Exchange Rate Volatility and Central Bank Interventions

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Abstract

This paper studies the impact of Swiss National Bank interventions, and news about these interventions, on the intraday volatility of the Swiss franc - U.S. dollar exchange rate. It extends the existing literature by characterising the the impact of different aspects of central bank interventions, like direction, size, frequency and time of intervention, on exchange rate volatility. Briefly, the paper finds that the effect of intervention on volatility varies depending on how volatility is defined. Interventions decrease volatility contemporaneously but this effect is reversed in the two hours afterwards. This relationship is symmetric with respect to the direction of the intervention, whether they be buy and sell interventions or with-the-wind and against-the-wind interventions. Analysis of the volatility and intervention size relationship finds that as we move from small to large interventions, the larger interventions tend to increase volatility relative to small interventions. The frequency of interventions has a small but positive impact on volatility, and this is underscored when the analysis is done by splitting the sample into low, average and high frequency interventions. The interaction between intervention size and intervention frequency results in a small positive effect on volatility for the squared return measure and the absolute return measure and a negative effect for both the realised volatility measures this effect is negative. As before the effect of the timing of the intervention varies with the volatility measure. The relationship is different for interventions at different times of the day. For the two realised volatility measures 9am interventions reduce volatility while for the other two measures the significant coefficients have an overall positive effect increasing volatility. 2pm interventions decrease volatility for both the squared return measures but increase volatility for both the absolute return measures. Reuters reports of sell interventions have a significant and lagged negative effect on volatility for the squared return measure and both the absolute return measures.

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1 Introduction

This paper studies the impact of Swiss National Bank (SNB) interventions, and news about these interventions, on the intraday volatility of the Swiss franc - U.S. dollar (CHFUSD) exchange rate.

While the effectiveness of interventions is important to policy makers, the consensus on the effectiveness has changed several times over the years. In the early 1970s and early 1980s it was believed that authorities could not affect the exchange rate while in the late 1970s, late 1980s and the early 1990s the view was that the authorities should intervene (see review by Sarno and Taylor 2001). Recently, interventions have been frequent for some currencies, like the euro and especially the yen, but infrequent for other major currencies.

Theoretically there are two standard models describing the effect of sterilised central bank interventions on exchange rates, the portfolio balance model and the signalling model. The portfolio balance approach is based on the idea that a sterilised intervention causes market players to change the composition of their portfolios by buying or selling foreign assets, which in turn leads to a change in the relative price of domestic assets and foreign assets i.e. the exchange rate. If domestic and foreign assets are perfect substitutes, then sterilised intervention cannot work via the portfolio balance channel. The signalling model, popularised by Mussa (1981), takes the view that agents interpret interventions as signals of future monetary policy i.e. the exchange rate is affected by changes in the expectations of future variables. For the signalling channel of intervention to work, transparency of interventions and credibility of the central bank are crucial[1]. Thus, theoretically both models (portfolio balance and signalling) predict that sterilised intervention can be effective.

The empirical literature on the portfolio balance model is not only scarce, but also finds very little evidence in favour of the model (exceptions to this are Ghosh 1992, Dominguez and Frankel 1993, Evans and Lyons 2001). This literature provides little support for significant imperfect substitution of domestic and foreign assets. Empirical evidence on the signalling model is mixed with some evidence for (Dominguez and Frankel 1993 b, c, Vitale 1999 lists papers which suggest that central bank interventions are informative about future monetary policy) and some evidence against (Dominguez 1992, Kaminsky and Lewis, 1996)[2]. Most of this evidence is based on low frequency data. Using daily data Chaboud and LeBaron (1999) study the impact of interventions by the Federal Reserve on trading volume for dollar-yen and dollar-mark futures markets and find a positive correlation between them. This positive relationship survives even after conditioning for daily volatility. The effect is stronger for secret interventions but weaker for Reuters reports about the interventions. Recently, access to disaggregated data on interventions has made it possible to test the signalling hypothesis within the market microstructure approach to exchange rates[3]. In this framework central banks are

[1]Related to the effectiveness of interventions via the signalling channel is the secrecy puzzle. The signalling channel should work better under transparency but until very recently interventions have been secret. This has prompted researchers to suggest that central banks might intervene secretly if their objectives conflict with the fundamental value of the exchange rate (Bhattacharya and Weller 1997 and Vitale 1999). However, the two papers differ on the concealment of interventions with Vitale (1999) claiming that the goals of the intervention should never be revealed while Bhattacharya and Weller (1997) conclude that under certain conditions central banks may prefer to reveal their objectives.

[2]Edison 1993 provides a review of the empirical literature on the effectiveness of central bank interventions. For references to recent low frequency work on the effectiveness of interventions see Chang and Taylor 1998.

[3]Prior to this interventions were inferred from changes in international reserves. This is an inaccurate proxy given that reserves are affected by interest receipts, valuations changes and sometimes do not include intervention transactions at all

viewed as informed players in the market and their trades (interventions) are expected to affect the price (exchange rate) since they reveal this information to the market. Assessing effectiveness based on central bank profits from intervention, Goodhart and Hesse (1993) find that interventions are profitable in the long run but not in the short run. Chang and Taylor (1998) examine the effect of Bank of Japan interventions on the Japanese yen - U.S. dollar (JPYUSD) exchange rate. They find that interventions have a significant positive impact on volatility, with the largest impact 30 - 45 minutes prior to the Reuters news report about the intervention (Reuters reports are used as a proxy for actual intervention)[4]. The data set used in the current paper is an improvement on that in Chang and Taylor (1998) since it consists of actual intervention data from the SNB and Reuters news reports about these interventions, allowing me to separate the effect of the intervention on volatility from the effect of the news. In addition to observing significant intervention effects on the level of the CHFUSD exchange rate Fischer and Zurlinden (1999) find that the time of the intervention may play an important role in the effectiveness of the intervention. While they use actual foreign exchange transactions data from the SNB which include information on the transacted amount, price and time of day, they do not have exchange rate data to match. So they proxy the change in the exchange rate by the difference between the exchange rates of two consecutive interventions.

Faust, Rogers, Wang and Wright (2003) study the effect of macroeconomic announcements on high frequency exchange rates (dollar-DM, dollar-euro and dollar-pound) and interest rates. They find that "stronger-than-expected" announcements lead to significant dollar appreciation. Using data on interest rates and interpreting results in the context of uncovered interest parity, they infer that "such releases either lower the risk premium for holding foreign currency or imply future expected dollar depreciation". Dominguez (2003a) studies intraday and daily effects of dollar interventions by G3 governments on exchange rate volatility. The underlying premise in the paper is that heterogeneity in trader's information can cause exchange rates to move away from fundamentals in the short run and if these heterogeneous traders interpret interventions differently, then interventions might actually increase volatility in the short run. She finds that interventions are associated with increases in intraday and daily volatility, but there is not much evidence that intervention affects long term volatility. Payne and Vitale (2003) expand on the results from Fischer and Zurlinden (1999) by including intraday indicative exchange rate quotes. They find that intervention has significant short run effects on the level of the exchange rate. Additionally, using the absolute value of the of exchange rate return as a measure of volatility, they find that in anticipation of the intervention and at the time of the intervention volatility increases but starts decreasing from 15 minutes after and the effect is completely reversed over the next 90 minutes.

This paper extends the existing literature by characterising the impact of central bank interventions on exchange rate volatility based on different aspects of interventions like direction, size, frequency and time of intervention. It asks the questions: Do interventions have an impact on exchange rate volatility? Do buy and sell interventions have different effects on volatility (Direction)? Do larger interventions mean lower volatility (Size)[5]? If there is a size effect, is it linear or non-linear? If

[4]Using SNB intervention data and Reuters reports Fischer (2003) finds that the latter are not good proxy for the former and hence Reuters reports need to be used with caution.

[5]It would not be surprising if there is no size effect given the large daily turnover in foreign exchange markets. In April 1998 the daily turnover in traditional foreign exchange instruments (spot, forwards and swaps) was $1.5 billion and in OTC foreign exchange derivatives it was $97 billion. Even though the turnover declined between 1998 and 2001, it was $1.2 billion in traditional foreign exchange instruments and $67 billion in OTC foreign exchange derivatives. Aprroximately

central banks do want to intervene, should they do so in one shot or via repeated interventions (Frequency)? Does one large intervention have a different effect than a set of smaller more frequent interventions i.e. is there any interaction between size and frequency? Do interventions affect volatility more or less when they are carried out during periods of high trading volume, for example, market opening and closing times (Time of intervention)?

The second aspect this paper considers is how markets react to news about interventions: Does news about interventions calm markets or make them volatile? Is this news important relative to the actual intervention? If the news report appears before the intervention, does the actual intervention have any effect? On the other hand, if the news report appears after the intervention (or is missed), does the actual intervention have a larger and/or more persistent impact?

To analyse these questions I use an event study methodology and data on the CHFUSD exchange rate, interventions by the SNB and Reuters reports of these interventions. As mentioned above this data allows more reliable analysis since I use actual interventions (and not proxies based on international reserves or Reuters reports), volatility measures based on changes in indicative quotes of the exchange rate (and not proxies based on intervention transaction price) and Reuters news reports that allow me to separate the effect of the intervention on volatility from the effect of the news.

Briefly, the paper finds that the effect of intervention on volatility varies depending on how volatility is defined. Interventions decrease volatility contemporaneously but this effect is reversed in the two hours afterwards. This relationship is symmetric with respect to the direction of the intervention, whether they be buy and sell interventions or with-the-wind and against-the-wind interventions. Analysis of the volatility and intervention size relationship finds that as we move from small to large interventions, the larger interventions tend to increase volatility relative to small interventions. The frequency of interventions has a small but positive impact on volatility, and this is underscored when the analysis is done by splitting the sample into low, average and high frequency interventions. The interaction between intervention size and intervention frequency results in a small positive effect on volatility for the squared return measure and the absolute return measure and a negative effect for both the realised volatility measures this effect is negative. As before the effect of the timing of the intervention varies with the volatility measure. The relationship is different for interventions at different times of the day. For the two realised volatility measures 9am interventions reduce volatility while for the other two measures the significant coefficients have an overall positive effect increasing volatility. 2pm interventions decrease volatility for both the squared return measures but increase volatility for both the absolute return measures. Reuters reports of sell interventions have a significant and lagged negative effect on volatility for the squared return measure and both the absolute return measures.

The data are described in Section 2 along with some descriptive statistics on the exchange rate and the intervention series. Section 3 describes the methodology briefly, Section 4 presents the results and Section 5 concludes.

2 Data

The data covers the time period 07 Oct 1986 - 15 Aug 1995 and comprises of three components. The first component of the data consists of intraday indicative quotes of the CHFUSD exchange rate at a 15 minute frequency and are provided by Olsen

5% of the global transactions in the forex market are accounted for by trading in CHFUSD. This makes it the fourth most traded currency pair. Source: Pasquariello (2003) and the BIS Triennial Central Bank Survey of Foreign Exchange and Derivatives Market Activity (1999).

& Associates (Zurich). The second component of the data is the SNB interventions. These interventions were conducted in the CHFUSD market and are time stamped to the exact time of the intervention. Also included is information on the size and direction of the intervention (whether the SNB was buying USD or selling USD)[6]. The final component of the data is news reports of central bank interventions based on Reuters headlines[7]. The interventions and news reports data are aggregated to 15 minute frequency to match the exchange rate data.

A plot of the exchange rate along with the interventions is in Figure 1. Eyeballing the figure it appears that the SNB is following an against-the-wind intervention policy for the majority of the time. A plot of the four volatility measures for an average non-intervention is in Figure 2. It is clear that there is a distinct intraday pattern in volatility which is motivation for deseasonalising the exchange rate volatility series before analysing it. I leave that discussion to the methodology section.

The SNB's intervention strategy consisted of conducting a number of small interventions in a short period of time and the majority of these were in conjunction with by the Federal Reserve (Fed) and/or the Bundesbank (Buba). Based on quotes gathered from commercial banks, SNB interventions were conducted in the dealer market. And while the SNB informed the counter-party on completion of the transaction that it was an intervention, it did not publicly declare that it had intervened[8]. It is worth pointing out that in any given intervention episode, the SNB either bought dollars or sold dollars, but never did both. From Table 1 we see that the SNB intervened 171 times over 97 days. They bought USD on 70 occasions (over 33 different days) and sold USD on 101 occasions (over 64 days). Figures 3 provides further description of the interventions. The SNB intervened more frequently in the early years of the sample but these interventions seem equally spread out during the week (Figures 3a and 3b). Figures 3c and 3d reiterate the point that the SNB intervened frequently and in small quantities rather than intervening a large amount in a single trade. Figure 3e is very interesting since it shows a bimodal distribution of interventions by time of day. Interventions are most often at 9am and 2pm GMT (Greenwich Mean Time) and can be interpreted as being timed to coincide with the opening of the London and New York markets respectively. These are typically times when trading volumes are high, indicating a possibility that the SNB might be trying to hide its trades from the market[9]. At this point it is worth noting that this data contains no information on whether the intervention was conducted jointly with another central bank or singly. Any information on joint interventions was retrieved from Reuters reports.

Reuters news reports have been used in numerous microstructure papers analysing interventions and are now a standard way of inferring when the market received information about interventions[10]. Most of this research assumes that the reports are released just after the intervention and typically, the time stamp on the report is taken to be the time the market learned about the intervention. Fischer (2003) carries out tests of the accuracy of these reports for SNB interventions. He finds that there are large prediction errors between Reuters reports and the actual interventions stemming in part from the fact that it is possible for reports to be released before the intervention in some cases and after the actual intervention in others.

[6] An example of a typical data point would be 'SNB bought US dollars 5 million on 05 June 1990 at 10:49 a.m.'.

[7] This data is from Kathryn Dominguez and covers headlines on all days when the Federal Reserve was in the market.

[8] For a more detailed description of the SNB's intervention strategy look at Fischer (2003).

[9] Admati and Pfleiderer 1988 and Easley and O'Hara 1987 are examples of microstructure models that show that informed traders have incentive to trade when volumes are high.

[10] Goodhart and Hesse 1993, Chang & Taylor 1998, Dominguez 2003 a, b, Payne & Vitale 2003 are some other papers that have used Reuters news reports on interventions.

So clearly, any results based on these reports must be viewed with caution. Since the Reuters reports data starts in Sept 1989, only a sub-sample (Sept 1989 - Aug 1995) of the interventions data is used to match the Reuters reports data. Table 3 provides a description of the Reuters reports data[11]. Reuters reports that the SNB bought USD on 16 occasions (of which 11 were joint interventions) and sold USD on 19 occasions (of which 15 were joint interventions). Comparing this with the information from the SNB it appears that Reuters falsely reports the SNB buying USD on 5 occasions and misses 28 occasions when the SNB sold USD[12].

3 Measuring Exchange Rate Volatility

I use an event study approach to analyse the impact of various intervention characteristics on exchange rate volatility[13]. I use four different measures of volatility in the analysis. Squared returns, absolute returns and two measures of realised volatility, sum of the squared returns for the past hour and the sum of the absolute returns for the past hour[14]. Returns are calculated as the log difference of the exchange rate series. There are two points I would like to raise at this stage. First, given that the realised volatility variable has a lag structure, the independent variables will have lagged effects on the dependent variable by definition. Secondly, it is widely recognised that seasonal patterns exist in high frequency exchange rate volatility and there is evidence of this in the data used in this paper as well (see Figure 2). The simplest method to control for seasonality would be to include a dummy variable for every 15-minute interval in the day[15]. Instead I use Flexible Fourier Forms (FFF) to adjust for seasonality[16]. Intuitively, this method captures seasonality in a non-linear way by taking combinations of periodic components (sine and cosine curves) at different frequencies. For each 15-minute interval indexed by 'j' the volatility seasonal is calculated by estimating the following equation over all non-intervention days[17],

$$s_j = c + \sum_{k=1}^{P} \left[\lambda_{2k-1,j} \ \cos k \ (\frac{2 \ \pi \ j}{N}) + \lambda_{2k,j} \sin k \ (\frac{2 \ \pi \ j}{N}) \right] \tag{1}$$

where j = 1,...,96 and N is the number of return intervals per day (96 in this data).

[11] An example of a Reuters report - 'Swiss National Bank buys dollars for francs in concerted intervention with Fed'.

[12] It is worth noting here that if there is a report corresponding to the first intervention of an episode it might be possible that the other interventions in the same episode are anticipated by the market, given the SNB's intervention implementation technique of small frequent interventions. So these interventions should be considered as reported even if there are no additional Reuters reports.

[13] Time series methods are not built to capture the effects of unequally spaced data like interventions. Fatum and Hutchinson (1999) argue that the event study methodology is more apt in this context, where an event is defined as one episode of interventions. Other papers conducting event studies in this context are Chang and Taylor, 1998, Fischer and Zurlinden, 1999, Payne and Vitale 2003, Dominguez 2003 a,b.

[14] These are standard ways of measuring volatility (used in Payne and Vitale 1999, Dominguez 2003 and Andersen and Bollerslev 1997).

[15] However this would mean an additional 96 right-hand side variables making computations slow.

[16] Other papers using FFF in this context are Andersen & Bollerslev 1997, Payne 1996 and Dominguez 2003. For a text book description of the method refer to chapter 6 (Spectral Analysis) in Hamilton 1994.

[17] I use only non-intervention days to capture the seasonal pattern since volatility on these days might differ from those on intervention days and I do not want to explain away any intervention day effects by imputing them in the seasonal. I estimate different seasonal components for the four different definitions of volatility.

The parameter 'P' controls the number of periodic components used[18]. Figure 2 graphs the average realised volatility pattern on non-intervention days along with the fitted FFF.

I regress the volatility variable on the estimated seasonal components. The residual from this regression, which is the deseasonalised volatility, is then used as the dependent variable for all further analysis. The independent variables are leads and lags of dummy variables corresponding to the different intervention characteristics.

4 Results

All regressions are run on a sample of 18621 observations spaced at 15-minute frequency. The data includes all 171 interventions over 97 days in the period Oct 1986 - Aug 1995. These are combined with a control sample of non-intervention days to give the final data set. The control sample was constructed by randomly choosing a non-intervention day that matched the day of week and the year of a given intervention day. The regressions were run for four different definitions of volatility - squared returns, absolute returns, realised volatility based on squared returns and realised volatility based on absolute returns.[19].

4.1 SNB Interventions

The first regression aims to confirm that interventions have an impact on exchange rate volatility. The deseasonalised volatility series is regressed on 8 leads and lags of an intervention indicator which takes value 1 when there is an intervention (buy or sell) and is 0 otherwise. The results in Table 4 show that the effect of intervention depends on how volatility is defined. There is a significant contemporaneous negative effect but only when volatility is defined as realised volatility. However, in the two hours after the intervention we observe that the majority of the significant coefficients are positive indicating an increase in volatility for all the measures.

4.2 Direction

Having established that depending on how you define volatility interventions volatility reduces contemporaneously but increases afterwards, I turn to the relationship between the direction of the intervention and volatility. Do buy interventions have a different impact than sell interventions? In this paper a buy (sell) intervention refers to the SNB buying (selling) USD which would lead to a depreciation (appreciation) in the CHF.

I test this hypothesis explicitly based on the following regression[20].

$$\begin{aligned} vol_t &= \alpha + \sum_{j=-8}^{8} \beta_j \ (B_{t+j} + S_{t+j}) + \sum_{k=-8}^{8} \gamma_k \ S_{t+k} + \theta_1 \ vol_{t-1} + \theta_2 \ vol_{t-2} + \varepsilon_t \\ &= \alpha + \sum_{j=-8}^{8} \beta_j \ B_{t+j} + \sum_{k=-8}^{8} (\beta_k + \gamma_k) \ S_{t+k} + \theta_1 \ vol_{t-1} + \theta_2 \ vol_{t-2} + \varepsilon_t \quad (2) \end{aligned}$$

[18] My current results are based on P = 8. Varying P to take different values (4, 6, 8, 10) did not affect the fir of the FFF to the data. Dominguez 2003 uses P = 8 for dem-usd and yen-usd data for the period Aug 89 - Aug 1995 while Andersen and Bollerslev 1997 use P = 6 for dem-usd data for the period 1992-93.

[19] In all the regressions I include two lags of the dependent variable. Newey-West t-statistics are used to correct for heteroskedasticity and serial correlation usually found in high frequency financial data.

[20] In later sections, the same specification is used to test if other characteristics of interventions have asymmetric effects on volatility.

where B_t and S_t are dummy variables for buy and sell interventions respectively.

Crucially, this regression tests whether $\gamma_k \neq 0$. A non-zero γ_k coefficient implies that buy and sell interventions have different relationships with volatility. The results in Table 5 indicate that almost all the γ_k are insignificant, which implies that buy and sell interventions have similar effects on volatility. The few significant γ_k coefficients are positive, which means that at these lags sell interventions reduce volatility by less than buy interventions.

Another interesting directional aspect is whether against-the-wind and with-the-wind interventions have different effects on volatility. Eye-balling Figure 1 and Table 2, it appears that the SNB intervenes against-the-wind more often than with-the-wind, presumably to calm markets. These indicators are calculated based on 1 day, 1 week, 2 week and 4 week moving averages. Using a specification similar to Eqn. (2), I find that almost all the gamma coefficients are insignificant implying that against-the-wind and with-the-wind interventions have similar effects on exchange rate volatility[21].

4.3 Size

We now turn to investigating the effect of the size of an intervention on exchange rate volatility. A priori if we believe that central banks intervene to calm markets then we would expect the size of the intervention and volatility to be negatively correlated. On the other hand, it would not be surprising to find that central bank interventions, which are typically small relative to the daily turnover in foreign exchange markets[22], do not affect volatility. Finally, some microstructure models (Kyle 1985) predict a positive relationship between intervention size and volatility since the central bank's (informed trader) demand is expected to move price (the exchange rate). So, what does the data tell us about the relationship between intervention size and volatility? Is this relationship linear or non-linear? To this end I regress the four volatility measures on indicators for intervention, size and squared intervention quantity. The size indicator variable is equal to the absolute amount of the intervention when there is one and zero otherwise. The squared quantity indicator is constructed similarly. The results, presented in Table 6, show that for the absolute return based volatility measures intervention size has a lagged negative effect on volatility which would support the idea that central banks intervene to calm markets. On the other hand, for the realised volatility based on squared returns there is no effect at all while for the squared return measure the lagged effect is positive. If we believed that interventions are informative trades then, we would expect increased volatility as the market absorbs this information. If we consider the realised volatility measure, we find a small, negative effect. So the effect of the size of an intervention on volatility depends on how volatility is defined. Looking at the coefficients on squared quantity we see that only a few are significant (at lead 8, contemporaneously and then at lags 5,6) and these are very small. This might be explained by the much larger scale of squared quantity relative to the volatility measures. This means that the size effect might be non-linear but that this non-linearity is small[23].

I analyse the volatility and intervention quantity relationship further by estimating the effect of small, average and large size interventions on volatility[24]. Results

[21] Due to constraints of space the results are not presented in the paper.

[22] Footnote 5 gives information on daily turnover in foreign markets.

[23] Payne & Vitale 2000 find that the size effect on the level of the exchange rate is non-linear but that this non-linearity is not economically significant.

[24] Small interventions are defined as sales or purchases of up to 5 mil USD, Average interventions as between 5 and 10 mil USD and Large interventions are those that are larger than 10 mil USD. With this classification there are 27 small, 26 average and 5 large interventions.

in Table 7 indicate that as we move from small to large interventions the positive coefficients on interventions decrease and the negative coefficients increase. This means that larger interventions tend to increase volatility relative to small interventions which is counter intuitive. This could be explained by the market interpreting larger intervention quantities as the central bank trying to push the exchange rate unsuccessfully, and this negative signal leads to higher volatility.

4.4 Frequency

Frequency is the next characteristic of intervention we turn to. How is volatility affected by a continued presence of the central bank in the market relative to a one-off trade? The results in Table 8 indicate that the frequency effect differs across the different volatility measures, with more coefficients on frequency significant for squared and absolute return than for both the realised volatility measures. The sum of the significant coefficients is small and positive indicating that more frequent interventions increase volatility. However, given that the coefficients are very small this could also be interpreted as the frequency of intervention actually having no relationship with volatility i.e. that the regression has estimated a significant coefficient of zero. Alternatively, it could be caused by the fact that the scale of the volatility measures is much smaller than that of the frequency variable and hence the estimated coefficient is small but non-zero. Finally, this might be the result of some kind of threshold effect i.e. if the central bank is in the market for long, this could be interpreted positively by the market to mean that the central bank is determined to achieve its goal or it could be interpreted negatively, sending a signal that the central bank is in a losing battle. To test this I estimate the effect of low, average and high frequency interventions using the following specification[25].

$$vol_t = \alpha + \sum_{j=-8}^{8} \beta_j \, I_{t+j} + \sum_{j=-8}^{8} \gamma_j \, LF_{t+j} + \sum_{k=-8}^{8} \delta_k \, AF_{t+k} + \sum_{l=-8}^{8} \phi_l \, HF_{t+l} + \theta_1 \, vol_{t-1} + \theta_2 \, vol_{t-2} + \varepsilon_t \quad (3)$$

The results in Table 9 indicate that low frequency interventions have virtually no effect on volatility while average and high frequency interventions have a small but significant and positive effect on volatility. So this would support the view that the market interprets the continued presence of the central bank in the market as the central bank fighting a losing battle and this increases volatility.

4.5 Size and Frequency

From Figures 3c and 3d we can see that the SNB's preferred strategy for intervention has been frequent interventions of small quantities we are now interested in the combined effect of the size and the frequency of interventions. In the last two sections we saw that large size and high frequency intervention episodes increase volatility, . Practically, we are asking do 5 interventions of USD 10 million each have the same effect on volatility as one intervention of USD 50 million? The results of regressing the volatility measure on intervention size, intervention frequency and a size-frequency interaction term are in Table 10. The sum of the significant quantity coefficients is positive for all except the absolute return measure confirming again that the larger the intervention, the higher the volatility. Almost all the frequency coefficients are insignificant. This might be explained by the possibility

[25] For a given 15 minute interval, the indicator for low frequency interventions takes value 1 when there are between 1 and 6 interventions (44 data points), the average frequency indicator takes the value 1 when there are between 7 and 12 interventions (12 data points), and the large frequency indicator is 1 when the SNB intervenes between 13 and 18 times (2 data points).

that size and frequency are highly correlated and hence are capturing the same effect. The few size-frequency interaction coefficients that are significant sum to give a small positive effect for the squared return measure and the absolute return measure. This means that for a given intervention size, the higher the frequency of intervention, the higher the volatility. For both the realised volatility measures the sum of the significant coefficients is negative indicating that for a given intervention size or intervention frequency, the higher the other characteristic the lower the volatility. So using the realised volatility measures would support the SNB's intervention strategy of small but frequent interventions.

4.6 Time of Intervention

Central banks intervene at their own discretion. Figure 3e shows that the maximum number of SNB interventions occur at 9am and 2pm GMT. Since the majority of the SNB's interventions were joint with either the Fed or the Buba or both[26], it is possible that the SNB timed its interventions to coincide with the opening of the London market and/or the New York markets. The interesting question then is, do interventions at different times of the day have different effects on volatility? I test this by splitting the sample of interventions into two sets, those at 9am (London open) and those at 2pm (New York open). The results of regressing exchange rate volatility on these two variables plus a dummy variable to control for joint interventions are in Table 11. As before the effect of the timing of the intervention varies with the volatility measure. For the two realised volatility measures 9am interventions reduce volatility while for the other two measures the significant coefficients have an overall positive effect increasing volatility. 2pm interventions decrease volatility for both the squared return measures but increase volatility for both the absolute return measures.

A possible explanation for the positive coefficients is that at opening times there uncertainty in the market and this leads to increased volatility. Alternatively, it could also be that the FFF seasonal has failed to capture the opening time volatility well enough. (reference to models which predict that events during high volume periods have stronger effects - Maureen O'Hara, Evans and Lyons).

Given that interventions appear to be concentrated around 9am and 2pm, I also combined morning and afternoon interventions[27] to see whether they have different relationships with volatility. The results[28] from a regression similar to Eqn. (2) show that morning and afternoon interventions have a similar effect on volatility (nearly all the gamma coefficients are insignificant).

4.7 All Characteristics

In an effort assess the combined effect of these different characteristics I regressed the volatility measures on the dummy variables for intervention, intervention size, frequency, a size-frequency interaction term, 9am interventions, 2pm interventions, interventions joint with the Fed and interventions joint with the Bundesbank. The results are in Table 12. Again the results depend on the choice of volatility measure but the measures are most responsive to interventions that are joint with the Fed, 2pm interventions and the size of the intervention. Counter intuitively, interventions that are joint with the Fed increase volatility for all measures except the squared return measure for which it decreases volatility. For the squared return

[26]Table 3 gives the number of interventions joint with the Fed only, the Buba only and joint with both the Fed and the Buba.

[27]Morning interventions include those from 7am to 10am and afternoon interventions include interventions from 1pm to 4pm.

[28]Not presented here for reasons of space

and absolute return measures interventions that are with the Buba, 9am and 2pm interventions and the size-frequency interaction term all increase volatility but the size of the intervention and the frequency of the intervention decreases volatility. For the two realised volatility measures interventions that are joint with the Buba, the size and the frequency of the intervention all increase volatility while 2pm interventions and the size-frequency interaction term both decrease volatility and 9 pm interventions have no effect on volatility. So if the SNB used the realised volatility measures we would expect to see them intervening in small quantities frequently or in one shot with a large quantity and time the intervention for 2pm GMT. If you used the other two measures, the same strategy would end up increasing exchange rate volatility. In fact the only thing we can conclude about these measures is that one shot, small size interventions would decrease volatility.

4.8 Reuters Reports

Since the data on Reuters reports starts Sept 1989, only a sub-sample of the interventions data is used to match the Reuters reports data. The period under consideration is Sept 1989 - Aug 1995 and during this time the SNB bought USD on 11 occasions (over 6 different days) and sold USD on 47 occasions (over 27 different days). See Table 1.

Regressing the volatility measures on a dummy variable for Reuters reports shows that the news reports have no overall effect on volatility. When split into reports of buy interventions and those of sell interventions one finds that reports of buys are mostly insignificant while reports of sell interventions have a negative effect on volatility, mostly anticipated but also with lag for the two realised volatility measures (Table 13)[29]. If foreign exchange markets are efficient they should absorb any new information immediately which makes it puzzling to observe a lagged effect of the news on volatility. One possible explanation for observing lagged news effect only for the realised volatility measures is that by construction they have a lagged structure. On the other hand, the anticipation effect might be indicative of information leakage, before the report is released. These effects on the timeliness of the news (comparing the timing of the report to the time of the intervention) are investigated further in the next sub-section.

These regressions give the impression that reports of buy interventions have a dissimilar impact than reports of sell interventions. However, testing this explicitly indicates that reports of buys and reports of sells have the same relationship with volatility[30].

4.9 SNB Interventions and Reuters Reports

Finally, it is interesting to see whether the market reacts to the actual intervention and news about the intervention. Intuitively, if a Reuters report was released before the intervention and if markets were efficient we would expect the intervention to have no impact on volatility since it does not convey new information. If the report is released after the intervention, then it could still have some effect on volatility since some market participants may still be unaware of the intervention. The strength of this effect will depend partly on how soon after the intervention the report is released. So it is interesting to examine the effect of Reuters reports on volatility in the presence of the actual intervention. I regress the volatility series on two dummy variables, one for the actual SNB interventions and the other for

[29] Only the table with results for the reports of sell interventions is presented for reasons of space.
[30] The results are not presented here for reasons of space

Reuters reports[31]. The results in Table 14 indicate that in the presence of the actual interventions, Reuters reports have almost no effect on volatility. For the squared return and both absolute return measures, Reuters reports have a small negative impact on volatility in contrast to the positive effect of the actual interventions. To understand this further I split these regressions into buy interventions and buy reports and sell interventions and sell reports. Looking at Table 15 we can see that this result is driven entirely by sell side interventions and reports. Reuters reports of buy interventions have an insignificant impact on volatility in the presence of the actual buy interventions while Reuters reports of sell interventions have a significant anticipated and lagged negative impact on volatility.

5 Conclusions

This paper has conducted an event study using the CHFUSD exchange rate and SNB interventions to study the relationship between the volatility of the exchange rate and the various characteristics of interventions. Additionally, using Reuters reports, it studies the impact of the news of these interventions on volatility. The data set contains information on the size, the direction, the frequency and the exact time of the intervention making it unique in many ways. The analysis was conducted using four different measures of volatility - absolute returns, squared returns, one hour realised volatility based on absolute returns and one hour realised volatility based on squared returns. The results vary depending on which measure is used but there are some general conclusions that can be drawn. With this rich data set I have identified that interventions decrease volatility contemporaneously but this effect is reversed in the two hours afterwards. This is in line with previous empirical work in the area (e.g. Chang and Taylor 1998 and Dominguez 2003a find a positive relationship between intervention and volatility; Chaboud and LeBaron 1999 find a positive relationship between intervention and trading volume). Further, the direction of the intervention does not seem to affect volatility. Buy and sell interventions have similar effects on volatility and the same is true for against-the-wind and with-the-wind interventions.

The analysis also identifies a lagged negative effect of intervention size for the absolute return based volatility measures which would support the idea that large interventions calm markets. On the other hand, for realised volatility based on squared returns there is no effect at all while for the squared return measure the lagged effect is positive. There is weak evidence of non-linearity in the size effect. Further analysis of the volatility and intervention size relationship finds that as we move from small to large interventions, the larger interventions tend to increase volatility relative to small interventions which is counter intuitive. This could be explained by the market interpreting larger intervention quantities as the central bank trying to push the exchange rate unsuccessfully, and this negative signal leads to higher volatility.

The frequency of interventions has a small but positive impact on volatility, and this is underscored when the analysis is done by splitting the sample into low, average and high frequency interventions. While small frequency interventions have no effect on volatility, average and high frequency interventions continue to have a significant positive effect.

The interaction between intervention size and intervention frequency results in a small positive effect on volatility for the squared return measure and the absolute return measure. This means that for a given intervention size, the higher the frequency of intervention, the higher the volatility. For both the realised volatility

[31] Note need to re-run these making the zero for the reports match with the zero for interventions to make any sensible inference.

measures this effect is negative indicating that for a given intervention size or intervention frequency, the higher the other characteristic the lower the volatility. So using the realised volatility measures would support the SNB's intervention strategy of small but frequent interventions.

As before the effect of the timing of the intervention varies with the volatility measure. After controlling for joint interventions with the Fed and the Buba, I find that for the two realised volatility measures 9am interventions reduce volatility while for the other two measures the significant coefficients have an overall positive effect increasing volatility. 2pm interventions decrease volatility for both the squared return measures but increase volatility for both the absolute return measures.

Overall, Reuters reports of interventions do not appear to affect exchange rate volatility. This result appears to be driven by reports of buy interventions since reports of sell interventions have a lagged negative impact on volatility. However, explicit testing of the difference of these impacts indicates that they are insignificant. Further, testing the impact of Reuters reports in the presence of actual interventions I find that Reuters reports have a small but significant and lagged negative effect on volatility for the squared return measure and both the absolute return measures. This overall effect is driven entirely by reports of sell interventions since reports of buy interventions are insignificant in the presence of buy intervention itself.

6 Bibliography

Admati, A and P. Pfleiderer, 1988, "A Theory of Intraday Trading Patterns", Review of Financial Studies, 1, 3 - 40

Andersen, Torben and Tim Bollerslev, 1997, "Intraday Periodicity and Volatility Persistence in Financial Markets", Journal of Empirical Finance, 4, 115 - 158

Bacchetta, P. and E. van Wincoop, 2003, "Can Information Heterogeneity Explain the Exchange Rate Determination Puzzle?", NBER Working Paper No. w9498

Bhattacharya, U. and P. Weller, 1997, "The Advantage to Hiding Ones Hand: Speculation and Central Bank Intervention in the Foreign Exchange Market", Journal of Monetary Economics, 39, 251 - 277

Chaboud, Alain and Blake LeBaron (1999), "Foreign Exchange Market Trading Volume and Federal Reserve Intervention", http://ssrn.com/abstract=177148

Chang, Yuanchen and Stephen J. Taylor, 1998, "Intraday Effects of Foreign Exchange Intervention by the Bank of Japan", Journal of International Money and Finance, 17, 191 - 210

Dominguez, Kathryn, 1992, "Exchange Rate Efficiency and the Behaviour of International Asset Markets", Garland, New York

Dominguez, Kathryn, 1999, "The Market Microstructure of Central Bank Intervention", NBER Working Paper No. w7337

Dominguez, Kathryn, July 2003a, "When Do Central Bank Interventions Influence Intra-Daily and Longer-Term Exchange Rate Movements?", NBER Working Paper 9875

Dominguez, Kathryn and Jeffrey Frankel, 1993 b, "Does Foreign Exchange Intervention Matter? The Portfolio Effect", American Economic Review, 83, 1356 - 1369

Dominguez, Kathryn and Jeffrey Frankel, 1993 c, "Foreign Exchange Interventions: An empirical Assessment", in Frankel, J. (Ed.), On Exchange Rates, The MIT Press, Cambridge, MA, 317 - 345

Easley, D. and Maureen O'Hara, 1987, "Price, Trade Size, and Information in Security Markets", Journal of Financial Economics, 19, 69 - 90

Evans, Martin D. and Richard K. Lyons, July 2001, "Portfolio Balance, Price Impact and Secret Intervention", NBER Working Paper No. w8356

Fatum, Rasmus and Michael M. Hutchinson, March 1999, "Is Sterilized Foreign Exchange Intervention Effective After All? An Event Study Approach", working paper available at http://econ.ucsc.edu/~hutch/

Faust, Jon, John H. Rogers, Shing-Yi B.Wang and Jonathan H. Wright (2003), "The High-Frequency Response of Exchange Rates and Interest Rates to Macroeconomic Announcements", Board of Governors of the Federal Reserve System, International Finance Discussion Paper No. 784

Fischer, Andreas, Sept 2003, "Reuters News Reports versus Official Interventions: A Cautionary Warning", unpublished manuscript

Goodhart, C.A.E. and T. Hesse, 1993,"Central Bank Forex Intervention Assessed in Continuous Time", Journal of International Money and Finance, 12, 368 - 389

Hamilton, James D., 1994, "Time Series Analysis", Princeton University Press

Kaminsky, G.L. and K.K. Lewis, 1996, "Does Foreign Exchange Intervention Signal Future Monetary Policy?", Journal of Monetary Economics, 37, 285 - 312

Kyle, Pete, 1985, "Continuous Auctions and Insider Trading", Econometrica, 53, 1315 - 1335

Lyons, Richard K., 1997, "A Simultaneous Trade Model for the Foreign Exchange Hot Potato", Journal of International Economics, ..., 275 - 298

Mussa, Michael, 1981, "The Role of Official Intervention", Group of Thirty, New York

Pasquariello, Paolo, 2003, "Informative Trading or Just Costly Noise? An Analysis of Central Bank Interventions", working paper

Payne, Richard, Mar 1996, "Announcement Effects and Seasonality in the intraday Foreign Exchange Market", Financial Markets Group Discussion Paper 238

Payne, Richard and Paolo Vitale, 2003, "A Transaction Level Study of the Effects of Central Bank Intervention on Exchange Rates", Journal of International Economics, 61, 331 - 352

Peiers, Bettina, 1997, "Informed Traders, Intervention and Price Leadership: A Deeper View of the Microstructure of the Foreign Exchange Market", Journal of Finance, 52, 1589 - 1614

Sarno, L. and Mark P. Taylor, 2001, "Official Intervention in the Foreign Exchange Market: Is it Effective and, if so, How Does it Work?", Journal of Economic Literature, 39 (3), 839 - 868

Vitale, Paolo, 1999, "Sterilised Central Bank Intervention in the Foreign Exchange Market", Journal of International Economics, 49, 245 - 267

Table 1: SNB Interventions

	No. of interventions	No. of intervention days
Oct 86 - Aug 95		
Total	171	97
Buy	70	33
Sell	101	64
Mar 89 - Aug 95		
Total	58	33
Buy	11	6
Sell	47	27

Table 2: Intervention Direction

	Moving Average			
	Daily	1 Week	2 Week	4 Week
Oct 86 - Aug 95				
Against-the-wind	86	143	145	146
With-the-wind	85	28	26	25
Mar 89 - Aug 95				
Against-the-wind	18	41	41	39
With-the-wind	40	17	17	19

Table 3: Reuters Reports

	Buy	Sell
Reuters Reports		
Total	16	19
of which Joint	4	2
of which Joint with Fed and Buba	1	1
of which Joint with Fed only	2	0
of which Joint with Buba only	1	1
SNB Interventions	11	47
Reuters		
Missed	...	28
False	5	...

Figure 1: Exchange Rates: Sep 1986 - Aug 1995

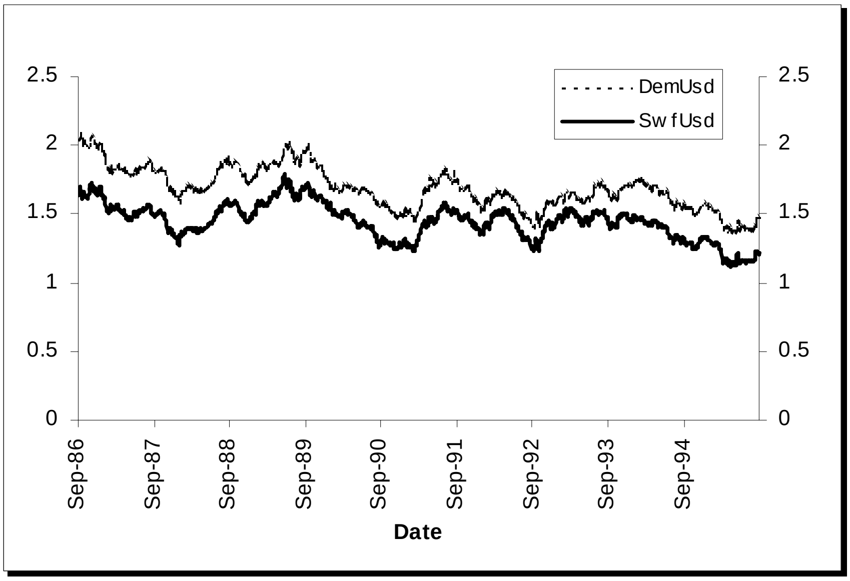

Table 4: Effect of Interventions on Volatility

$$vol_t = \alpha + \sum_{i=-8}^{8} \beta_i \; I_{t+i} + \theta_1 \; vol_{t-1} + \theta_2 \; vol_{t-2} + \varepsilon_t$$

	Volatility Measure							
	Realised Volatility				Squared		Absolute	
	Squared		Absolute		Return		Return	
α	0.0012	**	0.0029	**	0.0010	**	0.0026	**
β_{-1}	-0.0016		-0.0106		-0.0013		-0.0028	
β_0	-0.0091	*	-0.0208	*	-0.0012		0.0017	
β_1	-0.0034		-0.0163		-0.0012		-0.0037	
β_2	0.0048		0.0156		-0.0004		-0.0041	
β_3	0.0267	**	0.0287	*	0.0017		0.0071	
β_4	-0.0362		-0.0056		0.0130	**	0.0329	**
β_5	0.0112		0.0280	*	0.0093	*	0.0305	**
β_6	0.0292	**	0.0269	*	-0.0034		-0.0051	
β_7	-0.0255		-0.0123		-0.0174	*	-0.0053	
β_8	0.0721	*	0.0695	**	0.0674	*	0.0607	**
θ_1	1.0368	**	1.0460	**	0.1738	**	0.2373	**
θ_2	-0.2466	**	-0.2057	**	0.0819	*	0.1349	**
Adj R^2	0.7172		0.7697		0.0590		0.1059	

Note: The coefficient estimates are based on OLS regressions using Newey-West standard errors to correct for serial correlation and heteroskedasticity. A * (**) indicates significance at the 5% (1%) level. vol_t is the volatility measure and could be either the realised volatility (defined as the sum of squared returns for the past hour), or just squared returns or absolute returns. I_{t+i} is the intervention indicator which is 1 whenever the SNB intervenes (whether to buy or sell) and 0 otherwise.

Table 5: Effect of Direction of Interventions on Volatility - Buy versus Sell Interventions

$$vol_t = \alpha + \sum_{j=-8}^{8} \beta_j \ (B_{t+j} + S_{t+j}) + \sum_{k=-8}^{8} \gamma_k \ S_{t+k} + \theta_1 \ vol_{t-1} + \theta_2 \ vol_{t-2} + \varepsilon_t$$

	Volatility Measure							
	Realised Volatility				Squared		Absolute	
	Squared		Absolute		Return		Return	
α	0.0012	**	0.0028	**	0.0010	**	0.0026	**
γ_3	-0.0381		-0.0235		0.0152		0.0160	
γ_4	0.1100	*	0.0851		0.0157		0.0339	
γ_5	-0.0162		-0.0172		-0.0183	*	-0.0286	
γ_6	-0.0574	*	-0.0384		0.0041		-0.0024	
γ_7	0.0650		0.0628	*	0.0482	*	0.0465	*
γ_8	-0.1317		-0.0893		-0.1251		-0.0698	
θ_1	1.0382	**	1.0468	**	0.1736	**	0.2381	**
θ_2	-0.2478	**	-0.2060	**	0.0836	*	0.1352	**
Adj R^2	0.7218		0.7706		0.0719		0.1084	

Note: The coefficient estimates are based on OLS regressions using Newey-West standard errors to correct for serial correlation and heteroskedasticity. A * (**) indicates significance at the 5% (1%) level. vol_t is the volatility measure and could be either the realised volatility (defined as the sum of squared returns for the past hour), or just squared returns or absolute returns. B_{t+j} (S_{t+j})is the buy (Sell) intervention indicator which is 1 whenever the SNB buys (sells) USD and 0 otherwise. As noted in the main text, the coefficients of interest are the gammas. A non-zero γ_k coefficient implies that the two independent variables have different relationships with volatility.

Table 6: Effect of Intervention Size on Volatility

$$vol_t = \alpha + \sum_{i=-8}^{8} \beta_i \ I_{t+i} + \sum_{j=-8}^{8} \gamma_j \ Q_{t+j} + \sum_{k=-8}^{8} \delta_k \ Q_{t+k}^2 + \theta_1 \ vol_{t-1} + \theta_2 \ vol_{t-2} + \varepsilon_t$$

	Volatility Measure							
	Realised Volatility				Squared Return		Absolute Return	
	Squared		Absolute					
α	0.0012	**	0.0029	**	0.0010	**	0.0026	**
γ_{-8}	-0.0006		-0.0028		-0.0013		-0.0056	**
γ_{-6}	0.0003		0.0006		0.0012	*	0.0034	
γ_0	-0.0018		-0.0075	*	-0.0011		-0.0048	*
γ_5	0.0051		0.0063		0.0045	*	0.0076	*
γ_6	-0.0086		-0.0114	*	-0.0025		-0.0027	
δ_{-8}	0.0000		0.0001	**	0.0000	*	0.0002	**
δ_{-6}	0.0000		0.0000		0.0000	*	-0.0001	
δ_{-1}	-0.0001	*	-0.0002	*	0.0000		-0.0001	
δ_0	0.0001	*	0.0002	**	0.0000		0.0001	*
δ_1	0.0001		0.0001		0.0000		-0.0001	**
δ_2	-0.0001	*	-0.0001		0.0000		0.0001	
δ_3	0.0000		0.0001		0.0000		0.0001	*
δ_5	-0.0001		-0.0002		-0.0001	**	-0.0002	**
δ_6	0.0002	*	0.0004	**	0.0001	*	0.0002	
θ_1	1.0371	**	1.0474	**	0.1736	**	0.2378	**
θ_2	-0.2468	**	-0.2068	**	0.0829	*	0.1364	**
Adj R^2	0.7176		0.7705		0.0600		0.1092	

Note: The coefficient estimates are based on OLS regressions using Newey-West standard errors to correct for serial correlation and heteroskedasticity. A * (**) indicates significance at the 5% (1%) level. vol_t is the volatility measure and could be either the realised volatility (defined as the sum of squared returns for the past hour), or just squared returns or absolute returns. I_{t+i} is the intervention indicator which is 1 whenever the SNB intervenes (whether to buy or sell) and 0 otherwise. Q_{t+j} is the absolute magnitude of USD bought or sold by the SNB and Q_{t+k}^2 is the squared quantity.

Table 7: Effect of Intervention Size on Volatility: Small, Average and Large Size Interventions

$$vol_t = \alpha + \sum_{i=-8}^{8} \beta_i \, I_{t+i} + \sum_{j=-8}^{8} \gamma_j \, SQ_{t+j} + \sum_{k=-8}^{8} \delta_k \, AQ_{t+k} + \sum_{l=-8}^{8} \phi_l \, LQ_{t+l} + \theta_1 \, vol_{t-1} + \theta_2 \, vol_{t-2} + \varepsilon_t$$

	Volatility Measure (sum of significant coefficients)							
	Realised Volatility				Squared Return		Absolute Return	
	Squared		Absolute					
α	0.0012	**	0.0029	**	0.0010	**	0.0026	**
β	-0.1454		-0.1108		-0.1291		-0.0702	
γ	0.0162		0.0496		0.0111		0.0308	
δ	0.0116		0.0324		0.0117		0.0200	
ϕ	0.0081		0.0152		0.0037		0.0141	
θ_1	1.0368	**	1.0468	**	0.1735	**	0.2375	**
θ_2	-0.2464	**	-0.2061	**	0.0823	*	0.1365	**
Adj R^2	0.7177		0.7707		0.0600		0.1096	

Note: The coefficient estimates are based on OLS regressions using Newey-West standard errors to correct for serial correlation and heteroskedasticity. The sum of significant coefficients is based on those that are significant at 5% or 1%. A * (**) indicates significance at the 5% (1%) level. vol_t is the volatility measure and could be either the realised volatility (defined as the sum of squared returns for the past hour), or just squared returns or absolute returns. SQ_{t+j} is an indicator for small magnitude interventions which are defined as sales or purchases of up to 5 mil USD, AQ_{t+k} is an indicator for interventions between 5 and 10 mil USD and LQ_{t+l} is an indicator for interventions that are larger than 10 mil USD. With this classification there are 27 small, 26 average and 5 large interventions.

Table 8: Effect of Intervention Frequency on Volatility

$$vol_t = \alpha + \sum_{i=-8}^{8} \beta_i \ I_{t+i} + \sum_{j=-8}^{8} \gamma_j \ F_{t+j} + \theta_1 \ vol_{t-1} + \theta_2 \ vol_{t-2} + \varepsilon_t$$

	Volatility Measure							
	Realised Volatility				Squared		Absolute	
	Squared		Absolute		Return		Return	
α	0.0012	**	0.0028	**	0.0010	**	0.0026	**
γ_{-8}	-0.0024	*	-0.0074	**	-0.0003		-0.0019	
γ_{-6}	0.0016		0.0056	*	0.0000		-0.0005	
γ_{-4}	0.0027		0.0061	*	0.0032	*	0.0087	**
γ_1	0.0036	*	0.0076	*	0.0003		0.0019	
γ_2	0.0078	**	0.0139	**	0.0021		0.0034	
γ_3	0.0039		0.0074	*	0.0032		0.0067	*
γ_4	-0.0020		0.0007		0.0069	**	0.0130	**
γ_6	-0.0016		-0.0061		-0.0050	**	-0.0078	**
γ_8	0.0054		0.0090		0.0101		0.0122	*
θ_1	1.0356	**	1.0442	**	0.1720	**	0.2350	**
θ_2	-0.2461	**	-0.2045	**	0.0828	*	0.1355	**
Adj R^2	0.7177		0.7706		0.0628		0.1106	

Note: The coefficient estimates are based on OLS regressions using Newey-West standard errors to correct for serial correlation and heteroskedasticity. A * (**) indicates significance at the 5% (1%) level. vol_t is the volatility measure and could be either the realised volatility (defined as the sum of squared returns for the past hour), or just squared returns or absolute returns. I_{t+i} is the intervention indicator which is 1 whenever the SNB intervenes (whether to buy or sell) and 0 otherwise. F_{t+j} is a dummy variable for the frequency of the intervention.

Table 9: Effect of Intervention Frequency on Volatility: Low, Average and High Frequency Interventions

$$vol_t = \alpha + \sum_{i=-8}^{8} \beta_i \, I_{t+i} + \sum_{j=-8}^{8} \gamma_j \, LF_{t+j} + \sum_{k=-8}^{8} \delta_k \, AF_{t+k} + \sum_{l=-8}^{8} \phi_l \, HF_{t+l} + \theta_1 \, vol_{t-1} + \theta_2 \, vol_{t-2} + \varepsilon_t$$

	Volatility Measure (sum of significant coefficients)							
	Realised Volatility				Squared		Absolute	
	Squared		Absolute		Return		Return	
α	0.0012	**	0.0028	**	0.0010	**	0.0026	**
β	…		-0.0376		…		…	
γ	0.0053		0.0402		…		0.0303	
δ	0.0049		0.0054		0.0143		0.0178	
φ	0.0071		0.0235		0.0085		0.0279	
θ_1	1.0362	**	1.0434	**	0.1712	**	0.2343	**
θ_2	-0.2466	**	-0.2035	**	0.0821	*	0.1343	**
Adj R^2	0.7204		0.7718		0.0676		0.1128	

Note: The coefficient estimates are based on OLS regressions using Newey-West standard errors to correct for serial correlation and heteroskedasticity. The sum of significant coefficients is based on those that are significant at 5% or 1%. A * (**) indicates significance at the 5% (1%) level. vol_t is the volatility measure and could be either the realised volatility (defined as the sum of squared returns for the past hour), or just squared returns or absolute returns. I_{t+i} is the intervention indicator which is 1 whenever the SNB intervenes (whether to buy or sell) and 0 otherwise. LF_{t+j} is an indicator for low Frequency interventions (between 1 and 6 times in 15 minutes), AF_{t+k} is an indicator for intervention frequency between 7 and 12 times in 15 minutes and HF_{t+l} is an indicator for frequency of interventions larger than 13. With this classification there are 44 low, 12 average and 2 high frequency interventions.

Table 10: Effect of Intervention Size and Frequency on Volatility

$$vol_t = \alpha + \sum_{i=-8}^{8} \beta_i \, I_{t+i} + \sum_{j=-8}^{8} \gamma_j \, Q_{t+j} + \sum_{k=-8}^{8} \delta_k \, F_{t+k} + \sum_{l=-8}^{8} \phi_l \, Q_{t+l} * F_{t+l} + \theta_1 \, vol_{t-1} + \theta_2 \, vol_{t-2} + \varepsilon_t$$

	Volatility Measure							
	Realised Volatility				Squared		Absolute	
	Squared		Absolute		Return		Return	
α	0.0012	**	0.0028	**	0.0010	**	0.0026	**
γ_{-3}	0.0010		0.0043	*	0.0004		0.0016	
γ_{-2}	0.0029	**	0.0054	**	0.0009		0.0023	
γ_{-1}	-0.0014	*	-0.0040		0.0005		0.0010	
γ_1	-0.0009		-0.0036	*	-0.0009	**	-0.0035	**
γ_2	-0.0032		-0.0046		-0.0024	**	-0.0043	*
γ_3	0.0018		0.0046	**	0.0013		0.0038	*
δ_{-2}	0.0086	**	0.0148	*	0.0020		0.0046	
δ_{-1}	-0.0036		-0.0121	*	0.0011		-0.0005	
δ_2	-0.0020		0.0012		-0.0063	*	-0.0109	*
δ_3	0.0070		0.0167	*	0.0049		0.0120	
ϕ_{-2}	-0.0009	**	-0.0018	**	-0.0002		-0.0007	
ϕ_2	0.0009		0.0011		0.0008	**	0.0014	**
ϕ_3	-0.0003		-0.0009	*	-0.0001		-0.0004	
θ_1	1.0350	**	1.0446	**	0.1714	**	0.2354	**
θ_2	-0.2453	**	-0.2045	**	0.0836	*	0.1367	**
Adj R^2	0.7181		0.7711		0.0635		0.1128	

Note: The coefficient estimates are based on OLS regressions using Newey-West standard errors to correct for serial correlation and heteroskedasticity. A * (**) indicates significance at the 5% (1%) level. vol_t is the volatility measure and could be either the realised volatility (defined as the sum of squared returns for the past hour), or just squared returns or absolute returns. I_{t+i} is the intervention indicator which is 1 whenever the SNB intervenes (whether to buy or sell) and 0 otherwise. Q_{t+j} is the absolute magnitude of USD bought or sold by the SNB, F_{t+k} is a dummy variable for the frequency of the intervention and $Q_{t+l} * F_{t+l}$ is a dummy variable for the size-frequency interaction.

Table 11: Effect of Time of Interventions on Volatility: 9am versus 2pm

$$vol_t = \alpha + \sum_{i=-8}^{8} \beta_i \ 9am_{t+i} + \sum_{j=-8}^{8} \gamma_j \ 2pm_{t+j} + \sum_{k=-8}^{8} \delta_k \ J_{t+k} + \theta_1 \ vol_{t-1} + \theta_2 \ vol_{t-2} + \varepsilon_t$$

	Volatility Measure							
	Realised Volatility				Squared		Absolute	
	Squared		Absolute		Return		Return	
α	0.0014	**	0.0032	**	0.0011	**	0.0029	**
β_{-8}	-0.0119	**	-0.0186		-0.0117	**	-0.0177	
β_{-6}	-0.0081	**	-0.0267	*	-0.0069	**	-0.0214	**
β_0	-0.0080		-0.0127		0.0071		0.0282	*
β_4	0.0156		0.0595		0.0237	**	0.0631	**
γ_{-5}	-0.0071		-0.0211		-0.0083	**	-0.0251	**
γ_{-2}	0.0054		0.0293	*	-0.0013		0.0095	
γ_3	0.0373		0.0441	*	0.0003		0.0090	
γ_6	0.0456	**	0.0526	**	-0.0007		0.0091	
γ_7	-0.0724	*	-0.0508		-0.0294	*	-0.0202	
γ_8	0.0829		0.0726		0.0819		0.0753	*
δ_0	0.0240		0.0587	*	0.0049		0.0390	
δ_7	0.0348		0.0622	*	-0.0076		0.0093	
δ_8	0.1056		0.1413	*	0.0795		0.1171	*
θ_1	1.0448	**	1.0507	**	0.1786	**	0.2406	**
θ_2	-0.2549	**	-0.2101	**	0.0763		0.1317	**
Adj R^2	0.7186		0.7702		0.0566		0.1049	

Note: The coefficient estimates are based on OLS regressions using Newey-West standard errors to correct for serial correlation and heteroskedasticity. A * (**) indicates significance at the 5% (1%) level. vol_t is the volatility measure and could be either the realised volatility (defined as the sum of squared returns for the past hour), or just squared returns or absolute returns. $9am_{t+i}$ is a dummy variable for interventions occurring at 9am, $2pm_{t+j}$ is a dummy variable for interventions occurring at 2pm and J_{t+k} is a dummy variable that controls for interventions that were joint with either the Fed or the Buba or both.

Table 12: Effect of Different Intervention Characteristics on Volatility

$$vol_t = \alpha + \sum_{i=-8}^{8} \beta_i \; I_{t+i} + \sum_{j=-8}^{8} \gamma_j \; Q_{t+j} + \sum_{k=-8}^{8} \delta_k \; F_{t+k} + \sum_{l=-8}^{8} \eta_l \; Q_{t+l} * F_{t+l} \cdots$$
$$+ \sum_{m=-8}^{8} \kappa_m \; 9am_{t+m} + \sum_{n=-8}^{8} \lambda_n \; 2pm_{t+n} \cdots$$
$$+ \sum_{p=-8}^{8} \mu_p \; Fed_{t+p} + \sum_{q=-8}^{8} \phi_q \; Buba_{t+q} + \theta_1 \; vol_{t-1} + \theta_2 \; vol_{t-2} + \varepsilon_t$$

	Volatility Measure (sum of significant coefficients)							
	Realised Volatility				Squared		Absolute	
	Squared		Absolute		Return		Return	
α	0.0012	**	0.0028	**	0.0010	**	0.0026	**
β	-0.0334		…		-0.0226		-0.0674	
γ	0.0028		0.0139		-0.0019		-0.0036	
δ	0.0083		0.0281		-0.0059		-0.0102	
η	-0.0009		-0.0005		0.0008		0.0013	
κ	0.0201		…		0.0342		0.0448	
λ	-0.0993		-0.0786		0.0020		0.0317	
μ	0.6046		0.6472		0.3881		0.3245	
φ	0.0668		0.1630		0.1059		0.2335	
θ_1	1.0367	**	1.0423	**	0.1697	*	0.2334	**
θ_2	-0.2474	**	-0.2020	**	0.0848	*	0.1366	**
Adj R^2	0.7312		0.7744		0.1018		0.1234	

Note: The coefficient estimates are based on OLS regressions using Newey-West standard errors to correct for serial correlation and heteroskedasticity. The sum of significant coefficients is based on those that are significant at 5% or 1%. A * (**) indicates significance at the 5% (1%) level. vol_t is the volatility measure and could be either the realised volatility (defined as the sum of squared returns for the past hour), or just squared returns or absolute returns. I_{t+i} is the intervention indicator which is 1 whenever the SNB intervenes (whether to buy or sell) and 0 otherwise. Q_{t+j} is the absolute magnitude of USD bought or sold by the SNB, F_{t+k} is a dummy variable for the frequency of the intervention, $Q_{t+l} * F_{t+l}$ is a dummy variable for the size-frequency interaction., $9am_{t+i}$ is a dummy variable for interventions occurring at 9am, $2pm_{t+j}$ is a dummy variable for interventions occurring at 2pm, Fed_{t+p} is a dummy variable that controls for interventions that were joint with the Fed and $Buba_{t+q}$ is a dummy variable that controls for interventions that were joint with the Bundesbank.

Table 13: Effect of Reuters Reports of Sell Interventions on Volatility

$$vol_t = \alpha + \sum_{i=-8}^{8} \beta_i \; RS_{t+i} + \theta_1 \; vol_{t-1} + \theta_2 \; vol_{t-2} + \varepsilon_t$$

	Volatility Measure							
	Realised Volatility				Squared		Absolute	
	Squared		Absolute		Return		Return	
α	0.0001		0.0003		0.0001		0.0002	
β_{-8}	-0.0060	**	-0.0150		-0.0066	**	-0.0187	*
β_{-7}	-0.0045		-0.0085		-0.0026		-0.0048	
β_{-6}	-0.0044		-0.0057		-0.0031		-0.0054	
β_{-5}	-0.0060		-0.0217		-0.0055	*	-0.0179	
β_{-4}	-0.0096		-0.0442	*	-0.0051	*	-0.0151	
β_{-3}	-0.0071		-0.0162		-0.0025		-0.0109	
β_{-2}	0.0054		0.0019		-0.0025		-0.0155	
β_{-1}	-0.0040		0.0025		-0.0014		-0.0049	
β_0	0.0083		0.0455	*	0.0060		0.0321	
β_1	0.0093		0.0047		0.0063		0.0117	
β_2	-0.0077		-0.0056		-0.0048		-0.0052	
β_3	0.0054		-0.0043		0.0043		-0.0026	
β_4	-0.0090	**	-0.0360	*	-0.0033		-0.0178	
β_5	-0.0003		0.0115		-0.0041		0.0000	
β_6	-0.0074		-0.0257		0.0015		-0.0094	
β_7	0.0075		0.0115		-0.0011		-0.0007	
β_8	0.0079		0.0124		0.0064		0.0171	
θ_1	1.0666	**	1.0539	**	0.2037	**	0.2148	**
θ_2	-0.2702	**	-0.2297	**	0.0591	**	0.0931	**
Adj R^2	0.7266		0.7485		0.0501		0.0642	

Note: The coefficient estimates are based on OLS regressions using Newey-West standard errors to correct for serial correlation and heteroskedasticity. A * (**) indicates significance at the 5% (1%) level. vol_t is the volatility measure and could be either the realised volatility (defined as the sum of squared returns for the past hour), or just squared returns or absolute returns. RS_{t+i} is a dummy variable which is 1 whenever there is a Reuters report that the SNB sold USD and 0 otherwise.

Table 14: Effect of SNB Interventions and Reuters Reports on Volatility

$$vol_t = \alpha + \sum_{i=-8}^{8} \beta_i \; I_{t+i} + \sum_{j=-8}^{8} \gamma_j \; RR_{t+j} + \theta_1 \; vol_{t-1} + \theta_2 \; vol_{t-2} + \varepsilon_t$$

	Volatility Measure							
	Realised Volatility				Squared		Absolute	
	Squared		Absolute		Return		Return	
α	0.0001		0.0001		0.0001		0.0001	
β_{-3}	0.0060		0.0275	*	0.0031		0.0185	
β_3	0.0503	**	0.0735	**	0.0150	*	0.0383	**
β_4	-0.0606		-0.0164		0.0229	**	0.0526	**
β_5	0.0132		0.0328		0.0007		0.0280	*
β_6	0.0497	*	0.0520	**	-0.0023		0.0085	
β_7	-0.0511		-0.0228		-0.0237		-0.0083	
β_8	0.1189	*	0.1221	*	0.1124	*	0.1102	*
γ_{-5}	-0.0086		-0.0354	*	-0.0090	*	-0.0243	*
γ_4	-0.0419		-0.0592		-0.0132	*	-0.0204	
θ_1	1.0677	**	1.0535	**	0.2033	**	0.2137	**
θ_2	-0.2724	**	-0.2303	**	0.0583	**	0.0921	**
Adj R^2	0.7281		0.7489		0.0547		0.0661	

Note: The coefficient estimates are based on OLS regressions using Newey-West standard errors to correct for serial correlation and heteroskedasticity. A * (**) indicates significance at the 5% (1%) level. vol_t is the volatility measure and could be either the realised volatility (defined as the sum of squared returns for the past hour), or just squared returns or absolute returns. I_{t+i} is the intervention indicator which is 1 whenever the SNB intervenes (whether to buy or sell) and 0 otherwise and RR_{t+j} is a dummy variable indicating when there is a Reuters report of an SNB intervention.

Table 15: Effect of Sell Interventions and Sell Reports on Volatility

$$vol_t = \alpha + \sum_{i=-8}^{8} \beta_i \; IS_{t+i} + \sum_{j=-8}^{8} \gamma_j \; RS_{t+j} + \theta_1 \; vol_{t-1} + \theta_2 \; vol_{t-2} + \varepsilon_t$$

	Volatility Measure							
	Realised Volatility				Squared Return		Absolute Return	
	Squared		Absolute					
α	0.0001		0.0002		0.0001		0.0002	
β_{-3}	0.0070		0.0295	*	0.0004		0.0132	
β_0	-0.0089		-0.0097		0.0053		0.0277	*
β_2	0.0136		0.0461	*	0.0090		0.0225	
β_3	0.0280	**	0.0591	**	0.0125	*	0.0313	*
β_4	0.0083		0.0471		0.0280	**	0.0708	**
β_5	0.0156	*	0.0440	**	0.0060		0.0354	**
β_6	0.0146	*	0.0341		0.0071		0.0122	
β_8	0.0360	*	0.0541	*	0.0289		0.0484	*
γ_{-8}	-0.0063	**	-0.0171	*	-0.0072	**	-0.0233	*
γ_{-6}	-0.0076	*	-0.0138		-0.0072	*	-0.0155	
γ_{-5}	-0.0115	*	-0.0349	*	-0.0103	**	-0.0307	**
γ_{-4}	-0.0107		-0.0494	*	-0.0094	**	-0.0276	*
γ_4	-0.0176	**	-0.0533	**	-0.0088		-0.0294	*
γ_6	-0.0160	**	-0.0445	**	-0.0053		-0.0262	
θ_1	1.0664	**	1.0533	**	0.2035	**	0.2141	**
θ_2	-0.2703	**	-0.2296	**	0.0589	**	0.0926	**
Adj R^2	0.7267		0.7486		0.0506		0.0651	

Note: The coefficient estimates are based on OLS regressions using Newey-West standard errors to correct for serial correlation and heteroskedasticity. A * (**) indicates significance at the 5% (1%) level. vol_t is the volatility measure and could be either the realised volatility (defined as the sum of squared returns for the past hour), or just squared returns or absolute returns. IS_{t+i} is the intervention indicator which is 1 whenever the SNB sells USD and 0 otherwise and RS_{t+j} is a dummy variable which is 1 whenever there is a Reuters report that the SNB sold USD and 0 otherwise.

Figure 2: Intraday Seasonality and the Flexible Fourier Transform

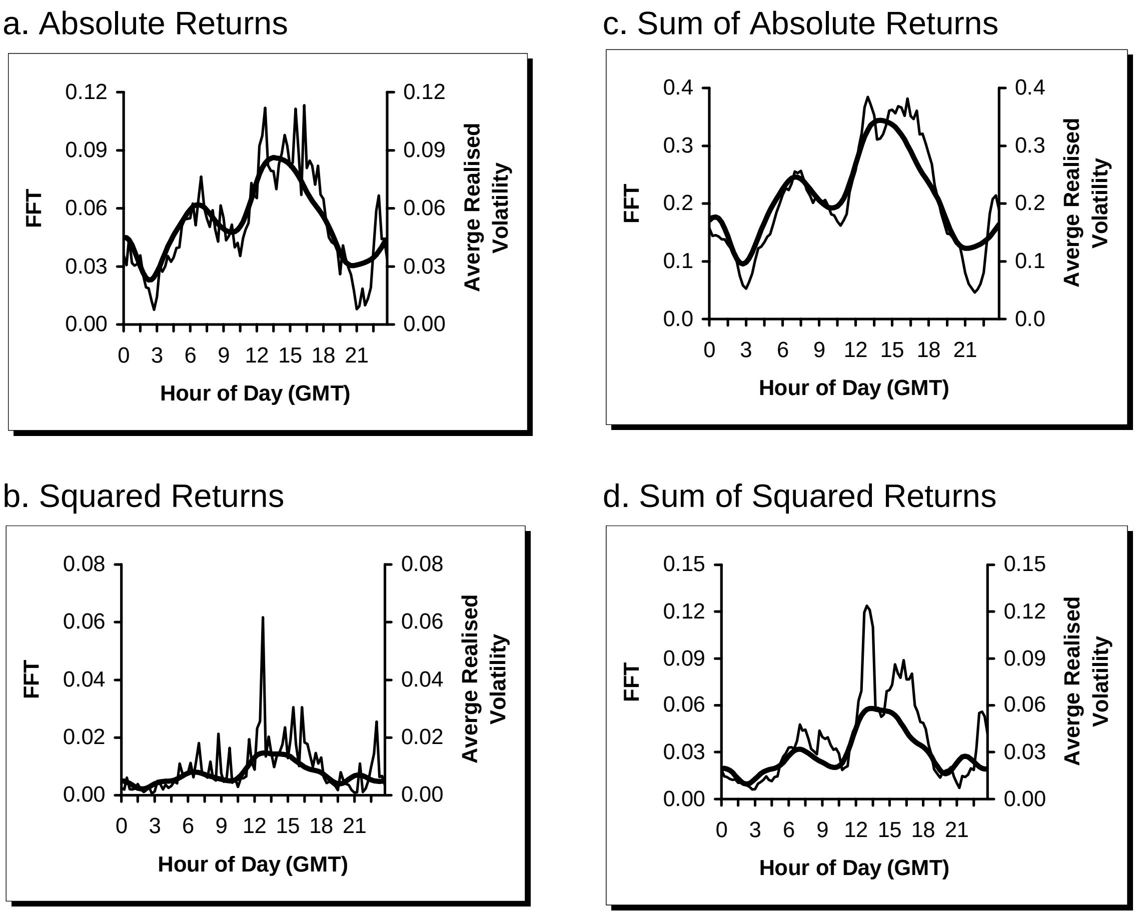

Figure 3: Characterising SNB Interventions