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When do central bank interventions influence intra-daily and longer-term exchange rate movements?

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Abstract

This paper examines dollar interventions by the G3 since 1989, and the reasons that trader reactions to these interventions might differ over time and across central banks. Market microstructure theory provides a framework for understanding the process by which sterilized central bank interventions are observed and interpreted by traders, and how this process, in turn, might influence exchange rates. Using intra-daily and daily exchange rate and intervention data, the paper analyzes the influence of interventions on exchange rate volatility, finding evidence of both within day and daily impact effects, but little evidence that interventions influence longer-term volatility.

JEL classification: F31; G14; G15; E58

Keywords: Central bank intervention; Exchange rate volatility; Market microstructure

1. Introduction

On May 31, 1995 the U.S. government purchased a total of $500 million against marks and $500 million against yen on three occasions between the hours of 1:45 pm and 2:26 pm (Eastern Standard Time), resulting in a 2% increase in the value of the dollar against both the mark and yen

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over the course of the day.[1] On other occasions when the U.S. government intervened in the dollar exchange rate market, however, the dollar either moved in the opposite direction to that expected, or did not move at all. This paper examines dollar interventions by the G3 since 1989, and the reasons that market reactions to these interventions might differ over time and across central banks.

Standard models of exchange rate determination identify at least two channels through which interventions might be expected to influence exchange rates: the portfolio balance channel and the signaling channel. However, neither of these channels is easily reconciled with the empirical evidence, which suggests that sometimes intervention works and sometimes it does not. Of course, standard exchange rate determination models have a difficult time explaining (often the lack of) exchange rate reactions to all kinds of purportedly fundamental information, suggesting that it may be worth reexamining standard models before drawing conclusions regarding the efficacy of intervention.

One approach to exchange rate modeling that has gone some distance toward reconciling observed short-term currency movements and economic theory is the market microstructure approach. In the context of intervention, market microstructure provides a framework for understanding the process by which central bank interventions are observed and interpreted by traders, and how this process, in turn, might result in exchange rate changes.

Recent advances in market microstructure theory, new sources of data on exchange rates and central bank interventions, and in particular, the availability of high frequency data, offer new tools with which to shed light on the old question of when central bank interventions are likely to influence exchange rates.[2] Section 2 introduces a role for intervention via the signaling and portfolio balance channels in the context of foreign exchange market microstructure. Section 3 describes the G3 intervention and exchange rate data. Section 4 provides an empirical examination of the intra-day and daily dynamics of interventions and exchange rate volatility. Section 5 is the conclusion.

2. Market microstructure and intervention

The exchange rate microstructure model developed by Bacchetta and van Wincoop (2006) provides a way to think about why trader heterogeneity (based on differences in information or the interpretation of information) might lead to short-run price and volatility effects in reaction to information revelation.[3] Information-based trades (including interventions that provide informative signals) and non-informative trades can both move exchange rates in the short run depending on aggregate market ability to differentiate noise from fundamentals.

Consider a standard asset pricing model of exchange rates in which the current exchange rate is the discounted present value of expected macro-fundamentals, and a risk premium associated with non-fundamentals trade. If market participants receive information (or signals) about

[1] During New York trading hours on May 31, 1995 the dem–usd rate opened at 1.385 and closed at 1.4135 and the yen–usd rate opened at 82.70 and closed at 84.40. Germany and Japan coordinated their interventions with the U.S. on this day. Reuters' reports indicate that the Bundesbank purchased $395.6 million against the mark on two occasions (starting just before the Fed was in the market), and the BOJ purchased $767.4 million against yen on one occasion (just before the last Fed operation).

[2] See Dominguez and Frankel (1993a,b) and Humpage (1999). Sarno and Taylor (2001) and Edison (1993) provide excellent surveys of the intervention literature. Also, see De Grauwe and Grimaldi (2003), Dominguez (2003b), Ito (2003), Payne and Vitale (2003), Pasquariello (2004, in press), and Vitale (2003b) for recent contributions.

[3] See Lyons (2001) for a thorough discussion of market microstructure in foreign exchange markets as well as Evans and Lyons (2002a,b). For a more general treatment of market microstructure see O'Hara (1995).

future fundamentals, but this information is not common knowledge (either because people receive different bits of information or because they interpret the information differently), then there is a common average signal among traders (assuming there are large numbers of market participants) but heterogeneity across individuals (and traders will expect their own expectation next period to differ from that of others). Bacchetta and van Wincoop (2006) show that this sort of information heterogeneity leads both to magnification and to endogenous persistence of the impact of non-fundamentals trade on the exchange rate.[4]

In this setting, official interventions have the potential to influence exchange rates through either the portfolio balance or signaling channel.[5] The portfolio balance channel requires that traders perceive domestic and foreign assets as imperfect substitutes. If this is the case, an intervention (regardless of whether it is observed by market participants) which changes the relative supply of domestic to foreign assets held by the market will lead to a change in the relative value of the domestic currency because traders will require a greater risk premium to induce them to hold the re-balanced portfolio. The signaling channel does not require that assets be considered imperfect substitutes, it is operative if at least some market participants observe the intervention operation and believe that it conveys price-relevant information, or information that allows them to distinguish more accurately between fundamental and non-fundamental information.[6] In the short run, however, the information content of intervention signals may not be common knowledge, so that intervention operations themselves may initially add to the rational confusion in the market.[7] This suggests that the very short-run influence of interventions via the signaling channel may differ from the longer run effects of operations.

In the very short run, the influence of interventions on volatility will be similar regardless of whether the signaling or portfolio balance channel is operative. If interventions are non-informative and only influence exchange rates via the portfolio balance channel, we would still expect short-run volatility to rise in reaction to an intervention until dealer inventories have fully absorbed the resulting liquidity shock. In the longer run, however, only interventions with information content should influence volatility. Further, if interventions serve to resolve market uncertainty, we should observe a decline in post-intervention volatility relative to pre-intervention conditions.[8]

[4] Vitale (2003a) provides a simplification of the Bacchetta and van Wincoop (2006) model that allows a closed form solution for the exchange rate equation and retains the result that non-fundamental news may have magnified and persistent effects on exchange rates.

[5] U.S. and German interventions over the period examined in this paper were sterilized, meaning that the Fed and Bundesbank always automatically (and contemporaneously) offset the effects of interventions on their respective monetary bases. Japanese interventions are not necessarily automatically sterilized by the BOJ, so it is not possible to strictly differentiate the influence of foreign exchange interventions and monetary policy for Japan.

[6] The so-called Plaza interventions are an example of the latter type of signal. The G5 governments intervened in September 1985 to bring down the value of the dollar. Ex post analysis in Dominguez and Frankel (1993b) suggests that the signal conveyed by these interventions did not contain information about future policy, but rather was an attempt by the G5 Governments to ‘‘burst the dollar bubble’’ by informing traders of their view that the dollar was over-valued in terms of its fundamentals.

[7] See Dominguez (2003a) for a detailed description of how traders learn that a central bank has intervened in the foreign exchange market.

[8] Dominguez (1998) describes that the expected influence of an intervention operation via the signaling channel depends on (1) the nature of the intervention signal (credible or non-credible), (2) the state of the market (efficient or inefficient), and (3) the perceived objective of the central bank (to influence the level or the volatility of the exchange rate). In this framework the only scenario under which an intervention will reduce exchange rate volatility is when intervention signals are credible, the foreign exchange market is efficient, and the perceived central bank objective is to lower volatility.

As a general matter, and in contrast to papers that study the longer-term effects of central bank interventions, studies examining intra-daily effects of intervention find strong evidence of impact effects. An exception is Goodhart and Hesse (1993), which was the first paper to examine interventions using intra-daily data captured on Reuters' screens over a twelve-week period in 1989. They find little evidence of an immediate, or short term, systematic effect of intervention. Dominguez (2003a) examines the influence of G3 interventions on intra-day dem–usd and yen–usd returns over a seven-year period and finds evidence of significant lead and impact effects. Likewise, Cai et al. (2001) and Chang and Taylor (1998) find evidence of positive lead and impact effects of Japanese interventions on yen–usd volatility.

Peiers (1997) examines how interactions between informed (defined to be indications provided by Deutsche Bank (DB)) and uninformed foreign exchange traders (indications given by all other banks) give rise to short-term price leadership during periods of central bank intervention. She finds that, during the period October 1992 through September 1993, volatility increases 5 min prior to Bundesbank interventions, and that there is evidence of DB price leadership from 60 to 25 min prior to Reuters' reports.

At a daily frequency LeBaron (1999) shows U.S. intervention days are the source of unusual profits for traders using technical analysis. He finds that simple moving average trading rule profits are significant in daily dollar exchange rate data if U.S. intervention days are included in the sample – when interventions are excluded, profits go to zero. Using more finely timed data, Neely (2002) however, finds that interventions are unlikely to have "caused" the increase in trading rule profits, but instead that U.S. interventions tend to arise during periods when dollar exchange rates are trending in a manner that would likely lead to technical trading rule profits.

Beattie and Fillion (1999) find evidence that unexpected interventions by the Bank of Canada reduced short-term intra-day volatility. While, D'Souza (2002) finds that dealers react to Bank of Canada interventions no differently than they do to any customer trade. Evans and Lyons (2005) make the assumption that interventions are private information, and therefore equivalent to any customer trade, and using a portfolio balance style model estimate an immediate price impact of 0.44% per $1 billion.

The Swiss National Bank (SNB) is the only central bank that provides time-stamped intraday information on their intervention transaction price and volume. Fischer and Zurlinden (1999), Fischer (2003), Pasquariello (in press), Payne and Vitale (2003), and Panthaki (2005) all examine different aspects of the SNB data and generally find evidence of significant lead and impact effects of interventions on Swiss Franc returns and volatility.[9]

3. G3 intervention and exchange rate data

The intra-daily exchange rate data used in this paper are the Reuters' FXFX series tick-by-tick indicative quotes on U.S. intervention days as well as a control sample of 25 days with no interventions.[10] A limitation of the FXFX data is that because they are quotes and not

[9] Given that the SNB provides the official transaction times, the finding of lead effects for the SNB is puzzling in that it suggests that some market participants were able to anticipate the interventions.

[10] The data are collected by Olsen and Associates (Research Institute for Applied Economics, Zurich Switzerland) using O&A proprietary real-time data collection software and are filtered as recommended by Dacorogna et al. (1993). The control dates were selected to provide a representative sample of non-intervention days over the period when the intervention operations take place. These data are used to create the volatility seasonal used in the empirical tests to follow.

transactions they do not provide volume information, so it is not possible to examine the joint dynamics of volume (or order flow) and price.[11] Another disadvantage of the intra-daily data set is that, because it includes only Fed intervention days, it is not possible to measure persistent effects of interventions. However, we will be able to test for longer run effects of interventions by the G3 central banks using daily volatility data that are available for all the days in the sample period.

The intra-day FXFX data used in the paper cover 69 days over the period August 1989 through August 1995 when the U.S. intervened in the dem–usd market, and 66 days when the U.S. intervened in the yen–usd market.[12] The propensity to intervene on a given day varied across the sample period. The U.S., Japan and Germany all intervened actively in the early part of the sample, while only Japan continued to actively intervene after 1992.[13]

The G3 central banks release historical daily intervention data. Unfortunately, they do not provide the exact timing of interventions, nor do they disclose how many operations occurred over the course of the day. Reuters' newswire reports are the only available source of timing information for G3 interventions. Reuters' reports are also the most likely source of intervention information for those traders in the market that are not directly involved in the intervention transaction.[14]

The Reuters' newswire reports used in this study are from the Reuters' AAMM Page News (Money Market Headline News). Along with reports of central bank intervention, the Reuters' data include announcements of various macroeconomic statistics, statements by central bank and government officials, and reports of major economic events. In order to control for the impact of other news on exchange rates, these Reuters' news reports are also included in the empirical work. In particular, dummy variables indicate the timing of all major macroeconomic announcements and statements regarding exchange rate policy by officials of the G3 central banks on the intervention sample days.[15]

The Reuters' reports indicate that central banks typically intervene during business hours in their respective markets.[16] Frequency distributions of the times of G3 intervention suggest that the BOJ is most likely to intervene at 3:56:36 GMT (or around 1 pm in Tokyo). The Bundesbank is most likely to intervene at 11:31:16 GMT (or at 12:30 pm in Frankfurt). And, the Fed is

[11] Goodhart et al. (1996) and Danielsson and Payne (2002) find that the basic characteristics of 5-min FXFX returns closely match those calculated for transactions prices but find that quote frequency and bid–ask spreads in the FXFX data are not good proxies for transaction volume or spreads.

[12] Two additional U.S. intervention operations have occurred since August 1995. On June 17, 1998 the Fed sold $833 million against the yen in cooperation with the BOJ and on September 22, 2000 the Fed purchased a total of 1.5 billion euros against the dollar in cooperation with the ECB, the BOJ, the Bank of Canada and the Bank of England.

[13] In the United States the Treasury has primary legal authority to intervene in foreign exchange markets. In practice, the U.S. Treasury and the Fed typically act jointly and split the costs of intervention equally against their separate accounts. The New York Fed implements intervention policy for the United States and for this reason I follow the convention of associating U.S. intervention operations with the Fed in the paper. Similarly, in Japan intervention decisions are made by the Ministry of Finance and implemented by the Bank of Japan (BOJ). The Bundesbank had sole jurisdiction over German intervention decisions and implemented intervention operations prior to 1999.

[14] The SNB is the only central bank that releases intra-day transaction time and quantity data for their interventions. Fischer (2003) compares these official times with corresponding Reuters' reports and finds that Reuters is very inaccurate. It is likely that Reuters better covers G3 operations, but in any case, Reuters is currently the only source of intra--day timing information for non-SNB interventions.

[15] Detailed information on these control variables is available in Dominguez (2003a).

[16] Neely (2000), Chiu (2003) and Lecourt and Raymond (2004) provide detailed information about the practice of central bank intervention based on survey data.

most likely to intervene at 14:57:10 GMT (or 10 am EST). It is worth noting that Tokyo business hours end just as the Frankfurt market opens, the New York market overlaps the Frankfurt market for 2 h, and the New York market closes 2 h before the Tokyo financial market opens.

Getting the timing of interventions right is critical to measuring the short-term influence of interventions on foreign exchange markets. Evidence in Almeida et al. (1998), Andersen et al. (2003b) and Bauwens et al. (2005) suggests that conditional mean adjustments of exchange rates to macro-news occur quickly, while conditional variance adjustments are more gradual. Table 1 provides descriptive information about the central bank interventions that are examined in Section 4. The Fed intervened on 268 occasions over 104 days (in either the dem–usd or yen–usd markets) over the sample period August 1989 through August 1995. Many of the Fed's intra-daily interventions were clustered in the same hour of the day. Most Fed interventions occurred during the overlap in New York and European trading hours. And 31% of Fed interventions were coordinated with the Bundesbank in the dem–usd market, while 54% were coordinated with the BOJ in the yen–usd market.[17]

4. Measuring the intra-day and daily influences of central bank interventions

A fundamental property of high frequency data is that observations can occur at varying time intervals resulting in irregular spacing of quotes. Standard econometric techniques require regularly spaced data. The approach to irregularly spaced data used in this paper is to create from these data a regularly spaced time series over a discrete time interval. Defining the tick-by-tick price (P) as the average of the bid and ask:

$$P_{t,h} \equiv \frac{\left[\log P_{t,h}^{\text{ask}} + \log P_{t,h}^{\text{bid}}\right]}{2}, \tag{1}$$

where t, h is the sequence of tick recording times which is irregularly spaced, then the regular-space price is defined as

$$P_{t,n} \equiv \frac{\left[\log P_{t,n}^{\text{ask}} + \log P_{t,n}^{\text{bid}}\right]}{2}, \tag{2}$$

where t, n is the sequence of the regular-spaced in time data and n is the time interval.[18] Equivalently, the nth return (R) on day t is defined as

$$R_{t,n} = P_{t,n} - P_{t,n-1}, \tag{3}$$

and volatility, $V_{t,n}$, is measured as the absolute value of the n-minute returns.

A number of previous studies have documented a strong seasonal pattern in intra-day exchange rate volatility (see, for example, Bollerslev and Domowitz, 1993; Dacorogna et al., 1993 and Guillaume et al., 1997). This seasonality is also readily apparent in both the sample of Fed intervention days and the control sample days. Failure to take account of these

[17] A "coordinated" Fed intervention is defined as an intervention that occurs on the same day (and in the same direction) as a BOJ or Bundesbank intervention.

[18] In practice the 5-min price series used in this paper is formed by averaging the two immediately adjacent bid and ask observations to the round 5-min mark with weights proportional to the distance from the end of the interval.

Table 1
G3 central bank intervention descriptive statistics 1989–1995

	Fed	Buba	BOJ	Any CB
Number of intervention days	104	39	63	206
Total number of intra-day interventions	268	83	145	496
Probability of a second intervention within 1 h of prior one	0.56	0.29	0.26	0.49
Number of interventions followed by another one within 1 h	156	24	37	244
Total number of intervention clusters[a]	44	25	16	83
Average duration of intervention clusters, each 1 h apart	0:44:49	0:45:30	0:35:08	0:42:48
Average number of interventions in a cluster	5.023	2.52	2.5	4.048

This table reports Reuters-based information on the characteristics of the intervention operations by the U.S. Federal Reserve (Fed), the German Bundesbank (Buba), and the Bank of Japan (BOJ) included in the intra-daily event studies. The data cover all Fed intervention days over the period 1989–1995.

[a] An intervention cluster is defined as at least two interventions that occur within the same hour.

intra-daily seasonals is likely to result in misleading statistical analyses. In this paper de-seasonalization of the volatility series is achieved using the Andersen and Bollerslev (1997a,b, 1998) version of Gallant's (1981) flexible Fourier form regression method.

Figs. 1 and 2 show average absolute dem–usd and yen–usd returns, respectively, for each 5-min interval across both the control sample days and the Fed intervention days, along with the estimated intra-day seasonal. In order to construct the intra-day seasonal we first decompose the demeaned n-minute returns, into a daily volatility factor, σ_t, a periodic component for the nth intra-day interval, $s_{t,n,}$ and an i.i.d. mean zero unit variance innovation term, $Z_{t,n}$, all divided by the square root of the number of uncorrelated intra-day return components, N.

$$R_{t,n} - E(R_{t,n}) = \frac{\sigma_t s_{t,n} Z_{t,n}}{N^{\frac{1}{2}}}. \tag{4}$$

The daily volatility component, σ_t, in practice is estimated from a MA(1)-FIGARCH(1,d,1) model for dem–usd and yen–usd fitted over 1752 daily returns from January 1989 through December 1995. The seasonal component, $s_{t,n}$, is then estimated using a flexible Fourier form (FFF) regression. Following Andersen and Bollerslev (1997a), and defining $x_{t,n}$ from Eq. (4) as

$$x_{t,n} \equiv 2\log[|R_{t,n} - E(R_{t,n})|] - \log\sigma_t^2 + \log N = \log s_{t,n}^2 + \log Z_{t,n}^2. \tag{5}$$

The approach is then based on a non-linear regression in the intra-day time interval, n, and the daily volatility factor, σ_t:

$$x_{t,n} = f_{t,n} + \log Z_{t,n}^2 - E\left(\log Z_{t,n}^2\right) = f_{t,n} + u_{t,n}, \tag{6}$$

where $u_{t,n}$ the error term, is i.i.d. mean zero. This non-linear regression function can be approximated by the following parametric function:

$$f_{t,n} = \mu_0 + \mu_1\frac{n}{N_1} + \mu_2\frac{n^2}{N_2} + \sum_{p=1}^{P}\left(\gamma_p\cos\frac{2\pi p}{N}n + \delta_p\sin\frac{2\pi p}{N}n\right), \tag{7}$$

where $\mu_0, \mu_1, \mu_2, \gamma_p, \delta_p$ are fixed coefficients, $N_1 = (N+1)/2$ and $N_2 = (N+1)(N+2)/6$ are normalized constants, N refers to the number of return intervals per day ($N = 288$), P is the

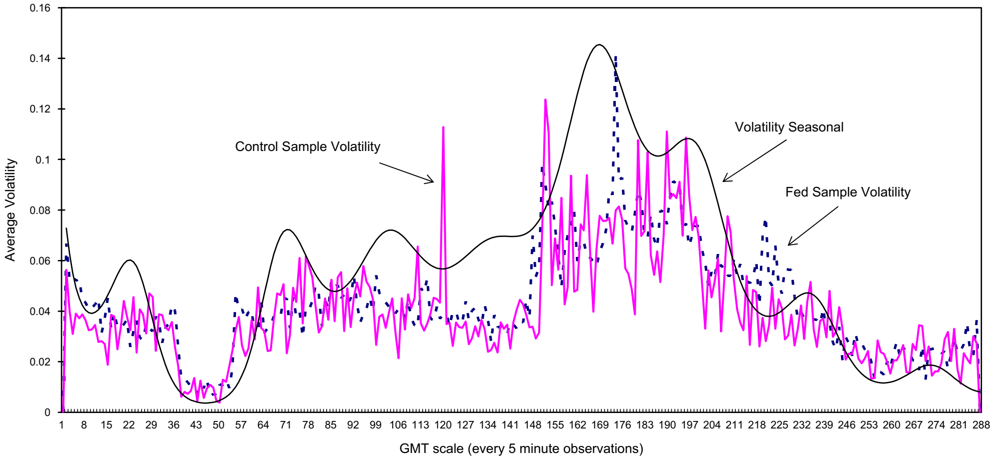

Fig. 1. Dem–usd intra-day volatility. This figure shows average dem–usd 5-min volatility over the day (288 observations) on Fed intervention days and control sample days over the period 1989–1995. The volatility seasonal is estimated using the FFF approach over the control sample days.

tuning parameter ($P=8$) which determines the order of the expansion,[19] and the flexible Fourier forms are parameterized by quadratic components (terms with μ-coefficients) and a number of sinusoids (the γ and δ coefficients). In practice estimation involved a two-step procedure where a generated $x_{t,n}$ series, $\widehat{x}_{t,n}$, is obtained by replacing $E(R_{t,n})$ with the sample mean of the 5-min returns and replacing σ_t with estimates from a daily volatility model, $\widehat{\sigma}_t$. By making these substitutions and treating $\widehat{x}_{t,n}$ as the dependent variable in the regression defined by Eqs. (6) and (7) the parameters of interest can be estimated by ordinary least squares. Further, if we let $\widehat{f}_{t,n}$ denote the resulting estimate for the right hand side of Eq. (7) and normalize, where T denotes the number of trading days in the sample, then an estimator of the intra-day periodic seasonal component for interval n on day t is

$$\widehat{s}_{t,n}=\frac{T\exp\left(\widehat{f}_{t,n}/2\right)}{\sum_{t=1}^{T}\sum_{n=1}^{N}\exp\left(\widehat{f}_{t,n}/2\right)}. \tag{8}$$

4.1. The intra-day effects of intervention on volatility

An "event-study" approach is used to examine the influence of central bank intervention (and other macro-announcements) on exchange rate volatility.[20] The general regression specification is

[19] Andersen and Bollerslev (1997a, 1998) and Cai et al. (2001) find that $P=6$ fits the dem–usd FXFX data over the sample 1992–1993 and the yen–usd FXFX data in 1998. Experimentation with $P=4$, 6 and 8 using both the control sample and Fed intervention day samples (over the years 1989–1995), indicate that $P=8$ offers the best fit with these data.

[20] See Dominguez (2003a) and Payne and Vitale (2003) for a similar "event-study" approach using returns rather than volatility.

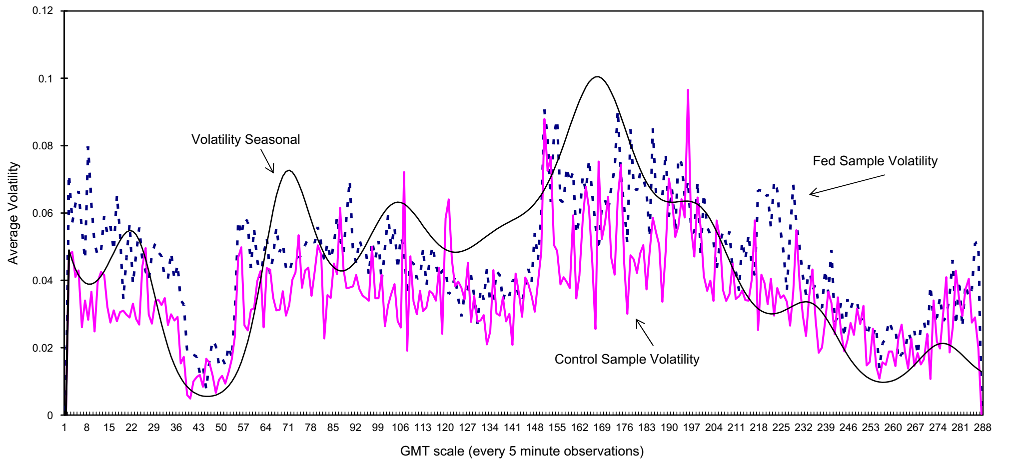

Fig. 2. Yen–usd intra-day volatility. This figure shows average 5-min yen–usd volatility over the day (288 observations) on Fed intervention days and control sample days over the period 1989–1995. The volatility seasonal is estimated using the FFF approach over the control sample days.

$$V_{t,n} = \alpha_0 + \sum_k \sum_i \alpha_{1,i}^k D_{t,n+i}^k + \alpha_2 \widehat{s}_{t,n} + \varepsilon_{t,n}, \tag{9}$$

where D^k denotes the (time-stamped to the nearest 5-min) intervention and other announcement dummy variables, $\widehat{s}_{t,n}$ is the FFF volatility seasonal estimated over the control sample days,[21] and $\varepsilon_{t,n}$ is the white noise error term. In the estimation of Eq. (9) three lags (15 min) of the dependent variable are also included and fully account for any remaining autocorrelation in the error term. Using this general regression specification it is possible to test for the impact and intra-day effects of intervention (and other macro-news) by examining whether the D^ks are statistically significant.[22]

Interventions by the three central banks in the event study take the value 1 if they involve a purchase or sale of dollars and 0 otherwise. Interventions are included as (1,0) dummy variables both because the dollar magnitudes are generally only available at a daily (not intra-daily) frequency, and because there is some evidence that the size of intervention operations may depend on market reactions to initial trades suggesting that including magnitudes might engender simultaneity bias.

[21] Estimates of the intra-daily seasonal using the Fed intervention days produced very similar results. Control sample days were used under the assumption that volatility on intervention days may differ from non-intervention days (indeed Figs. 1 and 2 suggest that especially for the yen–usd market Fed intervention days are more volatile than the control sample days), and while it is necessary to control for intra-day cycles, it is also important not to inadvertently explain away what is unusual about intervention days by only using intervention days to calculate the seasonal. I am grateful to Michael Melvin for suggesting I use the control sample days for this purpose.

[22] The intervention variables and macro-controls could equivalently be included directly into the FFF specification. Experimentation with GARCH and ARFIMA estimation of the intra-daily volatility series did not indicate a stable long-memory process. This may be due to the non-sequential nature of the intra-day data (recall that these data include only days when the Fed intervened in the dem–usd or yen–usd market). Including the conditional mean of the relevant exchange rate in the specification does not affect the volatility results.

Table 2 presents a summary of the results of the volatility event-study regression using the FXFX 5-min dem–usd data. Fig. 3 presents a visual picture of the cumulative effects (as estimated by partial sums of the coefficients on the leads and lags) of Fed intervention, starting 1 h before the Reuters' report, on dem–usd volatility. The dashed lines show a 95% confidence interval for the total volatility impact. The graph shows that the maximum (positive) impact of the Fed intervention occurs 15 min before the Reuters' announcement. The graph also shows evidence of mean reversion, volatility falls dramatically starting 10 min before the Reuters' announcement and is significantly negative for about 30 min, though the cumulative effect is positive and significant after 1.4 h.

The regression results indicate that intervention operations by all three central banks significantly influenced volatility up to 1-h prior to the Reuters' announcement, suggesting that some traders know about these operations well before the Reuters' news release.[23] Bundesbank interventions in the sample had the largest (positive) influence on volatility by a factor of two relative either to Fed or BOJ interventions. Fed interventions continued to influence dem–usd volatility for 80 min after the Reuters' report, while Bundesbank interventions had statistically significant effects for 25 min after the report, and BOJ interventions had effects for just 10 min after the report.[24]

The regression coefficients on the macro-controls indicate that only announcements by the Fed (and not the Bundesbank or BOJ) significantly influenced volatility.[25] Seven of the 12 U.S. and German macro-announcements are also found to be significant, with significant lags varying from impact to 15 min after the Reuters' time-stamp. The announcement with the largest average influence on dem–usd variability is U.S. GNP. The intra-day seasonal is highly significant in the regression. The interventions, announcements, macro-controls and seasonal together explain just under 25% of intra-day dem–usd volatility.

Fig. 4 presents a graph of the cumulative effects of Fed intervention on yen–usd volatility, with the dashed lines showing a 95% confidence interval for the total volatility impact. The graph shows that the influence of Fed interventions on yen–usd volatility is very similar to that in the dem–usd market. Again the maximum (positive) impact of the Fed intervention occurs 15 min before the Reuters' announcement and there is evidence of mean reversion, though volatility in this case never goes significantly negative. The cumulative effect is positive and significant after 1.75 h.

A summary of the results of the yen–usd volatility event-study regression are presented in Table 3. In contrast to the analogous dem–usd regression, Bundesbank interventions do not have a statistically significant influence on volatility in the yen–usd market. There is evidence of 1-h Reuters' announcement lags for both the Fed and the BOJ. Fed interventions continue to have effects for an hour and three quarters after the Reuters' report, and BOJ interventions continue to have effects for 1 h after the report. Both Fed and BOJ central bank announcements also influence volatility. Six of 12 U.S. and Japanese macro-announcements are significant. U.S. GNP again has the largest effect.

[23] Various regression specifications were attempted, including imposing a polynomial distributed lag (pdl) structure on the leads and lags of the intervention variables. Tests of the pdl restrictions suggested that the data do not conform to this specification. Experimentation with various lead and lag combinations indicated that a [−1 h,+2 h] window for the intervention variables and a [0 h,1 h] window for the macroeconomic announcements was appropriate.

[24] Bauwens et al. (2005) measure the influence of news, including rumors of intervention, on euro–usd volatility over a six-month period in 2001. They find that the most significant pre-announcement increase in volatility is related to rumors of central bank interventions. They also find that once a rumor is refuted, volatility stabilizes or drops.

[25] Fratzscher (2004) finds evidence in daily data that official exchange rate communications, which he terms "oral interventions", by the G3 reduced daily exchange rate volatility over the period 1990–2003.

Table 2
Influence of interventions on intra-day dem–usd volatility

$$V_{t,n} = \alpha_0 + \sum_k \sum_i \alpha^k_{1,i} D^k_{t,n+i} + \alpha_2 \hat{s}_{t,n} + \varepsilon_{t,n}$$

Independent variable	Do all G3 interventions matter?	Does trade volume matter?[a]	Does proximity to macro-news matter?[b]	Does coordination matter?[c]
	Coeff sum[d]	Coeff sum	Coeff sum	Coeff sum
Fed intervention	0.121**			
Buba intervention	0.213**	0.212**	0.214**	na
BOJ intervention	0.103**	0.103**	0.104**	na
Official announcements	Yes	Yes	Yes	Yes
Macro-controls	Yes	Yes	Yes	Yes
Fed interventions during high trade volume		0.122**		
Fed interventions during low trade volume		0.121**		
Fed interventions close to macro-news			0.138**	
Isolated Fed interventions			0.116**	
Coordinated G3 interventions				0.139**
Unilateral Fed interventions				0.122*
FFF seasonal	0.169**	0.169**	0.169**	0.173**
R2	0.237	0.237	0.237	0.236
D.W.	1.99	1.99	1.99	1.99

In the above equation, V is 5-min dem–usd volatility (measured as the absolute value of the 5-min returns); the D^ks include intervention, official central bank announcements and macro-announcements; $i = -1$ to $+2$ h for the G3 intervention variables and official announcements and $i = 0$ to $+1$ h for the macro-announcements; t, n is the sequence of the regular-spaced (every 5 min) intra-daily data for all the days on which the Fed intervened against the mark from 1989 to 1995 (19,833 observations; 69 days and a total of 151 reports of Fed operations). The reported coefficients are multiplied by 100. This table reports the intra-day event-study regression results of the effects of G3 interventions on dem–usd volatility. Three lags of the dependent variable are included in the specification. **, * denote statistical significance (of the 36 leads and lags) at the 1%, and 5% levels, respectively, using robust standard errors.

[a] High trade volume is defined as the overlap in U.S. and European trading hours.

[b] Interventions that occur within 2 h of a macro-news announcement are defined as “close”.

[c] Coordinated interventions are defined as Fed interventions that occur on the same day as at least one other of the G3 central banks.

[d] The coefficient is the sum of the 36 (unconstrained) lead and lag coefficients on each of the intervention variables.

Tables 2 and 3 include results from three alternative regression specifications. The first of these alternative hypotheses asks whether the relationship between interventions and volatility is related to the volume of trade. In particular, the regressions test whether Fed interventions that occurred during the overlap in New York and European trading, when volume is generally highest, had different effects than those that occurred during other time periods.[26] The results for both the dem–usd and yen–usd suggest that, regardless of volume, Fed interventions have statistically significant lead, impact and lag effects. In both the high and low trade volume times, Fed interventions continued to have 1-h lead effects and roughly 1-h lag effects in the dem–usd market, and 1-h and 20 min lag effects in the yen–usd market. Results for the

[26] The hypothesis is that traders with private information (for example, traders that observe interventions before they are reported by Reuters) will prefer to trade during periods of high volume in order to maximize their potential information-based profits. DeGennaro and Shrieves (1997), Evans and Lyons (2002b) and Bauwens et al. (2005) provide empirical support for this hypothesis.

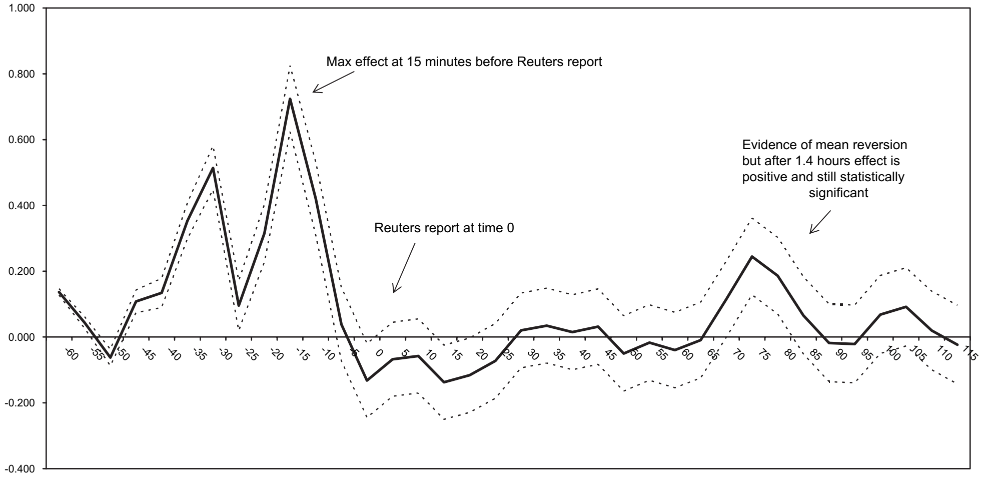

Fig. 3. Intra-day effects of U.S. intervention on dem–usd volatility. This figure shows the cumulative effects of U.S. interventions, starting 1 h before and going 2 h after the corresponding Reuters' report (time 0), on dem–usd volatility. The dashed lines show the 95% confidence interval for the total volatility impact.

remaining variables in the regression were little changed by the inclusion of the interactive trade volume dummy. The relative size of the estimated coefficients suggest that Fed interventions during high volume periods in the yen–usd market had a slightly larger overall effect, and it is worth noting that 61% of Fed interventions occurred during high trade volume times.

The second alternative specification serves as a test of whether interventions that are timed close to a (scheduled) macro-announcement have different effects than those that are not. The dummy variable distinguishing those interventions that occurred within a 2-h window of a macro-announcement are significant in both the dem–usd and yen–usd volatility regressions. The relative size of the coefficients on the interactive dummy suggests that these interventions have larger effects on volatility than interventions that are not closely timed to other announcements (although these continue to be significant in the regressions). One possible explanation for this result is that traders are more sensitive to news (including intervention news) at times when other major announcements are released.[27]

The final set of alternative specifications examines the extent to which coordination matters. Interventions are defined as being "coordinated" if at least one other of the G3 central banks intervened on the same day (and in the same direction). In the case of the dem–usd market, 31% of all Fed interventions over this period were coordinated with the Bundesbank. The results suggest that those interventions that were coordinated have a slightly larger influence on volatility than unilateral interventions. Interestingly, the lag effects for coordinated interventions last a good hour beyond those for unilateral interventions. In the yen–usd market, 54% of all Fed interventions over this period were coordinated with the BOJ. Results again suggest that both coordinated and unilateral Fed interventions influence volatility, though the size of the effect is actually larger for unilateral interventions. As was the case in the dem–usd market,

[27] Evans and Lyons (2002b) also find that currency trades have greater price impact if they are closely timed with macro-announcements.

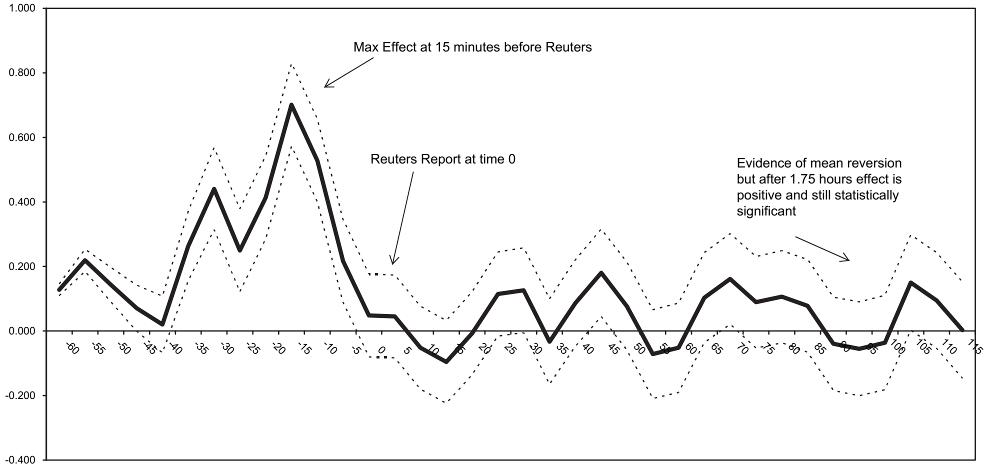

Fig. 4. Intra-day effects of U.S. intervention on yen–usd volatility. This figure shows the cumulative effects of U.S. interventions, starting 1 h before and going 2 h after the corresponding Reuters' report (time 0), on yen–usd volatility. The dashed lines show the 95% confidence interval for the total volatility impact.

coordinated interventions had significant lag effects on yen–usd volatility for an hour and a half after the Reuters' report, while the influence of unilateral interventions lasted for about 45 min.

The event study results indicate that G3 interventions systematically influenced intra-day exchange rate volatility over the sample period examined, August 1989 through August 1995. The coefficient estimates suggest that Reuters' reports generally lag interventions by 1 h, and intervention continues to influence volatility up to one and three quarters of an hour after the Reuters' report release. It is also worth noting that all the coefficients on intervention in Tables 2 and 3 are positive, indicating that in the very short-run interventions are always associated with increases in volatility.

4.2. *Longer term effects of intervention on volatility*

The next set of tests, reported in Tables 4–6, examine the influence of G3 interventions on daily volatility.[28] Recall from the discussion in Section 2 that trader heterogeneity can make even informative intervention increase very short-run exchange rate volatility, though over time interventions should become common knowledge, and traders should sort out any misinterpretation of intervention's information content. So that over the longer run we should expect volatility to return to its pre-intervention level, or even decline, if interventions serve to resolve market uncertainty.

[28] A number of papers have examined the influence of intervention operations on daily exchange rate volatility and generally find evidence that interventions increase volatility. Bonser-Neal and Tanner (1996), Dominguez (1998), Galati et al. (2005), and Frenkel et al. (2005) find that interventions lead to increases in implied volatilities measured using options data. Chaboud and LeBaron (2001) find a positive correlation between daily (futures) trading volume and Fed interventions. Dominguez (1998) using a GARCH model, Beine et al. (2002) using a FIGARCH model, and Beine and Laurent (2003) using a model that allows for a time-varying jump probability associated with interventions, all find evidence that interventions tend to increase exchange rate volatility. A few papers find evidence that situation-specific interventions lead to decreases in volatility. For example, Beine et al. (2003a) allow for a regime-dependent specification using a Markov switching model and find that when the market is highly volatile concerted interventions decrease volatility. Dominguez (1998) finds that reported interventions in the mid-1980s reduced exchange rate volatility.

Table 3
Influence of interventions on intra-day yen–usd volatility

$$V_{t,n} = \alpha_0 + \sum_k \sum_i \alpha_{1,i}^k D_{t,n+i}^k + \alpha_2 \widehat{s}_{t,n} + \varepsilon_{t,n}$$

Independent variable	Do all G3 interventions matter?	Does trade volume matter?[a]	Does proximity to macro-news matter?[b]	Does coordination matter?[c]
	Coeff sum[d]	Coeff sum	Coeff sum	Coeff sum
Fed intervention	0.175**			
Buba intervention	0.063	0.058	0.066	na
BOJ intervention	0.121**	0.121**	0.123**	na
Official announcements	Yes	Yes	Yes	Yes
Macro-controls	Yes	Yes	Yes	Yes
Fed interventions during high trade volume		0.183**		
Fed interventions during low trade volume		0.164**		
Fed interventions close to macro-news			0.192**	
Isolated Fed interventions			0.148**	
Coordinated G3 interventions				0.149**
Unilateral Fed interventions				0.271*
FFF seasonal	0.168**	0.166**	0.168**	0.164**
R2	0.188	0.188	0.188	0.189
D.W.	2.00	2.00	2.00	2.00

In the above equation, V is 5-min yen–usd volatility; D^ks include intervention, official central bank announcements and macro-announcements; $i = -1$ to $+2$ h for the G3 intervention variables and official announcements and $i = 0$ to $+1$ h for the macro-announcements; t, n is the sequence of the regular-spaced (every 5 min) intra-daily data for all the days on which the Fed intervened against the yen from 1989 to 1995 (18,969 observations; 66 days and a total of 192 reports of Fed operations). The reported coefficients are multiplied by 100. This table reports the intra-day event-study regression results of the effects of G3 interventions on yen–usd volatility. Three lags of the dependent variable are included in the specification. **, * denote statistical significance (of the 36 leads and lags) at the 1%, and 5% levels, respectively, using robust standard errors.

[a] High trade volume is defined as the overlap in U.S. and European trading hours.

[b] Interventions that occur within 2 h of a macro-news announcement are defined as "close".

[c] Coordinated interventions are defined as Fed interventions that occur on the same day as at least one other of the G3 central banks.

[d] The coefficient is the sum of the 36 (unconstrained) lead and lag coefficients on each of the intervention variables.

Daily realized dem–usd and yen–usd volatility is measured using the intra-daily returns data. Following Andersen and Bollerslev (1998) we sum the squared 5-min FXFX indicative quote returns over each day (through 22 GMT),[29] such that:

$$\sigma_t^{\mathrm{FXFX}} = \sqrt{\sum_{n=1}^{264} R_{t,n}^2}, \tag{10}$$

to create a daily integrated volatility series. This measure better captures current volatility relative to standard models such as GARCH because it is able to exploit contemporaneous intra-day information. As Andersen et al. (2003a) explain,

[29] The daily integrated volatilities were created by Steve Weinberg. The daily cutoff is 22 GMT when volatility is generally very low. Weekends are excluded and the volatilities are expressed as annualized standard deviations.

Table 4
Summary statistics for daily dem–usd and yen–usd log realized volatility on intervention and non-intervention days (1989–1995)

	Mean	Std dev	Max	Min	Skewness	Kurtosis	$Q(20)$	d	AR	Obs
Full sample[a]										
Dem–usd	−2.224	0.425	−0.967	−5.776	−2.565	20.336	1811.0	0.273	0.203	1564
Yen–usd	−2.250	0.396	−0.703	−5.133	−1.204	9.137	3318.8	0.424	0.046	1564
Non-intervention days[a]										
Dem–usd	−2.234	0.425	−0.967	−5.776	−2.727	21.254	1644.2	0.267	0.204	1477
Yen–usd	−2.288	0.392	−1.075	−5.133	−1.475	10.624	2378.9	0.413	0.059	1313
All intervention days[b]										
Dem–usd	−2.067	0.391	−1.067	−2.750	0.494	−0.540	123.2	0.395	na	87
Yen–usd	−2.050	0.352	−0.703	−2.945	0.259	0.334	454.8	0.400	na	251
Coordinated intervention days[c]										
Dem–usd	−1.935	0.386	−1.169	−2.750	0.025	−0.614	26.6	0.280	na	33
Yen–usd	−2.052	0.423	−1.127	−2.945	0.115	−0.666	72.9	0.477	na	59
Day before (all) intervention days[d]										
Dem–usd	−2.100	0.365	−1.261	−2.703	0.470	−0.726	17.1	na	na	44
Yen–usd	−2.204	0.346	−1.075	−2.891	0.819	1.193	58.7	0.331	na	84
Day after (all) intervention days[d]										
Dem–usd	−2.176	0.337	−1.284	−3.056	−0.014	0.617	29.2	na	na	44
Yen–usd	−2.271	0.441	−1.075	−4.920	−2.085	15.220	35.7	0.323	na	84

This table characterizes daily realized volatility on intervention and non-intervention days. The sample covers the period August 15, 1989 through August 15, 1995. The daily realized volatilities are constructed from sums of 5-min squared returns, and are expressed as annualized standard deviations. The statistics refer to the distribution of logarithmic realized standard deviations. The column labeled $Q(20)$ contains Ljung–Box test statistics for up to the twentieth order serial correlation. The column labeled "d" gives the regression estimate of the fractional integration parameter, d, from an ARFIMA(1,d,0) model. The column labeled "AR" is the regression estimate of the autoregressive parameter from the ARFIMA(1,d,0) model.

[a] Five observations in the dem–usd realized volatility series were significant outliers (deemed to be typos) and are excluded from the full and non-intervention samples.

[b] "All" intervention days include days of unilateral and coordinated Fed, Bundesbank and BOJ intervention operations.

[c] Coordinated intervention days are defined as days when the Fed intervened with either the Bundesbank or the BOJ (or both).

[d] The sample days before and after an intervention exclude intervention days that follow or precede other intervention days.

> "Suppose, for example, that the true volatility has been low for many days, $t = 1, \ldots, T-1$, so that both realized and GARCH volatilities are presently low as well. Now suppose that the true volatility increases sharply on day T and that the effect is highly persistent as is typical. Realized volatility for day, T, which makes effective use of the day T information, will increase sharply as well, as is appropriate. GARCH or RiskMetrics volatility, in contrast, will not change at all on day T, as they depend only on squared returns from days $T-1$, $T-2, \ldots$, and they will increase only gradually on subsequent days, as they approximate volatility via a long and slowly decaying exponentially weighted moving average." [613]

In the context of measuring the impact of interventions on volatility – it is particularly important that our measure of volatility reflects current (and not necessarily past) market conditions.

Table 4 presents statistics on the distribution of the logarithm of realized volatility for dem–usd and yen–usd, over the full sample period as well as on intervention days. For the full sample (and the non-intervention day sample) the measures of skewness and kurtosis

Table 5
Influence of interventions on realized daily dem–usd and yen–usd volatility

$$(1-L)^d(1-\phi L)(v_t-\mu_t)=\varepsilon_t,$$
$$\mu_t=\alpha_0+\alpha_1^{k\prime}D_t^k+\alpha_2 H_t$$
$$\varepsilon_t \sim N(0,\omega)$$

Independent variables	Dem–usd		Yen–usd	
ARFIMA parameters	Coeff	*t*-Stat	Coeff	*t*-Stat
α_0	−2.257**	−37.452	−2.374**	−18.122
d	0.270**	5.951	0.455**	7.019
ϕ	0.223*	2.325		
ω	0.119**	7.052	0.083**	8.470
Holiday dummy	0.083	1.507	0.006	0.134
Fed unilateral intervention	0.148*	2.245	0.354	1.379
Lag $t-1$	−0.030	−0.543	0.216	1.601
Lag $t-2$	−0.025	−0.448	0.139	0.978
Lag $t-3$	−0.033	−0.575	0.197†	1.811
Lag $t-4$	0.083	1.442	0.223	1.250
Lag $t-5$	0.100	1.522	−0.034	−0.329
Fed coordinated intervention	0.296**	4.487	0.317**	5.951
Lag $t-1$	−0.030	−0.543	0.042	0.902
Lag $t-2$	−0.025	−0.448	0.004	0.098
Lag $t-3$	−0.033	−0.575	0.045	0.882
Lag $t-4$	0.083	1.442	0.046	0.967
Lag $t-5$	0.100	1.522	−0.033	−0.687
Buba/BOJ unilateral intervention	0.152†	1.885	0.083**	8.470
Log likelihood	−552.749		−276.532	
No of daily observations	1564		1564	

In the above equation, v_t is the log of the sum of intra-day squared 5-min returns (through 22 GMT) excluding weekends, H_t is a dummy variable indicating the day after a holiday or market closure and the D^ks are dummy variables that denote daily G3 unilateral and coordinated intervention operations and other macro-controls. This table reports results of regressions that test whether intervention operations influence daily volatility. An ARFIMA(1,d,0) was used to model dem–usd integrated volatility and an ARFIMA(0,d,0) was used to model yen–usd integrated volatility. Coefficient estimates for the variables of interest were robust to alternative ARFIMA specifications. **, * and † denote statistical significance at the 1%, 5% and 10% levels, respectively, using robust standard errors.

suggest the series are approximately Gaussian and the Ljung–Box statistics indicate strong serial correlation.[30] Further, the estimates of the degree of fractional integration, d, are significantly greater than zero and less than 0.5, which indicates evidence of long-run dependence in the logarithmic volatilities. It is interesting to note that on "all" interventions days, and

[30] Five observations in the dem–usd realized volatility series were significant outliers and are excluded from the sample. Realized volatility on September 14, 1992 is two times higher than the second highest day and realized volatilities on September 3–4, 1991 and May 12–13, 1994 are three times smaller than the next lowest day. An examination of economic and financial reports on these days did not reveal any news that would explain these unusually sized observations, indicating that they are likely to be typos. We replaced these outliers with values from the next highest (or lowest) realized volatilities in the sample distribution. Replacing these outliers does not significantly change the regression results in Tables 5 and 6, but does influence the skewness and kurtosis statistics for the full and non-intervention samples in Table 4. There were no apparent outliers in the yen–usd realized volatility series.

Table 6
Influence of shocks on realized volatility on non-intervention and intervention days

$$\begin{aligned}
&v_t = \alpha_0^n + v_t^n + v_t^I + \alpha_2 D_t^k + \alpha_3 H_t + \varepsilon_t\\
&v_t^n = \alpha_1^n\left(1 + D_{t-1}^k\right)\varepsilon_{t-1} + \beta^n v_{t-1}^n\\
&v_t^I = D_{t-1}^k\left(\alpha_0^I + \alpha_1^I \varepsilon_{t-1}\right) + \beta^I v_{t-1}^I\\
&\varepsilon_t \sim N(0,\omega)
\end{aligned}$$

Independent variables	Dem–usd		Yen–usd	
Parameters	Coeff	t-Stat	Coeff	t-Stat
α_0^n	−2.240	−89.848**	−2.311	−60.965**
α_0^I	0.012	0.239	0.030	1.615
α_1^n	0.513	4.244**	0.451	5.346**
α_1^I	0.647	2.364*	0.479	6.706**
α_2	0.203	3.857**	0.204	7.536**
α_3	0.081	1.258	0.005	0.131
β^n	0.633	4.236**	0.849	11.306**
β^I	0.736	10.775**	0.838	5.703**
ω	0.123	7.418**	0.085	9.599**
Log likelihood	−576.48		−293.319	
Likelihood ratio statistic	2.371		4.304	

In the above equation, v_t^n and v_t^I are the log of the sum of intra-day squared 5-min returns (through 22 GMT) excluding weekends on non-intervention and intervention days, respectively. H_t is a dummy variable indicating the day after a holiday or market closure and the D^k is a dummy variable that denotes G3 intervention operations and other macro-controls. This table reports results of regressions that test whether the persistence of shocks to volatility differ on intervention days. ** and * denote statistical significance at the 1% and 5% levels, respectively, using robust standard errors. The likelihood ratio statistics suggest that we cannot reject the hypothesis that $\alpha_0^I = 0$, $\alpha_1^n = \alpha_1^I$ and $\beta^n = \beta^I$, or in other words, that the persistence of shocks on intervention and non-intervention days is not statistically different. The β^I estimates suggest that the effects of shocks on intervention days fall by half in 1.5 days for dem–usd and 3 days for yen–usd.

particularly on coordinated intervention days, the mean realized volatility is significantly larger than on non-intervention days. Realized volatility on the day after an intervention remains higher for the dem–usd but not for yen–usd, and volatility on the day before an intervention is no higher, on average, than on other non-intervention days.

The statistics in Table 4 suggest that the long-memory dynamics of the realized logarithmic volatilities are best modeled using a fractional integration or ARFIMA (autoregressive, fractionally integrated, moving average) model. Experimentation with the two realized volatility series suggests that for the dem–usd an ARFIMA(1,d,0) best describes the data, while for the yen–usd we use an ARFIMA(0,d,0) model. In order to test whether daily interventions are correlated with realized volatility we include a holiday dummy variable (H) to control for holiday and market closure effects as well as daily contemporaneous and lagged macro-controls and G3 intervention indicators (the D^ks) as explanatory variables:

$$\begin{aligned}
&(1-L)^d(1-\phi L)(v_t-\mu_t) = \varepsilon_t,\\
&\mu_t = \alpha_0 + \alpha_1^{k\prime} D_t^k + \alpha_2 H_t,\\
&\varepsilon_t \sim N(0,\omega),
\end{aligned} \tag{11}$$

where d is the fractional parameter, L denotes the lag operator, ϕ denotes the AR parameter (set to 0 in the case of yen–usd), v_t denotes the log of the integrated volatility (σ^{FXFX}) at time t, σ_0 is an intercept, α_1^k is the intervention parameter vector, and σ_2 is the holiday parameter.[31]

The results in Table 5 indicate that coordinated interventions continue to systematically influence daily contemporaneous dem–usd and yen–usd volatility, though there is no evidence that the influence of coordinated interventions extends beyond the day of the operations.[32] Similarly, contemporaneous unilateral Fed, Bundesbank and BOJ operations all influence daily realized volatility in both markets. (Note that for these daily tests unilateral interventions by the Bundesbank and the BOJ, on days when the Fed did not intervene, are also included.) In the yen–usd market unilateral Fed interventions are marginally significant after 3 days. The relative magnitudes of the coefficients in the daily regressions suggest that coordinated interventions have a substantially larger impact on daily volatility than do unilateral interventions. Coordinated operations were also significant in the intra-day tests, though the relative size of the coefficients on coordinated and unilateral operations were similar. This suggests that over the course of the day the influence of coordinated operations (which may have a higher probability of containing fundamental information) increases. Overall, the results in the tables indicate that interventions by all three central banks positively influenced intra-day and daily (contemporaneous) exchange rate volatility. There is little evidence that interventions systematically influence volatility beyond the day of the operations.[33]

The ARFIMA model specification in Eq. (11) implicitly assumes that shocks on intervention days are as persistent as shocks on non-intervention days. A final set of regressions tests whether this assumption is valid by allowing the persistence of volatility to differ across intervention and non-intervention days,[34] specifically:

$$\begin{aligned} v_t &= \alpha_0^n + v_t^n + v_t^I + \alpha_2 D_t^k + \alpha_3 H_t + \varepsilon_t \\ v_t^n &= \alpha_1^n\left(1 + D_{t-1}^k\right)\varepsilon_{t-1} + \beta^n v_{t-1}^n \\ v_t^I &= D_{t-1}^k\left(\alpha_0^I + \alpha_1^I \varepsilon_{t-1}\right) + \beta^I v_{t-1}^I \\ \varepsilon_t &\sim N(0,\omega), \end{aligned} \tag{12}$$

where v_t^n and v_t^I are daily realized volatility on non-intervention and intervention days, respectively. Note that if $\alpha_0^I = 0$, $\alpha_1^n = \alpha_1^I$ and $\beta^n = \beta^I$ Eq. (12) approximately reduces to an ARMA(1,1) model. Regression estimates of this model are given in Table 6 and indicate that the persistence of shocks on intervention and non-intervention days is not statistically different. The likelihood ratio statistics suggest that we cannot reject the joint hypothesis that $\alpha_0^I = 0$, $\alpha_1^n = \alpha_1^I$ and $\beta^n = \beta^I$. Further, the estimates of β^I (the coefficient on lagged volatility on intervention days) suggest that the effects of shocks to volatility on intervention days fall by half in 1.5 days for dem–usd and 3 days for yen–usd.

[31] Estimation is based on the numerical quasi-maximum likelihood (QML) algorithm, where the likelihood function is based on the Wold representation of the ARFIMA(1,d,0) processes with a Gaussian assumption. The t-statistics reported in the tables are calculated using the corresponding heteroskedastic-consistent standard errors based on finite difference approximation.

[32] Beine et al. (2003b) also examine the effects of G3 interventions on daily realized volatility using an ARFIMA model. Their results are similar to those reported here; they find coordinated interventions have a positive, but short-term, influence on volatility.

[33] One day leads of coordinated and unilateral Fed interventions were also included in the regression specification but lead coefficients were never statistically significant and are not reported in Table 5.

[34] Jones et al. (1998) estimate a similar model to measure the influence of macroeconomic information on the persistence of bond market volatility.

5. Conclusions

This paper identifies circumstances in which central bank interventions influence exchange rates. Microstructure theory suggests that trader heterogeneity can lead to short-run price and volatility effects in reaction to both fundamental and non-fundamental information revelation. Interventions have the potential to provide price-relevant information to market participants, or information that allows them to distinguish more accurately between fundamental and non-fundamental information. In the short run, however, the information content of interventions may not be common knowledge, and so operations may initially add to the rational confusion in the market. This suggests that the influence of interventions on exchange rates may well differ over the very short and longer runs.

The empirical tests in this paper examine the influence of G3 interventions on dem–usd and yen–usd intra-daily (5 min) indicative quote volatility as well as a measure of realized daily volatility. Results suggest that intervention operations, especially those that were coordinated, were consistently associated with increases in intra-day and daily volatility, while there is little evidence that interventions influenced longer-term volatility. The short-run results are supportive of both the portfolio balance and signaling channels, and suggest that interventions, like other macroeconomic news variables, influence exchange rates at least within the day. The results also indicate that interventions do not lead to declines in volatility, suggesting that the information conveyed by intervention did not serve to resolve market uncertainty.[35] At the same time, the fact that interventions did not lead to long-term increases in volatility may help explain why some governments, who presumably prefer not to increase market volatility, continue to rely on interventions to influence currency values.

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[35] It may be that intervention conveys information, but that this information only influences the level and not the volatility of exchange rates. For example, the May 31, 1995 intervention operations described at the beginning of the paper resulted in a 2% increase in the value of the dollar, but no long-term change in dollar market volatility.

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