir_{t_2}^{no,b}$ and $ir_{t_2}^{no,c}$. More precisely, we will add Δ as a superscript when Norges Bank changes its main policy interest rate, and we will add a 0 when it does not. Specifically, in the partial inflation targeting period, $ir_{t_2}^{no,b0}$ is equal to $ir_{t_2}^{no,b}$ when Norges Bank does not change the policy interest rate and zero otherwise, and $ir_{t_2}^{no,b\Delta}$ is equal to $ir_{t_2}^{no,b}$ when it does and zero otherwise. Similarly the corresponding variables for the full inflation period are denoted as $ir_{t_2}^{no,c0}$ and $ir_{t_2}^{no,c\Delta}$. By construction it follows that $ir_{t_2}^{no,b0} + ir_{t_2}^{no,b\Delta} = ir_{t_2}^{no,b}$, and that $ir_{t_2}^{no,c0} + ir_{t_2}^{no,c\Delta} = ir_{t_2}^{no,c}$.

As a measure of changes in short-term EMU interest rates we use a 3-month market rate. Specifically, if $(\Delta ir_{t_2}^{emu})^2$ denote the square of the change in the market interest rate in the second part of week t, then we will use $ir_{t_2}^{emu}$ as a shorthand for this expression. As a measure of general currency market turbulence we use EUR/USD-variability. If Δm_{t_2} denotes the log-return of EUR/USD in the second part of week t, then $M_{t_2}^{se}$ stands for variability and $m_{t_2}^{se}$ its log-counterpart. The petroleum sector plays a major role in the Norwegian economy, so we also include a measure of oilprice variability. If the log-return of oilprice over the second part of week t is denoted Δo_{t_2}, then its variability is $O_{t_2}^{se}$ and its log-counterpart $o_{t_2}^{se}$. We proceed similarly for Norwegian and US stock market variables, where X and U denotes the Norwegian and US stock markets, respectively. We also include two impulse dummies to deal with two extreme (negative) observations in the regressions of $v^{se}_{t_2}$. These two observations are due to the log-transformation being applied on period variability $(r^{se}_{t_2})^2$ when return $r^{se}_{t_2}$ is unusually close to zero. Not neutralising these two observations by means of impulse dummies has the consequence that no regressor is significant. The two impulse dummies are denoted $id^2_{t_2}$ and $id^3_{t_2}$, respectively.

4 Empirical results

This section proceeds in four steps. In the first subsection we provide a direct comparison of the global data with the local data in explaining variation in exchange rate variability. The second subsection explores to what extent the market activity variables accounts for variability persistence—a hypothesis that has played a central role in the finance literature, whereas the third subsection sheds light on the role played by total local market activity. Finally, the fourth subsection addresses the question of whether local bank-size matters.

All models in this section are nested within the general specification[13]

$$\begin{aligned} v_{t_2} = b_0 + b_1\text{persistence} + b_{10}\Delta z^{tot}_{t_2} + b_{11}\bar{z}^{tot}_{t_2} + \\ b_{12}\Delta z^{big}_{t_2} + b_{13}\bar{z}^{big}_{t_2} + b_{14}\Delta z^{med}_{t_2} + b_{15}\bar{z}^{med}_{t_2} + b_{16}\Delta z^{sma}_{t_2} + \\ b_{17}\bar{z}^{sma}_{t_2} + b_{18}\Delta q_{t_2} + b_{19}\bar{q}_{t_2} + \text{the rest} + \nu_{t_2}. \end{aligned} \quad (9)$$

The left side variable v_{t_2} stands for the log of variability in question, that is, either $v^{se}_{t_2}$ or $v^{hl}_{t_2}$, "persistence" (made explicit below) stands for the associated persistence in variability, the $\bar{z}_{t_2}$ variables stand for volume based measures of long-term market activity, $\bar{q}_{t_2}$ stands for a quote based measure of long-term market activity, "the rest" (made explicit below) stands for the other variables that are included in our regressions, and ν_{t_2} denotes the error term. Regressions of log-period and log-range variability, respectively, require different types of lag structures in order to adequately account for persistence. In their specific parsimonious form they are defined as

$$\text{persistence}^{se} = v^{hl}_{t_1} \quad (10)$$

$$\text{persistence}^{hl} = 3v^{hl}_{t_1} + 9v^{hl}_{t_2-1} + v^{hl}_{t_1-1}, \quad (11)$$

respectively.[14] The presence of only $v^{hl}_{t_1}$ on the right hand side of (10) means that past values of log-range variability is a better predictor of log-period variability $v^{se}_{t_2}$ than past

[13]We do not run this regression, only submodels nested within it, because it produces inference problems due to strong correlation between the measures of long-term market activity.

[14]These expressions were obtained through simplification of $b_2v^{se}_{t_1} + b_3v^{hl}_{t_1} + b_4v^{se}_{t_2-1} + b_5v^{hl}_{t_2-1}$ in the period variability case, and $b_3v^{hl}_{t_1} + b_5v^{hl}_{t_2-1} + b_7v^{hl}_{t_1-1} + b_9v^{hl}_{t_2-2}$ in the range variability case. In the range case the specific form of persistence is required for residuals to be serially uncorrelated.

values of log-period variability. Since our main focus will be on the quote and volume variables we will at times for convenience reasons refer to the other variables as "the rest". Specifically this term is defined as

$$\text{the rest} = b_{20}m^{se}_{t_2} + b_{21}o^{se}_{t_2} + b_{22}x^{se}_{t_2} + b_{23}u^{se}_{t_2} + b_{24}ir^{no,b0}_{t_2} + b_{25}ir^{no,b\Delta}_{t_2} + b_{26}ir^{no,c0}_{t_2} + b_{27}ir^{no,c\Delta}_{t_2} + b_{28}ir^{emu}_{t_2} + b_{29}ia_{t_2} + b_{30}r^{se}_{t_1} + b_{31}id^2_{t_2} + b_{32}id^3_{t_2}. \quad (12)$$

It should be noted that the impulse dummies $id^2_{t_2}$ and $id^3_{t_2}$ are only included in the log-period variability regressions.

4.1 Local data vs. global data

The purpose of this subsection is to compare how well the two types of market activity data explain variability before controlling for the impact of other variables, and to this end we run separate regressions that only contain each set of market activity variables. The motivation for this is that the data are overlapping in the sense that the quote data also contain the quotes of banks within Norwegian regulatory borders. The motivation for not including other variables in the regression is to shed light on the hypothesis that variation in market activity is a major cause of variability persistence, a hypothesis that has played a central role in the financial variability literature, see amongst other Lamoureux and Lastrapes (1990) and Shephard (2005). Table 5 contains estimates of the period variability regressions

$$v^{se}_{t_2} = b_0 + b_{10}\Delta z^{tot}_{t_2} + b_{11}\bar{z}^{tot/2}_{t_2-1} + b_{31}id^2_{t_2} + b_{32}id^3_{t_2} + \nu_{t_2} \quad (13)$$

$$v^{se}_{t_2} = b_0 + b_{18}\Delta q_{t_2} + b_{19}\bar{q}^{15}_{t_2-1} + b_{31}id^2_{t_2} + b_{32}id^3_{t_2} + \nu_{t_2}, \quad (14)$$

whereas table 6 contains estimates of the range variability regressions

$$v^{hl}_{t_2} = b_0 + b_{10}\Delta z^{tot}_{t_2} + b_{11}\bar{z}^{tot/2}_{t_2-1} + \nu_{t_2} \quad (15)$$

$$v^{hl}_{t_2} = b_0 + b_{18}\Delta q_{t_2} + b_{19}\bar{q}^{15}_{t_2-1} + \nu_{t_2}. \quad (16)$$

The long-term market activity measures $\bar{z}^{tot/2}_{t_2-1}$ and $\bar{q}^{15}_{t_2-1}$ are chosen on the basis of R^2. Both tables suggest the quote-based variables fare better in terms of R^2, and the diagnostic tests suggest that errors are not serially correlated. An interpretation of this is that the market activity variables adequately account for variability persistence, since they all are serially correlated (naturally, the long-term variables substantially more than the short-term variables). However, it should be noted that a regression of $v^{se}_{t_2}$ on only a constant (not reported) does not produce serially correlated residuals neither. In other, words, there is little (detectable) variability persistence in $\{v^{se}_{t_2}\}$ to explain. The range regressions (15) and (16) on the other hand produce serially correlated residuals. So there are signs also here that the market activity variables alone are unable to adequately account for time-varying variability.

4.2 Persistence vs. market activity

Here we seek to shed further light on the relation between persistence and market activity. In particular, our aim is to shed light on the hypothesis that financial return variability persistence is explained by variation in market activity. Again we first run regressions of variability on the persistence term, and then we add the market activity variables to see to what extent the persistence estimates and significance results are affected.

Table 7 contains estimates of the period and range variability regressions

$$v_{t_2}^{se} = b_0 + b_1 \text{persistence} + b_{31} id_{t_2}^2 + b_{32} id_{t_2}^3 + \nu_{t_2} \tag{17}$$

$$v_{t_2}^{hl} = b_0 + b_1 \text{persistence} + \nu_{t_2}. \tag{18}$$

In the period variability regression (17) the persistence term contains a single variable, namely range variability in the first part of the week $v_{t_1}^{hl}$, as explained above. In the range variability regression (18) the persistence dynamics is richer, and in contrast to the previous subsection the residuals are no longer serially correlated.

Table 8 contains estimates of the period variability regressions

$$v_{t_2}^{se} = b_0 + b_1 \text{persistence} + b_{10} \Delta z_{t_2}^{tot} + b_{11} \bar{z}_{t_2-1}^{tot/2} + b_{31} id_{t_2}^2 + b_{32} id_{t_2}^3 + \nu_{t_2} \tag{19}$$

$$v_{t_2}^{se} = b_0 + b_1 \text{persistence} + b_{18} \Delta q_{t_2} + b_{19} \bar{q}_{t_2-1}^{15} + b_{31} id_{t_2}^2 + b_{32} id_{t_2}^3 + \nu_{t_2}, \tag{20}$$

whereas table 9 contains estimates of the range variability regressions

$$v_{t_2}^{hl} = b_0 + b_1 \text{persistence} + b_{10} \Delta z_{t_2}^{tot} + b_{11} \bar{z}_{t_2-1}^{tot/2} + \nu_{t_2} \tag{21}$$

$$v_{t_2}^{hl} = b_0 + b_1 \text{persistence} + b_{18} \Delta q_{t_2} + b_{19} \bar{q}_{t_2-1}^{15} + \nu_{t_2}. \tag{22}$$

The results of the period variability regressions are contained in table 8. Adding the global market activity variables increases the persistence estimate from 0.100 to 0.111, whereas adding the local market activity variables decreases the persistence estimate from 0.100 to 0.087. However, a Wald coefficient restriction tests of $b_1 = 0.100$ in (19) and (20) are not rejected at the 10% level (both p-values are above 80%), so statistically the persistence estimates do not change by adding the market activity variables. The results of the range variability regressions are contained in table 9. The coefficient estimate of persistence falls slightly in both regressions, but again Wald coefficient restriction tests do not reject the restriction of $b_1 = 0.027$ at the 10% level (the p-values are above 50% in both cases). All in all, then, although three of the four persistence estimates fall when the market activity variables are added, the results do not provide statistical support of the hypothesis that market activity accounts for the persistence in variability.

4.3 Local vs. global market activity

In contrast with the previous two subsections here we control for the impact of other variables than those of market activity and persistence. Table 10 contains estimates of specifications obtained through simplification of

$$v_{t_2}^{se} = b_0 + b_1\text{persistence} + b_{10}\Delta z_{t_2}^{tot} + b_{11}\bar{z}_{t_2-1}^{tot/2} + \text{the rest} + \nu_{t_2} \tag{23}$$

$$v_{t_2}^{se} = b_0 + b_1\text{persistence} + b_{10}\Delta z_{t_2}^{tot} + b_{11}\bar{z}_{t_2-1}^{tot/2} + b_{18}\Delta q_{t_2} + b_{19}\bar{q}_{t_2-1}^{15} + \text{the rest} + \nu_{t_2} \tag{24}$$

with the constant and the market activity variables fixed, that is, they are not removed if insignificant at 10% in a two-sided coefficient test with zero as the null, whereas table 11 contains estimates of specifications obtained through simplification of

$$v_{t_2}^{hl} = b_0 + b_1\text{persistence} + b_{10}\Delta z_{t_2}^{tot} + b_{11}\bar{z}_{t_2-1}^{tot/2} + \text{the rest} + \nu_{t_2} \tag{25}$$

$$v_{t_2}^{hl} = b_0 + b_1\text{persistence} + b_{10}\Delta z_{t_2}^{tot} + b_{11}\bar{z}_{t_2-1}^{tot/2} + b_{18}\Delta q_{t_2} + b_{19}\bar{q}_{t_2-1}^{15} + \text{the rest} + \nu_{t_2} \tag{26}$$

with the constant and the market activity variables fixed. In each pair of regressions the first of the regressions only contain the volume variables as regressors, whereas the second contain both the volume and quote variables. The motivation behind the pairs of regressions is that the volume and quote variables are overlapping in the sense that the quote variables also comprise quotes from banks in Norway. Comparing the two regressions in each pair thus enable us to shed light on three questions: Whether local activity matters, whether global activity matters, and to what extent the impacts of the two types of market activities overlap in their impact.

The results of the period variability regressions are contained in table 10. Neither in (23), where only the local market activity variables enter, nor in (24), where both local and global variables enter, are any of the market activity variables significant at conventional levels of significance. In other words, our results do not support the hypothesis that there is any impact of local nor global market activity on period variability when controlling for other variables. As for overlap, the drop in the coefficient values of $\Delta z_{t_2}^{tot}$ and $\bar{z}_{t_2-1}^{tot/2}$ when the global market activity variables are added can be interpreted as some overlap. Similarly, the almost significance of $\bar{q}_{t_2-1}^{15}$ (p-value equal to 13%) could possibly be attributed to overlap. Indeed, removing $\bar{z}_{t_2-1}^{tot/2}$ (not reported) lowers the p-value of $\bar{q}_{t_2-1}^{15}$ to 8%.

The results of the range variability regressions in table 11 are more supportive of the hypothesis that market activity has an impact on variability when controlling for other variables. Unfortunately, though, our results do not provide insight into whether this is due to range variability being "less noisy", or whether this is due to range variability being conceptually different from period variability. In specification (25), where only local market activity enters, long-term market activity $\bar{z}_{t_2-1}^{tot/2}$ is significant at 4%. Local short-term market activity $\Delta z_{t_2}^{tot}$, however, is not significant. Adding global interbank measures of market activity (specification (26)) reduces the parameter estimates of the local variables, which can be interpreted as the presence of some overlap. Contrary to the period variability regressions, though, short-term global market activity is significant at 8%. Long-term global interbank market activity $\bar{q}^{15}_{t_2-1}$ is almost significant with a p-value of 12%, and also here does it become significant (p-value equal to 2%) if $\bar{z}^{tot/2}_{t_2-1}$ is removed.

Another finding that emerges from tables 10 and 11 and which deserves mention concerns the impact of exchange rate regime on the impact of interest rates. The findings in Bauwens et al. (2006) and Bauwens and Sucarrat (2007), who to some extent make use of the same underlying daily raw data but at a weekly frequency, suggest that central bank changes in the interest rate only affects exchange rates in the full inflation targeting regime. The results in tables 10 and 11 are compatible with this finding, although with a slight modification. Contrary to the studies by Bauwens et al. (2006) and Bauwens and Sucarrat (2007), tables 10 and 11 suggest that central bank changes has a statistically significant effect in the partial inflation targeting regime in three out of the four specifications. However, in all of these three specifications the effect is between 15% ($\approx \frac{0.001}{0.007}$) and 40% ($\approx \frac{0.006}{0.015}$) of the effect in the full inflation targeting regime. One possible interpretation of this finding is that it sheds light on the socalled excess volatility puzzle, see Baxter and Stockman (1989), Flood and Rose (1995), and Killeen et al. (2006).

4.4 Does local bank size matter?

The purpose of this subsection is to shed light on whether groups of similarly sized banks—large, medium, small—impact differently upon variability. Or, whether size matters. Table 12 contains estimates of parsimonious specifications obtained through simplification of

$$v^{se}_{t_2} = b_0 + b_2\text{persistence} + b_{12}\Delta z^{big}_{t_2} + b_{13}\bar{z}^{big}_{t_2} + b_{14}\Delta z^{med}_{t_2} + b_{15}\bar{z}^{med}_{t_2} + b_{16}\Delta z^{sma}_{t_2} + b_{17}\bar{z}^{sma}_{t_2} + \text{the rest} + \nu_{t_2} \quad (27)$$

$$v^{hl}_{t_2} = b_0 + b_2\text{persistence} + b_{12}\Delta z^{big}_{t_2} + b_{13}\bar{z}^{big}_{t_2} + b_{14}\Delta z^{med}_{t_2} + b_{15}\bar{z}^{med}_{t_2} + b_{16}\Delta z^{sma}_{t_2} + b_{17}\bar{z}^{sma}_{t_2} + \text{the rest} + \nu_{t_2} \quad (28)$$

keeping the constant and all the local market activity variables regardless of their significance at 10% (global market activity variables are not included in neither of the regressions). The results of the period variability specification (27) suggest that none of the market activity variables are significant at the 10% level, whereas in the range variability specification (28) only one of the variables exhibit significance, namely long-term market activity of big banks. The estimate is positive, which can be interpreted in favour of the hypothesis that increased liquidity by provided by the big local banks increases variability.

Not removing insignificant variables produces higher standard errors associated with the coefficient estimates, with the possible consequence that significant impacts of market activity are not revealed. To explore this possibility table 13 contains estimates of parsimonious specifications obtained through simplification of the same specifications (27) and (28), but this time only the constant is kept if insignificant at 10%. In the range variability specification there is little change in the significance results, since the only retained market activity variable is that of big banks' long-term activity. However, there is a change in the significance results in the period variability specification. Not fixing the market activity variables yields a significant estimate of small banks' long-term market activity $\bar{z}_{t_2}^{sma}$ in table 13. The impact is negative and therefore the opposite sign of the estimated impact of large banks' long-term activity $\bar{z}_{t_2}^{big}$ on range variability. Effects are small and significance results fragile to changes in specifications, so one should be careful when interpreting the results. Nevertheless, the results suggest large and small local banks' liquidity having opposite effects on variability.

5 Conclusions

This study has sought to shed light on the role played by heterogeneity in the relation between market activity and exchange rate variability. Whereas an increase in global short-term market activity—which can be interpreted as due to information arrival—increases range variability, our results do not support the hypothesis that increases in local short-term market activity has an impact on neither period nor range variability. Moreover, we do not find support for the hypothesis that the trading of groups of local banks, for example big banks, have an impact on variability through their short-term market activity. One interpretation of this is that local banks do not possess information of sufficient importance to have an important effect on the determination of exchange rates. With respect to the impact of long-term market activity, however, which can be interpreted as a measure of liquidity, our results do suggest that local trading has an impact. Indeed, our results suggest large and small banks have adverse effects on variability through their liquidity supply. We find that whereas an increase in large banks' liquidity supply increases range variability, an increase in small banks' liquidity supply reduces period variability. Finally, two additional findings that are not directly related to market activity emerge from our investigations. First, the effect of central bank interest changes is greater in full inflation targeting regimes (as opposed to regimes in which the inflation serves as a means to stabilising the exchange rate). Second, comparison of our local spot NOK/EUR volume data with BIS data suggests the latter can substantially underestimate average daily volume at times.

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A. Sources and transformations of bi-weekly data

t, t_2, t_1 Time indices. t denotes the week in question, t_2 stands for the period that comprises the last two trading days in Norway of week t, that is, Thursday and Friday when neither is a holiday, and t_1 stands for the period that comprises the other trading days in Norway of week t, that is, typically Monday, Tuesday and Wednesday. The symbolism $t_2 - 1$ denotes the second part of week $t-1$, $t_1 - 1$ denotes the first part of week $t-1$, $t_2 - 2$ denotes the second part of week $t-2$, and so on.

s_{t_2}, s_{t_1} $\log S_{t_2}$, $\log S_{t_1}$. S variables denote BID NOK/1EUR exchange rates: Open (07:00 GMT), close (21:50 GMT), high and low. $S^C_{t_2}$ stands for the closing value in the last trading day of t_2, $S^C_{t_1}$ stands for the closing value in the last trading day of t_1, $S^O_{t_2}$ stands for the opening value in the first trading day of t_2, $S^O_{t_1}$ stands for the opening value in the first trading day of t_1, $S^H_{t_2}$ stands for the highest value in t_2, $S^H_{t_1}$ stands for the highest value in t_1, $S^L_{t_2}$ stands for the lowest value in t_2 and $S^L_{t_1}$ stands for the lowest value in t_1. The corresponding log-transformed exchange rates are denoted in small letters, that is, $s^c_{t_2}$, $s^c_{t_1}$, $s^o_{t_2}$, $s^o_{t_1}$, $s^h_{t_2}$, $s^h_{t_1}$, $s^l_{t_2}$ and $s^l_{t_1}$. The source of the daily untransformed data is Reuters.

$r^{se}_{t_2}$, $r^{se}_{t_1}$ Period or "start-end" log-returns in percent. Specifically, $r^{se}_{t_2} = (s^c_{t_2} - s^o_{t_2}) \times 100$, and $r^{se}_{t_1} = (s^c_{t_1} - s^c_{t_2-1}) \times 100$.

$r^{hl}_{t_2}$, $r^{hl}_{t_1}$ Range or "high-low" log-returns in percent. Specifically, $r^{hl}_{t_2} = (s^h_{t_2} - s^l_{t_2}) \times 100$, and $r^{hl}_{t_1} = (s^h_{t_1} - s^l_{t_1}) \times 100$.

$v^{se}_{t_2}$, $v^{se}_{t_1}$ $\log V^{se}_{t_2}$, $\log V^{se}_{t_1}$. V^{se} variables denote period variability in basis points. Specifically, $V^{se}_{t_2} = (r^{se}_{t_2} \times 100)^2$ and $V^{se}_{t_1} = (r^{se}_{t_1} \times 100)^2$. In order to avoid the log-transformation being applied on zero-values, $r^{se}_{t_2}$ is replaced by min $|r^{se}_{t_2}|$ when $r^{se}_{t_2} = 0$ where the minimum is taken over the set of non-zero values of $r^{se}_{t_2}$. Similarly $r^{se}_{t_1}$ is replaced by min $|r^{se}_{t_1}|$ when $r^{se}_{t_1} = 0$ where the minimum is taken over the set of non-zero values of $r^{se}_{t_1}$.

$v^{hl}_{t_2}$, $v^{hl}_{t_1}$ $\log V^{hl}_{t_2}$, $\log V^{hl}_{t_1}$. V^{hl} variables denote range variability in basis points. Specifically, $V^{hl}_{t_2} = (r^{hl}_{t_2} \times 100)^2$ and $V^{hl}_{t_1} = (r^{hl}_{t_1} \times 100)^2$. There is no need to handle zero-values since neither $r^{hl}_{t_2} = 0$ nor $r^{hl}_{t_1} = 0$ occur.

q_{t_2}, q_{t_1} — $\log Q_{t_2}$, $\log Q_{t_1}$. Q_{t_2} is the number of NOK/EUR quotes in t_2, whereas Q_{t_1} is the number of NOK/EUR quotes in t_1. The source of the untransformed data is Olsen Financial Technologies (OFT) and the variables have been adjusted for changes in the underlying quote collection methodology at OFT. More precisely q_{t_2} (q_{t_2}) has been generated under the assumption that Δq_{t_2} (Δq_{t_2}) is equal to zero in the weeks containing Friday 17 August 2001 and Friday 5 September 2003, respectively. In the first week the underlying data feed was changed from Reuters to Tenfore, and on the second a feed from Oanda was added to the Tenfore feed.

$\bar{q}_{t_2-1}$, $\bar{q}_{t_1-1}$ — Lagged averages of q_{t_2} and q_{t_1}, respectively, where a superscript indicates the number of terms in the average. For example, $\bar{q}^2_{t_2-1} = \frac{1}{2}(q_{t_2-1} + q_{t_2-2})$, $\bar{q}^2_{t_2-1} = \frac{1}{3}(q_{t_2-1} + q_{t_2-2} + q_{t_2-3})$, and so on.

z_{t_2} — $\log Z_{t_2}$. Z_{t_2} variables denote measures of spot NOK/EUR transaction volumes by banks in Norway in t_2: Total volume, the volume of big banks, the volume of medium-sized banks and the volume of small banks. The four variables are denoted $Z^{tot}_{t_2}$, $Z^{big}_{t_2}$, $Z^{med}_{t_2}$ and $Z^{sma}_{t_2}$, and by definition $Z^{tot}_{t_2} = Z^{big}_{t_2} + Z^{med}_{t_2} + Z^{sma}_{t_2}$. The source of the untransformed data is Norges Bank, see appendix 2 for more details.

$\bar{z}_{t_2-1}$ — Lagged averages of z_{t_2} where a superscript indicates the volume category in question and the number of terms in the average. For example, $\bar{z}^{tot/2}_{t_2-1} = \frac{1}{2}(z^{tot}_{t_2-1} + z^{tot}_{t_2-2})$, $\bar{z}^{tot/3}_{t_2-1} = \frac{1}{3}(z^{tot}_{t_2-1} + z^{tot}_{t_2-2} + z^{tot}_{t_2-3})$, and so on.

$m^{se}_{t_2}$ — $\log M^{se}_{t_2}$, where $M^{se}_{t_2}$ is USD/EUR variability in basis points constructed in the same way as $V^{se}_{t_2}$. The source of the untransformed daily BID USD/EUR series is Reuters.

$o^{se}_{t_2}$ — $\log O^{se}_{t_2}$, where $O^{se}_{t_2}$ is oilprice variability in basis points at t_2 . If $o^c_{t_2}$ and $o^c_{t_1}$ denote the log of the Brent Blend spot oilprice in USD per barrel in the last trading day of t_2 and t_1, respectively, then $O^{se}_{t_2} = [(o^c_{t_2} - o^c_{t_1}) \times 100^2]^2$, where $(o^c_{t_2} - o^c_{t_1})$ has been zero-adjusted in the same way as $r^{se}_{t_2}$ so that the log is not applied on zero values. The underlying untransformed daily series consists of Norges Bank database series D2001712.

$x^{se}_{t_2}$ — $\log X^{se}_{t_2}$, where $X^{se}_{t_2}$ is the variability in basis points of the main index (TOTX) of the Norwegian stock exchange at t_2. If $x^c_{t_2}$ and $x^c_{t_1}$ denote the log of the closing values in the last trading day of t_2 and t_1, respectively, then $X^{se}_{t_2} = [(x^c_{t_2} - x^c_{t_1}) \times 100^2]^2$, where $(x^c_{t_2} - x^c_{t_1})$ has been zero-adjusted in the same way as $r^{se}_{t_2}$ so that the log is not applied on zero values. The underlying untransformed daily series consists of EcoWin database series ew:nor15565.

$u^{se}_{t_2}$ — $\log U^{se}_{t_2}$, where $U^{se}_{t_2}$ is the variability in basis points of the New York Stock Exchange (NYSE) index at t_2. If $u^c_{t_2}$ and $u^c_{t_1}$ denote the log of the closing values in the last trading day of t_2 and t_1, respectively, then $U^{se}_{t_2} = [(u^c_{t_2} - u^c_{t_1}) \times 100^2]^2$, where $(x^c_{t_2} - x^c_{t_1})$ has been zero-adjusted in the same way as $r^{se}_{t_2}$ so that the log is not applied on zero values. The underlying untransformed daily series consists of EcoWin database series ew:usa15540.

$ir^{emu}_{t_2}$ — A measure of EU short-term market interest rate variability in basis points. If $IR^{emu}_{t_2}$ and $IR^{emu}_{t_1}$ denote the averages of the EMU countries' 3-month money market interest rates in percent (closing values) in the last trading day of t_2 and t_1, respectively, then $ir^{emu}_{t_2} = [(IR^{emu}_{t_2} - IR^{emu}_{t_1}) \times 100]^2$. The underlying untransformed daily series consists of EcoWin database series ew:emu36103.

$ir^{no}_{t_2}$ — A measure of Norwegian short-term market interest rate variation in basis points. If $IR^{no}_{t_2}$ and $IR^{no}_{t_1}$ denote Norwegian 3-month money market interest rates in percent (closing values) in the last trading day of t_2 and t_1, respectively, then $ir^{no}_{t_2} = [(IR^{no}_{t_2} - IR^{no}_{t_1}) \times 100]^2$. The variable $ir^{no,b}_{t_2}$ is the short-term interest rate variation in the partial inflation targeting regime, and $ir^{no,c}_{t_2}$ in the full inflation targeting regime. Specifically, $ir^{no,b}_{t_2} = ir^{no}_{t_2}$ until 30 March 2001 and zero afterwards, and $ir^{no,c}_{t_2} = ir^{no}_{t_2}$ after 30 March 2001 and zero before. The $ir^{no,b}_{t_2}$ and $ir^{no,c}_{t_2}$ variables are further decomposed according to whether the Norwegian central bank (Norges Bank) changes its policy rate (the socalled "Folio") or not, and these variables appear with the additional superscripts 0 or Δ. For example, $ir^{no,c0}_{t_2}$ is equal to $ir^{no,c}_{t_2}$ when Norges Bank does not change its policy rate in the full inflation period and zero when it does, whereas $ir^{no,c\Delta}_{t_2}$ is equal to $ir^{no,c}_{t_2}$ when Norges Bank changes its policy interest rate in the full inflation period and zero otherwise. Similarly for $ir^{no,b0}_{t_2}$ and $ir^{no,b\Delta}_{t_2}$ in the partial inflation targeting period. The underlying untransformed daily series consists of EcoWin database series ew:nor14103.

$id^2_{t_2}$, $id^3_{t_2}$ — Impulse dummies. $id^2_{t_2}$ is equal to 1 in the week containing Friday 11 January 2002 and 0 elsewhere, and $id^3_{t_2}$ is equal to 1 in the week containing Friday 23 April 2004 and 0 elsewhere.

ia_{t_2} — Skewness variable equal to 1 when $r^{se}_{t_2} > 0$ and 0 otherwise.

B. Sources and transformation of the spot NOK/EUR volume data

The Z_{t_2} variables are constructed using information obtained from a form that the most important currency banks within Norwegian regulatory borders fill out and send to Norges Bank every week.[15] The data have been collected since the beginning of the 1990s, but have undergone significant changes with respect to data definitions, data collection methodology and data correction methodology. Table 14 contains a form similar to the one which each reporting bank submitted electronically over the period 1 January 1999 - 7 January 2005. Collection of the data discontinued after 7 January 2005 in order to prepare for an entirely new, more detailed and comprehensive data methodology, which was implemented in October 2005, see Meyer and Skjelvik (2006). An "asset" refers to a purchase contract, that is, a purchase of non-Norwegian currency paying with Norwegian kroner, and a "liability" refers to a sales contract, that is, a sales of non-Norwegian currency paid with Norwegian kroner. For all fields the amount reported is in Norwegian kroner even if the contract is denominated in Euros. If the contract is denominated in Euros then the value of the contract is transformed to Norwegian kroner using the official *daily* exchange rate of Norges Bank of the day in which the contract is made, that is, not the exchange rate corresponding to the day in which the contract is cleared. Accordingly, the trading volume of reporting banks comprise not only NOK/EUR trading, but also NOK/USD trading, NOK/GBP trading, and so on. For this reason we use only fields 2 and 7, that is, "uncleared" spot assets and liabilities, since the spot market on Norwegian currency is dominated by NOK/EUR trading. In the interbank spot market currency purchases and sales are made with actual delivery typically taking place two trading days later. The category uncleared thus refers to transactions which took place in the last two trading days of the week. This explains our focus on exchange rate variability over the last two trading days of the week.

Let $Z^j_{it_2}$ to denote the value of field j for bank i at t_2, and for convenience we will refer to Z_{it_2} variables as NOK/EUR trading although it strictly speaking may comprise some non-Euro trading against the NOK. Total spot NOK/EUR transaction volume is then defined as

$$Z^{tot}_{t_2} = \sum_i (Z^2_{it_2} + Z^5_{it_2}).$$

In words, the sum of all banks' purchase and sales volumes of spot NOK/EUR in the last two trading days of week t. The volume of big, medium sized and small banks are all sub sums of this expression. If *big* refers to the set of big banks in terms of currency volume, *med* to the set of medium sized banks and *sma* to the set of small sized banks, then the variables are defined as

[15] We are greatly indebted to Erik Meyer at the statistics department of Norges Bank for clarifying many of the details concerning the data collection process. We are also indebted to Janett Skjelvik, also at the Statistics Department of Norges Bank, for substantial help in the early stages of preparing data.

$$Z_{t_2}^{big} = \sum_{i \in big}(Z_{it_2}^2 + Z_{it_2}^5)$$

$$Z_{t_2}^{med} = \sum_{i \in med}(Z_{it_2}^2 + Z_{it_2}^5)$$

$$Z_{t_2}^{sma} = \sum_{i \in sma}(Z_{it_2}^2 + Z_{it_2}^5),$$

where by definition $Z_{t_2}^{tot} = Z_{t_2}^{big} + Z_{t_2}^{med} + Z_{t_2}^{sma}$. When comparing the volumes of the individual banks, which are relatively stable over the sample, the banks classified as big are substantially bigger than the others in terms of spot NOK/EUR volume, and the banks classified as small are substantially smaller than than the others in terms of spot NOK/EUR volume. For confidentiality reasons we cannot disclose which banks enter in which category.

Table 15 compares our spot NOK/EUR data with BIS data, and the numbers suggest there are substantial differences. Possible reasons are that Norges Bank's and BIS's data collection methodologies differ, and that the daily averages are computed in different ways (the BIS data are collected daily and globally but only during one month, whereas the Norges Bank data comprise only Norwegian trading during two days per week but are collected throughout the year). We cannot identify the exact source of the discrepancies, but the numbers suggest the BIS data at times may substantially underestimate spot volume. The most striking differences are those between the first and second rows. The first row comprises only spot volume whereas notionally the second row comprises both spot and forward volume. However, in 1998/1999 and in 2001 the Norges Bank data suggest spot NOK/EUR volume in Norway was about double of spot plus forward as suggested by BIS. One interpretation of this is that the Norges Bank data do not correct for double-counting (the BIS data do), but this is not consistent with the numbers for 2004, since there the BIS data suggest that—on average—total NOK/EUR volume in Norway was 30 millions USD more than average spot NOK/EUR volume. Although this is to some extent consistent with the fact that the Norwegian spot market is dominated by the NOK/EUR currency pair and that the Norwegian forward market is dominated by NOK/USD, the difference of only 30 millions appears small. Comparison of the BIS data in the second, third and fourth rows suggest that the Norwegian spot market is substantially smaller than the Norwegian forward market, and that the majority of NOK trading (about 78 % in 2001 and about 64 % in 2004) takes place in Norway. Nevertheless, the fact that BIS estimated global total NOK volume for 1998 is about 1400 millions USD less that Norges Bank estimated Norwegian total volume, suggests serious weaknesses with the BIS estimates—or at least for 1998.

Table 1: Descriptive statistics of period return, and period and range variabilities

		15/1/1999– 7/1/2005 ($T = 313$)	15/1/1999– 30/3/2001 ($T = 116$)	6/4/2001– 7/1/2005 ($T = 197$)
$r_{t_2}^{se}$	*Avg.*	-0.04	-0.08	-0.01
	Med.	-0.06	-0.08	-0.04
	Max.	3.05	1.06	3.05
	Min	-2.14	-1.58	-2.14
	S.e.	0.52	0.45	0.55
$V_{t_2}^{se}$	*Avg.*	0.27	0.21	0.30
	Med.	0.10	0.10	0.10
	Max.	9.28	2.49	9.28
	Min	0.00	0.00	0.00
	S.e.	0.66	0.34	0.78
$V_{t_2}^{hl}$	*Avg.*	0.78	0.62	0.88
	Med.	0.56	0.45	0.62
	Max.	13.21	2.63	13.21
	Min	0.10	0.10	0.10
	S.e.	0.96	0.48	1.14
$v_{t_2}^{se}$	*Avg.*	-2.71	-2.85	-2.63
	Med.	-2.30	-2.34	-2.28
	Max.	2.23	0.91	2.23
	Min	-13.43	-10.21	-13.43
	S.e.	2.17	2.11	2.20
$v_{t_2}^{hl}$	*Avg.*	-0.57	-0.73	-0.48
	Med.	-0.58	-0.80	-0.48
	Max.	2.58	0.97	2.58
	Min	-2.31	-2.31	-2.29
	S.e.	0.78	0.72	0.8

Table 2: Sample correlations between period and range variabilities

Sample		$V_{t_2}^{se}$	$V_{t_2}^{hl}$		$v_{t_2}^{se}$	$v_{t_2}^{hl}$
15/01/1999 -	$V_{t_2}^{se}$	1.00		$v_{t_2}^{se}$	1.00	
7/1/2005	$V_{t_2}^{hl}$	0.90	1.00	$v_{t_2}^{hl}$	0.58	1.00
(T=313)						
15/1/1999 -	$V_{t_2}^{se}$	1.00		$v_{t_2}^{se}$	1.00	
30/3/2001	$V_{t_2}^{hl}$	0.70	1.00	$v_{t_2}^{hl}$	0.47	1.00
(T=116)						
6/4/2001 -	$V_{t_2}^{se}$	1.00		$v_{t_2}^{se}$	1.00	
7/1/2005	$V_{t_2}^{hl}$	0.93	1.00	$v_{t_2}^{hl}$	0.64	1.00
(T=197)						

Table 3: Descriptive statistics of volume and quote data

	Average	*Median*	*Max.*	*Min.*	*S.e.*
$Z_{t_2}^{tot}$	322672	317256	611128	107163	81303
$Z_{t_2}^{big}$	234255	232059	498021	65667	75207
$Z_{t_2}^{med}$	78972	77861	183174	3515	38336
$Z_{t_2}^{sma}$	9446	8377	27042	954	5548
Q_{t_2}	10304	2771	54917	75	15314
$\Delta z_{t_2}^{tot}$	0.0019	0.037	0.972	-0.998	0.26
$\Delta z_{t_2}^{big}$	0.0035	0.033	0.835	-1.120	0.30
$\Delta z_{t_2}^{med}$	-0.0035	0.000	2.493	-2.013	0.49
$\Delta z_{t_2}^{sma}$	0.0000	-0.015	1.926	-2.221	0.55
Δq_{t_2}	0.0118	0.001	2.996	-1.351	0.38

Note: The sample period is 15 January 1999 - 7 January 2005 (313 observations) and the Z_{t_2} variables in the four upper rows are in thousands of Norwegian kroner.

Table 4: Sample correlations between variables based on volume and quote data

	q_{t_2}	$\hat{q}_{t_2}$	q_{t_2-1}	$\bar{q}^{5}_{t_2-1}$	$\bar{q}^{15}_{t_2-1}$
q_{t_2}	1.00				
$\hat{q}_{t_2}$	0.86	1.00			
q_{t_2-1}	0.83	0.96	1.00		
$\bar{q}^{5}_{t_2-1}$	0.83	0.95	0.89	1.00	
$\bar{q}^{15}_{t_2-1}$	0.80	0.94	0.83	0.94	1.00

	$z^{tot}_{t_2}$	$\hat{z}^{tot}_{t_2}$	$z^{tot}_{t_2-1}$	$\bar{z}^{tot/2}_{t_2-1}$	$\bar{z}^{tot/3}_{t_2-1}$
$z^{tot}_{t_2}$	1.00				
$\hat{z}^{tot}_{t_2}$	0.60	1.00			
$z^{tot}_{t_2-1}$	0.50	0.82	1.00		
$\bar{z}^{tot/2}_{t_2-1}$	0.52	0.88	0.87	1.00	
$\bar{z}^{tot/3}_{t_2-1}$	0.55	0.91	0.79	0.94	1.00

	$z^{big}_{t_2}$	$\hat{z}^{big}_{t_2}$	$z^{big}_{t_2-1}$	$\bar{z}^{big/2}_{t_2-1}$	$\bar{z}^{big/3}_{t_2-1}$
$z^{big}_{t_2}$	1.00				
$\hat{z}^{big}_{t_2}$	0.73	1.00			
$z^{big}_{t_2-1}$	0.62	0.84	1.00		
$\bar{z}^{big/2}_{t_2-1}$	0.64	0.87	0.90	1.00	
$\bar{z}^{big/3}_{t_2-1}$	0.67	0.91	0.84	0.95	1.00

	$z^{med}_{t_2}$	$\hat{z}^{med}_{t_2}$	$z^{med}_{t_2-1}$	$\bar{z}^{med/2}_{t_2-1}$	$\bar{z}^{med/3}_{t_2-1}$
$z^{med}_{t_2}$	1.00				
$\hat{z}^{med}_{t_2}$	0.80	1.00			
$z^{med}_{t_2-1}$	0.73	0.91	1.00		
$\bar{z}^{med/2}_{t_2-1}$	0.76	0.95	0.93	1.00	
$\bar{z}^{med/3}_{t_2-1}$	0.78	0.97	0.89	0.97	1.00

	$z^{sma}_{t_2}$	$\hat{z}^{sma}_{t_2}$	$z^{sma}_{t_2-1}$	$\bar{z}^{sma/2}_{t_2-1}$	$\bar{z}^{sma/3}_{t_2-1}$
$z^{sma}_{t_2}$	1.00				
$\hat{z}^{sma}_{t_2}$	0.72	1.00			
$z^{sma}_{t_2-1}$	0.64	0.87	1.00		
$\bar{z}^{sma/2}_{t_2-1}$	0.67	0.91	0.91	1.00	
$\bar{z}^{sma/3}_{t_2-1}$	0.67	0.92	0.85	0.96	1.00

Note: The sample period is 15 January 1999 - 7 January 2005 (313 weekly observations).

Table 5: Regressions of log of period variability $v_{t_2}^{se}$ on a constant and market activity variables

	(13)		(14)	
	$Est.$	$Pval.$	$Est.$	$Pval.$
$const.$	-12.383	0.09	-5.789	0.00
$\Delta z_{t_2}^{tot}$	0.583	0.26		
$\bar{z}_{t_2-1}^{tot/2}$	0.769	0.18		
Δq_{t_2}			0.448	0.11
$\bar{q}_{t_2-1}^{15}$			0.451	0.04
$id_{t_2}^2$	-10.985	0.00	-10.518	0.00
$id_{t_2}^3$	-11.082	0.00	-11.212	0.00
R^2	0.17		0.18	
AR_{1-10}	5.31	0.87	3.57	0.96
$ARCH_{1-10}$	10.81	0.37	14.40	0.16
$Het.$	2.15	0.91	3.62	0.73
$Hetero.$	4.43	0.73	4.09	0.77
JB	53.91	0.00	54.14	0.00
$Obs.$	311		298	

Note: The sample period is 15 January 1999 - 7 January 2005 (313 weekly observations), computations are in EViews 5.1 with OLS estimation and standard errors are 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 6: Regressions of log of range variability $v^{hl}_{t_2}$ on a constant and market activity variables

	(15)		(16)	
	Est.	*Pval.*	*Est.*	*Pval.*
const.	-10.678	0.00	-2.852	0.00
$\Delta z^{tot}_{t_2}$	0.213	0.31		
$\bar{z}^{tot/2}_{t_2-1}$	0.798	0.00		
Δq_{t_2}			0.284	0.15
$\bar{q}^{15}_{t_2-1}$			0.324	0.00
R^2	0.05		0.06	
AR_{1-10}	29.33	0.00	26.28	0.00
$ARCH_{1-10}$	4.86	0.90	10.65	0.39
Het.	5.90	0.21	7.62	0.11
Hetero.	27.82	0.00	7.94	0.16
JB	1.69	0.43	4.80	0.09
Obs.	311		298	

Note: Standard errors are of the Newey and West (1987) type, otherwise see table 5.

Table 7: Regressions of log of variabilities $v_{t_2}^{se}$ and $v_{t_2}^{hl}$, respectively, on a constant and persistence

	(17)		(18)	
	$Est.$	$Pval.$	$Est.$	$Pval.$
$const.$	-2.640	0.00	-0.432	0.00
$persistence$	0.100	0.07	0.027	0.00
$id_{t_2}^2$	-10.728	0.00		
$id_{t_2}^3$	-10.739	0.00		
R^2	0.16		0.11	
AR_{1-10}	4.98	0.89	11.03	0.36
$ARCH_{1-10}$	8.01	0.63	6.35	0.78
$Het.$	1.41	0.84	1.02	0.60
$Hetero.$	1.41	0.84	1.02	0.60
JB	54.32	0.00	2.10	0.35
$Obs.$	313		312	

Note: See table 5.

Table 8: Regressions of log of period variability $v_{t_2}^{se}$ on a constant, persistence and market activity variables

	(19)		(20)	
	Est.	*Pval.*	*Est.*	*Pval.*
$const.$	-11.523	0.12	-5.467	0.00
$persistence$	0.087	0.12	0.111	0.03
$\Delta z_{t_2}^{tot}$	0.579	0.26		
$\bar{z}_{t_2-1}^{tot/2}$	0.701	0.23		
Δq_{t_2}			0.376	0.19
$\bar{q}_{t_2-1}^{15}$			0.406	0.06
$id_{t_2}^{2}$	-10.916	0.00	-10.478	0.00
$id_{t_2}^{3}$	-11.016	0.00	-11.114	0.00
R^2	0.17		0.19	
AR_{1-10}	4.98	0.89	3.34	0.97
$ARCH_{1-10}$	11.44	0.32	15.00	0.13
$Het.$	2.85	0.94	4.92	0.77
$Hetero.$	6.20	0.86	6.01	0.87
JB	52.48	0.00	52.88	0.00
$Obs.$	311		298	

Note: See table 5.

Table 9: Regressions of log of range variability $v_{t_2}^{hl}$ on a constant, persistence and market activity variables

	(21)		(22)	
	Est.	*Pval.*	*Est.*	*Pval.*
const.	-7.248	0.02	-1.960	0.00
persistence	0.024	0.00	0.025	0.00
$\Delta z_{t_2}^{tot}$	0.141	0.50		
$\bar{z}_{t_2-1}^{tot/2}$	0.538	0.03		
Δq_{t_2}			0.287	0.07
$\bar{q}_{t_2-1}^{15}$			0.216	0.01
R^2	0.13		0.14	
AR_{1-10}	10.30	0.41	7.85	0.64
$ARCH_{1-10}$	4.42	0.93	5.34	0.87
Het.	4.43	0.62	7.61	0.27
Hetero.	31.28	0.00	10.37	0.32
JB	1.94	0.38	2.88	0.24
Obs.	311		298	

Note: See table 5.

Table 10: Parsimonious regressions of log of period variability $v_{t_2}^{se}$ on a constant, persistence and market activity controlling for other variables

	(23)		(24)	
	Est.	*Pval.*	*Est.*	*Pval.*
$const.$	-9.116	0.20	-7.401	0.34
$persistence$	0.096	0.08	0.105	0.04
$\Delta z_{t_2}^{tot}$	0.446	0.37	0.398	0.45
$\bar{z}_{t_2-1}^{tot/2}$	0.512	0.36	0.179	0.78
Δq_{t_2}			0.334	0.25
$\bar{q}_{t_2-1}^{15}$			0.352	0.13
$x_{t_2}^{w}$	0.111	0.06		
$ir_{t_2}^{no,b\Delta}$			0.006	0.00
$ir_{t_2}^{no,c\Delta}$	0.015	0.00	0.015	0.00
id_1	-10.866	0.00	-10.549	0.00
id_2	-10.462	0.00	-11.134	0.00
R^2	0.20		0.21	
AR_{1-10}	5.35	0.87	3.40	0.97
$ARCH_{1-10}$	12.20	0.27	17.56	0.06
$Het.$	11.23	0.51	9.90	0.87
$Hetero.$	19.99	0.58	17.43	0.99
JB	44.25	0.00	54.98	0.00
$Obs.$	311		298	

Note: See table 5.

Table 11: Parsimonious regressions of log of range variability $v_{t_2}^{hl}$ on a constant, persistence and market activity controlling for other variables

	(25)		(26)	
	$Est.$	$Pval.$	$Est.$	$Pval.$
$const.$	-6.863	0.02	-6.996	0.03
$persistence$	0.023	0.00	0.021	0.00
$\Delta z_{t_2}^{tot}$	0.103	0.62	0.020	0.93
$\bar{z}_{t_2-1}^{tot/2}$	0.504	0.04	0.431	0.11
Δq_{t_2}			0.250	0.08
$\bar{q}_{t_2-1}^{15}$			0.147	0.12
$ir_{t_2}^{no,b\Delta}$	0.001	0.00	0.002	0.00
$ir_{t_2}^{no,c}$	0.001	0.03	0.001	0.02
$ir_{t_2}^{no,c\Delta}$	0.007	0.00	0.007	0.00
r_{t_1}	0.137	0.02	0.103	0.07
R^2	0.17		0.20	
AR_{1-10}	11.55	0.32	9.95	0.45
$ARCH_{1-10}$	4.31	0.93	4.52	0.92
$Het.$	21.62	0.09	27.63	0.07
$Hetero.$	73.07	0.00	101.31	0.00
JB	1.23	0.54	2.44	0.29
$Obs.$	311		298	

Note: See table 5.

Table 12: Parsimonious regressions of log of period and range variabilities $v_{t_2}^{se}$ and $v_{t_2}^{hl}$, respectively, with the constant, persistence and disaggregated volume variables fixed while controlling for other significant variables

	(27)		(28)	
	$Est.$	$Pval.$	$Est.$	$Pval.$
$const.$	-2.886	0.70	-4.804	0.13
$persistence$	0.091	0.10	0.023	0.00
$\Delta z_{t_2}^{big}$	0.027	0.95	-0.093	0.60
$\bar{z}_{t_2-1}^{big/2}$	0.265	0.56	0.378	0.05
$\Delta z_{t_2}^{med}$	-0.110	0.65	0.014	0.90
$\bar{z}_{t_2-1}^{med/2}$	-0.067	0.73	0.043	0.58
$\Delta z_{t_2}^{sma}$	0.387	0.18	0.090	0.37
$\bar{z}_{t_2-1}^{sma/2}$	-0.253	0.29	-0.093	0.29
$x_{t_2}^{w}$	0.115	0.05		
$ir_{t_2}^{no,b}$			0.001	0.07
$ir_{t_2}^{no,b\Delta}$			0.001	0.00
$ir_{t_2}^{no,c}$			0.001	0.05
$ir_{t_2}^{no,c\Delta}$	0.014	0.00	0.007	0.00
r_{t_1}			0.122	0.04
id_1	-10.636	0.00		
id_2	-10.146	0.00		
R^2	0.21		0.19	
AR_{1-10}	4.72	0.91	12.12	0.28
$ARCH_{1-10}$	12.62	0.25	3.37	0.97
$Het.$	23.71	0.26	27.59	0.28
$Hetero.$	43.89	0.88	128.36	0.00
JB	38.61	0.00	1.08	0.58
$Obs.$	311		311	

Note: See table 5.

Table 13: Parsimonious regressions of log of period and range variabilities $v_{t_2}^{se}$ and $v_{t_2}^{hl}$, respectively, with only the constant fixed while controlling for other significant variables

	$(27)^*$		$(28)^*$	
	$Est.$	$Pval.$	$Est.$	$Pval.$
$const.$	1.077	0.54	-5.847	0.00
$persistence$	0.098	0.07	0.023	0.00
$\bar{z}_{t_2-1}^{big/2}$			0.434	0.00
$\bar{z}_{t_2-1}^{sma/2}$	-0.414	0.04		
$x_{t_2}^{w}$	0.113	0.06		
$ir_{t_2}^{no,b}$			0.001	0.07
$ir_{t_2}^{no,b\Delta}$			0.001	0.00
$ir_{t_2}^{no,c}$			0.001	0.02
$ir_{t_2}^{no,c\Delta}$	0.015	0.00	0.007	0.00
r_{t_1}			0.134	0.02
id_1	-10.666	0.00		
id_2	-10.529	0.00		
R^2	0.20		0.18	
AR_{1-10}	5.02	0.89	12.57	0.25
$ARCH_{1-10}$	12.18	0.27	3.93	0.95
$Het.$	14.84	0.14	16.88	0.26
$Hetero.$	18.88	0.27	48.07	0.01
JB	39.71	0.00	1.53	0.47
$Obs.$	311		311	

Note: See table 5.

Table 14: Norges Bank's currency volume form

		Field	Amount (in NOK)
Spot assets	Total	1	
	Uncleared	2	
	Norwegian banks	3	
	Norwegian customers	4	
	Foreign customers	5	
Spot liabilities	Total	6	
	Uncleared	7	
	Norwegian banks	8	
	Norwegian customers	9	
	Foreign customers	10	
Forward assets	Total	11	
	Norges Bank	12	
	Other Norwegian banks	13	
	Norwegian customers	14	
	Foreign customers	15	
Forward liabilities	Total	16	
	Norges Bank	17	
	Other Norwegian banks	18	
	Norwegian customers	19	
	Foreign customers	20	

Table 15: Estimates (in millions of USD) of average daily NOK trading volume in April

	1998	1999	2001	2004
Norwegian spot NOK/EUR volume		1333	1705	1633
Norwegian total NOK/EUR volume	656		932	1663
Norwegian total NOK/USD volume	4421		7054	8424
Global total NOK volume (total)	2980		9000	13160

Note: The estimate of average daily Norwegian spot NOK/EUR trading volume is computed using the $Z_{t_2}^{tot}$ variables and NOK/USD midday Norges Bank exchange rates in the last trading day of the week in question. The estimates of average daily Norwegian total NOK/EUR and NOK/USD trading volumes are from table E.7 in the statistical annexes (1999, 2002 p. 64, 2005 p. 62) of the BIS Triennal Central Bank Surveys of the foreign exchange markets. The estimates of average daily global total (spot, forwards, etc.) NOK trading volume is computed using estimated global market share (BIS 2005, the numbers in table B.3 p. 9 divided by two) multiplied by estimated average daily global total turnover of all currencies (BIS 2005, table D.1 p. 43).[a]

[a]We are indebted to Erik Meyer for suggesting this approach in estimating average daily global total NOK trading volume.

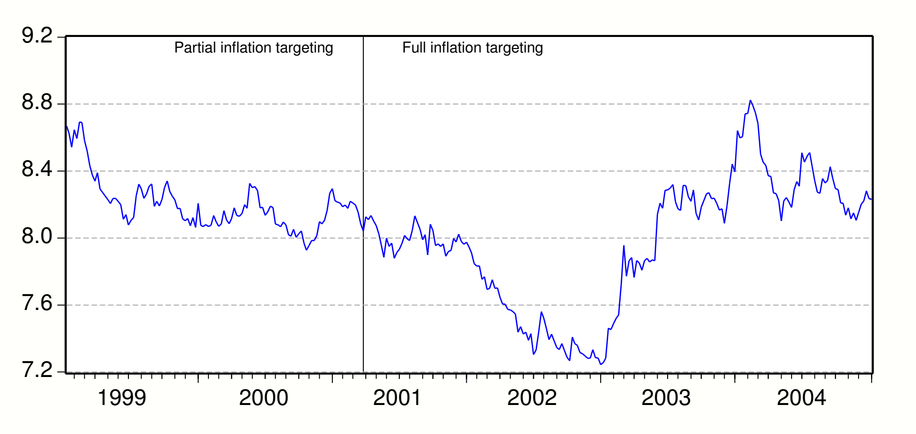

Figure 1: Bid NOK/EUR exchange rate at 21:50 GMT in the last day of trading of the week from 15 January 1999 to 7 January 2005

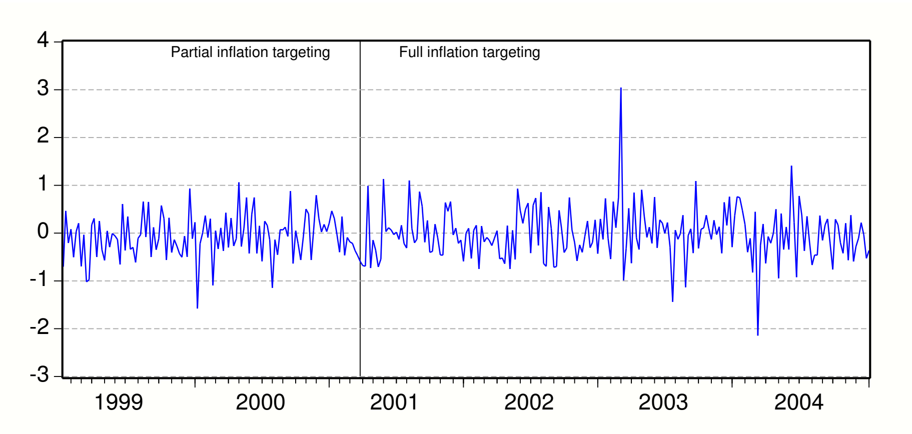

Figure 2: Period return $r^{se}_{t_2}$ over the last two trading days of week t from 15 January 1999 to 7 January 2005

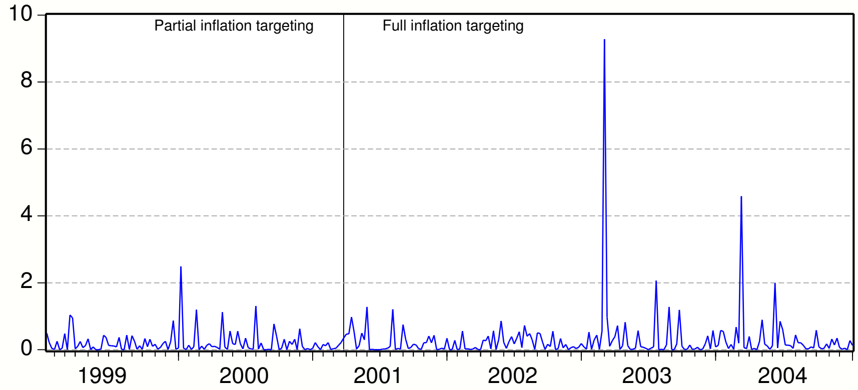

Figure 3: Period variability $V_{t_2}^{se}$ from 15 January 1999 to 7 January 2005

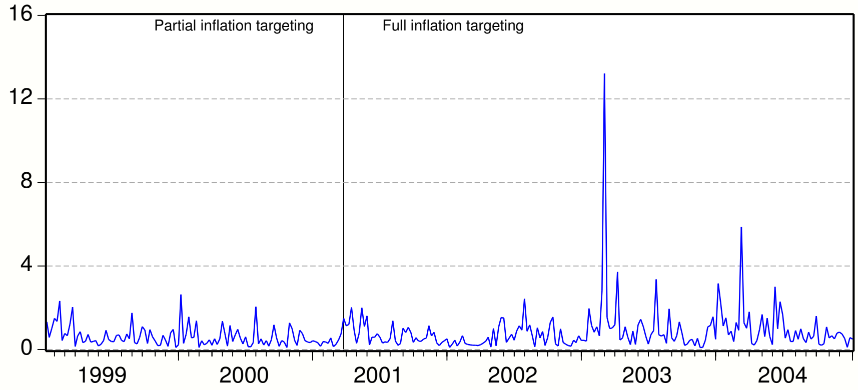

Figure 4: Range variability $V_{t_2}^{hl}$ from 15 January 1999 to 7 January 2005

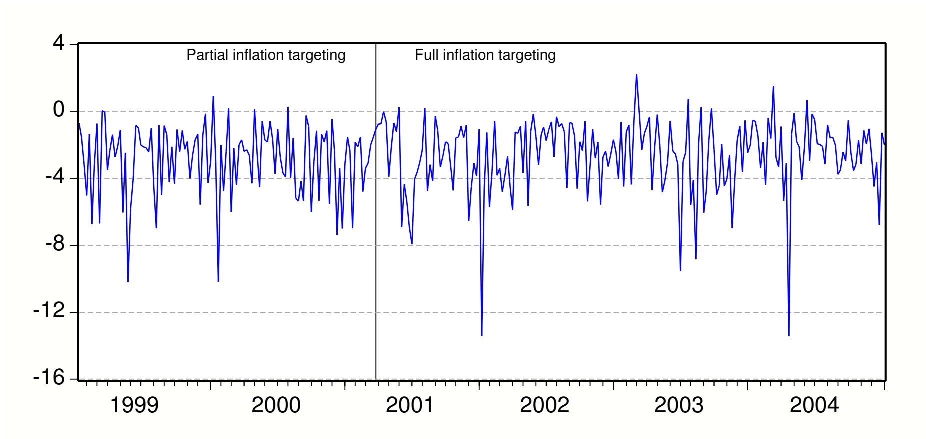

Figure 5: Log of period variability $v_{t_2}^{se}$ from 15 January 1999 to 7 January 2005

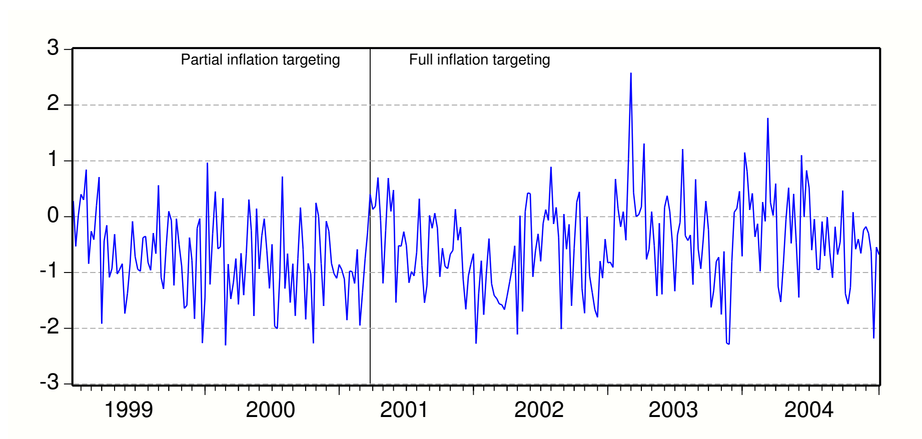

Figure 6: Log of range variability $v_{t_2}^{hl}$ from 15 January 1999 to 7 January 2005