A Transaction Level Study of the Effects of Central Bank Intervention on Exchange Rates*

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Abstract

We study the effects of sterilised intervention operations executed on behalf of the Swiss National Bank (SNB) using tick-by-tick transactions data between 1986 and 1995. We extend the preliminary analysis of Fischer and Zurlinden (1999) by matching these data with indicative intra-day exchange rate quotes and news-wire reports of central bank activity. Using an event study approach we find that intervention has important short-run effects on exchange rate returns. In particular, among various results, we find that i) intervention has a stronger impact when the SNB moves *with-the-market* and when its activity is *concerted* with that of other central banks and ii) exchange rate returns move in the 15 minute interval prior to interventions.

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1 Introduction

Scholars have long debated whether central bank intervention operations in the markets for foreign exchange have important effects on exchange rate levels and volatility and on market conditions. While it can be theoretically established that sterilised intervention affects the value of currencies and level of activity in FX markets, either through a portfolio-balance effect or via a signalling channel (Mussa (1981), Bhattacharya and Weller (1997), and Vitale (1999,2002)), the effectiveness of sterilised intervention remains an unresolved issue from an empirical point of view.

A contributory factor to the unresolved nature of this issue has been a lack of adequate data on central bank intervention transactions. Indeed, until recently, researchers only had access to data sets in which intervention operations were aggregated to daily or lower frequencies.[1] This has proved a serious impediment to empirical analysis of the effects of intervention on exchange rates as, with coarsely sampled data, it is difficult/impossible to overcome simultaneity problems and to characterise the high-frequency effects of intervention on market conditions.

However, recently the Swiss National Bank (SNB) has made an innovative data set available to researchers, containing tick-by-tick observations on its intervention operations in FX markets between 1986 and 1995. We extend a preliminary analysis of this data set by Fischer and Zurlinden (1999), by combining the information it contains with indicative exchange rate quotes recorded by Olsen and Associates and with Reuters news-wire reports of central banks' activity.

These data allow us to conduct a high-frequency analysis of the effects of signed intervention operations on exchange returns. We construct time-series for the USD/CHF exchange rate and signed intervention quantities sampled once every 15 minutes and use these data to analyse the effects of intervention via an event study.[2]

The particular focus of our study is the empirical relevance of the *signalling hypothesis*. This hypothesis suggests that intervention operations are used by monetary authorities to convey information to FX markets and hence alter market expectations and exchange rates. Thus, if central bank operations are informative signed intervention should have a significant and permanent effect on the value of currencies.

[1] See Dominguez and Frankel (1993b), Dominguez and Frankel (1993a). Edison (1993) and Sarno and Taylor (2000) contain extensive reviews of this literature.

[2] Several recent studies also focus on the intra-day effects of intervention on exchange rates (Peiers 1997, Dominguez 1999, Evans and Lyons 2000) although none of these use actual intra-day intervention data.

Other important issues we can analyse using the event study methodology include: i) the speed with which intervention influences markets, ii) the impact of intervention size and iii) the effects of market conditions on the effectiveness of intervention. With respect to the first issue, it is usually presumed that FX markets are very resilient and process information very quickly. The current analysis gives us an opportunity to test this assertion. Analysis of the impact of intervention size is also important, in that the signalling hypothesis suggests that intervention is effective because it is potentially expensive. Hence larger trades should have a bigger impact on exchange rates and market characteristics. Finally, we investigate whether interventions that seek to reinforce prior exchange rate movements have different effects than those which seek to reverse such movements.

The main findings from our analysis are the following.

1. Intervention events have a positive effect on exchange rates: when the SNB purchases (sells) US dollars, the American currency appreciates (depreciates). The impact of intervention is immediate, as the exchange rate moves within the 15 minute interval during which an intervention event is reported, and persistent, as the cumulative effect is still significant after few hours. We also observe market anticipation of intervention information, as the exchange rate moves (significantly) in the direction of the operation in the 15 minute interval that precedes that in which the event occurs. Likewise, we detect partial reversal of the intervention effect in the 15 minute period immediately after the event interval.

2. These conclusions hold: i) when we simply consider the direction of intervention as an explanatory variable, ii) when we employ the signed intervention size in the regression analysis of the exchange rate return and iii) even when we account for the effects of the intervention activity of other central banks, notably the Fed and the Buba. On the contrary these conclusions are not valid when we use non-intervention trades carried out by the SNB instead of intervention operations.

3. The impact of SNB activity is larger and more persistent: i) when operations are concerted with those of the Buba and the Fed than when they are conducted unilaterally and ii) when intervention follows the current trend rather than opposing it.

The rest of the paper is organised as follows. In Section 2 we briefly describe our data set and the statistical properties of the exchange rate and intervention series. In Section 3 we present our results. Section 4 concludes.

2 Data

As noted in the introduction, the main innovation of the current study is the use of a transactions-level data set on central bank spot purchases and sales of US dollars, time stamped to the minute. These transactions were conducted by the SNB in the USD/CHF market and are recorded for the period covering 1986 to 1995.

The deals that comprise our data are of two types: *interventions* and *customer transactions*. The aim of SNB interventions is to influence the value of the Swiss franc exchange rate,[3] while customer transactions are triggered by the need of the Swiss government for foreign currency. In the period these data cover the SNB dealing desk would first negotiate a buy or sell order with a FX dealer. After completion, it would *notify* the counterparty if the transaction was part of an intervention operation or not. Given the different nature of the two types of transactions, our work will focus mainly on the interventions although we provide some analysis of customer trades for comparison.

The second component of our data set consists of tick-by-tick indicative exchange rate quotes on the USD/CHF. These exchange rate data cover the period from March 1986 to November 1999. Simultaneous examination of the exchange rate data and the SNB transactions will allow us to provide very accurate, high-frequency characterisations of the manner in which intervention operations affect FX rates.

The final segment of the data we employ is a set of Reuters news-wire reports of central bank activity in FX markets. We have, for the period from August 1989 to the end of 1995, Reuters news headline data, timestamped to the second, for every day upon which the Federal Reserve intervened in FX markets. As such, we can retrieve all reports of Fed intervention activity for this period and a significant number of intervention reports for the Buba and the SNB given the correlation between the timings of Fed interventions and interventions by the other two banks. Clearly, though, we do not have news headline data for those interventions undertaken by the SNB and the Buba on days upon which the Fed did not intervene. Also, it should be noted that the sample period for our news headline data is shorter than that for the transaction-level SNB data.

Fischer and Zurlinden (1999) propose a prior analysis of the transactions data, providing

[3] Fischer and Zurlinden (1999) discuss the objectives behind SNB interventions. They indicate that "The SNB intervened to affect the trend of the exchange rate or counteract market disturbances. Solidarity with other central banks may also have been an important motive (...)". However, they also note that "This does not imply that the SNB always followed the lead of key central banks. The Federal Reserve and the Bundesbank intervened more frequently than the SNB during the sample period."

an analysis of the signalling hypothesis that uses *only* the actual SNB intervention data. Hence, the only price data used in their study are the actual transactions prices at which SNB interventions were completed. This necessitates the use of an empirical model which accounts for the fact that interventions (and hence price observations) are irregularly spaced in time. Their results imply that, given that the SNB was in the market on a given day, purchases of dollars lead to dollar appreciations and sales lead to dollar depreciation. This effect is only significant for the *first intervention on a given day*.

Panel (a) of Table 1 gives basic statistical information on the frequency, size and direction of individual intervention transactions and SNB customer trades. The table shows that there were almost twice as many interventions to sell dollars than interventions to buy. Hence, the mean intervention quantity is significantly negative and median intervention size is -$5m. Also, intervention quantity has negative skew and is leptokurtic. Positive and negative interventions (taken separately) both have median size of $10m. and, further, negative interventions (i.e. dollar sales) are more dispersed in magnitude. The statistics for customer transactions demonstrate that they tend to be larger and more dispersed in size than interventions.[4] Moreover, while interventions are predominantly dollar sales, customer transactions are largely purchases of dollars.

Summary statistics for the data series derived from the indicative exchange rate quotes are given in panel (b) of Table 1. As the statistical properties of these indicative quote data are well known (see, for example, Andersen and Bollerslev (1997)) we only give a brief analysis of the data here. The statistics in the Table are based on a 15 minute calendar time sampling of the data. We use this sampling frequency in the majority of our analysis and it was chosen so as to allow us to characterise the fine detail of the high-frequency data without uncovering the statistical distortions that emerge when indicative data are sampled too frequently (see Danielsson and Payne (2000)).[5]

Examining the first row of panel (b) of Table 1 we see the standard statistical features of intra-day exchange rate returns i.e. zero mean, little skew and strong leptokurtosis, plus negative autocorrelation in returns at displacement 1. This means that when studying the effects of interventions on returns we should take account of the low displacement return

[4]While on the basis of daily data it seems that for the Buba and Fed the size of interventions is larger, the difference might just be apparent, given that SNB intervention operations are generally split in a number trades.

[5]We have also studied the relationship between the prices at which interventions actually take place and the indicative quote data, comparing the intervention price with the final midquote from the intervention interval. The mean discrepancy between these two numbers is not significantly different from zero and is about 0.02 percent of the midquote. There is some tendency for the (absolute) pricing discrepancy to increase with the size of the intervention as one might expect.

autocorrelation and employ Newey-West standard errors.

3 High-Frequency Effects of Sterilised Intervention

3.1 A simple test of the signalling hypothesis

An empirical analysis of the relationship between exchange rate changes and the interventions of central banks would ideally be founded on a structural model. Using such a model, in which exchange rate returns and intervention operations were determined simultaneously, one could deal with identification issues and isolate the exchange rate effects of unexpected components of intervention. However, no straightforward and empirically implementable model exists. Thus, we base our empirical analysis of effects of intervention on the USD/CHF on a standard event study.

In Table 2 and Figure 1 we present results from a linear regression of the 15 minute percentage return on the USD/CHF on leads and lags of a signed intervention indicator, I_t (i.e. I_t is +1 in any interval where the SNB purchased dollars, -1 in intervals when the SNB sold dollars and zero otherwise. There was no 15 minute interval where the SNB both bought and sold dollars.) This specification, displayed below, is estimated using the entire sample of 343680 return observations, covering nine years of intervention activity on the part of the SNB between 1986 and 1995;

$$r_t = \alpha + \sum_{j=8}^{-8} \beta_j I_{t+j} + \gamma_1 r_{t-1} + \gamma_2 r_{t-2} + \varepsilon_t. \tag{1}$$

We consider 8 leads and lags of the intervention variable so as to capture the effects of intervention in the 2 hours before and after any intervention event. Two lags of the dependent variable are included to pick up the low displacement return autocorrelation identified in Section 2. We have considered specifications with a larger number of leads and lags, obtaining qualitatively similar results.

The results from estimation of equation (1) are given in the second column of Table 2. We see that only the contemporaneous intervention indicator, I_t, one lead, I_{t+1}, and one lag, I_{t-1}, have significant coefficients. Since the coefficient on I_{t+1} is positive and significant, Table 2 implies that an intervention impacts the return in the 15 minute interval *before* it actually occurs, possibly because market participants are able to anticipate central bank intervention. The total impact of an intervention operation is not completely anticipated

though, as the coefficient on I_t is large, positive and significant. Furthermore, the significant, negative coefficient on I_{t-1} implies that the impact on the USD/CHF is partially reversed in the 15 minute interval that *follows* an intervention event. This indicates that market participants over-react in response to the information contained in interventions.

The total effect of an intervention operation is best displayed through a graphical representation of the results reported in Table 2. In the left panel of Figure 1 we plot the effect of a dollar purchase by the SNB on the USD/CHF exchange rate (as estimated by partial sums of the coefficients on leads and lags of I_t in the second column of Table 2). The dashed lines trace out a 2 standard deviation confidence interval for the total exchange rate impact. The plot of the cumulative intervention effect confirms the conclusions drawn from Table 2, as we observe a large impact, of around 20 basis points, from a purchase of US dollars. Despite the clear mean-reverting behaviour of the cumulative exchange rate impact, after two hours the impact is still positive, roughly equal to 10 basis points.

Hence, interventions appear to have significant and persitent effects on exchange rate levels.[6,7] Notice that, since during the sample period the SNB sterilised all of its intervention transactions, we cannot attribute this effect to changes in monetary aggregates.[8] Instead, these results suggest that SNB intervention activity "carries" information.

3.2 The impact of customer trades on exchange rates

A refined way to test the signalling hypothesis compares the effects of SNB interventions on the USD/CHF with those of customer trades. If the impact on exchange rates of intervention operations was of comparable magnitude to that of non-intervention order flows, one might argue that there is nothing "special" about interventions and the results reported in subsection 3.1 could be due to a liquidity effect rather than an information-based one

[6]We obtain qualitatively similar results from estimations of equation (1) using lower frequencies (i.e hourly, 2 hourly, 4 hourly, 12 hourly, and daily) exchange rate return and intervention data. Results are available upon request.

[7]We have checked the temporal stability of our regression results via a simply dummy variable analysis that splits the intervention data into two equally sized subsamples. The first subsample roughly contains all interventions during the years 1986 through 1990 and the second subsample 1991 through 1995. The results from the two subsamples were qualitatively very similar but, interestingly, the size of the intervention coefficients was much larger in the second subsample. Thus SNB interventions had greater exchange rate effects in the 1990s.

[8]The effects on monetary aggregates of any purchase or sale of US dollars would be sterilisised within the same day through a compensatory open market operation. While there could be a time lag between the two operations, this discrepancy should not bear any effect on the USD/CHF exchange rate, as market participants would anticipate that any temporary change in liquidity would be negligible.

(Evans and Lyons 2000). Thus we compare the effects of those transactions carried out by the SNB on behalf of the Swiss government with those of interventions. As the former are the consequence of the liquidity needs of the Swiss government, these operations are analogous to any transaction of US dollars in the USD/CHF market by private operators.

To test whether intervention operations have a stronger exchange rate impact than other trading activity, we construct the variable CT_t which is a signed SNB customer trading activity indicator: CT_t takes a value of +1 (-1) for those intervals in which the SNB purchases (sells) US dollars as a consequence of the Swiss government's needs. In the last column of Table 2 we report results from estimation of equation (2), which is entirely analogous to the specification we used to asses the effects of interventions:

$$r_t = \alpha + \sum_{j=8}^{-8} \beta_j CT_{t+j} + \sum_{j=1}^{2} \gamma_j r_{t-j} + \varepsilon_t. \tag{2}$$

Similar to the results of Fischer and Zurlinden (1999), we find that the coefficients of the leads and lags of SNB customer trades often have the *wrong* sign and are, in general, *not* significantly different from zero. More tellingly, in the right panel of Figure 1 we present the cumulative exchange rate impact of a customer purchase of dollars. In stark contrast to the left panel of Figure 1, there is no clear pattern in this picture and at no point is the cumulative effect significantly different from zero.

Since their effects are neither significant nor persistent, we conclude that SNB customer trades are qualitatively different to SNB intervention activity. The latter has a significant and persistent effect on the USD/CHF in the expected direction while the former do not even temporarily affect prices. This confirms that interventions carry information.

3.3 The impact of the intervention size on exchange rates

To further investigate the signalling hypothesis, in Table 3 we report the results from estimation of two new specifications for the USD/CHF return. In the first we regress r_t on leads and lags of the signed intervention indicator, I_t, alongside those of the signed intervention *quantity*, X_t. In the second, we substitute the leads and lags of the signed indicator with corresponding leads and lags of *signed, squared quantity*:

$$r_t = \alpha + \sum_{j=8}^{-8} \beta_j I_{t+j} + \sum_{j=8}^{-8} \delta_j X_{t+j} + \sum_{j=1}^{2} \gamma_j r_{t-j} + \varepsilon_t, \tag{3}$$

$$r_t \;=\; \alpha + \sum_{j=8}^{-8} \delta_j X_{t+j} + \sum_{j=8}^{-8} \theta_j \,\mathrm{sign}(X_{t+j})\, X_{t+j}^2 + \sum_{j=1}^{2} \gamma_j r_{t-j} + \varepsilon_t. \qquad (4)$$

Equation (3) allows to assess the relevance of the *size* of intervention. Equation (4) indicates if the relationship between intervention size and the USD/CHF return is non-linear.

Table 3 shows the estimation results for equations (3) and (4). Results for the first regression indicate that the introduction of the signed quantity variables does not alter the sign or significance of the coefficients on leads and lags of the indicator. However, the size of the intervention operation is important as the coefficient on current intervention, δ_0, is significantly positive, suggesting that the larger the magnitude of intervention, the larger its immediate impact on the exchange rate. The relationship between intervention size and the exchange rate is shown in the left panel of Figure 2, where we present the cumulative effect of dollar purchases of different sizes. We see that a purchase of $50 million by the SNB has a large immediate impact, of nearly 30 basis points, on the exchange rate.

This impact is an order of magnitude larger than the lower bound estimated by Evans and Lyons (2000) for the impact of central bank intervention in the USD/DEM market (5 basis points for operations of $100 million). The difference may be generated by either the different sizes of the two markets or the absence of actual interventions in their data set, which precludes the direct evaluation of the information content of intervention operations.

Results for the second regression indicate that the relation between the exchange rate and intervention size is *not* linear: the coefficient on the contemporaneous value of signed, squared size is significantly *negative*. To judge the importance of the concavity, consider the right panel of Figure 2, where we present the contemporaneous impact, implied by the estimates of equation (4), of US dollar purchases of different sizes: the graphical representation clearly suggests that the non-linearity is not economically significant.

In summary, for this Section, our results seem to confirm the signalling hypothesis. Intervention operations in FX markets represent an *expensive* instrument of policymaking. Then, because of their potential cost, they can be employed by monetary authorities to credibly convey information to market participants and hence condition market sentiment and currency values. Moreover, since large operations are potentially more expensive they have a bigger impact on exchange rate returns than small ones.[9]

[9]For a formal discussion see Bhattacharya and Weller (1997) and Vitale (1999,2002).

3.4 Intervention and market momentum

Dominguez and Frankel (1993b) list several reasons that might induce monetary authorities to intervene in FX markets, among which prevails the desire to calm disorderly markets. In practice, this often means that central banks purchase or sell currency in order to reverse a recent change in price. This motivates an analysis of whether interventions that are *with the wind* have significantly different effects on rates than those that *lean against the wind*.

To test for differences, we use two different definitions of intervention *with/against-the-trend*. We denote an intervention operation as with-the-trend if its sign is the same as that of the change in the exchange rate over the previous 6 or 24 hours.[10,11] Against-the-trend observations are defined in the corresponding fashion. We then run separate regressions of USD/CHF returns on leads and lags of with/against-the-trend interventions, identical in structure to equation (1). We experimented with the use of current signed intervention quantities and signed, squared quantities in the specification (as Table 3 implies we should) but in no case was either significant.

The results from these regressions are reported in Table 4. In Figure 3 we present plots of the cumulative intervention effects for the two regressions that use the daily definition of trend. Table 4 and Figure 3 indicate two important conclusions.

First, the impact of a purchase of US dollars by the SNB is much more pronounced, persistent and significant when intervention is with-the-trend, especially for the regression based on the 6 hour trend definition. In Figure 3, the immediate increase in the USD/CHF due to a with-the-wind intervention is of the order of 35 basis points and after two hours the total impact is still significant and around 25 basis points. On the contrary, for against-the trend interventions we observe a much smaller impact at the time of the intervention and the cumulative abnormal return drops to zero within a couple of hours.

The second interesting result from these regressions is that the " anticipation effect" identified in Section 3.1 is still present for the the with-the-wind regressions but is entirely absent for the against-the-wind regressions.

This finding is suggestive of an SNB policy of intervening with the wind on a very high-frequency basis. Note in fact from Table 4 that, using the trend definition based on the 6

[10] Given the particular focus of our analysis, we employ an high-frequency notion of "trend" that differs from common practice. However, qualitatively similar conclusions are derived using more common definitions of "trend", based on weekly or monthly returns.

[11] Note that these "trend" periods are measured so as to end two hours before any intervention such that it does not overlap with any of the leads of I_t in the regression specification.

hour return, there are almost twice as many with-trend interventions than against-trend interventions and for the with-trend regressions, the coefficients on the leads of intervention tend to be positive. Based on this, we conjecture that one factor underlying our "anticipation effect" is that not only does the SNB *choose* to intervene after a few hours during which the change in the rate has been in the desired direction, but it also tends to time interventions such that they are *immediately* after price moves in the right direction.

3.5 Coordination, anticipation and news-wire reports

In the previous subsection we conjectured that the SNB chose to intervene after short-run price moves in the direction it wished to push the rate, so that the effect of its activity on the USD/CHF return is felt in the 15 minutes before interventions occur. An alternative explanation for the "anticipation effect" is the presence of small reporting lags in the intervention data set. In the mid 1980s and the early 1990s intervention operations were completed on the phone and subsequently registered on report slips.

We investigate the possibility that this process led to reported intervention times being slightly later than actual intervention times by examining the effects of interventions occurring in the first 5 minutes of any 15 minute interval separately from all others. If there was a reporting lag we would expect to see such interventions strongly affecting returns in the interval prior to that in which the intervention was reported whilst the remaining intervention observations would not. This is not the case in the data.

A third explanation for the "anticipation effect" is related to the way SNB intervention operations are co-ordinated with those of other central banks. As noted by Fischer and Zurlinden (1999), practically all SNB intervention operations occurring within our sample period were "coordinated" with either the Fed or the Buba, meaning that they would take place on those days in which at least one of these two central banks was also present in the market. Thus, one might argue that coordinated intervention activity explains why i) interventions have greater exchange rate effects when they are with-the-trend and ii) exchange rates move in the direction of SNB intervention 15 minutes *before* the intervention actually takes place. If the activity of the SNB follows the lead of the Fed and Buba (and their intervention is effective) then we will see SNB interventions with large effects which appear to be with-the-trend and anticipated by movements in the USD/CHF return.

To check this hypothesis we attempt to differentiate the effects of coordinated and non-coordinated intervention. For such an exercise, we would ideally require full transactions

data on Fed and Buba interventions for our sample period. Since these data are not available we use, as a second best solution, the news-wire reports of Fed and Buba interventions discussed in Section 2. Note that, given the partial overlap between the headline and intervention data, this means we must work with a smaller data sample for this analysis, covering the period from August 1989 and December 1995.[12]

Using the news headline data we employ a narrow notion of coordination intervention: an SNB intervention is said to be *closely-timed* or *concerted* if the Fed and Buba were both reported to be intervening in the market up to 1 hour before the SNB action or 45 minutes afterwards.[13] All other SNB interventions are classed as non-concerted. Using this split of the SNB interventions we can estimate extended versions of equation (1) that separate the effects of concerted/non-concerted activity. Specifically, defining C_t to be a concerted intervention indicator taking the value +1 in intervals during which a concerted intervention occurred and zero otherwise, we estimate

$$r_t = \alpha + \sum_{j=8}^{-8} \beta_j I_{t+j} + \sum_{j=1}^{-1} \kappa_j C_{t+j} I_{t+j} + \sum_{j=1}^{2} \gamma_j r_{t-j} + \varepsilon_t, \quad (5)$$

$$r_t = \alpha + \sum_{j=8}^{-8} \beta_j I_{t+j} + \sum_{j=1}^{-1} \kappa_j C_{t+j} I_{t+j} + \delta_0 X_t + \lambda_0 C_t X_t + \sum_{j=1}^{2} \gamma_j r_{t-j} + \varepsilon_t, \quad (6)$$

where I_t is a signed SNB intervention indicator and X_t is signed SNB intervention size as before. Note that in equation (6) we also allow current intervention quantity to affect returns, both in isolation and in interaction with the concerted intervention dummy.

In Table 5 we report the estimated coefficients for equations (5) and (6). We notice two interesting results: i) the effect of SNB intervention activity is more pronounced when it is concerted with that of the Buba and the Fed; ii) the "anticipation effect" does not disappear.

In particular, the coefficients of the first lead and the contemporaneous value of the product of the concerted intervention indicator, C_t, with the signed intervention indicator, I_t, and the signed intervention quantity, X_t, are positive. Moreover, even though none

[12] As a check of the quality of such data we cross the information contained in the news-wire reports with that for the SNB intervention. We find that 74% of all SNB intervention operations were reported by Reuters. Moreover, of those intervention operations which were concerted with the Buba and the Fed 84% were reported. Finally, of the intervention operations which were reported, the median of the time lag between the actual operation and the corresponding report is 11 minutes and 30 seconds for all operations and 11 minutes for the concerted ones.

[13] Of the 62 interventions in the August 1989 to December 1995 sub-sample, 22 are classified as concerted. We have experimented with alternative definitions for concerted intervention, for example defining concerted interventions as those when the SNB, Buba and Fed were all in the market on the same day. The results derived are qualitatively similar to those presented here.

of these coefficients is significant at the 5% level, several are close to significance at the 10% level. This confirms common wisdom that intervention is more effective when it is coordinated, as then market participants observe a clear consensus among monetary authorities over the desired direction of movement for the exchange rate.

It should also be noted that the first lead of the SNB intervention indicator retains significance at the 1% level in equation (5) and at the 10% level in equation (6), suggesting that it is not simply coordinated intervention activity that explains the movement of the exchange rate return in intervals immediately before an SNB intervention operation.

To further investigate the effects of co-ordinated intervention, we proceed to directly and separately evaluate the effects of Fed and Buba activity on the USD/CHF using the newswire data. Rather than combining them with the SNB interventions to create a concerted intervention dummy we now create separate signed intervention indicators for the Fed and Buba from the news headlines.[14] We then estimate the following specification;

$$r_t = \alpha + \sum_{j=8}^{-8} \beta_j I_{t+j} + \sum_{j=4}^{-4} \phi_j I^F_{t+j} + \sum_{j=4}^{-4} \psi_j I^B_{t+j} + \sum_{j=1}^{2} \gamma_j r_{t-j} + \varepsilon_t, \qquad (7)$$

where I^F_t is the signed Fed intervention indicator and I^B_t is the signed Buba intervention indicator. We do not use SNB intervention quantities anywhere in equation (7) as we do not have quantity data for the other interventions of the other two banks. In Table 6 we present the estimated coefficients from this specification.

The coefficients confirm that reports of Fed and Buba intervention activity have a significant effect on the USD/CHF return. As expected, purchases (sales) of the American currency on the part of the Fed or the Buba tend to appreciate (depreciate) the US dollar. Consistent with prior results in Dominguez (1999), we also see that the effect of these intervention reports is felt well before the reporting interval: the third lead of Fed intervention, I^F_{t+3}, and the second and third leads of Buba intervention, I^B_{t+2} and I^B_{t+3}, are positive and significantly so at the 1% level. Hence, exchange rates react up to 45 minutes ahead of Reuters intervention reports, due to the delay in these reports' publication.

More importantly, in Table 6 we see that the coefficients on the first lead of the SNB intervention indicator and its contemporaneous value are still positive and significant at the 1% level. Once more, this indicates that even when accounting for the reports of other central bank activity i) purchases and sales of US dollars on the part of the SNB have an

[14] The indicators can be signed as the news headlines always include an indication of the direction of the intervention.

important impact on USD/CHF returns and ii) the impact of these SNB operations is in part felt *before* their completion.

Thus these results confirm the importance of SNB activity, even after accounting for Fed and Buba operations, but the "anticipation" puzzle remains. We cannot, however, rule out the possibility that the shortcomings in our data on Fed and Buba interventions – we don't have actual transactions information but only a set of news-wire reports for days on which the Fed intervened and only for a subperiod of our entire sample – are behind our inability to explain the "anticipation effect" via co-ordination. If we had full transaction information on Fed and Buba operations we could test for coordination effects far more cleanly.

4 Concluding Remarks

We have conducted an investigation of the effects of sterilised intervention in the spot USD/CHF market. The novelty of this study lies in the use of a transaction based data set of SNB activity between 1986 and 1995, the information from which we combine with indicative exchange rate quotes recorded by Olsen and Associates and Reuters news-wire reports. With such a rich data set we have been able to identify a clear and significant link between FX intervention and exchange rate returns. In particular, using an event study, we have exactly quantified the effects of single intervention operations on the USD/CHF rate at a 15 minute sampling frequency.

Our analysis suggests four important results: i) SNB intervention operations have strong and persistent effects on the USD/CHF which remain after accounting for the operations of other central banks; ii) SNB interventions are more effective in conditioning exchange rates when they are coordinated with other central banks; iii) interventions which are with-the-trend have stronger exchange rate impacts; iv) the exchange rate moves in the direction of the intervention in the minutes before the actual intervention takes place.

Clearly, the latter result is puzzling as it may indicate that some market participants learn about upcoming SNB interventions shortly before they actually occur. We find that the result persists even after accounting for the effects of co-ordinated intervention among central banks using news-wire reports of Fed and Buba activity. Our interpretation of this result is that the SNB chose to intervene with-the-wind on a very high-frequency basis i.e. it is not that intervention *affects* returns one-period ahead of its reported time (due, for example, to leakage of intervention information) but that intervention is timed by the SNB to *follow* high-frequency price moves in the direction that the SNB desires to push

the exchange rate. Perhaps this is due to the SNB recognising that interventions that follow a recent trend are more likely to be successful than those opposing recent trends.

A clearer picture of the anticipated intervention effect could be given via a structural analysis of the effects of intervention on exchange rates, as this would solve identification problems and isolate the effects of the *unexpected* components of intervention. However, such an analysis is very hard to implement, in that it is quite difficult to predict intervention operations. This difficulty is particularly acute for the initial operations within single intervention episodes. This is unfortunate, because exactly these operations appear (Fischer and Zurlinden 1999) to be responsible for most of the effects on exchange rates of FX intervention. We leave this avenue to future research.

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Table 1: Summary statistics for intervention transactions, customer trades and indicative USD/CHF data

Panel (a)

Variable	Obs.	Mean	s.d.	Median	Skew	Kurt
I_t	709	-3.29*	10.41	-5	-1.40*	11.54*
C_t	455	15.46*	27.06	10	2.48*	14.06*
Variable	Obs.	Mean	s.d.	Median	Min	Max
I_t^+	243	8.39*	3.23	10	5	35
I_t^-	466	-9.39*	7.14	-10	-100	-5
C_t^+	415	19.01*	24.70	10	0.7	200
C_t^-	40	-21.33*	22.93	-11.59	-91.85	-5.68

Panel (b)

Variable	Mean	s.d.	Skew	Kurtosis	$\hat{\rho}_1$	$Q(10)$
r_t	-2.8 $\times 10^{-5}$	0.086	0.054	28.472	-0.112	4383.875
q_t	27.333	742.561	1.477	5.491	0.893	1734989.700
$\|r_t\|$	0.052	0.068	4.544	53.490	0.292	98366.779

Notes: Intervention and customer trades statistics are calculated from the tick-by-tick transaction series. Statistics on indicative USD/CHF data are based on 343680 observations with a 15 minute sampling frequency. This sample omits exchange rate data from weekends. I_t is signed intervention quantity (positive for dollar purchases.) I_t^+ and I_t^- are the subsamples of interventions with positive and negative sizes respectively. C_t is signed customer trade quantity (positive for dollar purchases.) C_t^+ and C_t^- are the subsamples of customer trades with positive and negative sizes respectively. r_t is the percentage return on the USD/CHF and q_t is the count of the number of quote entries in a given 15 minute period. The final variable $|r_t|$ is the absolute exchange rate return. A * indicates that the given statistic is significantly different from zero at the 5% level. *s.d.* is the standard deviation of the given variable, *Skew* is the coefficient of skewness and *Kurt* is excess kurtosis.

Table 2: Effects of signed SNB trading activity on percentage return

Equation (1)		Equation (2)	
Regressor	Coefficient	Regressor	Coefficient
α	0.0000	α	0.0000
β_8	-0.0120	β_8	-0.0047
β_7	0.0117	β_7	-0.0008
β_6	0.0077	β_6	-0.0117**
β_5	-0.0207	β_5	-0.0018
β_4	-0.0023	β_4	-0.0056
β_3	0.0261	β_3	-0.0072
β_2	0.0080	β_2	-0.0036
β_1	0.0467**	β_1	-0.0229**
β_0	0.1241**	β_0	-0.0095
β_{-1}	-0.0338**	β_{-1}	0.0048
β_{-2}	-0.0069	β_{-2}	0.0006
β_{-3}	-0.0174	β_{-3}	0.0029
β_{-4}	-0.0162	β_{-4}	0.0061
β_{-5}	0.0120	β_{-5}	-0.0058
β_{-6}	-0.0032	β_{-6}	0.0009
β_{-7}	-0.0069	β_{-7}	-0.0041
β_{-8}	-0.0103	β_{-8}	0.0072
γ_1	-0.1146^{**}	γ_1	-0.1142^{**}
γ_2	-0.0167^{**}	γ_2	-0.0175^{**}
$\bar{R}^2$	0.014	$\bar{R}^2$	0.013
$Q(5)$	30.32**	$Q(5)$	3.97

Notes: Regression coefficients are estimated using the OLS method with Newey-West standard errors and 2 lags in the dependent variable. I_t is signed SNB intervention while CT_t is signed SNB customer trading activity (+1 for dollar purchases, -1 for dollar sales). r_t is the percentage return on the USD/CHF. A * (**) indicates that the given statistic is significantly different from zero at the 5% (1%) level. $Q[5]$ is the fifth order Box-Ljung statistic for serial correlation.

Table 3: Effects of intervention size on returns

Equation (3)		Equation (4)	
Regression	Coefficient	Regression	Coefficient
α	-0.00002**	α	-0.00002
β_4	-0.00906	δ_4	0.00004
β_3	0.03121	δ_3	0.0009
β_2	0.00549	δ_2	0.00062
β_1	0.04614**	δ_1	0.00164*
β_0	0.06687**	δ_0	0.00371**
β_{-1}	-0.03858*	δ_{-1}	-0.00106*
β_{-2}	-0.01035	δ_{-2}	-0.00018
β_{-3}	-0.01056	δ_{-3}	-0.00071*
β_{-4}	-0.02174	δ_{-4}	-0.00043
δ_4	0.00019	θ_4	0.000000
δ_3	-0.00015	θ_3	-0.000004
δ_2	0.00004	θ_2	-0.000003
δ_1	0.00004	θ_1	-0.000006
δ_0	0.00159**	θ_0	-0.000008**
δ_{-1}	0.00003	θ_{-1}	0.000004
δ_{-2}	0.00005	θ_{-2}	0.000001
δ_{-3}	-0.00017	θ_{-3}	0.000002
δ_{-4}	0.00018	θ_{-4}	0.000002
γ_1	-0.11455**	γ_1	-0.11459**
γ_2	-0.01676**	γ_2	-0.01684**
$\bar{R}^2$	0.015	$\bar{R}^2$	0.015
$Q(5)$	30.16**	$Q(5)$	29.8**

Notes: regression coefficients are estimated using the OLS method with Newey-West standard errors and 2 lags in the dependent variable. I_t is signed intervention (+1 for dollar purchases, -1 for dollar sales), X_t is signed intervention *magnitude* (in millions of US dollars) and r_t is the percentage return on the USD/CHF. A * (**) indicates that the given statistic is significantly different from zero at the 5% (1%) level. $Q[5]$ is the fifth order Box-Ljung statistic for serial correlation. The coefficient values which are not reported for reason of space are not significant.

Table 4: Effects of prior exchange rate trend on intervention effect

	24 hour trend		6 hour trend	
Regressor	With	Against	With	Against
α	0.0000	0.0000	0.0000	0.0000
β_8	-0.0131	-0.0109	-0.0029	-0.0290
β_7	0.0139	0.0107	0.0154	0.0009
β_6	0.0301	-0.0065	0.0172	-0.0086
β_5	-0.0145	-0.0253	-0.0068	-0.0432*
β_4	0.0374	-0.0293	0.0064	-0.0196
β_3	0.0646*	0.0005	0.0460*	-0.0071
β_2	0.01	0.0043	0.0183	-0.0074
β_1	0.0661*	0.0333	0.0738**	0.0030
β_0	0.1866**	0.0820**	0.17836**	0.0276
β_{-1}	-0.0350	-0.0325*	-0.0298	-0.0376
β_{-2}	0.0026	-0.013	-0.0077	-0.0068
β_{-3}	-0.0278*	-0.0091	-0.0152	-0.0225
β_{-4}	-0.023	-0.0113	-0.0225	-0.0067
β_{-5}	0.007	0.0178	0.0014	0.0285*
β_{-6}	-0.0023	-0.0014	-0.0082	0.0031
β_{-7}	-0.00237	0.0048	-0.0123	-0.0017
β_{-8}	-0.0153	-0.007	-0.0117	-0.0096
γ_1	-0.1147**	-0.1142**	-0.1150**	-0.1141**
γ_2	-0.0170**	-0.0165**	-0.0170**	-0.0166**
Num. of Obs.	72	105	112	65
$\bar{R}^2$	0.014	0.013	0.015	0.013
$Q(5)$	27.90**	29.33**	28.76**	27.87**

Notes: the table presents results from estimations of the with/against the trend regressions and the concerted/non-concerted specifications. Coefficients are estimated using the OLS method with Newey-West standard errors and 2 lags in the dependent variable. I_t is signed intervention (+1 for dollar purchases, -1 for dollar sales) and r_t is the percentage return on the USD/CHF. A * (**) indicates that the given statistic is significantly different from zero at the 5% (1%) level. $Q[5]$ is the fifth order Box-Ljung statistic for serial correlation.

Table 5: Concerted intervention regressions

	Equation (5)				Equation (6)		
Regr.	Coeff.	Regr.	Coeff.	Regr.	Coeff.	Regr.	Coeff.
α_0	0.0000	κ_1	0.1153	α_0	0.0000	κ_1	0.1267
β_8	-0.0056	κ_0	0.1230	β_8	-0.0057	κ_0	0.1120
β_7	-0.0101	κ_{-1}	-0.0685	β_7	-0.0101	κ_{-1}	-0.0652
β_6	0.0054			β_6	0.0053	δ_0	0.0012**
β_5	-0.0437**			β_5	-0.0437**	λ_0	0.0007
β_4	0.0011	γ_1	-0.1416**	β_4	0.0011	γ_1	-0.1416**
β_3	0.0575	γ_2	-0.0220**	β_3	0.0591	γ_2	-0.0221**
β_2	0.0238			β_2	0.0215		
β_1	0.0485**			β_1	0.0425		
β_0	0.1576**			β_0	0.0996**		
β_{-1}	-0.0089			β_{-1}	-0.0214		
β_{-2}	-0.0063			β_{-2}	-0.0083		
β_{-3}	-0.0199			β_{-3}	-0.0175		
β_{-4}	0.0243			β_{-4}	0.0246		
β_{-5}	0.0040			β_{-5}	0.0038		
β_{-6}	-0.0144			β_{-6}	-0.0145		
β_{-7}	0.0096			β_{-7}	0.0097		
β_{-8}	-0.0034			β_{-8}	-0.0034		
$\bar{R}^2$	0.014			$\bar{R}^2$	0.0218		
$Q(5)$	30.60**			$Q(5)$	29.84**		

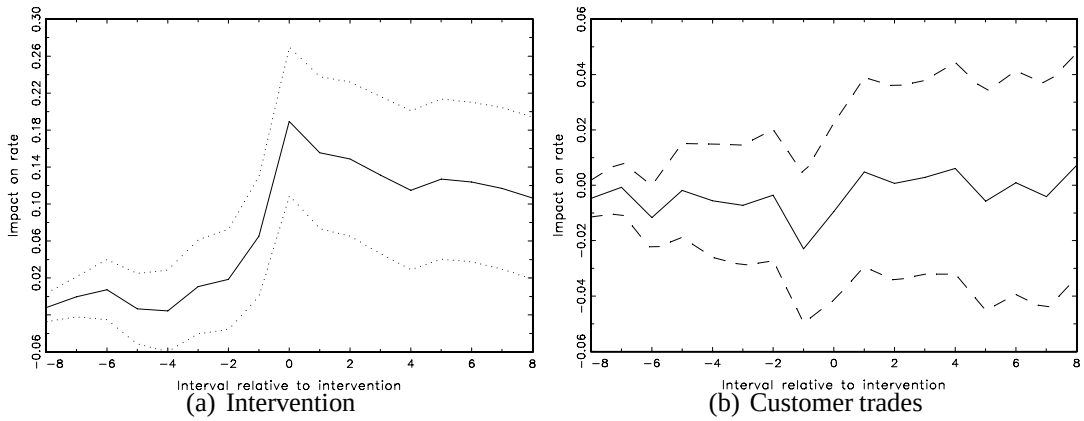
Notes: regression coefficients are estimated using the OLS method with Newey-West standard errors. I_t is signed intervention (+1 for dollar purchases, -1 for dollar sales), X_t is signed intervention quantity (positive for dollar purchases, negative for dollar sales), C_t is a concerted intervention indicator, which is unity for intervals in which the SNB intervened *and* the Fed and Buba were both reported to be in the market up to 1 hour beforehand or 45 minutes afterwards. A * (**) indicates that the given statistic is significantly different from zero at the 5% (1%) level. $Q[5]$ is the fifth order Box-Ljung statistic for serial correlation.

Table 6: Regression of returns on separate signed SNB, Fed and Buba intervention indicators

Regressor	Coefficient	Regressor	Coefficient
α	-0.0002	ϕ_4	0.0153
β_8	-0.0057	ϕ_3	0.0617**
β_7	-0.0084	ϕ_2	-0.0003
β_6	0.0071	ϕ_1	-0.0142
β_5	-0.0442**	ϕ_0	-0.0112
β_4	-0.0015	ϕ_{-1}	-0.0082
β_3	0.0474	ϕ_{-2}	-0.0224**
β_2	0.0210	ϕ_{-3}	-0.0220**
β_1	0.0674**	ϕ_{-4}	0.0013
β_0	0.1670**	ψ_4	-0.0008
β_{-1}	-0.0491	ψ_3	0.0511**
β_{-2}	-0.0056	ψ_2	0.0659**
β_{-3}	-0.0165	ψ_1	0.0039
β_{-4}	0.0184	ψ_0	-0.0128
β_{-5}	0.0045	ψ_{-1}	-0.0183
β_{-6}	-0.0016	ψ_{-2}	0.0109
β_{-7}	0.0193	ψ_{-3}	0.0014
β_{-8}	0.0025	ψ_{-4}	-0.0396**
γ_1	-0.1308**	γ_2	-0.0219**
$\bar{R}^2$	0.020	$Q(5)$	43.51**

Notes: Regression coefficients are estimated using the OLS method with Newey-West standard errors. I_t is signed intervention (+1 for dollar purchases, -1 for dollar sales), I_t^F is a signed indicator of Reuters reports of Fed intervention and I_t^B is a signed indicator of Reuters reports of Buba intervention. A * (**) indicates that the given statistic is significantly different from zero at the 5% (1%) level. $Q[5]$ is the fifth order Box-Ljung statistic for serial correlation.

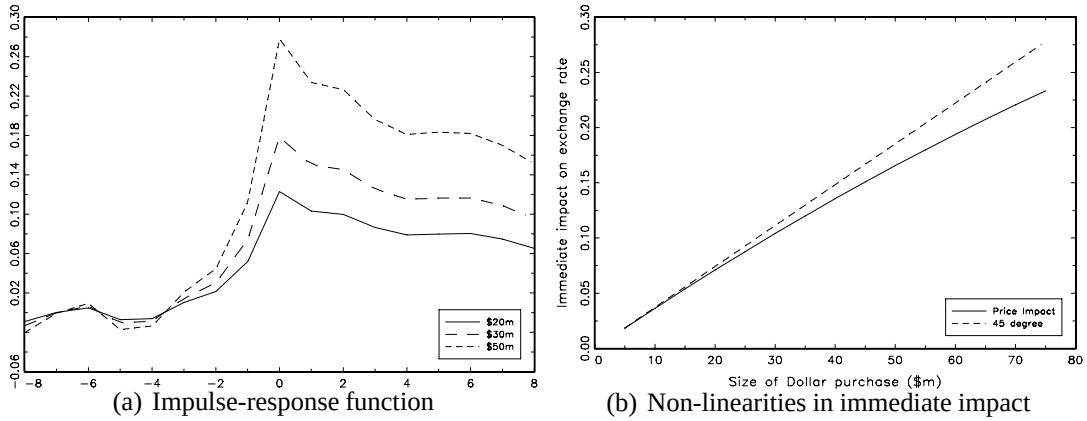
Figure 1: Basic effects of intervention and customer trades on the USD/CHF



(a) Intervention (b) Customer trades

Notes: Basic effects of intervention and customer trades on the USD/CHF. Results are based on exchange rates and intervention events defined using a 15 minutes sampling frequency. Time is measured in 15 minute intervals relative to intervention. The dashed lines indicate the 95% confidence interval for the cumulative intervention effect.

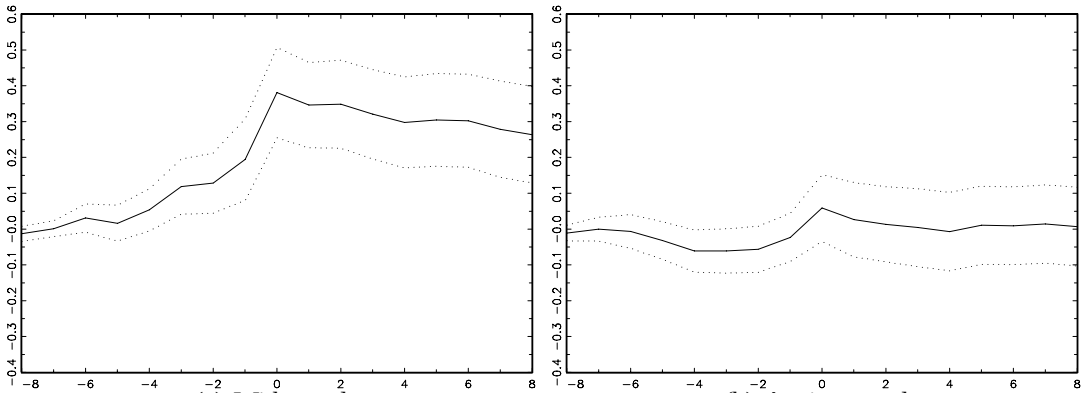
Figure 2: Size effects of intervention on the USD/CHF



(a) Impulse-response function (b) Non-linearities in immediate impact

Notes: Results are based on exchange rates and intervention events defined using a 15 minutes sampling frequency. The *x*-axis for panel (a) gives the (15 minute) interval relative to the intervention. In panel (a), the three selected values for the intervention size correspond to the 25th percentile, median, and 75th percentile of the distribution of intervention size. Panel (b) shows the relationship between intervention size and the change in the exchange rate. The dashed line is the exchange rate impact implied by considering the estimated linear terms in equation (4) only while the solid line is the impact generated by considering the estimated linear and quadratic terms from equation (4).

Figure 3: Effects of trend on intervention impact (24 hour trend definition)



(a) With trend (b) Against trend

Notes: Results are based on exchange rates and intervention events defined using a 15 minutes sampling frequency. An intervention event is defined to be with the trend if its sign is the same as that of the change in the rate of the prior 24 hours. Time is measured in 15 minute intervals relative to the intervention. The dashed lines indicate the 95% confidence interval for the cumulative intervention effect.