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The effects of intraday FY market operations in Latin America: Results for Chile, Colombia, Mexico and Peru[1]

Introduction

Latin American central banks have intervened in foreign exchange market operations for extended periods. Two motives for such operations may be highlighted.[2] The first is to accumulate foreign reserves for precautionary reasons during periods of foreign currency inflows or exchange rate appreciation, in order to then deploy these reserves during episodes of financial stress when the supply of foreign currency suddenly declines.

The second motive is to influence the exchange rate. Authorities in the region from time to time will state explicitly that their main goal is not to target an exchange rate level (which can lead to speculative attacks), but to dampen exchange rate volatility or to reduce deviations from some perceived or estimated equilibrium exchange rate.

In either case, foreign exchange operations raise a number of questions, including: (i) what are the effects of intervention on the exchange rate (ii) are the effects persistent or transitory? (iii) are any effects more apparent on the level of the exchange rate or its volatility? (iv) do the effects of intervention differ when goals (quantities or prices) or intervention approaches; (eg discretionary vs nondiscretionary) are not the same? (iv) what are the implications of intervention for market turnover? (v) what is the relationship between the volatility of returns and market turnover?

In order to shed light on these questions, this paper uses intraday data on exchange rate returns or turnover in foreign exchange markets, macroeconomic announcements and foreign exchange operations[3] by central banks in four Latin American countries, Chile, Colombia, Mexico and Peru. As some of the data are confidential, the results are estimated for each foreign exchange markets by the authors of the corresponding central banks using a common methodology based on the work of Kathryn Dominguez (1999, 2003 and 2006).

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[1] The opinions expressed in this paper are those of the authors and do not necessarily reflect the views of the central banks that contributed to this project or of the BIS. This joint paper was prepared under the auspices of the BIS Consultative Council for the Americas, a group of central bank governors from the Americas region. The contributors were Miguel Fuentes and Pablo Pincheira (Central Bank of Chile), Hernan Rincon and Juan Manuel Julio (Bank of the Republic, Colombia), Santiago Garcia-Verdu (Bank of Mexico), Marco Vega and Erick Lahura (Central Reserve Bank of Peru) and Ramon Moreno (BIS). This project was coordinated by Ramon Moreno, with the assistance of Carlos Montoro. Kathryn Dominguez advised on project design and implementation. Additional results for this project are available from the respective central bank authors, in their contributions to the detailed outline. Comments on this version by Carlos Montoro, are gratefully acknowledged. Alan Villegas created the dataset on US announcements and with Diego Urbina provided research assistance in preparing the first draft of this paper.

[2] In this paper we will use the terms foreign exchange market intervention and operations interchangeably.

[3] At this time, results describing the characteristics of intervention and non-intervention days are available. However, detailed regression results are only available for Colombia and Mexico.

For the periods covered in this study, these central banks maintained inflation targeting regimes with floating exchange rates (for Peru, managed floating). However, the motives for intervention in the foreign exchange market varied. The Central Bank of Chile and the Bank of the Republic (Colombia) entered the foreign exchange market with the stated intention of purchasing foreign currency in order to accumulate foreign reserves, while the Bank of Mexico sold foreign currency in order to provide liquidity to markets and deal with market uncertainty. Foreign exchange operations for these central banks were not purely discretionary: the amounts were based on preannounced targets of foreign currency to be purchased or sold over a certain period. In contrast foreign exchange market intervention by the Central Reserve Bank of Peru was discretionary, not being based on pre-announced amounts (the total daily amount of intervention was published at the end of the day). Nevertheless, the central bank sought to avoid signalling an exchange rate path (Rossini and others, 2011) while seeking to dampen exchange rate volatility.

II. Data coverage and properties

A. Data description and sources

The analysis in this paper involves three types of high-frequency data: (i) Intraday price or quantity (for Colombia) data for the foreign exchange market; (ii) time stamped US or country (for Colombia) macro announcements compiled from Bloomberg and (iii) time or volume of intervention in the foreign exchange market (see Annex Tables A1 to A3).

Intraday price or transactions volume data.

The data are time-stamped (transactions) prices in the spot foreign exchange interbank markets of Chile, Colombia, Mexico and Peru. For Colombia time-stamped data on quantities traded are also available. In Chile, all the operations of the Central Bank are conducted through centralized trading platforms. The interbank exchange from which the intra-day data are taken represents around 70% of the spot market. In *Colombia* the dataset reflects wholesale spot interbank trades of US currency performed through SET-FX, the centralized interbank foreign exchange electronic market service, which belongs to the Colombian Stock Exchange (BVC). These data from the electronic spot market cover about 70% of the wholesale spot market in Colombia. In *Mexico,* transactions are those reported by Reuters for the Mexican market, but does not include trading of the peso outside Mexico. The Mexican market data are taken as representative because of the size and depth of the peso[4] exchange market and on the assumption that the peso market is globally integrated so no arbitrage opportunities remain.

B. Data transformations and sample size

Construction of the samples involves data transformation and the selection of windows that vary from country to country (see also Annex Table A1).

In Chile, the sample covers the episodes of intervention in 2008 and 2011, where the goal was to increase foreign assets. In *Colombia*, the full sample is from 2 May 2007 to 23 November 2011. Trade prices are marked with the real transaction time to the last second. From these prices, the price on each time mark is calculated as follows. If transactions occur

[4] For more details, see discussion in García, Páramo and Cerecoro (2012), a paper presented at this conference.

on the time mark, the price at the mark is the average price of these trades. If there are no transactions on the time mark, the price at the mark is the average of the two nearest prices, before and after the time mark, weighted by their corresponding distances to the mark. Data transformations were implemented so as to ensure the most "data gain" (in terms of maximizing the number of data points that reflect actual market activity) while ensuring good quality in the reported data. In particular the optimal interval width and data loss at the beginning of the trading day were studied carefully.[5] The preceding analysis for the Colombian FX market resulted in a sample of 1,025 trading days, with 43 prices per trading day (reflecting precise price measurements for each 7 minute time mark from 8:06 to 1:00 pm for each trading day), for a total of 44,705 prices.

In Mexico, The FX returns are estimated using the returns from 8:30 am to 3:00 pm (which coincides with 9:30 am to 4:00 pm EST, i.e. NYSE is open). Based on the prices, the returns are first estimated and then the time window is defined (the return on 8:30 am for a 1 hr. interval is the return from 7:30 am to 8:30 am). Intervention days are only those referred to above, or in the paper by García-Verdu et al (2012). The treatment sample (intervention) is 9 October 2008 to April 2010. The control sample (non-intervention) comprises days between April 12, 2010 and November 29, 2011 that had no intervention whatsoever.[6]

In Peru, 5 minute price data were used for the sample period January 5, 2009 to 27 April 2011 which is the sample for FX intervention data available for this project. The FX market in Peru is local, it lasts about 4½ hours from 9:00 AM to 1:30 PM. Transactions between 9 AM and 9:15 are scarce so the dataset starts at five minute intervals at 9:15-9:20. In the 5 minute time series the time index starts at 9:20 and ends at 13:30 for the business day. When calculating the 5-minute return series, the returns for 9:20 are left out. FX trading in the market is done through Datatec and Reuter platforms.

Time stamped US or country macroeconomic announcements

The empirical analysis reported in this paper includes data on macroeconomic announcements compiled from Bloomberg. In all cases except Chile[7] these are used to construct a set of control variables, and also to compare the relative impact of intervention to the effects of external macroeconomic announcements, which are represented by the following US macroeconomic announcements: US Consumer Confidence, CPI, Durable Good, Fed Funds Rate, Unemployment, Housing, Industrial Production, PPI, NAPM, Retail Sales, GDP, Trade Balance. In some cases, data on domestic macroeconomic announcements (eg Colombia) have also been included as control variables. For more details, see Annex Table A2.

Time or volume of intervention in the foreign exchange market. The explanatory variable for intervention is constructed in three different ways. First, an indicator (dummy) variable

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[5] For Colombia it was found that: (i) The first 6 minutes of the trading day should not be taken into account: this reduces to a minimum the need to carry back the first trading price and conveniently completes the 5 trading hours so that no data is lost at the end of the trading day; (ii) The optimal interval width is 7 minutes, after that the data gain from increasing the width of the time interval decreases; (iii) Days containing too few trades should be deleted. Few trades within a day arise because the market is particularly slow (30-Dec of any year, for instance) or because of poor record keeping (price information for whole days or important parts of particular trading days is missing). For consistency, however, the information included was cross checked with Bid/Offer quotes and the TRM (Tasa Representativa del Mercado), the official daily exchange rate of the forex market.

[6] In Mexico, the period from November 30 to December 31, 2011 is excluded as the type of intervention considered in this paper (type 3, see García et al (2012)) took place time at a different time of the day. Notice these are less than 30 days.

[7] In Chile, relevant domestic macro announcements (monetary policy decisions, inflation) are reported when the foreign exchange market is closed,

indicating the time of a foreign exchange market operation. [8] Second, in some cases (Colombia) time stamped data with the amount of foreign exchange operations are also used. For Colombia the impact of intervention on market turnover is also analysed. The sample periods for intervention are identified in the next section.

C. Intervention and factors that could influence its impact

An important question is how intervention was implemented, and what this could imply for its impact on the exchange rate. In particular, we would expect the effect on the exchange rate to be larger if foreign exchange operations (i) were unsterilized; (ii) targeted the exchange rate level or limited volatility to very narrow bands; (iii) were large; (iv) surprised markets. In this regard, the following point may be highlighted

Sterilisation. All FX operations *were sterilized*, as all four central banks contributing to this paper adjusted liquidity to meet an interest rate operating target within the framework of inflation targeting regimes.[9] FX intervention could be seen as signaling a possible change in monetary policy if the goal of were to influence the level of the exchange rate. This, however was not the stated objective of the central banks for the period under review (see below). In addition, exchange rates may not have served as a signal of future changes in monetary policy but rather an effort to dampen its effects. At least one official has suggested that its central bank resorted to intervention to smooth exchange rates because high inflation *limited* its ability to adjust monetary policy.[10]

Target. No central bank explicitly targeted the exchange rate level. Three of the four central banks explicitly targeted predetermined foreign currency *quantities.* Thus Central Bank of Chile over the periods 14 April 2008 – 29 September 2008 and 03 January 2011-16 December 2011 and Bank of the Republic (Colombia) over three uninterrupted rounds between 24 June 2008 and 30 Sep 2011 purchased foreign currency to *meet preannounced foreign reserve accumulation targets.* Except for the periods September-December 2011, these were for the most part periods of capital inflows in Latin American foreign exchange markets.[11] In contrast, over the period 9 October 2008-9 April 2010[12], Mexico *sold* foreign

[8] In Peru, foreign exchange market operations are mediated through the Datatec platform and the sample comprises intervention data at transaction level as described in the Table.

Peru: Intervention Data.
(Sample period January 5, 2009 to April 27, 2011)

	2009	2010	2011[a/]
Number of transactions	1933	5050	487
Number 5 min interval observations	181	505	38

[a/] Intervention data up to 27 April.

[10] For example, one explanation for intervention in Mexico over certain periods (outside the sample studied in this paper) in which the exchange rate faced appreciation pressures or carry trades and the central bank could not lower the policy rate to discourage such carry trades because of still high inflation. See Sidaoui (2012).

[11] However, intraday exchange rate returns show depreciation over certain time intervals.

[12] Mexico also sold foreign currency during the period after 30 November 2011 but this is not included because the time of the auctions changes.

currency (implementing auctions of dollars with a minimum price), in order to provide the necessary liquidity to meet the conditions of uncertainty and lack of liquidity in the foreign exchange market. In contrast, foreign exchange market intervention by the Central Bank of Peru - which was operated by a committee that implements open market operations on a daily basis - was aimed at reducing excess volatility as perceived by policymakers that implement the intervention. Intervention was fully discretionary in amounts and in timing, with markets always aware about the possibility of intervention. Markets only learned the total intervention level at the end of the day because this figure is made public.

Size of intervention. Intervention was *large by some metrics* (eg compared to intervention in advanced economies prior to the global financial crisis, or compared to foreign reserves) over the sample periods covered in this paper. In Chile, the goal was to increase foreign reserves in 2008 by $8 billion (in effect, however, the operation was suspended on 29 September 2008, shortly after the Lehman bankruptcy, having reached US$5.75 billion) and $ 12 billion in 2011, through daily purchases of $50 million. These totals may be compared to foreign reserves of **XX** $_billion at the end of 2010, and intervention of $2 billion in 2001. In Colombia[13], the preannounced interventions were $20 million a day and in its third round of intervention between September 2010 and September 2011 the Bank of the Republic accumulated nearly $5.2 billion (compared to foreign reserves of $32.4 billion at the end of September 2011). In Mexico, between 9 October 2008 and 9 April 2010 the central bank offered a total of $351.1 billion, compared to foreign reserves totaling **XX** billion at the end of April 2010.[14] In Peru (*sample 5 January 2009 to 27 April 2011).* However, the amount of daily intervention is not necessarily large compared to market turnover. In the case of Chile, intervention in 2011 of $50 million a day was small in relation to market (turnover) of $18 billion).

Market "surprises". The scope for "market surprises" was limited in three of the four countries studied in this paper – Chile, Colombia and Mexico - in the sense that the target daily amounts of foreign currency to be purchased or sold over well-defined intervention periods were preannounced. While there was therefore little or no uncertainty about the amounts of foreign currency available for purchase or sale, the actual transaction amounts would depend on the auction procedures. In Colombia the Bank of the Republic used a 3-minute Dutch auction procedure, under which prices could adjust until most if not all the foreign currency amount targeted was purchased.[15] In contrast in Mexico the use of a minimum price procedure suggests that the target amount of foreign currency might not be sold if the minimum price floor was reached.

A possibly important source of "surprises" which could strengthen the impact of intervention on exchange rate returns was *uncertainty about the timing of intervention during the day*. Apart from Mexico, the timing of auctions was not preannounced: for example, in Colombia, sales were announced 2 minutes in advance. In the case of Peru, intervention could occur on a daily basis at any time during trading hours and contingent on the state of the market (eg a

[13] The Bank of the Republic accumulated $1.4 billion in the first round of intervention ending in October 2008 and $1.6 billion in the March-June 2010 round of intervention.

[14] For a fuller description of this type of foreign exchange market operations in Mexico, see García, Páramo and Zerecero (2012). These sales of foreign currency may at least partly offset large accumulation in foreign reserves from direct foreign currency sales (to meet tax obligations) to the Bank Mexico by Mexican government institutions, notably the state oil company Pemex. However, as noted by García et al, while the goal of US dollar sales has sometimes been to offset such foreign reserve accumulation, this was not the stated objective during the period considered in this paper.

[15] In Colombia, whenever there was any (usually small) residual amount not allotted left over in the daily auction would be carried forward to the next day. Therefore, a slight variation around the USD 20 million target may be observed between the days of an intervention round.

substantial drop in the spot price early in the trading day relative to the closing price the day before). The time of intervention during the day (as well as the amount of intervention) was at the discretion of the authorities.

In line with the preceding, the target amounts of foreign currency purchased or offered for sale varied in the course of the day in Chile, Colombia and Peru, but not in Mexico. For example, in Chile, Graph 1, panel A (which depicts times of intervention in each 20 minute period) shows that most of the foreign exchange operations took place before 12 pm In Colombia, the highest concentration of interventions was between 9:23 and 10:40, accounting for 46.25% of the sample (179 days). Between 9:23 and 11:57 lies 75.7% of the sample (293 days).[16] However, two extreme intervals, 08:48-08:55 and 12:39-12:46 contain 5.68% of the sample (22 days). Moreover, interventions at the end of the trading day tend to be more frequent than at the beginning.

In the case of Peru, the graph depicts the frequency distribution of intraday timing of interventions for each 5 minute interval during trading hours. For each 5 minute interval, the number of days are counted with data within all intervention days[17]. About 15 percent of all interventions occur in the last 5 minutes and about 66 percent of interventions occur in the last hour of a typical trading day (between 12:25 and 13:30).

In contrast, in Mexico foreign currency was offered for sale three times a day, at predetermined times (9:30 am, 11:30 am and 1:00 pm, lasting 5 minutes each) and in equal amounts.[18]

[16] In Colombia the distributions of (intervention and control samples) are based on the returns for non-overlapping intervals. The distributions for returns on wider intervals are not shown because whole trading days are missing, which may affect the effective width and thus the returns on these intervals.

[17] For Peru, the resulting variable N is constructed over 5 minute intervals. For example, for the 9:15-9:20 interval, only 7 intervention data are recorded from all intervention days in the sample. Intervention frequencies are calculated using $freq_j = \frac{N_j}{\sum_1^{51} N_j}$ because there are 51 intervals in each trading day. There have been 126 intervention days for a total of NN trading days.

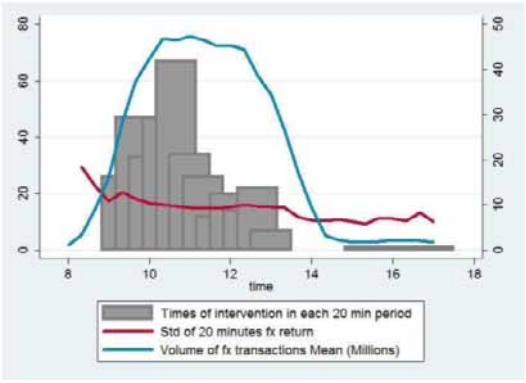
[18] For Mexico, the amounts shown are the foreign currency offered for sale, not the actual amounts. In a second episode of similar interventions in Mexico starting November 30, 2011, these schedules were changed to 9:00 am, 12:00 pm and 3:00 pm, respectively. This episode is not included in the analysis.

Graph 1

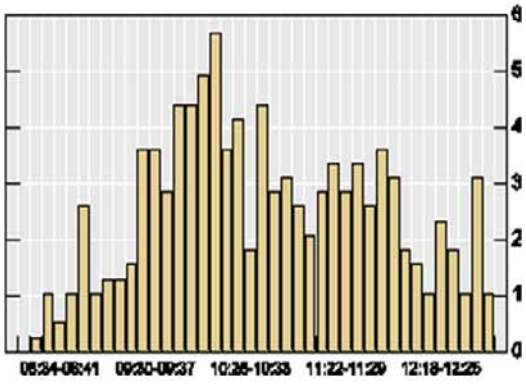
Distribution of intervention during the day

In per cent

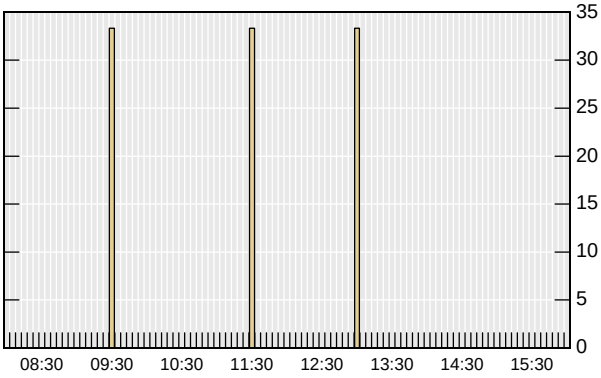
Chile



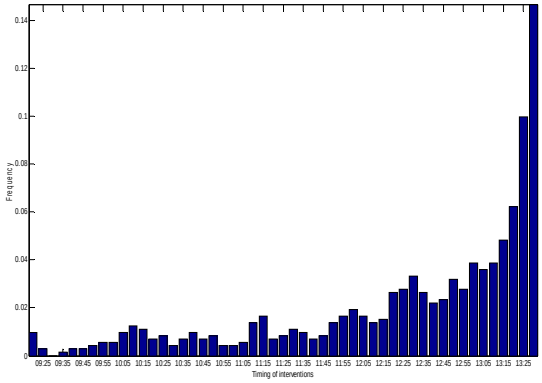
Colombia[1]



Mexico



Peru



[1] Based on actual transactions, except for Mexico (amounts offered for sale). [2]Relative frequency, number of days as a percentage of 387.

Source: Central banks.

A question of interest is whether the differences in approaches to intervention reported above (notably the reliance on discretionary surprise intervention in Peru versus the use of preannounced quantity targets over certain periods in Chile, Colombia and Mexico) are reflected in differences in the impact of intervention on foreign exchange returns and the volatility of such returns.

D. Descriptive statistics: intraday foreign exchange distribution whole sample, treatment and control groups

As shown in Annex Tables A4 to A6, the distribution of returns over the full sample in Chile, Colombia, Mexico and Peru, show the following characteristics

- Mean values of returns differ across countries and over time intervals. For example, at short horizons the exchange rate tends to depreciate (ie changes are positive) in Colombia, while appreciating in Mexico (however at a 24 hour interval, the exchange rate in Mexico also depreciates). In Chile the exchange rate change is zero at short horizons, but tends to appreciate at long horizons. In Peru the mean value is zero across all time intervals.

- Mean and variance of returns increase in absolute value as the time interval increases in Chile, Colombia and Mexico. [19] In contrast, in Peru the mean is constant and variance declines as the time interval rises.
- Skewness of returns is negative at short horizons but turns positive at longer horizons (ie at longer horizons the mass of the distribution is concentrated around smaller values).
- Kurtosis (ie evidence of heavy tails) declines as the time interval increases.

Comparison of intervention and non-intervention days

A comparison of intervention (treatment) and non-intervention (control) days reveals the following properties[20]:

- *Mean return.* This is positive and larger during intervention days in Chile and Colombia.[21] However, there is no clear pattern in Mexico, and the return is the same (zero) in both samples in Peru[22]
- *Volatility of returns*. This is higher during intervention days in Chile, Mexico and Peru. However, in Peru the difference in return volatility between intervention and non-intervention days is only important at the highest frequency of 5 minutes returns and disappears at lower frequencies. In Colombia there is also no difference in volatility of returns, but at all frequencies.
- *Skewness.* This generally becomes negative for intervention days in Colombia, Mexico and Peru (it is positive on non-intervention days).
- *Kurtosis.* This tends to be higher on intervention days in Colombia and Mexico, but lower in Chile and Peru. This is consistent with a situation in which Colombia and Mexico enter the market during periods of unusual pressure in the foreign exchange market but because the intervention is based on preannounced amounts, there is no impact on the tails of the distribution. In contrast, the data may be consistent with an outcome in which discretionary intervention in Peru limits the incidence of extreme values.[23] However, this interpretation would not apply to Chile.

The preceding data suggest deviations from normality in the behaviour of intraday exchange returns with skewness away from zero and generally large kurtosis. Having said that, as the interval increases to a span comprising a large proportion of the trading day (5 hours for

[19] One interpretation is that a higher return is on average associated with higher risk.

[20] As a reference, the results in the text using transactions may be compared with results using average bid ask statistics for Mexico. The general pattern in the transaction data are similar to the average bid ask data except perhaps for two features. First, in the case of the means, it seems that the average bid ask means are smaller than transaction data. Second, in the case of kurtosis, one, its magnitude between intervention and non-intervention days does not change as much in the transaction data. Moreover, for the 5 min interval kurtosis increases on the non-intervention days, the opposite results compared to the transaction case.

[21] A similar result is obtained for the median one hour and one day (but not 7 minute) returns.

[22] While the very high frequency data show no trend in Peru, when the central bank intervened, the exchange rate tended to appreciate and when the central bank did not intervene, the exchange rate tended to depreciate.

[23] To put it differently, this might mean that during non-intervention days relatively more extreme exchange rate movements have been allowed, for example sharp (extreme) depreciation on non-intervention day t following a series of high (but not extreme) appreciations on intervention day t-1.

Colombia and 6 hours for Mexico) the returns distribution tends to a normal distribution (however, deviations from normality appear to recur at a longer horizon in Mexico). In the case of Peru, the Bai and Ng (2005) test was implemented to test for normality but this gave mixed results. While the symmetry of FX returns could not be rejected (ie the sample skewness of -1.12 and 2.71 are not significantly different from zero, which appears to be compatible with the result that all median values across intervention and non-intervention samples at all frequencies are zero), the null hypothesis that kurtosis=3 (implying normality) is rejected.

Table 2
Peru: Bai and Ng test for
Skewness and Kurtosis (Bartlett Kernel) for 5 minute returns

No Prewhitening and no DoF correction			
	Whole sample	Intervention	Non-intervention
Skewness	-0.11	-0.82	0.67
Kurtosis	2.72*	2.22*	1.61
Prewhitening and DoF correction			
	Whole sample	Intervention	Non-intervention
Skewness	-0.76	-1.81	1.69
Kurtosis	11.15**	7.00**	8.11**

* Reject kurtosis=3 at 5 percent, ** Reject kurtosis=3 at 1 percent

Additional perspective on the properties of the distribution of returns in intervention and non intervention samples can be gained by examining Annex Graph A1, which illustrates the densities for Mexico and Peru.

Why are deviations from normality a concern? The main reason is that they could be associated with risks of very sharp movements in the value of portfolios, which in turn can pose financial stability risks. For example, in an empirical study of eight major currencies' exchange rates relative to the US dollar, Brunnermeier, Nagel and Pedersen (2009) find that countries with high interest rate differentials (ie destination or investment currencies) tend to have negative skewness, implying that carry trade returns have crash risks. The reverse would be true for funding currencies. As a possible explanation, Brunnermeier and Pedersen (2009) show – in a setting where agents are liquidity constrained - that securities that speculators invest in have a positive average return (a reward for providing liquidity) and a negative skewness. (because shocks that lead to speculator losses are amplified when speculators hit funding constraints and unwind their positions, while shocks that lead to speculator gains are not amplified. In this context, the comparison of intervention and non-intervention days suggest that central banks intervene during periods when the crash risk tends to be high.

As for heavy tails, a traditional explanation is that they are the result of "irrational behaviour", such as trend-following. However, recent research also highlights the potential importance of leverage in explaining heavy tails, which has financial stability implications. For example, Thurner, Farmer and Geanakopolos (2012) develop a model of leveraged asset purchases with margin calls, with "value investors" and noise traders. Using a line of reasoning that can apply to foreign exchange markets, they show that when funds are not allowed to borrow, asset price fluctuations are approximately normally distributed and uncorrelated across time. However, when leverage is permitted, so that funds can borrow to increase their investments, funds have higher profits during good times, but a downward shock to prices when funds are fully leveraged can lead to margin calls and to sales into already falling markets. This amplifies the downward movement in the asset price and can lead to large

losses. This can lead to clustered volatility, in which volatility is low before a crash because value investors are able to dampen volatility, but rises sharply after the crash when they suffer severe losses. Another implication is heavy tails, due to leverage-induced crashes, and due to clustered volatility.

E. Average return volatility for intervention and non-intervention days

Following Dominguez (2003), with the exception of Chile, samples of intervention and non-intervention time windows were matched according to the time of intervention and the day of the week. The idea is to control for volatility seasonality by day of the week as well as intraday.

For Chile, Graph 2 (Panel A) shows the standard deviations of returns for the 2011 and 2008 interventions, with the red line for the intervention sample and the blue line for the counterfactual. Since there was only one intervention each day and they took place on contiguous periods, the counterfactual sample corresponds to two hours after the intervention. To avoid considering periods of the day where there are not as many trades interventions that occurred after 11:00 am were dropped from the sample.

In Colombia, the volatility tends to increase slightly 7 to 14 minutes before the intervention, and the duration of this increase lasts until impact, to return very fast to the volatility of the control sample. However, a slight volatility spike may be observed 35 minutes after the intervention.[24]

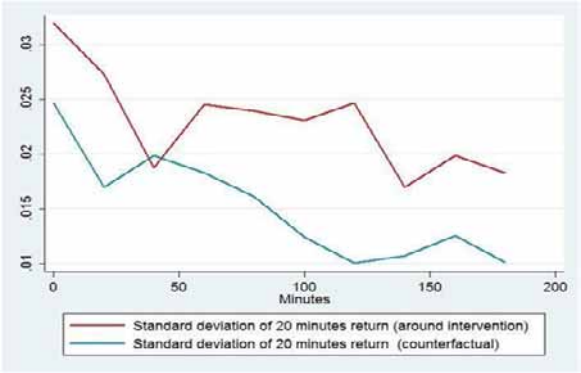
For Mexico, average return volatility for intervention and non-intervention days were examined at 9:30 am, 11:30 am and 1:00 pm using transactions data. It was found that (i) average return volatility on intervention days is on average greater than on non-intervention days; (ii) the average return volatility for intervention days is much higher at 9:30 am than at 11:30 am and 1:00 pm spiking approximately 15 minutes after intervention), as illustrated in Graph 2.

[24] For Colombia, a disaggregated comparison of mean square returns between the control and intervention matched samples is available from the Juan Manuel Julio and Hernan Rincon. It suggests that the response of mean square returns to intervention is not homogenous, varying with the time and day of the week of the intervention. However, on average, the mean square of seven minutes returns tends to increase slightly 7 to 14 minutes before the intervention and spikes on impact to return very fast to the level of volatility of the control sample. However, this type of analysis does not rule out longer term effects on volatility. Aggregate results for Colombia are shown in Graph 2. Assuming there is no intraday seasonality, all the control and interventions samples may be pooled to observe the average relationship between the volatility of returns and intervention over the sample.

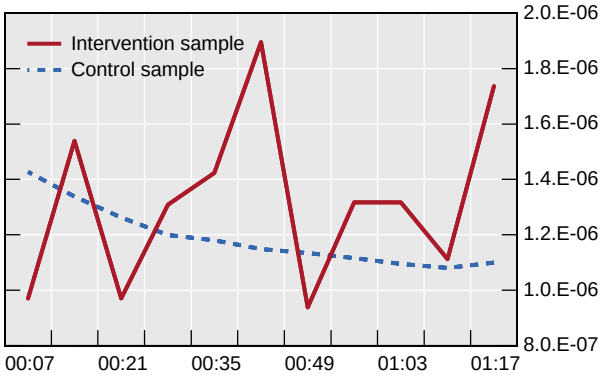
Graph 2

Comparison of the return volatility for intervention and control sample

Chile

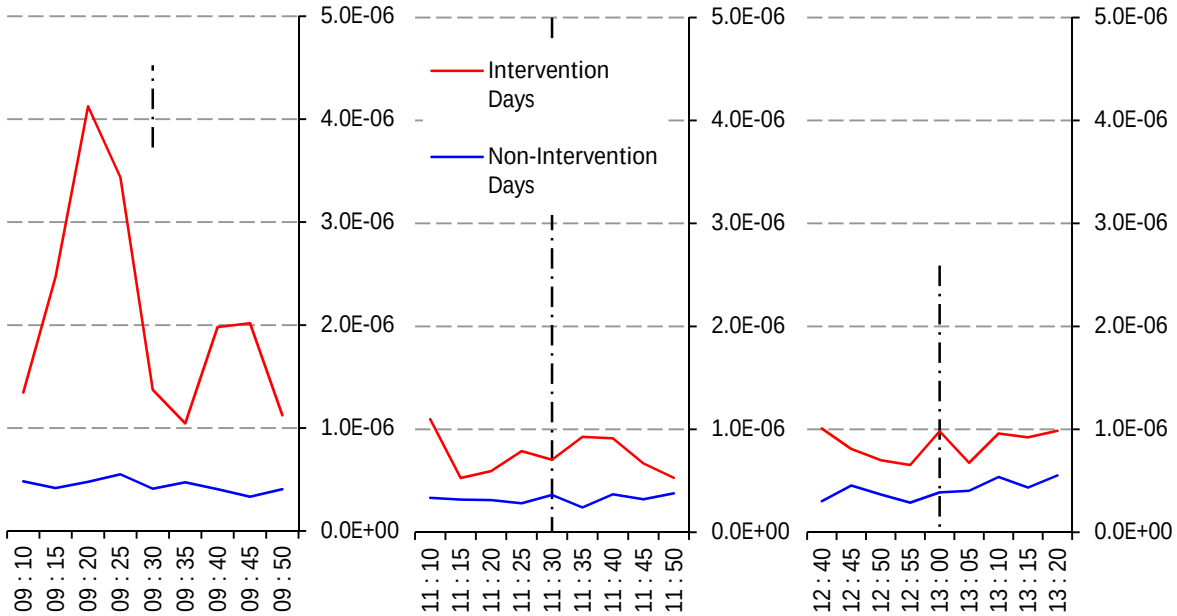


Colombia



Mexico: Average (Transaction) Return Volatility: intervention vs. non-intervention days.

9:30 hrs. 11:30 hrs. 13:00 hrs.



F. The Brown and Forsythe Homoscedasticity Test[25]

To test for homoscedasticity, the Brown and Forsythe test was implemented. In Colombia the test was for homoscedasticity between the pooled control and intervention samples corresponding to the intervention times (In graph A7, interventions are shown in the x-axis

[25] Detailed results for Chile and Peru were still not available from this section to the end of this paper.

with the p-values in the y axis). The findings suggest that for particular times of intervention – but not for others - there is strong evidence of heteroscedasticity. By pooling the control and intervention samples over the times of intervention, the Brown and Forsythe's test yields a statistic of 27.06 with a p-value lower than 0.0001, supporting the hypothesis that the volatility of 7 minutes returns is not equal between the control and intervention samples. However, this result might not hold for all intervention times in the sample.

In Mexico, the null hypothesis of homoscedasticity *within* the intervention and non-intervention or control samples (*but not across them*) was tested. In all cases using transactions data (except at the 11:30 am control sample), the null hypothesis of homoscedastic variances is not rejected at conventional significance levels.

Table 3 Mexico: Brown Forsythe test of equality of return variances through time in period surrounding intervention event (Transactions data)

Rate	Equality of return variance in CB intervention sample	Equality of return variance in control sample
	F-statistic	
9:30 am	0.31	1.07
11:30 am	1.20	2.32
1:00 pm	0.32	1.61

G. Volatility seasonal

Following Dominguez (2006), the intraday seasonal component of the volatility of returns was estimated for Colombia and Mexico.

In the case of Colombia, an ARCH(2) model with T distributed residuals was fitted to the 1,025 average daily returns. From this model the daily volatility factor σ_t was estimated for each day t in the sample.[26] By estimating $E[R_{t,n}]$ with the sample mean return over the sample, the estimate of $x_{t,n}$ in Dominguez (2006, equation 6, page 1057), was computed for each intraday sub-interval n and day t, where $N=42$ is the number of intraday intervals in the trading day. Results of the estimated volatility seasonal for a tuning parameter (*P*) between 4 and 9 were compared. Evidence of over fitting at the end of the trading was found for *P* greater than 6. In the same way, evidence of under fitting was found for *P* below 4, and the results are basically the same for *P* between 4 and 6. Therefore a tuning parameter of *P*=5 was chosen.

Graph 3[27] depicts the mean absolute return on the pooled intervention and control samples, along with the volatility seasonal calculated as in Dominguez (2006) (black line on right scale).[28] Except for a normalization constant, the volatility seasonal picks up the features of intra-daily volatility. On an average trading day the volatility of returns starts high and falls

[26] Alternative ARCH and GARCH specifications were tried and GARCH terms did not significantly affect the volatility of mean daily returns.

[27] Figure 5 of Colombia contribution.

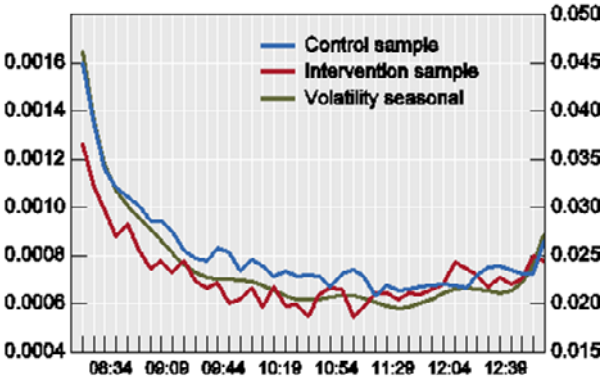
[28] Dominguez (2006, equation (8), page 1058).

slowly as the market agrees on the effect of exogenous information on prices. Moreover, the volatility tends to pick up at the end of the trading day when trades are less frequent.

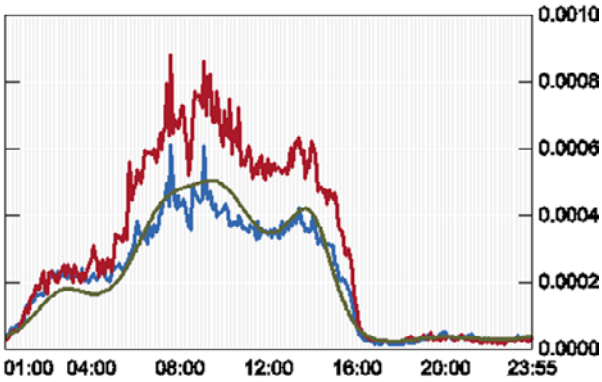
In Mexico, the seasonal component was estimated first by using non-intervention days, and then by considering the whole sample, the underlying assumption being that the seasonal component does not change through the sample. A GARCH model (instead of a FIGARCH) was used, with parameter P=6. The results are illustrated in Graph 3.

Graph 3
Volatility seasonal

Colombia (average absolute returns)



Mexico[1]: Average (transaction) return volatility



Peru

[1] 40-minute windows around 9:30, 11:30 and 13:30 interventions.

Source: Central banks.

III. Empirical analysis

A. Event Study style regression

Following Dominguez (2003 and 2006) a set of regressions was estimated to study the effect of foreign exchange market intervention on the mean return, return volatility, and (for Colombia) market turnover.[29] Further details are available in the contributions of individual central banks to the detailed outline for this paper.

The following specifications, which are available for all four central banks, are first reported in this paper:

- Regression of mean return on dummy variables for intervention and macroeconomic announcements[30].
- Regression of the volatility of returns on dummy variables for intervention and macroeconomic announcements, and intraday seasonal (Colombia).

29 For Colombia, The general equation specification for the effect of the intervention on the mean return and turnover follows Dominguez (2003, equation (1), page 34), and the equation to study the effect of intervention on the mean volatility of returns follows Dominguez (2006, equation 9, page 1059).

30 For Colombia, we report results in which signed dummies are used for standardized surprises of macroeconomic announcements, all the auctions involved sales of foreign currency over the sample so signed and unsigned dummies for intervention give the same results. For macroeconomic announcements, a set of 15 news releases (12 for USA and 3 for Colombia) were included in all the regressions below.

The general specification of these equations may be described as follows:

Table 2

Event style regression with macroeconomic/announcements control variables

$$R_{t,i+m} = c + \Sigma_m \beta_{1,m} D_{t,i+m} + \Sigma_m \gamma_{a,m} DN_{t,i+m} + \Sigma_{k=1}^{3} \alpha_k R_{t,m+i-k} + \varepsilon_{t,i+m}$$

$$V_{t,i+m} = c + \Sigma_m \beta_{1,m} D_{t,i+m} + \Sigma_m \gamma_{a,m} DN_{t,i+m} + \Sigma_{k=1}^{3} \alpha_k V_{t,m+i-k} + \partial S_{i+m} + \varepsilon_{t,i+m}$$

R exchange rate returns

V volatility of returns

D dummy variable

N macroeconomic announcements

t intervention date

i time of intervention

m leads and lags

a is the type of macroeconomic announcement (1 to 12 for international announcements)

These models were estimated using GMM.

The following additional results are reported

- Results for above regressions at different times of the day (reported by Mexico).
- Regression of mean return on intervention *volume* and standardized surprises of macroeconomic announcements (reported by Colombia)
- Regression of market turnover on intervention volume and standardized surprises of macroeconomic announcements (reported by Colombia)
- Analysis of intervention volume and volatility (reported by Colombia)

Dummy variable specification

Before reporting the regression results, it is useful to describe how the dummy variables are specified, and the window around which estimation was performed.

In general, if an intervention takes place on day t at time i the lag and lead with respect to the intervention time is set at m. Then $D_{t,i+m} = 1$ at the time of intervention and for a symmetric time window of a prespecified length before and after the intervention. Also $D_{t,i+m} = 0$ if there was no intervention on day t. The coefficient $\beta_{1,m}$ is thus associated to the time before, at and after the intervention. These are the coefficients that are plotted in Graph 4.

In Colombia, after fitting several models with windows as wide as two hours before and after the intervention for the leads and lags of the intervention and news indicators, a symmetric window of 70 minutes that contains each intervention, was chosen. In line with this choice, the intervention occurs sometime between 00:35 and 00:42 time marks and its effect on any of the three variables is estimated on a time window consisting of 35 minutes before and 35 after the intervention (the value of m thus ranges from m=-35 to m=35).

Moreover, an analysis of the frequency of occurrence of news releases in windows around interventions reveals that there are just 23 news releases (observations) in a 70 minute window around interventions, only 15 in a 42 minutes widow, and only one on impact (in a 7

minutes interval). A closer look at these releases shows, also, that there is no concentration of interventions near to announcements of any particular macro indicator. Therefore, for Colombia, *there does not seem to be enough sample information to study the effect of the interaction between intervention and the macro announcements of particular variables*.

In the case of Mexico, intervention in the sample occurs only three times a day, rather than continuously throughout the day. Dummies are specified by setting a symmetric time window of 40 minutes day t at time of intervention i (ie either 9:30 am, 11:30 am or 1:00 pm), so that the lag and lead values of m with respect to the intervention time range from -20 minutes to +20 minutes.

As for macroeconomic news announcement dummies, in Colombia, Mexico and Peru, twelve types of US macroeconomic announcements listed earlier were included, denoted by a=1,…., 12. Colombia also included 3 domestic announcements (see Annex Table A2).

The announcement dummies are constructed in a similar way to intervention dummies, but to capture the varying direction of surprises they are signed. Thus, in the case of Mexico, if an announcement takes place on day t at time i (ie 9:30 am, 11:30 am or 1:00 pm), the lag and lead is set at m, also ranging from -20 minutes to +20 minutes. $D_{t,i+m} = 1$ if there is a positive news announcement on day t, on the 40 minute time window surrounding the intervention. $D_{t,j+m} = -1$, if there was a negative news announcement on day t within the window, and $D_{t,i+m} = 0$ if there was no news announcement on day t within the window.

For the specific case of Mexico, positive and negative news announcements are defined quantitatively. Positive news announcements are defined as realized values for the variable in question above the median plus the standard deviation.[31] Negative news announcements are defined as a realized value for the variable in question below the median minus the standard deviation. The standard deviation is approximated by the difference of the maximum minus the minimum divided by six.

Since many news announcements' time stamps are earlier than 9:10 am, the intervals of the days were extended accordingly For example, if there is a news announcement at 7:30 am, data starting at 7:10 am is considered. In fact, data can go from 7:10 am to 2:35 pm, as 7:30 am is the earliest time and 2:15 pm is the latest time news announcements take place in the Mexican database.

For the intervention and announcement series, observations outside the windows on intervention days are not included. Non-intervention days are also excluded (these data are considered uninformative).

C. Impact of intervention on mean returns and volatility

1. The effect of the intervention on mean returns

Graph 4 shows shows the estimated coefficients of leading, contemporary and lagged intervention signed dummy variables.

In the case of Colombia, Graph 4 Panel B illustrates the impact of intervention – measured in basis points - on 7-minutes mean returns of the COP/USD exchange rate. The solid line corresponds to the coefficient estimates, while the dashed lines show two standard deviation confidence intervals derived from a GMM estimation procedure. The graph shows a highly significant increase in mean returns, close to 3 basis points (bp), on impact, and marginally significant reductions of 1 bp half an hour before and 7 minutes after the intervention.

[31] Mexico's discussion of positive and negative announcements here.

Mexico Graph 4 Panel C. There seems to be significant positive effects some minutes before and after the intervention.

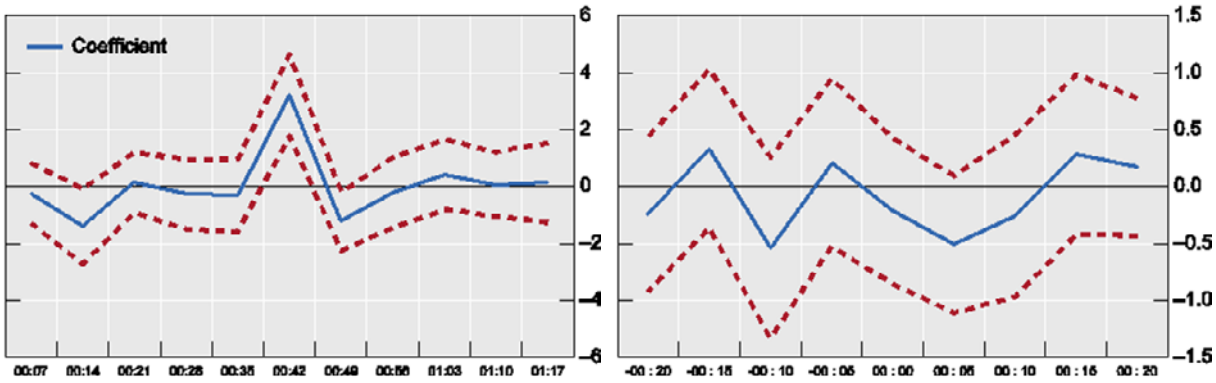
Graph 4

The effects of intervention on mean returns

(lead and lag coefficients within intervention window)

Basis points

Colombia (Figure 6 of contribution) Mexico (version with controls, Graph 8 of contribution)



Source: Central bank authors. Note: For Colombia (as indicated in the text) the intervention window is between 00:35 and 00:42.

2. The effects of US announcements on mean returns

To compare the effect of intervention to that of macroeconomic surprises, the effect of the signed dummy corresponding to US macroeconomic surprises (consumer confidence surprises in the case of Colombia), for instance, is illustrated in Graph 5.

In the case of Colombia, a positive surprise to US consumer confidence lowers the 7-minutes mean return around 8 bps on impact. Moreover, the confidence bands suggest that there are also borderline significant leading effects, and also significant lagged effects on average returns.[32] Moreover, the responses of the mean returns to a positive average surprise to the US consumer confidence are, on average, greater than the effect of the intervention, particularly on impact. To sum up, the effect of intervention in Colombia during the sample period was modest relative to the effect of US macroeconomic announcements. The market also reacted in anticipation and with a lag to this surprise. The effects of other US macro surprises showed similar characteristics.[33]

In the case of Mexico, news announcements have, in absolute magnitude, a much greater effect than intervention. However, there is a clear “regress to the mean” effect on the return after the news announcements.

[32] The estimated effect of any other macroeconomic surprise may be requested from Hernan Rincon and Juan Manuel Julio, Bank of the Republic (Colombia).

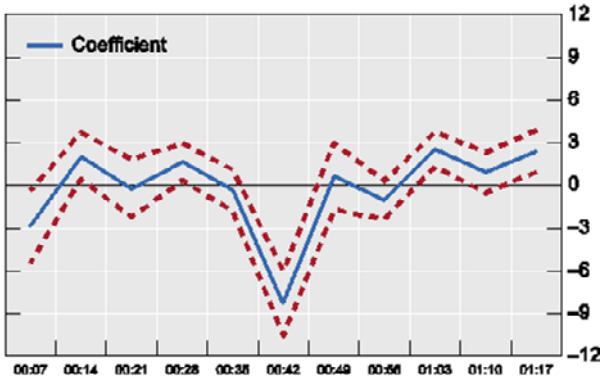
[33] The estimation of the effect of Colombian macroeconomic announcements is more involved as these interventions tend to be off market hours, and were therefore carried forward to the 8:06 minutes time mark of the following trading day. The coefficient estimates related to these announcements may be biased and thus are not shown here.

Graph 5

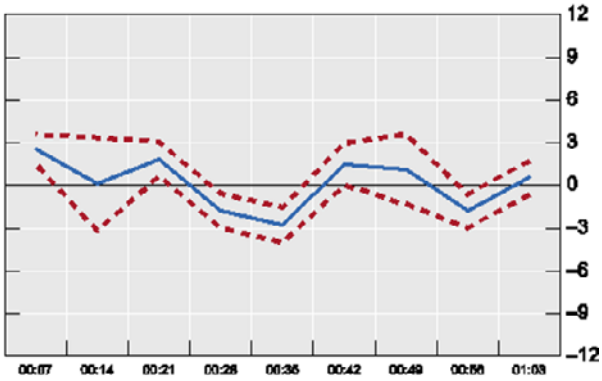
The effects of US announcements on mean returns

Basis points

Colombia (consumer confidence)



Mexico[34]



Source: Central bank authors.

3. Cumulative effects of intervention and US announcements

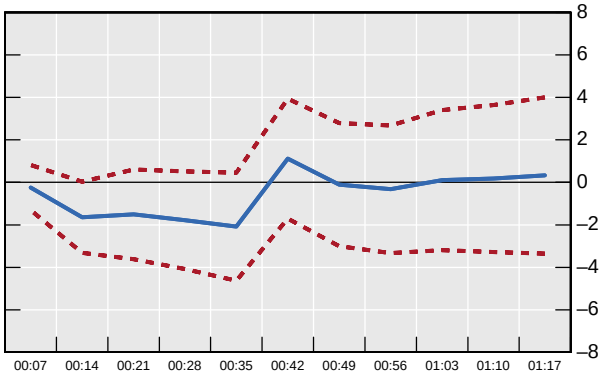
Additional perspective is provided by estimates of the cumulative effects of intervention and US announcements, shown for Colombia. As illustrated in Graph 6, Panel A intervention shows no significant cumulative effects of intervention on 7-minutes mean return. Graph 6 Panel B also reveals that the cumulative effect of a standard deviation surprise US macroeconomic announcement (represented by US consumer confidence in Colombia) has a significant negative effect on mean returns after the impact, lasting around 15 minutes. However the effect reverts to zero afterwards.

Graph 6

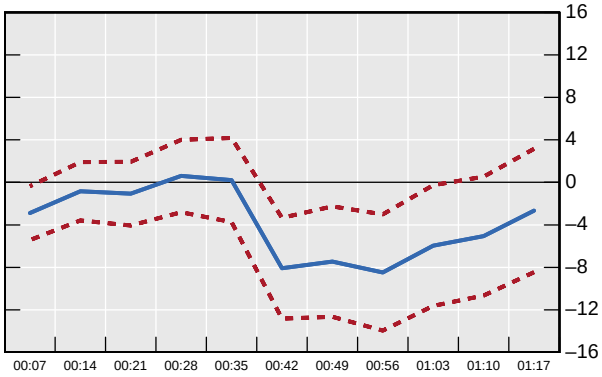
Cumulative effects of intervention and US announcements on returns (Colombia)[35]

Basis points

Cumulative effect of the intervention signed dummy on mean returns



Cumulative effect of surprises to US consumer confidence signed dummies on mean return



Source: Authors from Bank of the Republic (Colombia)

[34] Graph 8 of Bank of Mexico contribution.

[35] Figure 7 and Figure 9 of Colombia contribution.

4. The effects of intervention and macro announcements on the volatility of returns

In this section the effects of intervention and macro announcements on the intraday volatility of returns are studied. Following the specification shown in Table 2, the endogenous variable is the standard deviation or the absolute return. Intervention and macroeconomic announcement indicator variables are entered as explanatory variables, as is the intraday seasonal corresponding to the period of time within the day.

a. The effects of intervention on the volatility of returns

In Chile (results not yet available)

In Colombia, Graph 7 Panel B displays the estimated coefficients of leading, contemporary and lagged intervention signed dummies in the explanation of the 7-minutes volatility of returns. It suggests that the volatility of returns falls significantly between 35 and 21 minutes before the intervention, and also 7 minutes after the intervention. However, the intervention does not seem to have a significant effect on the volatility of returns on impact or with a higher lag, at least during the time window considered. As can be seen Graph 7, Panel B[36] in which the volatility of returns on the intervention sample is smaller than the volatility on the control sample before 11:22 am, when, according to Graph 1, almost all interventions had already occurred. To sum up, the volatility of returns falls before the intervention auction is announced. Beyond this, the intervention does not seem to modify the volatility during or after the intervention, except perhaps for a slight reduction 7 minutes after the intervention.

In Mexico, intervention appears to have no significant effect on volatility along the window considered.

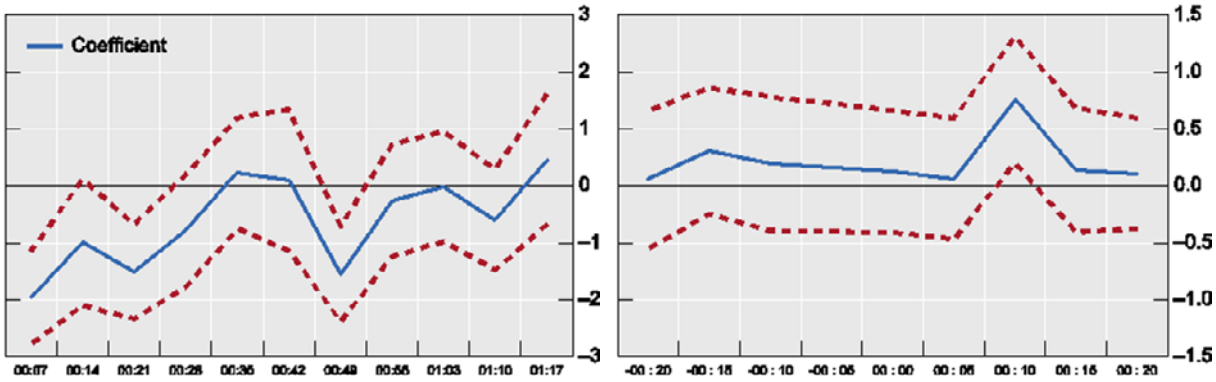
In Peru (results not yet available).

Graph 7

The effect of intervention dummy on the volatility of returns

Basis points

Colombia[37] Mexico



Source: Central bank authors.

[36] Figure 5 from Bank of the Republic contribution.

[37] Figure 18 of detailed outline submitted by Bank of the Republic.

b. The effects of US macroeconomic announcements on the volatility of returns

The effects are illustrated in Graph 8. For Colombia, a surprise to US consumer confidence (as represented by a signed dummy) has no effect on the volatility of returns on impact, but reduces the 7-minutes returns volatility 7 and 28 minutes later. Moreover, the volatility increases significantly 21 minutes prior to the intervention. However, it is worth noticing that the volatility before the announcement tends to be higher than the volatility after the announcement.

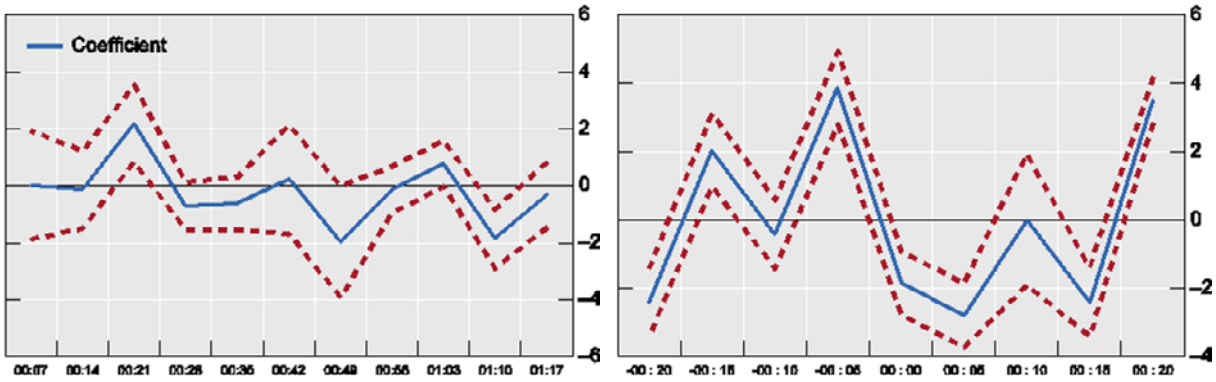
For Mexico, news announcements have, in absolute magnitude, a much greater effect on volatility than intervention.

Graph 8

The effects of US announcements on the volatility of returns

Basis points

Colombia[38] Mexico



Source: Central banks

Additional perspective may be gained by once again looking at the cumulative effects of intervention and US announcements on the volatility of returns which are available for Colombia. Graph 9 panel A shows that the cumulative effect of the intervention on the variance of returns on the 7-minutes volatility seems to be negative and significant. Furthermore, these effects appear to persist beyond the time horizon shown.

Graph 9 Panel B shows that a surprise to US consumer confidence has no effect on the volatility of returns on impact, but reduces the 7-minutes returns volatility 7 and 28 minutes later. Furthermore, volatility increases significantly 21 minutes prior to the announcement, and volatility before the announcement tends to be higher than the volatility after the announcement.

[38] Figure 20 of Colombia contribution.

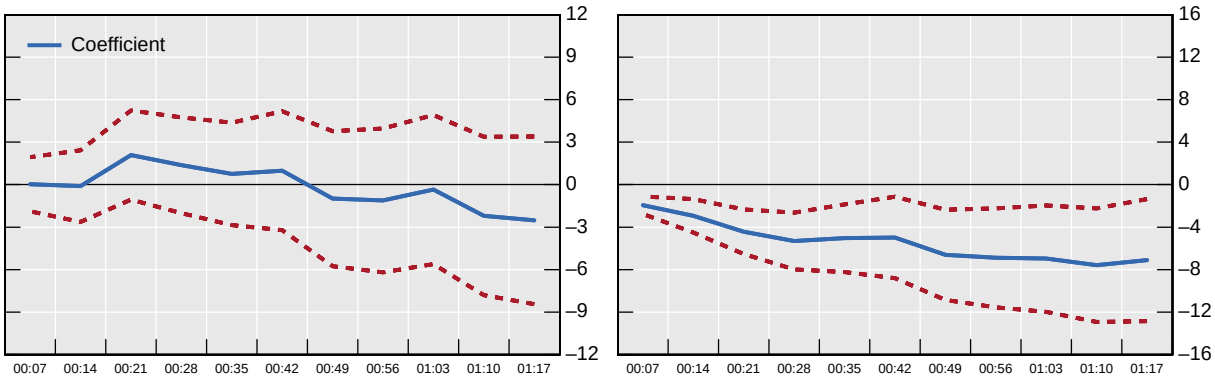
Graph 9

Cumulative effects of intervention and US announcements on volatility of returns (Colombia)

Basis points

A. Cumulative effect of the intervention signed dummy on volatility of returns[39]

B. Cumulative effect of surprises to US consumer confidence signed dummies on volatility of returns[40]



Source: Authors from Bank of the Republic, Colombia

5. Additional results

a. Effects of intervention at different times of the day (Mexico)

A question of interest is whether the effects of intervention vary in the course of the day. Results are available for Mexico, where the authors implemented event study style regressions following the specifications in table 1 using GMM for a SUR estimation in order to analyse the effects of intervention on returns and volatility of returns during the three auction times of the day (9:30 am, 11:30 am, and 1 pm). The results are reported in Graphs 10 and 11.[41]

The findings may be summarized as follows: First intervention has no significant effects on on returns at the various times of the day. Second, intervention has no significant effects on volatility for all of the interventions, except for one case. Specifically, for the 11:30 hrs. intervention there is an decrease in the volatility 5 minutes before the intervention.

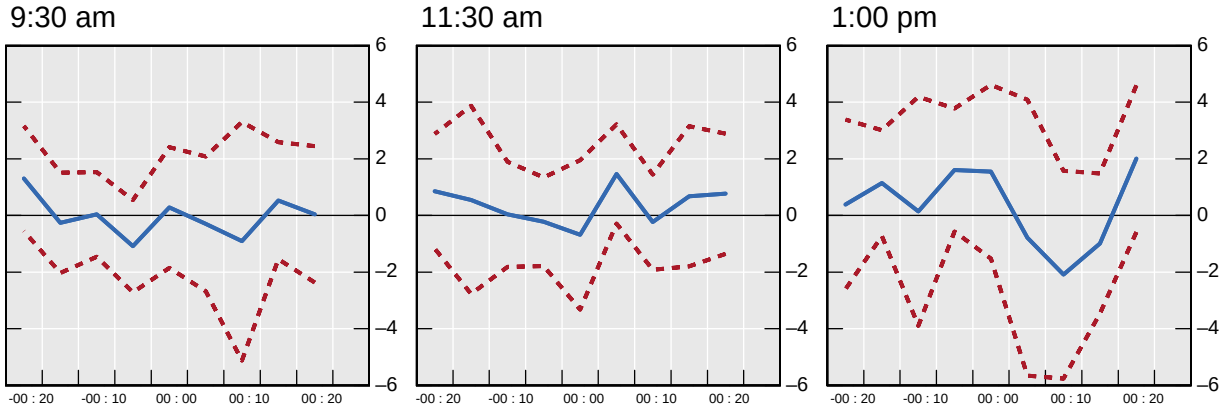
[39] Fig 19 Detailed outline p 22 of Bank of the Republic contribution.

[40] Fig 21 detailed outline p. 23 of Bank of the Republic contribution.

[41] See Graphs of the same number in Bank of Mexico's contribution to the detailed outline for this joint paper. GMM accounts for possible heteroscedasticity in the residuals and SUR estimation increases estimator efficiency by dealing with possible correlation in residuals.

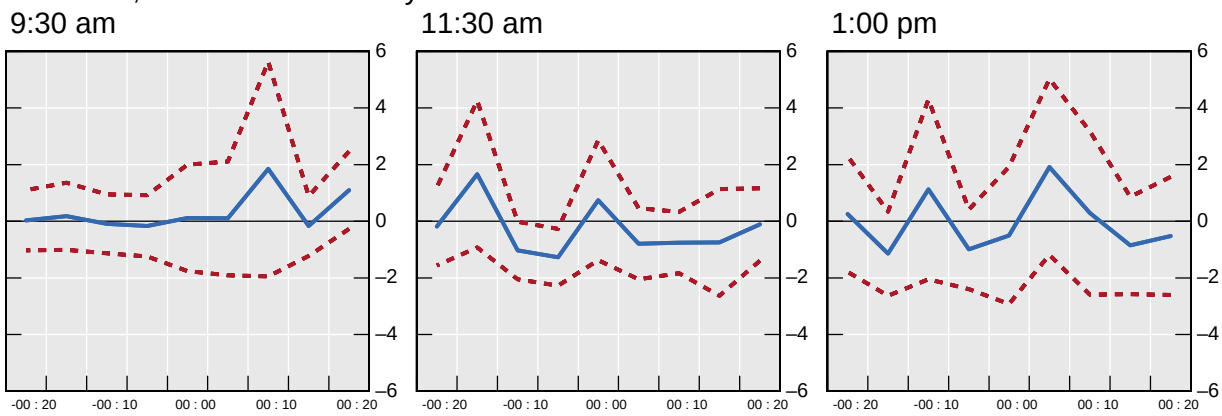
Graph 10 Mexico

Coefficients for intervention: Event study style regression with Macroeconomic Control Variables, Transaction Returns



Graph 11 Mexico

Coefficients for intervention: Event study style regression with Macroeconomic Control Variables, Transaction Volatility



b. Effects of intervention volumes and standardized US surprises on returns (Colombia)

In Colombia,[42] the cumulative effects of intervention volume are similar to those reported for the intervention dummy, ie at no point within the time window does the intervention have a significant cumulative effect on the mean return. In this regression, the effect of a standard deviation surprise to a US consumer is also similar to those shown in Graph 6, there is a significant drop in mean returns that disappears after 28 minutes.

This result confirms that the effect of intervention on returns is moderate and very short lived relative to the effect of a US consumer confidence macro announcement.

[42] Graphs are not shown but are available in the Detailed Outline contributed by Colombia for this joint paper, Figures 10 to 13.

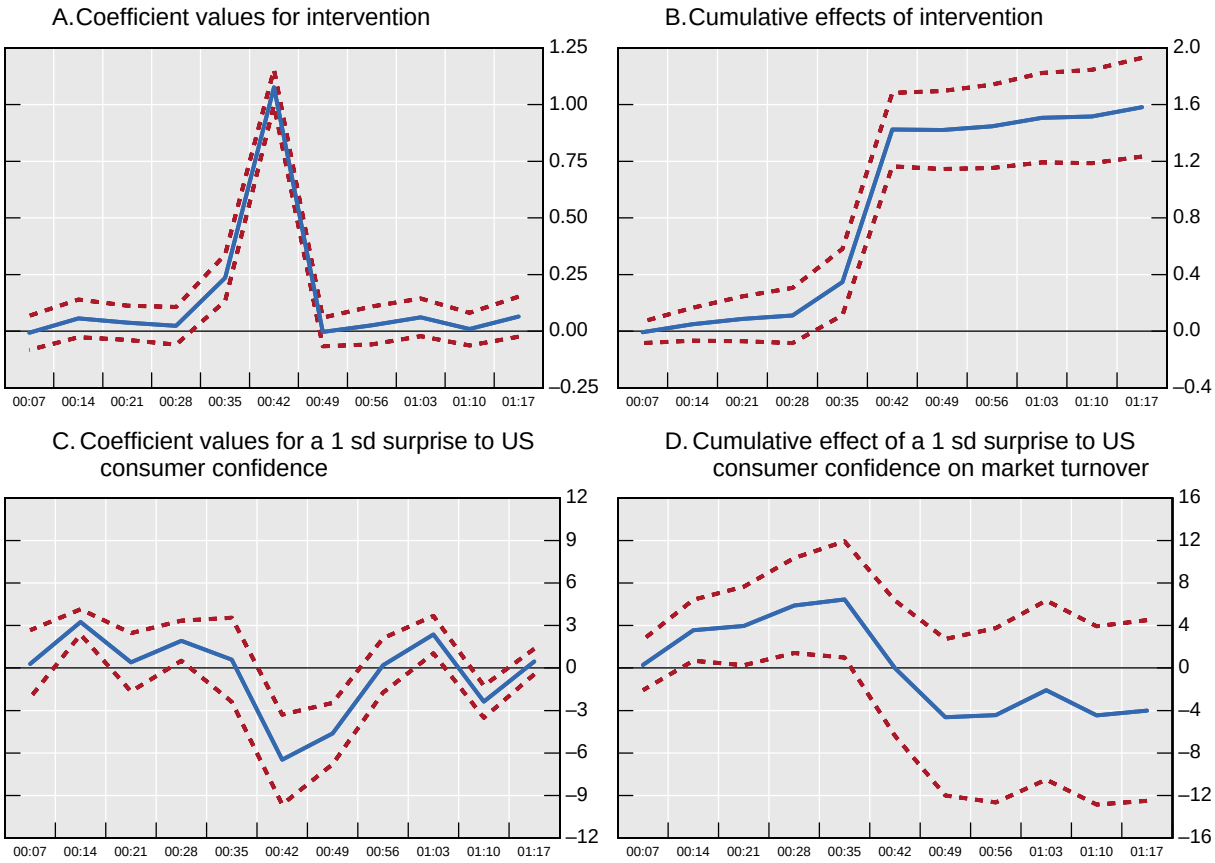
c. Effects of intervention and US announcements on market turnover (Colombia)

Graph 12, Panel A[43] displays the estimated coefficients of leading, contemporary and lagged intervention volume in Colombia for explaining 7-minutes market turnover. The results show that the market turnover starts to increase 7 minutes before the intervention and reaches just USD 1 million on impact. However, it returns rapidly to zero.

Graph 12

Colombia: Effects of intervention and US announcements on market turnover

Millions of US dollars



Source: To be filled.

Panel B shows the cumulative effect of the intervention volume on the 7-minutes market turnover. The intervention seems to have no significant cumulative effect on the market turnover up to 7 minutes before the intervention, but the effect on market turnover is long-lasting.

Panel C reveals that a one standard deviation surprise to US consumer confidence is associated with a sharp decline in market turnover; Panel D reveals that this effect is permanent.

To sum up, intervention increases the turnover on impact in an amount equivalent to its size, USD 20 million. There seems to be an increase of the turnover during the time

[43] From Fig 34 of Detailed outline contribution of Bank of the Republic.

interval prior to the intervention, which may arise from the fact that the auction is announced two minutes before it begins. Therefore, if the intervention starts within the first two minutes of the interval, the announcement is made in the previous interval. Finally, the market turnover seems to increase prior to the announcements related to the US consumer confidence, but this announcement does not seem to have an important effect on impact or afterwards.

d. Discussion of the effect of foreign exchange intervention on volatility and market turnover (Colombia)

As noted earlier a 20 million USD intervention significantly increases mean returns by 2.8 bp on impact, and reduces mean returns by 1.17 bp 7 minutes after the intervention. Therefore, the exchange rate would increase permanently by 1.63 bp after the intervention. However, volatility falls both before and after the intervention.

According to Dominguez (1998, Table 1.1.1, page 167), these results might suggest that the Colombian central bank sent a credible and unambiguous devaluation signal to an efficient FOREX market. The effect of the intervention on mean returns is economically small, statistically significant and short lived. This implies a permanent, though small, increase of 1.63 bp in the level of the exchange rate.

A novel feature of the Colombian dataset is that the volume of each trade is recorded, which allows computation of the market turnover on any set of intraday intervals of time. Therefore, the effect of the intervention on the market turnover may be assessed through an event study regression as in Dominguez (1999, 2003 and 2006).

The regression results indicate that market turnover increases USD 4 million 7 minutes before intervention and USD 20 million on impact[44]. Furthermore, volatility falls both before and after the intervention (see Graph 7 above). These results are at odds with the view that the effect of intervention on market turnover should be similar to the effect of intervention on volatility since volatility and turnover are related.

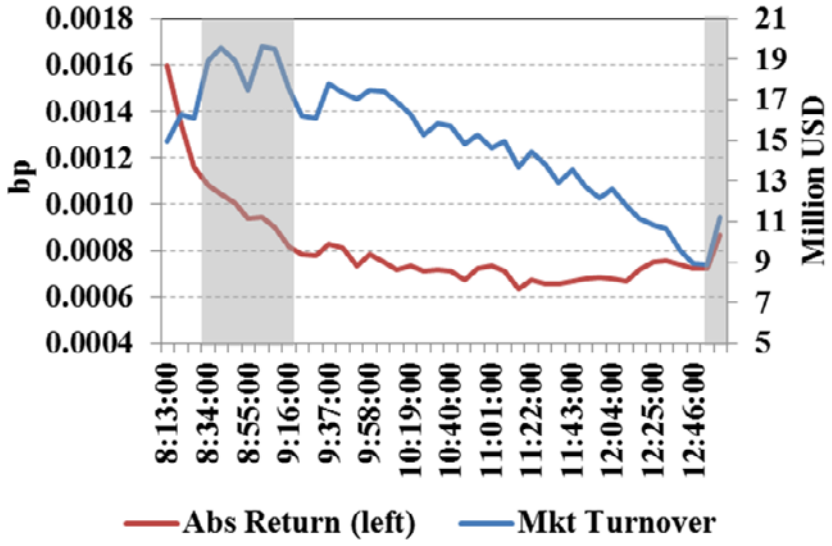
At market opening, 8:00 am, volatility is high and market turnover is low because of the information arriving off-market hours that is not carried to the market opening price of the following trading day [45]. Subsequently, from 8:00 to 8:30 am (un-shaded area to the left), while the market agrees on the effect of off-market-hours announcements, volatility reduces sharply while turnover increases in like fashion. Afterwards, from 8:30 to 9:30 am (shaded area to the left), and depending on the daylight saving time, the bulk of US announcements arrive while volatility is moderately high and turnover reaches its peak. Next, from 9:30 am to 12:53 pm, the rate of arrival of announcements falls, leading to a decrease on both, volatility

[44] The increase of market turnover 7 minutes before intervention may arise when turnover increases with intervention announcement (two minutes before the auction), and some interventions takes place within the first two minutes of the 7 minute interval.

[45] Colombian spot market hours range from 8:00 am to 13:00 pm on every Colombian and US business day. Colombian, European and Asian macroeconomic news announcements arrive when the Colombian spot FOREX market is closed.

and market turnover. Towards market closing, 12:53 pm, volatility is slightly higher than its minimum while turnover falls to its minimum. And finally, from 12:53 pm to market closing, both volatility and turnover increase sharply.

Graph 13. Average absolute returns (red line on the left axis), and average market turnover during a nonintervention trading day



(i) The effect of day trading and the flow of macroeconomic surprise announcements on the intraday dynamics of volatility and turnover

The behavior of day traders may help explain the intraday relationship of turnover and volatility. We argue that day traders profit from beating market expectations on the effect of announcements.

To illustrate this, let us assume there are two consecutive non-overlapping intervals of time, $T_0 < T_1$, within a trading day, where T_0 has a large number of surprise announcements and T_1 has fewer surprise announcements. This assumption implies that expected returns and return volatility within T_0 is higher than within T_1.

In this setting, if day traders beat market expectations, as the market moves from T_0 to T_1, their expected returns fall faster than their expected volatility, thus leading to a higher Sharpe ratio within T_0 compared to T_1. This reduction creates incentives to trade within T_0, which leads to a smaller turnover within T_1.

A similar explanation follows from day traders having lower degrees of risk aversion than other agents in the market. Under these circumstances, day traders profit from taking and exiting positions within T_0. See Durn & Huberman (2010) for instance.

Evidence supporting these claims arises from a natural experiment of recent weeks in the Colombian spot FOREX market. An internal report written by the Colombian Central Bank trading desk showed that the share of the day-traders turnover dropped sharply in a recent period of unusually high exchange rate stability, that is, in a period of unsurprising announcements. This observation suggests that in the absence of macroeconomic surprises (i.e. low volatility), day traders are not willing to buy or sell, thus revealing that their level of risk aversion is lower than other agents', or an effort to profit from beating market expectations. Yet another explanation we explore below may be found in Tauchen & Pitts (1983).

These explanations account for the positive correlation of intraday volatility and market turnover from 8:30 am to 12:53 pm in Graph 13. Otherwise, the relationship is idiosyncratic.[46] Therefore, the effect of intervention on market turnover could be similar to the effect of intervention on volatility because volatility and turnover are positive correlated.

(ii) Explaining the different effects of intervention on volatility and turnover

As noted above, the behavior described in the previous section also fits the model of Tauchen & Pitts (1983) in which, according to Jorion (1999), the volatility/turnover relationship may take two forms; "(1) as the number of traders grows, market prices, which can be considered as an average of traders' reservation prices, become less volatile because averaging involves more observations; (2) with a fixed number of traders, higher trading volume reveals higher disagreement among traders and is thus associated with higher price variability. This link is stronger when new information flows to the market at a higher rate".

Following the proposition in page 490 of Tauchen & Pitts (1983), the joint distribution of the i-th intraday price change, ΔP_i, and turnover, V_i, is

$$\Delta P_i = \phi_i + \bar{\psi}_i \sim N\left(0, \sigma_\phi^2 + \frac{\sigma_\psi^2}{J}\right)$$

$$V_i = \frac{\alpha}{2}\sum_{j=1}^{J}\left|\psi_{ij} - \bar{\psi}_i\right| \sim N\left(\frac{\alpha}{2}\sigma_\psi\sqrt{\frac{2}{\pi}J(J-1)}, \sigma_V^2\right)$$

where ΔP_i and V_i are independent, σ_V^2 is the variance of the turnover, and J is the number of active traders. The reservation price change of the j-th trader at time i is the sum of two independent zero mean normal components; a common random component between traders, ϕ_i, and a trader specific component, ψ_{ij}, with variances σ_ϕ^2 and σ_ψ^2 respectively. Furthermore, $\bar{\psi}_i$ is the average trader specific component, $\alpha > 0$ relates the position of each

[46] From 8:00 to 8:30 am this relationship arises from the amount of information arriving off-market hours that is not carried to the market opening price of the following trading day. In turn, the sharp increase of volatility and market turnover after 12:53 pm arises from day traders exiting their positions before market closing because volatility spikes sharply after that.

trader with the difference between its reservation price and market price, $Q_{ij} = \alpha\left[P_{ij}^{*} - P_i\right]$, and inactive traders reservation price equals market price. Finally, α is assumed to be time invariant.

In this model there are three parameters; the number of active traders J, and the variances of the common and trader specific shocks, σ_{ϕ}^2 and σ_{ψ}^2, and two types of shocks; the common component shock ϕ_i, and trader specific component shocks ψ_{ij}.

Let us assume that intervention is performed at time i and consider two periods of time before and after intervention, $i_0 < i < i_1$. And let us also assume that no other information arrives to the market on this interval.

In this model, market returns depend on the size of both types of shocks, market turnover depends only on trader specific shocks, and volatility depends on all parameters. In order for this model to mimic the responses observed in for the case of Colombia, the following restrictions, which may not be unique, should be imposed.

- $\phi_i + \bar{\psi}_i > 0$ and $\phi_{i_0} + \bar{\psi}_{i_0} = \phi_{i_1} + \bar{\psi}_{i_1} = 0$ in order for intervention to affect returns exclusively on impact.
- $\sum_{j=1}^{J}\left|\psi_{i_0 j} - \bar{\psi}_{i_0}\right| = \sum_{j=1}^{J}\left|\psi_{i_1 j} - \bar{\psi}_{i_1}\right| = \frac{\alpha}{2}\sigma_{\psi}\sqrt{\frac{2}{\pi}J(J-1)}$ and $\sum_{j=1}^{J}\left|\psi_{ij} - \bar{\psi}_i\right| > \frac{\alpha}{2}\sigma_{\psi}\sqrt{\frac{2}{\pi}J(J-1)}$ in order for intervention to increase turnover above its average only on impact. This can be achieved when σ_{ψ} is lower at i_0 and i_1 that at i.
- In order for return volatility to fall before and after intervention, given the previous restrictions, no further restrictions are required, but if needed, σ_{ϕ}^2 might be lower at i_0 and i_1 that at i.

Therefore, the response of traders before and after intervention is more unanimous than on impact. This might be the result of sending a credible and unambiguous signal to an efficient FOREX market.

Different combinations of parameter values might lead to similar results. However, at least for this set of restrictions, the responses to intervention observed in Colombia seem to be plausible in a model that predicts a positive correlation between market turnover and volatility.

Conclusions

The analysis of intervention in (two) Latin American countries using intraday data yields the following results.

First, high frequency intraday exchange returns are characterised by deviations from normality, which highlight the risk of sudden crashes. In particular, returns exhibit negative skewness during intervention days and heavy tails (high kurtosis).

Second, sterilised, rule-based intervention that targets purchases/sales of preannounced quantities of foreign reserves has an impact on foreign exchange returns but, perhaps not surprisingly, the effects are small and transitory.

Third, the effects of such intervention on exchange rate volatility appear to be larger, but are also transitory.

Fourth, the effects of intervention on exchange rate returns and volatility appear to be much smaller than the effects of US macroeconomic policy announcements, but such announcements also appear to have transitory effects.

Fifth, the effects as measured by amounts of intervention are qualitatively similar to those using intervention dummies. These results are available for Colombia, and appear to reflect the fact that during the sample period studied quantities of intervention were fixed.

Sixth, an analysis of Colombian data suggests that intervention appears to have highly permanent or persistent effects on market turnover. This is surprising in part because volatility appears to fall in response to intervention, and this is contrary to the conventional view that turnover and volatility are (positively) correlated.

The preceding results suggest that rule-based FX operations in Latin America appear to have posed little or no risk of distorting pricing in FX markets in the region in spite of the fairly large amounts of intervention involved. Further research would be useful to examine whether intervention outcomes are very different if intervention is discretionary.

ANNEX

Table A1. FX market data description and sources

	Colombia	Mexico
Sample period (estimation)	2 May 2007-23 Nov 2011	9 Oct 2008-29 Nov 2011 (excluding 30 Nov-31 Dec 2011 because interventions occurred at different time of day). This is subset of full sample Jan 2003-Dec 2011 (June and Dec 2003 not available).
Days covered and Time span within day	(M-F except Colombian and US holidays). 8:00 am to 1 pm (5 hours long)[47]	9:10 am-1:20 pm (no macro announcements), 7:10 am-2:35 pm (with announcements) Full span is 12:00 am-11:55 pm
Time stamped measurements	Time-stamped transactions prices (COP/USD) and quantities. traded in the electronic spot market (about 70% of the wholesale spot market in Colombia)	Time-stamped transactions prices (MXN/USD).
Data transformations		Estimate weighted average of exchange rate prices closest to the time considered (see

[47] Colombia: "Next-day" trades are excluded from the dataset because this market is too shallow and represents less than 5% of the forex market.

		Dominguez, 1999). For data points for which there are no contemporaneous bid and ask prices, estimate the equidistant bid and ask separately, and then take an average
Sampling frequency	7 minute intervals, 8:06 am-1 pm (ie drop first 6 minutes of trading day). Implies 43 price records per day, of which 42 used (overnight returns deleted).	Equidistant 5 minute intervals
Sample size (transformed data used in estimation) Prices	44705 prices including overnight returns (however overnight returns were deleted, as were days containing too few trades). These are over 1025 days (out of 1114 initial sample) taking into account optimal interval and data loss at beginning of trading day.	Estimation sample 215424 (out of total sample of 622,367) intervention 102240, nonintervention 113184
Sample size market turnover	44705 market turnover observations (one for each 7 minute interval)	
Coverage intervention		
Coverage		

macroeconomic announcements		
Sources	SET-FX (centralized interbank FX electronic market service of Colombian Stock Exchange, BVC), Bloomberg	Reuters. (only covers transactions in peso market, and not peso transactions worldwide). Reuters data are taken as representative given the size and depth of the peso exchange market (eg see BIS Triennial Survey, 2010) and barring arbitrage opportunities.

Table A2 – Macroeconomic announcements (control variables)

Countries	International	Domestic	Source/comments
Colombia, Mexico, Peru	US Consumer Confidence, CPI, Durable Good, Fed Funds Rate, Unemployment, Housing, Industrial Production, PPI, NAPM, Retail Sales, GDP, Trade Balance		Bloomberg. Motivation for these variables: A study by Andersen et al (2003) found that these variables affected the US dollar exchange rate against major currencies. They are therefore likely to affect the value of the US dollar against Latin American currencies.
Colombia		Monthly CPI inflation releases (usually in the evening), year-to-year GDP growth (usually during forex spot market trading hours), Bank of the Republic monetary intervention interest rate (usually after 1 pm). Time stamp of these releases is rounded to the minute of the release (no apparent prespecified schedule followed). Two types of announcements used in regression analysis (i) dummy variable for time stamp; (ii) standardized surprise with respect to current expectation for the variable	Bank of the Republic (Colombia)

Table A3 Intervention operations

Type of intervention and description		The Bank of the Republic (the central bank) announces a round of daily intervention lasting several months for USD 20 million through a 3 minute Dutch auction, in which the central bank purchases US dollars.	Dollar auctions at minimum price	
Timing of intervention within day		Timing discretionary, announced to market participants 2 minutes before the start of auction		
Treatment (intervention) sample:		387 days. From 24-Jun-2008 to 30-Sep-2011 three rounds of intervention: (i) 24-Jun-08 to 06-Oct-08, (ii) 03-Mar-10 to 30-Jun-10, and (iii) 15-Sep-10 to 30-Sep-11. In all rounds, the Bank of the Republic bought USD. The sample starts right after a period of fully discretionary intervention which ended	102240 observations. 9 Oct 2008-April 2010	

		on 1-May-2007		
Control (non-intervention) sample		638 days. Four no-intervention periods in the sample: (i) 2-May-2007 to 23-Jun-2007, (ii) 07-Oct-2008 to 02-Mar-2010, (iii) 1-Jul-2010 to 14-Sep-2010, and (iv) 3-Oct-2011 to 23-Nov-2011.	113184. Days with no intervention between 12 Apr 2010-29 Nov 2011	
Other considerations		Whenever there is a (usually small) residual amount not allotted in the auction, it is carried forward to the next day. Therefore, a slight variation around the USD 20 million target may be observed between the days of an intervention round. An intervention round may be extended or finished any time after a public announcement by the CCB.		
Data source-comments		Bank of the Republic (Colombia)	Bank of Mexico	

Table A4 **Intraday FC return general distribution (Average Bid-Ask)**

1. Rate	Time interval	Mean	Median	Variance (sdev)	Skewness	Kurtosis
CLP/USD	5 min	0		8.70E-02	-1.70E-01	12.60
	20 min	0		1.49E-01	-1.31E-01	19.38
	1 h	-1.00E-03		2.57E-01	4.59E-01	18.33
	6 h	-5.00E-03		5.16E-01	3.29E-01	9.84
	24 h	-1.00E-02		7.62E-01	1.37E-01	5.83
COP/USD	7 min	6.00E-06	2.86E-06	1.22E-03	-0.08	16.21
	1 h	3.51E-05	4.97E-05	3.22E-03	-0.15	8.17
	5 h	2.52E-04	2.07E-05	7.32E-03	0.11	4.52
MXP/USD	5 min	7.34E-06		7.39E-07	-1.45	150.02
	1 h	6.33E-05		8.13E-06	-0.33	28.77
	6 h	9.27E-05		4.21E-05	-0.28	11.84
	24 h	1.49E-04		9.35E-05	0.14	12.00
PEN/USD	5 min	0		3.48E-07	-0.16	211.00
	1 h	0		2.29E-08	1.79	74.00
	6 h	0		4.04E-09	0.14	11.00
	24 h	0		2.27E-09	0.56	12.00

Source: Central bank authors.

Table A5 **Intraday FC return general distribution on intervention days (Average Bid-Ask)**

2. Rate	Time interval	Mean	Median	Variance (sdev)	Skewness	Kurtosis
CLP/USD	5 min	1.00E-03		9.00E-02	1.07E-01	8.01
	20 min	3.00E-03		1.57E-01	-1.20E-02	11.38
	1 h	7.00E-03		2.89E-01	1.70E-02	14.40
	6 h	3.80E-02		5.87E-01	2.14E-01	6.67
	24 h	7.10E-02		8.91E-01	1.76E-01	4.26
COP/USD	7 min	1.05E-05	9.47E-07	1.25E-03	-0.09	26.42
	1 h	7.06E-05	8.67E-05	3.28E-03	-0.53	14.10
	5 h	4.39E-04	5.39E-04	7.84E-03	-0.12	7.90
MXP/USD	5 min	8.69E-06		1.16E-06	-1.65	129.67
	1 h	7.20E-05		1.22E-05	-0.40	24.92
	6 h	-8.45E-06		6.40E-05	-0.34	10.16
	24 h	-5.47E-05		1.35E-04	0.05	11.19
PEN/USD	5 min	0		4.26E-07	-1.12	172.00
	1 h	0		2.28E-08	1.22	49.00
	6 h	0		4.11E-09	-0.33	11.00
	24 h	0		2.36E-09	-0.32	7.00

Source: Central bank authors.

Table A6 **Intraday FC return general distribution on non-intervention days (Average Bid-Ask)**

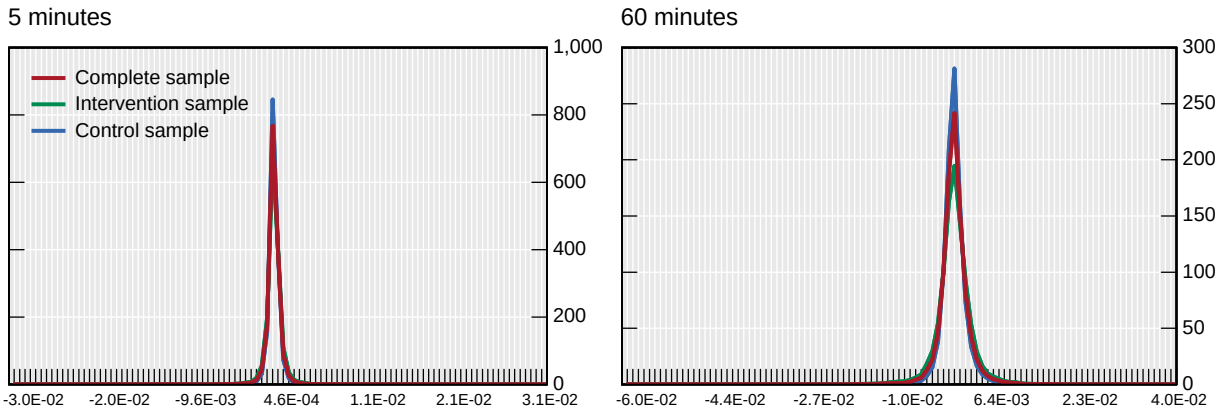
3. Rate	Time interval	Mean	Median	Variance (sdev)	Skewness	Kurtosis
CLP/USD	5 min	0		8.60E-02	-2.50E-01	13.94
	20 min	-1.00E-03		1.47E-01	-1.68E-01	21.90
	1 h	-3.00E-03		2.49E-01	6.09E-01	19.60
	6 h	-1.40E-02		4.99E-01	3.46E-01	10.92
	24 h	-2.70E-02		7.30E-01	8.60E-02	6.33
COP/USD	7 min	3.29E-06	4.60E-06	1.20E-03	-0.08	8.82
	1 h	1.36E-05	1.75E-05	3.18E-03	0.09	4.14
	5 h	1.38E-04	-3.61E-04	7.65E-03	0.25	2.35
MXP/USD	5 min	6.16E-06		3.77E-07	0.26	17.53
	1 h	5.58E-05		4.59E-06	0.04	15.54
	6 h	1.80E-04		2.32E-05	0.15	5.88
	24 h	3.30E-04		5.81E-05	0.47	6.02
PEN/USD	5 min	0		2.47E-07	2.71	302.00
	1 h	0		2.29E-08	2.53	107.00
	6 h	0		3.95E-09	0.80	12.00
	24 h	0		2.14E-09	1.93	19.00

Source: Central bank authors.

Graphical view of the distribution of returns

Graph A1

Transaction return density function under intervention, non-intervention and full samples (Mexico)



Source: To be filled.

In Panel A, the full sample PDF is indistinguishable from that of the intervention sample at 5 minutes. However, the full sample and nonintervention PDF peaks are much higher than the intervention peak at 5 minutes (the divergence is apparent at lower frequencies up to the 24 hour average).

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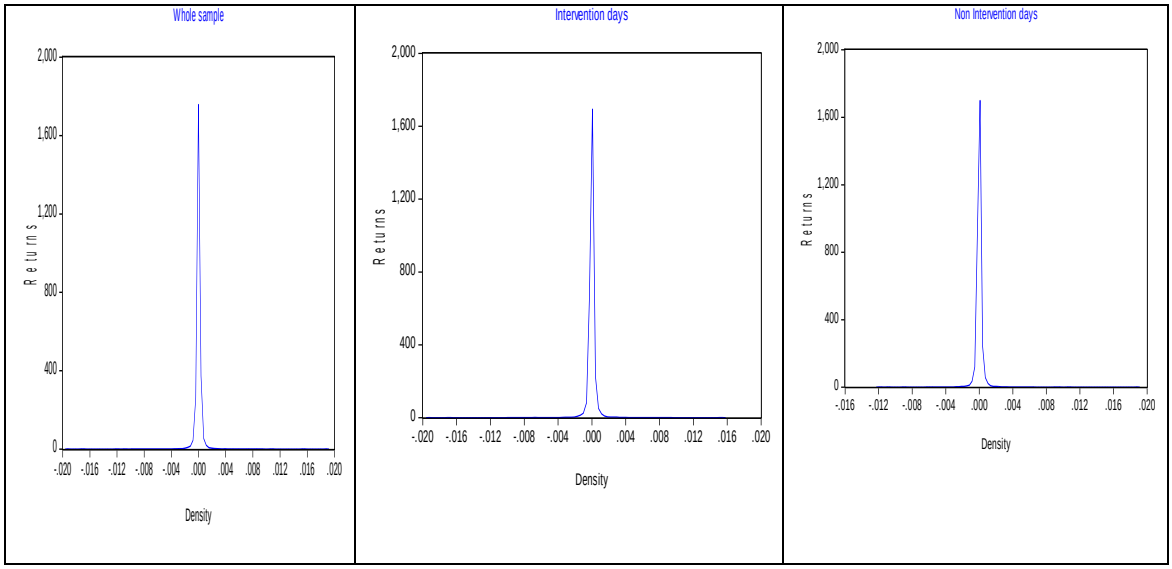
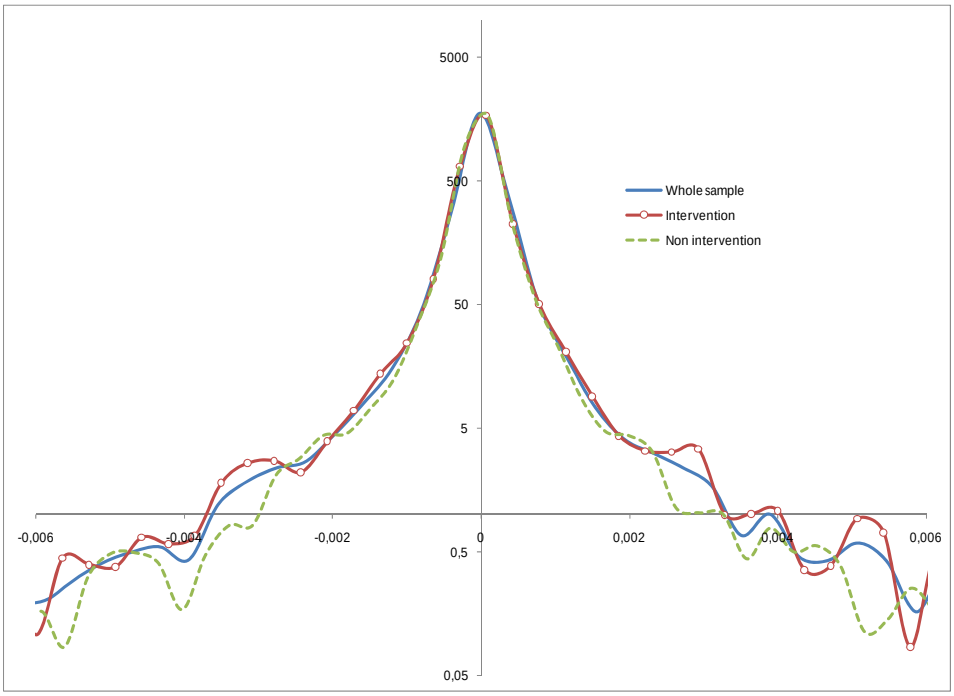
Graph A2. Peru: PDF of transactions returns 5 minutes



A closer look at the properties of the above distributions can be performed logscaling the densities as shown in Graph 4. We can see that for small returns the densities are very similar but as returns get larger in absolute value, the density values in non-intervention days become smaller. This fact is associated with a smaller variance of returns in those days. This fact also means that the density function during non-intervention days have to have more kurtosis (in order for the integral above the densities to be unity) for returns larger than 0,6% in absolute value. For example, there are extreme returns as large as 1,9% or as low as -1,2%. This graphical inspection then confirms the statics reported in the tables so far.

Graph A1. Peru: Empirical distribution of 5min returns with logarithmic densities



References

Andersen, T G, T Bollerslev, F X Diebold and Clara Vega “Micro Effects of Macro Announcements: Real-Time Price Discovery in Foreign Exchange” *American Economic Review*, 93, 38-62.

Brunnermeier, M K, S Nagel, and Lasse Heje Pedersen (2009): “Carry Trades and Currency Crashes,” In Daron Acemoglu, Kenneth Rogoff and Michael Woodford, editors *NBER Macroeconomics Annual 2008*, Volume 23.

Brunnermeier, M. K., and L. H. Pedersen (2009): “Market Liquidity and Funding Liquidity," *Review of Financial Studies* 22(6):2201-2238.

Dominguez, K (2003): "The Market Microstructure of Central Bank Intervention" Journal of International Economics, Vol 59/1, 25-45, January.

Dominguez, K (2006): "When Do Central Bank Interventions Influence Intra-Daily and Longer-Term Exchange Rate Movements?", *Journal of International Money and Financ*e, 25, 2006, 1051-1071.

Dorn, D. and Huberman, G. (2010) “Preferred Risk Habitat of Individual Investors” Journal of Financial Economics, 97, 1, pages 155-173.

Jorion, P. (1996) “Risk and Turnover in the Foreign Exchange Market”, Chapter 1 of the book “The Microstructure of Foreign Exchange Markets” edited by Frankel, J., Galli, G. and Giovannini, A., University of Chicago Press, http://www.nber.org/books/fran96-1.

Moreno, R (2005): “Motives for Intervention,” In Bank for International Settlements (ed), *Foreign exchange market intervention in emerging markets: motives, techniques and implications*, BIS Papers No. 24, Bank for International Settlements.

Tauchen, G., & Pitts, M. (1983) “The price variability-volume relationship on speculative markets”, Econometrica 51, pages 485-505.

Thurner, S, JD Farmer and J Geanakoplos (2012). “Leverage causes fat tails and clustered volatility,” Quantitative Finance (12(5)): May, pp 695-707.