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The Empirics of Foreign Exchange Intervention in Emerging Market Countries: The Cases of Mexico and Turkey

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Abstract

This paper analyzes the effects of intervention on the level and volatility of the exchange rate in Mexico and Turkey, two emerging countries that have floating exchange rate regimes. The paper finds mixed evidence on the effectiveness of intervention. In Mexico, foreign exchange sales have a small impact on the exchange rate level and raise short-term volatility, while in Turkey, intervention does not appear to affect the exchange rate level but reduces its shortterm volatility. In both cases, the findings are consistent with officially stated policy objectives, which aim to minimize the effect of intervention on the exchange rate, but cast doubt on claims that intervention is a useful tool for smoothing volatility. Although these findings cannot be generalized to other emerging markets, intervention's apparently limited effectiveness highlights the need for central banks to use their scarce foreign reserves selectively and parsimoniously.

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I. Introduction

Central banks in emerging market countries intervene in the foreign exchange market frequently and sometimes in very large amounts. Interventions usually aim to correct exchange rate misalignment, moderate exchange rate volatility, accumulate reserves, and supply foreign exchange to the market. But most interventions are directed at the exchange rate, whether it be to fix it, realign it, or reduce its volatility. Under flexible exchange rate regimes, the timing and amount of intervention—including whether or not to intervene at all—become critical policy decisions.[2] Central banks have an overriding interest in the *effectiveness* of intervention since intervention exposes them to reputational and financial risks. In many countries, intervention remains important even after moving to managed and independently floating exchange rates from various forms of pegs (Bubula and Otker-Robe, 2002, and Reinhart and Rogoff, 2003).

While adopting greater exchange rate flexibility, many countries are reluctant to allow the exchange rate to fluctuate. Exchange rate stability still commands a high premium in emerging markets where policy credibility is lower and pass-through from exchange rate movements to inflation is higher (Calvo and Reinhart, 2002). Liability dollarization and an inability to borrow abroad in their own currencies—which heighten domestic borrowers' exposure to exchange rate risk—also lower countries' tolerance of exchange rate volatility (Hausmann and others, 2001). A small number of market makers, low turnover in the interbank foreign exchange market, and greater exposure to external shocks are added sources of volatility in several emerging market economies. Intervention thus remains widespread.[3]

Despite the prevalence of intervention in emerging markets, empirical research on its effectiveness is limited.[4] This primarily reflects the absence of publicly available data on intervention in emerging markets. Moreover, it is difficult to model or control for changes in policy reaction functions and central bank credibility in high-frequency time-series analysis.

Intervention may be more effective in emerging markets than in advanced ones for several reasons. Many countries intervene in amounts that are large relative to market

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[2] Under a fixed exchange rate regime, foreign currency supply and demand conditions dictate the timing and amounts of official intervention.

[3] See the results of the IMF's 2001 Survey of Foreign Exchange Market Organization reported in Canales-Kriljenko (2003).

[4] Domac and Mendoza (2003) and Tapia and Tokman (2004) are rare exceptions. By contrast, there is a vast literature on *advanced* economies, which finds mixed evidence in favor of intervention. Where evidence of effectiveness is found, the impact is short lived (see next section).

turnover. They also use a variety of foreign exchange, monetary, and banking regulations that effectively constrict the size of the market, increasing the central bank's size in it. The central bank may also have an information advantage over the market stemming from reporting requirements (Canales-Kriljenko, 2003).

Against this background, this paper evaluates the effectiveness of intervention in two emerging market economies—Mexico and Turkey—which were chosen because of the availability of daily intervention data and because they have flexible exchange rate regimes. Using standard methodologies in the literature, effectiveness is measured in terms of the impact of intervention on the level and volatility of the exchange rate. In addition, the paper differentiates between intervention's effects on short-term versus long-term exchange rate volatility.

The paper finds mixed evidence on the effectiveness of intervention. In the case of Mexico, foreign exchange sales (but not purchases) have a small but statistically significant impact on the exchange rate level. Since the bulk of interventions by the *Banco de Mexico* during the period considered here consisted of foreign exchange purchases aimed at accumulating reserves, this is broadly in line with the authorities' objective of intervening without affecting the underlying exchange rate trend. In Turkey, official intervention does not appear to systematically affect the exchange rate levels, a result consistent with the authorities' goal of maintaining a market-determined exchange rate regime. Intervention's impact on exchange rate volatility also differs in both countries: It raises short-term exchange rate volatility in Mexico, but reduces it in Turkey. These findings cannot be generalized to other emerging markets and can only be interpreted in the context of specific country circumstances.

The remainder of the paper is organized as follows. Section II reviews the analytical techniques used to evaluate intervention and the empirical evidence—most of it on G-10 countries—on its effectiveness. Section III discusses the intervention policies of Mexico and Turkey. Section IV presents the data, empirical methodology and results, and Section V concludes.

II. Empirical Analysis and Evidence on Intervention

A. Channels of Influence

The vast literature on foreign exchange intervention focuses on three main channels of influence: signaling, portfolio balancing, and market microstructure.

- Intervention can be effective through the *signaling channel* if it is perceived as a credible signal on the future stance of monetary policy. To the extent that intervention, even when sterilized, influences expectations on *future* money supply, then it can influence the exchange rate.

- According to the *portfolio balance channel,* domestic and foreign currency denominated bonds assets are imperfect substitutes (and therefore, the "riskier" bond pays a risk premium) and intervention can be effective by modifying the currency composition of agents' asset portfolios.[5] Sterilized intervention alters the relative supply of domestic versus foreign currency bonds, leading agents to rebalance their portfolios to equalize risk-adjusted returns, which causes a change in the exchange rate.

- The *microstructure approach* emphasizes the effects of order flow, market participants, information asymmetries, and price discovery in the foreign exchange market. Central bank trades are assumed to emit information to the market, which modifies exchange rate expectations and ignites a tide of foreign exchange orders, magnified in part by trend-chasing traders (Lyons, 2001). Intervention-induced order flow, in turn, tends to increase short-term exchange rate volatility.

B. Analytical Techniques

A wide array of analytical techniques have been used to evaluate the effectiveness of intervention.[6] Analyses have examined intervention's impact on the exchange rate level using OLS regressions of the mean and risk premium equations or through event studies of intervention episodes (Appendix Table 1). Intervention's impact on exchange rate volatility has been gauged through various forms of generalized autoregressive conditional heteroskedasticity (GARCH) models.

Regression analyses all suffer from simultaneity problems. In particular, the regression of exchange rate changes over intervention fails to disentangle the degree to which intervention reacts to exchange rate movements rather than the other way around. As a result, the coefficient can assume the wrong sign or overstate the impact of intervention on the exchange rate.[7] Another key shortcoming of existing techniques, including event studies, is

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[5] There is a rich literature, surveyed in Engel (1996), showing that there is a sizeable time-varying risk premium, which is a necessary but not sufficient condition for intervention to impact the exchange rate through the portfolio balance channel. Most of the evidence on risk premia concentrates on advanced economies. The limited evidence for emerging markets suggests that the risk premium may be substantial, but results are weakened by small sample size and structural changes (e.g., exchange rate regime changes).

[6] See Edison (1993) and Sarno and Taylor (2001) for excellent surveys of methodologies used and the empirical evidence on the effectiveness of intervention. It is often the case that empirical studies cannot disentangle the effects of the different channels through which intervention affects the exchange rate, see for example, Dominguez and Frankel (1993a, b).

[7] Researchers have also analyzed central bank reaction functions, inclusive of the exchange rate, to gauge the extent to which intervention responds to the exchange rate. However,

(continued…)

the short time horizon—typically the same day—over which intervention's effectiveness is analyzed.

More recently, attempts have been made to overcome the simultaneity and time horizon problems through a joint analysis of monetary and exchange rate operations. Using an identified vector autoregression framework (IVAR), Kim (2003) and Guimarães (2004), empirically analyze the impact of monetary and intervention operations on the exchange rate and the extent to which intervention occurs in reaction to exchange rate movements. The IVAR framework can estimate the longer-term effects of intervention through an analysis of cumulative impulse responses. Moreover, the use of monthly data eases the limitation imposed by the absence of daily data (though intervention data are still obtained through the aggregation of daily data). However, there are some disadvantages to the use of IVAR, including the limited degrees of freedom (small sample and too many parameters), the validity of the identifying restrictions, and the plausibility of the structural shocks (Guimarães, 2004).

Another strand of the literature on the effects of intervention examines the links between intervention and exchange rate volatility. The potential impact of intervention on volatility is worth studying since many central banks intervene to smooth volatility, even when they are not targeting a particular level of the exchange rate. In addition, exchange rate volatility has often been associated with economic crisis and may be a signal of lack of policy credibility, which gives rise to fear of floating (Calvo and Reinhart, 2002).[8] Finally, volatility may have harmful effects on trade and capital flows, although evidence supporting this claim is weak (Rogoff, 1999).

The single most important impediment to empirical work on intervention's effectiveness is the lack of publicly available data on daily intervention. Attempts to use proxies of intervention—e.g., the change in the stock of central bank reserves—have not worked. Neely (2001) has shown that even for G-7 countries, changes in reserves are a poor proxy for intervention: Correlation coefficients between foreign exchange intervention and reserve changes are usually less than 0.4. The use of such proxies in developing countries can be even more misleading since reserve changes may reflect, *inter alia*, withdrawals of funds from multilateral organizations, government debt repayments, receipts from state-owned companies, and inflows of foreign aid.

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analyses of central bank reactions also suffer from the same weakness, but in reverse. Intervention is assumed to be ineffective; otherwise, simultaneity arises once again.

[8] More generally, *excessive* volatility may be a symptom of disorderly markets, which involve a collapse of liquidity. However, it is often difficult to identify empirically (*ex-ante*) episodes of excessive exchange rate movements that are unwarranted (Canales-Kriljenko and others, 2003).

C. Empirical Evidence

Empirical studies on the effectiveness of central bank sterilized intervention have focused almost exclusively on advanced countries. The research bias towards advanced countries primarily reflects the availability of data and the depth and sophistication of their foreign exchange markets assumed in many models of intervention.

Empirical tests have found mixed evidence in favor of the signaling and portfolio balance channels. For example, Dominguez and Frankel (1993a) estimate the effect of intervention on contemporaneous exchange rate movements and on forecasts of future exchange rates. Using survey data to measure exchange rate expectations, they find a significant effect of intervention on market expectations, especially if interventions are announced and coordinated. They also show that secret interventions are largely ineffective. Obstfeld (1990) finds that portfolio balance effects are statistically significant, but small in size. The consensus in the literature until recently was that the portfolio effect gives a limited role for intervention to influence the exchange rate. One exception was a study that found a significant and potentially large portfolio effect during the 1984–88 period, using *survey data* to measure exchange rate expectations and risk premium (Dominguez and Frankel, 1993b).

Recent research using data on order flow, however, identifies permanent price effects through the portfolio balance channel. Evans and Lyons (2001, 2002) found that intervention has a significant price impact in the most liquid currency pair market (before the introduction of the euro), the U.S. dollar-deutsche mark. The *permanent* effect of a US$1 billion dollar purchase was to appreciate the dollar by about 0.35 percent.[9] They also found that foreign exchange transactions have the largest impact on the exchange rate when the flow of macroeconomic announcements is high.[10]

More generally, in a series of papers using an event study approach, Fatum (2000) and Fatum and Hutchison (2003a, b) find strong evidence in favor of intervention. In analyses of both the US dollar-deutsche mark and U.S. dollar-Japanese yen bilateral exchange rates, they find that sterilized intervention systematically affects the exchange rate level, regardless of whether it is secret or announced. The probability of success is much higher, however, when interventions are coordinated among central banks and when they are conducted on a large scale (i.e., greater than $1 billion). Also using an event study approach, Edison and others (2003) find that the Reserve Bank of Australia's interventions had some

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[9] Their estimate for the immediate price impact of trades was 0.44 percent per $1 billion (of which, about 80 percent persists indefinitely).

[10] The estimated impact of intervention is at best an indicator of the impact of intervention under normal market conditions. In a speculative attack, for example, the credibility of the central bank is so low and liquidity so unpredictable that the estimates above should not even be used as a first approximation.

success—albeit a modest one—in moderating the depreciating tendency of the Australian dollar, but interventions also increased exchange rate volatility.

The impact of intervention on exchange rate volatility has also been extensively researched. Intervention appears to be ineffective in reducing volatility, and oftentimes, increases it.[11] Both Dominguez (1998) and Hung (1997) provide evidence that following the Plaza Accord (September 1985) intervention tended to reduce exchange rate volatility among the G-3 currencies, but when the post-Louvre (1987–1989) period is examined, intervention increased volatility. Bonser-Neal and Tanner (1995) use implied volatilities from currency option prices and find that intervention raises exchange rate volatility. Beine and others (2002) study a longer period of interventions spanning 1985–1995 and also find that intervention increases exchange rate volatility in the short run. Cheung and Chinn (1999) conducted a survey with foreign exchange traders, 60 percent of whom view intervention as increasing exchange rate volatility.

Joint analyses of monetary and exchange rate policy actions find that intervention is effective in the case of the U.S. during the period 1973–1996 (Kim, 2003) and Japan (Guimarães, 2004). The approach is based on a structural VAR model similar to those used to study the monetary transmission mechanism. The identifying restrictions used in these models allow the exchange rate to have a contemporaneous impact on intervention, which captures the leaning against (or with) the wind by the intervening authorities. Moreover, the VAR model also permits the estimation of the impact of conventional monetary policy shocks (money or interest rate) on the exchange rate. The results also suggest that intervention in those two countries is sterilized and has an impact (small but significant) beyond the short-term considered in most studies that use daily data.

In contrast with most findings for advanced economies, empirical evidence on the effects of intervention in emerging market economies has been scant. In their empirical analysis of intervention in Mexico and Turkey, Domac and Mendoza (2002) conclude that central bank foreign exchange sales (but not purchases) were highly effective in influencing the exchange rate and in reducing volatility in both countries. In particular, they find that a net sale of US$100 million appreciates the exchange rate by 0.08 percent in Mexico and 0.2 percent in Turkey. A more recent study on Chile found that intervention had a small and generally insignificant effect on contemporaneous exchange rate movements, but in contrast,

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[11] The measurement of exchange rate volatility is typically based on two approaches. The first method is to use a statistical model, such as GARCH. This approach has the advantage of being simple and is increasingly used in the market to estimate asset price volatility. Several market participants use GARCH based models of volatility, such as *Riskmetrics,* to help monitor their positions and calculate value at risk. Another approach is to use options-based measures of volatility. Options pricing models can be "inverted" to yield implied volatilities of the underlying asset.

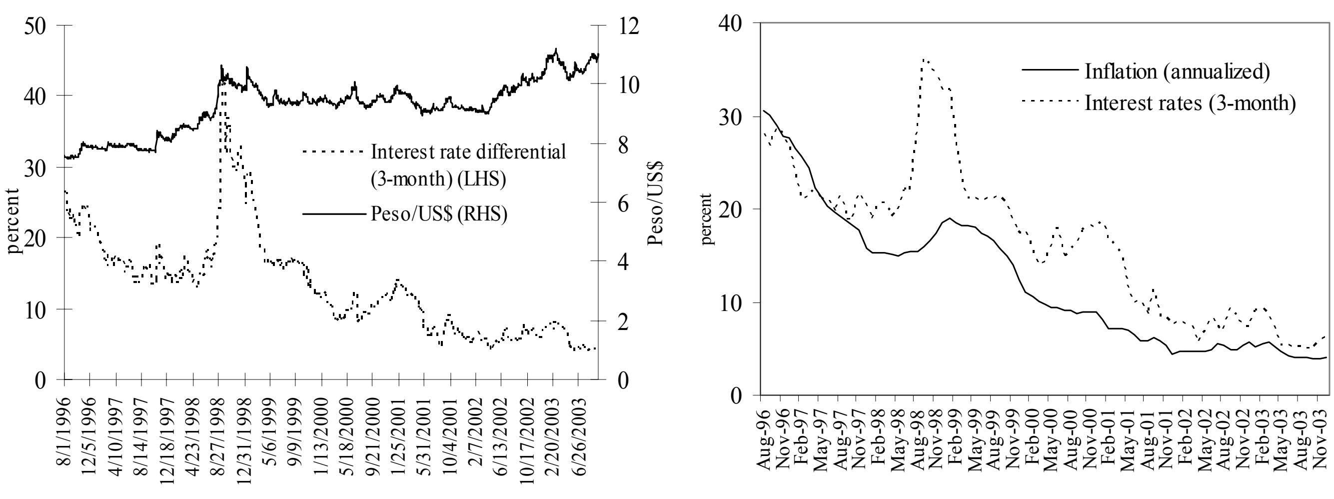
public announcements on *potential* intervention had a statistically significant impact on the level and trend of the exchange rate (Tapia and Tokman, 2004).

III. Intervention in Mexico and Turkey: The Policy Context

A. Mexico

Despite the peso's floatation in 1994, the Mexican central bank has continued to intervene in the foreign exchange market to smooth exchange rate volatility. The concern over exchange rate volatility has stemmed from the exchange rate's role as a key monetary policy variable, even though it has lost its anchor role to inflation targets since 1999. As in other emerging markets, the exchange rate has remained a determinant of inflationary expectations, even under the inflation targeting framework (Carstens and Werner, 1998, Ho and McCauley, 2003). Under inflation targeting, inflation and interest rates have come down substantially since the mid-1990s (Figure 1).

Figure 1. Mexico: Exchange Rate, Interest Rate, and Inflation

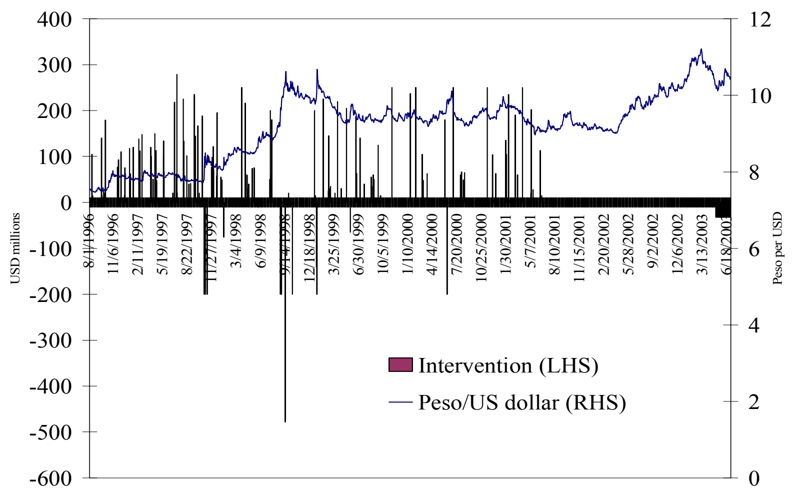


Source: Bank of Mexico and Datastream.

The authorities intervened to accumulate reserves, given the low level of international reserves in the immediate aftermath of the peso crisis. To this end, the central bank began auctioning put options with the objective of gradually building up reserves in August 1996. The central bank sold put options on the last business day of each month, allowing the holders of the option to sell U.S. dollars to the central bank anytime during the life of the option provided that the exercise price, the exchange rate of the day before, was more appreciated than the 20-day moving average of the interbank spot exchange rate. This condition limited the potential loss faced by the Banco de Mexico since the option could only be exercised if the peso was stronger than its 20-day moving average.[12] The auction of put options continued until June 2001, and resulted in an accumulation of reserves equivalent to 30 percent of reserves when the program ended (about US$14 billion). Intervention amounts and the peso-dollar exchange rate are shown in Figure 2.

During 1996–2003, the central bank also intervened 14 times in a discretionary fashion, selling foreign exchange to stabilize the exchange rate, but no particular level was targeted. Sales of U.S. dollars were large, totaling US$2.9 billion, but still relatively low compared to the dollar *purchases* made through auctions of put options.[13]

Figure 2. Mexico: Exchange Rate and Foreign Exchange Intervention



Source: Bank of Mexico.

A significant accumulation of reserves prompted the authorities to start selling foreign exchange directly to the market by May 2003. The amount to be sold to the market in a given quarter is pre-announced and equivalent to 50 percent of the reserves accumulated in the preceding quarter. The daily amount is based on the total amount for the quarter evenly distributed over the number of business days of the period in question. The switch was aimed at reducing the pace of reserve accumulation and the cost of holding additional international reserves, which had reached US$50 billion at end-2002, equivalent to more than 120 percent of short-term debt (by residual maturity) or about 50 percent of the monetary base, up from

[12] The holder of the option could profit from exercising the option only if the exchange rate on the day of its exercise was stronger than the day before, i.e., the strike price.

[13] The average size of U.S. dollar sales approached US$205 million, similar to a typical intervention by the U.S. authorities in the first half of the 1990s. Importantly, official interventions (both options-based and discretionary) represented a sizable fraction of daily turnover in the foreign exchange market.

less than US$20 billion at end-1996. Dollar sales have been comparatively small in magnitude (up to US$32 million-daily), but much more frequent relative to the earlier program. According to the authorities, a major feature of both the options mechanism and the pre-announced sales is that they minimize the impacts on the market mechanism (e.g., pricing decisions) with negligible consequences for exchange rate volatility, claims that can be tested empirically (next section).

B. Turkey

The case of Turkey offers important insights on the challenges and limitations of empirically analyzing the effectiveness of intervention. Among emerging market economies, Turkey is one of the few countries with a (managed) floating exchange rate regime, where daily intervention data, albeit somewhat incomplete, is available. During the period studied here (March 2001–October 2003), the country implemented substantial economic reforms, lived through bouts of domestic political uncertainty, and was hit by contagion from financial market shocks.

Turkey's exit from a crawling peg in February 2001 shifted the burden of price discovery to the foreign exchange market at a time when it was still undeveloped. During the crawling peg exchange rate regime, the foreign exchange market was heavily influenced by the Central Bank of Turkey (CBT), with most banks trading bilaterally with the CBT rather than among themselves. At the time of the exit from peg foreign exchange market liquidity was low, hedging instruments were virtually nonexistent, and financial institutions were caught with sizable short foreign currency positions and with limited capacity to manage foreign exchange risk. As a result, low turnover in the foreign exchange market may have been a dominant factor in the determination of the exchange rate compared to CBT's interventions, at least during the early phases of the period analyzed here.

Since the floatation of the lira, the CBT's interventions have undergone several phases (Table 1). The CBT initially sold foreign exchange through auctions to sterilize the liquidity injections associated with the Turkish Treasury's use of external financial resources. These were combined with discretionary interventions to smooth exchange rate volatility related to negative external developments and domestic political problems (CBT, 2001). The CBT began conducting *pre-announced* (timing and amount) foreign exchange sale auctions in March 2001. Preannounced auctions were designed to enhance the transparency of official intervention and minimize their price impact. Auctions remained the main form of intervention throughout 2001, with brief interludes of discretionary intervention in lieu of or in parallel with preannounced auctions. Throughout 2001, the CBT sold US$6.5 billion in foreign exchange, enabling financial institutions to cover their short positions.

The month of April 2002 marked the beginning of the second set of intervention phases, characterized by foreign exchange purchase operations. The move from foreign exchange sales to purchases was driven in part by reverse currency substitution engendered by growing confidence in the policy formulation and implementation, and a pick up in capital inflows (CBT, 2002). Foreign exchange purchases—first through preannounced auctions, then on a discretionary basis—were suspended in July 2002 amidst uncertainties before the November 2002 general elections, but resumed in May 2003 as uncertainties faded and reverse currency substitution continued.

Table 1. Turkey: Central Bank Foreign Exchange Intervention (March 2001–December 2003)

Dates	Duration (Days)	Type of Intervention	Frequency	Amounts Sold (+) or Purchased (-) (US$, millions)
2/23/01–3/28/01	...	Discretionary auctions and **sales**	Ad-hoc	...
3/29/01–5/17/01	37	Preannounced **sales**	Daily	2,040
5/18/01–7/11/01	39	Discretionary **sales**[1]	Ad-hoc	1,678
7/12/01–8/31/01	38	Preannounced and discretionary **sales**	Bi weekly	1,575
9/4/01–11/30/01	64	Preannounced **sales**	Daily	1,180
12/1/01–3/31/02	85	No intervention	...	...
4/1/02–4/30/02	22	Preannounced **purchases**	Daily	(280)
5/1/02–6/28/02	43	Discretionary **purchases**	Ad-hoc	(515)
7/1/02–5/5/03	212	No intervention[2]	...	...
5/6/03–8/31/03	83	Preannounced and discretionary **purchases**[3]	Daily	(2,960)
9/1/03–10/1/03	29	Preannounced **purchases** with option for additional purchases	Daily	(1,824)

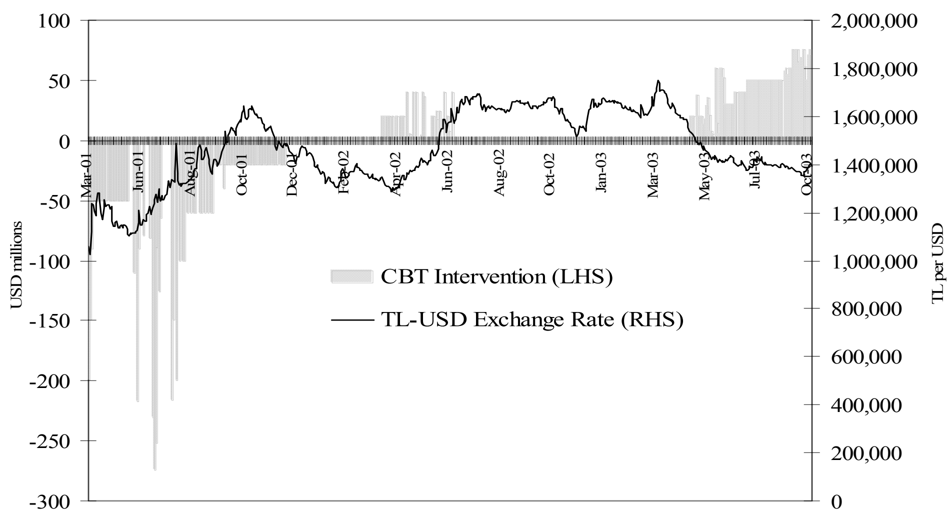
Source: Central Bank of Turkey, annual reports, press releases, and website (www.tcmb.gov.tr).
[1] Data on the CBT's discretionary interventions is not available.
[2] From July to December 2002, the CBT intervened three times (purchases) on a discretionary basis.
[3] The amounts of discretionary purchases were not disclosed.

Strong upward pressure on the lira caused the CBT to combine preannounced purchase auctions with discretionary or optional foreign exchange purchases. As a result, the CBT accumulated close to US$5 billion in reserves from May through October 2003. It is also worth noting that there were lengthy periods when the CBT did not intervene in the market at all (December 2001–March 2002 and July 2002–April 2003).

Despite its frequent presence in the market over long periods, the CBT has stated repeatedly through press releases and official policy statements that its interventions do not target a specific exchange rate level (CBT, 2003). These policy pronouncements, in principle, may be interpreted as having been designed to undercut the signaling channel by which intervention can influence the exchange rate.

Nevertheless, the CBT has been concerned about exchange rate misalignment and volatility (CBT, 2001, 2002, and 2003). The exchange rate has remained an important determinant of inflationary outcomes and expectations even after the float, and the authorities have been vigilant against volatility and have resisted it, market conditions and international reserve levels permitting. Figure 3 suggests that CBT interventions tended to "lean against the wind," particularly during June–October 2001 and May–October 2003, among the two periods of heaviest intervention. Moreover, its interventions appear to have been more successful in tempering exchange rate movements when the lira was under upward rather than downward pressure.

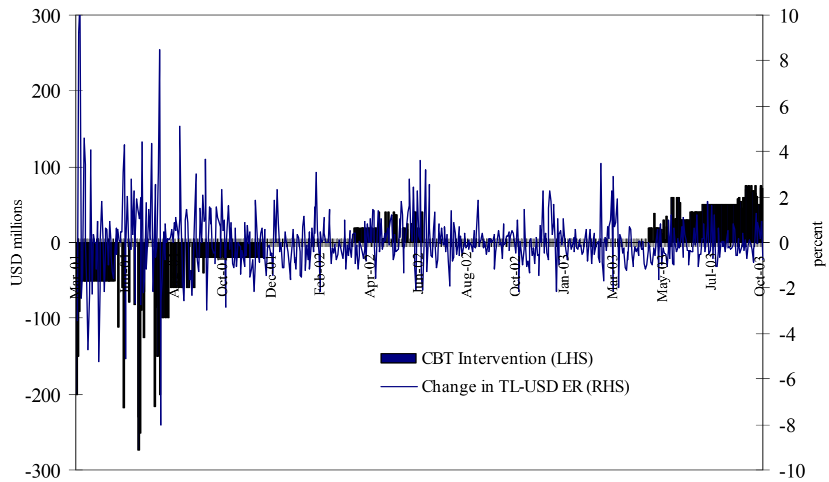
Figures 3. Turkey: Central Bank Intervention in the Foreign Exchange Market
March 29, 2001–October 3, 2003



Source: Central Bank of Turkey and Datastream.

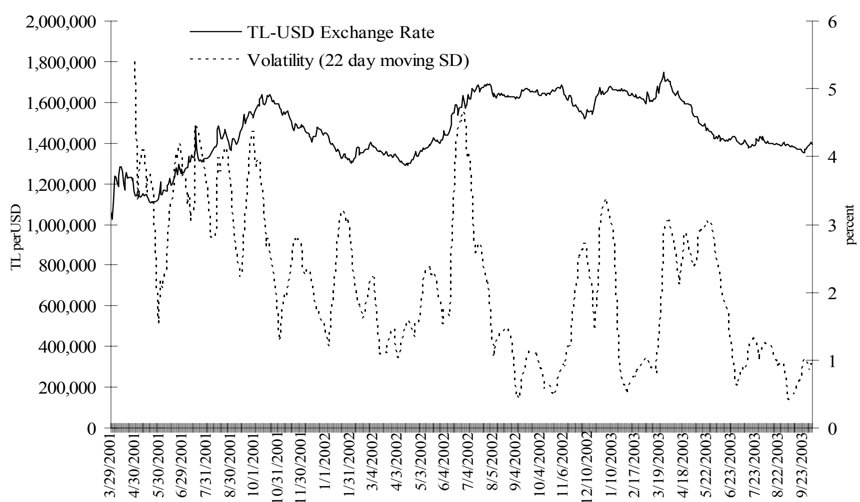
Over the period of interventions analyzed here, market conditions and the CBT's operating environment became more favorable. First, the CBT gradually regained credibility as it adhered to its monetary program and exercised restraint and transparency in the conduct of foreign exchange intervention. Second, the shift to the new nominal anchors, from base money to the inflation target, have become increasingly entrenched, reducing the pass through from the exchange rate to inflation (CBT, 2003). Third, favorable external finances and reverse currency substitution put upward pressure on the Turkish lira, aiding efforts to reduce inflation, lower interest rates, and bolster debt sustainability. As a result, the supply of foreign exchange in the market consistently exceeded preannounced amounts set for the purchase auctions. Exchange rate volatility also declined, albeit gradually (Figures 4 and 5). Fourth, the emergence of a vibrant interbank foreign exchange market and CBT's less dominant role in it created more room for market participants to price foreign exchange and manage currency risks.

Figure 4. Turkey: Central Bank Intervention in the Foreign Exchange Market
March 29, 2001–October 3, 2003



Source: Central Bank of Turkey and Datastream.

Figure 5. Turkey: Exchange Rate Trend and Volatility



Source: Datastream

IV. THE EFFECTIVENESS OF FOREIGN EXCHANGE INTERVENTION

Empirical work on foreign exchange intervention in emerging market countries has been limited, despite the factors that suggest that intervention may be more effective in these countries.[14] The evidence surveyed by Canales-Kriljenko (2003) suggests that official intervention in developing countries may be more effective because (i) its size is usually large relative to the local market (order flow, bonds outstanding), (ii) domestic and foreign bonds are more likely to be imperfect substitutes,[15] and (iii) the central bank may enjoy additional informational advantages due to the market size/infrastructure and reporting requirements.

A. Data Description

Mexico

Data on foreign exchange interventions are publicly available in daily frequency and cover the period August 1996 through June 2003. Both option-based and discretionary interventions are included. The data were obtained from Banco de Mexico's website (www.banxico.org.mx) and consist of a total of 1800 observations, including no-intervention days. The other data include the spot exchange rate (peso per U.S. dollar), Mexican interest rate (Cetes 90-day), U.S. 3-month T-bill rate, yields on the Brady bond, and turnover and open interest on the Mexican peso contract traded on the Chicago Mercantile Exchange's International Money Market (IMM). The second part of the data set was obtained from Datastream.

Table 2 presents the descriptive statistics for the exchange rate, the (log) first-difference of the exchange rate, interest rate differential, and spreads on Brady bond yields. The results for the ADF unit root test for the variables used in the regressions indicate that the series are nonstationary (with the exception of the differenced series) and some display other characteristics shared by financial time series, including departures from normality (e.g., fat tails and skewness) and volatility clustering, which are explored in the empirical models used in this paper.[16]

[14] The papers by Canales-Kriljenko (2003) and Canales-Kriljenko and others (2003) discuss those arguments in more detail.

[15] Cumby and Obstfeld (1983) present evidence supporting the imperfect substitutability between peso-denominated and foreign currency assets for Mexico using data from the 1970s.

[16] The ADF regression is run with up to 5 lags and the number of lags included is selected according to the Bayesian Information Criteria (BIC). The DF-GLS tests yield similar results.

Table 2. Mexico: Descriptive Statistics

Sample Period	Mean	Standard deviation	Skewness	Kurtosis	Jacque-Bera	Stationarity[1]
Total Sample (Aug. 1996-Jun. 2003)						
Peso-dollar ER	9.1944	0.8490	-0.3226	2.4231	56.2	Non-stat
1st Diff of Log ER	0.0179	0.5636	1.4430	21.1448	25317.4	Stat
Interest Diff (%)	13.3929	7.0010	1.0783	4.2810	471.9	Non-stat
Spreads (bps)	11.0762	1.5447	1.0606	4.1467	436.1	Non-stat
Sub-Sample I (Aug. 1996-Jun. 2001)						
Peso-dollar ER	8.9513	0.8086	-0.3583	1.7697	108.3	Non-stat
1st Diff of Log ER	0.0139	0.6008	1.6036	22.4679	20794.5	Stat
Interest Diff (%)	16.2928	6.2505	1.2933	4.9176	553.8	Non-stat
Spreads (bps)	11.2855	1.5988	1.0690	3.8231	280.4	Non-stat

Source: Bank of Mexico and authors' calculations. [1]
According to the Augmented Dickey-Fuller Test with a trend term and a maximum number of 15 lags selected according to the Bayesian Information Criteria, at the 90, 95, 99 percent confidence intervals. Stat (Non-stat) refers to stationary (nonstationary), i.e. rejection of the unit root null at the 5 percent level.

Turkey

Daily data on foreign exchange sale and purchase auctions were obtained from the CBT's website (www.tcmb.gov.tr). The data set spans March 29th 2001 through October 3rd 2003 with over 600 observations. It excludes discretionary foreign exchange sales and purchases through brokers and banks, including the CBT's large discretionary purchases that exceeded those through auctions between May–October 2003. However, the absence of data on discretionary interventions, which we model through the use of a dummy variable, does not seem to be an important handicap in the empirical analysis.

Descriptive statistics on variables used to analyze the effectiveness of intervention are presented in Table 3. Distributions of all variables are asymmetric and nonnormal. Augmented Dickey-Fuller tests indicate that nearly all variables are nonstationary; and thus we take first differences before including them in the regressions.

The data sample was divided into two subperiods and separate GARCH regressions were run on the subperiods as well as the entire sample. Dividing the sample into two facilitates the analysis of important differences in the type of interventions (sales versus purchases) and the environment in which they were conducted. The first subperiod, spanning March 2001 through June 2002, was dominated by foreign exchange sales and characterized by greater market and political uncertainty. The second subperiod, from July 2002 through October 2003, represented a period of greater confidence in the policy environment in which virtually all of the CBT's interventions were purchase operations. Compared to the first, interest rates and spreads were substantially lower and their volatility, along with that of exchange rates, was considerably less during the second subperiod.

Table 3. Turkey: Descriptive Statistics

Sample Period	Mean	Standard deviation	Skewness	Kurtosis	Jacque-Bera	Stationarity[1]
Total Sample (3/29/01- 10/1/03)						
TL-US$ ER	1,468,505	153,143	(0.313445)	2.266825	24.50417	Non-stat
1st Diff of Log ER	0.000489	0.013502	1.201994	15.52918	4279.219	Stat
Interest Diff (%)	48.75443	10.58766	0.449373	3.080784	21.44245	Stat
Spreads (bps)	790.4415	153.7943	0.255735	2.016018	32.38531	Non-stat
Sub-Sample I (3/29/01- 6/30/02)						
TL-US$ ER	1,375,984	131,347.8	(0.103088)	2.542028	3.300235	Non-stat
1st Diff of Log ER	0.001374	0.017393	0.935264	10.96643	873.3082	Stat
Interest Diff (%)	57.25809	7.534352	0.884976	4.090351	56.54089	Non-stat
Spreads (bps)	809.0573	161.0070	0.24335	1.872148	19.79255	Non-stat
Sub-Sample II (7/1/02-10/3/03)						
TL-US$ ER	1,559,861	113,125.6	(0.531649)	1.657559	38.85893	Non-stat
1st Diff of Log ER	(0.000383)	0.007939	0.827176	5.574887	124.1117	Stat
Interest Diff (%)	40.35774	4.983065	(1.095038)	2.969123	63.56535	Non-stat
Spreads (bps)	772.0597	144.2331	0.186389	2.024692	114.44501	Non-stat

Source: Central Bank of Turkey, Datastream and authors' calculations.

[1] According to the Augmented Dickey-Fuller Test with a trend term and a maximum number of 15 lags selected according to the Bayesian Information Criteria, at the 90, 95, 99 percent confidence intervals. Stat (Non-stat) refers to stationary (nonstationary), i.e. rejection of the unit root null at the 5 percent level.

B. Empirical Model

The effects of intervention on the level and volatility of exchange rates is analyzed within the GARCH framework. The primary advantage of GARCH models is that they provide a unified framework to gauge the impact of intervention on the mean *and* conditional variance of exchange rate returns simultaneously. The empirical model allows the estimated conditional volatility to enter the mean equation (i.e., the "GARCH-in-mean" effect) and tests for asymmetric effects on volatility of "negative" shocks, defined as unexpected exchange rate depreciations. In addition to its computational simplicity, GARCH models provide relatively good forecasts of realized volatility, and have proved useful for modeling the volatility dynamics of exchange rates and asset prices more generally (Andersen and Bollerslev, 1998).

The empirical analysis of the effectiveness of intervention is based on the Asymmetric Component Threshold GARCH (ACT-GARCH) specification, which jointly estimates the impacts of intervention on volatility at different time horizons. The volatility part of the model allows for asymmetric responses of the conditional volatility to unexpected exchange rate depreciations. Furthermore, the model is consistent with stylized facts in asset pricing empirics, including persistence and volatility clustering.

The baseline model is given by:

(1) $$\Delta s_t = \beta_0 + \beta_1 I_t^- + \beta_2 I_t^+ + \beta_3 \Delta d_t + \beta_4 \Delta sp_t + \varepsilon_t$$

(2) $$h_t = q_t + \alpha\,(\varepsilon^2_{t-1} - q_{t-1}) + \tau((\varepsilon^2_{t-1} - q_{t-1})z_{t-1} + \delta(h_{t-1} - q_{t-1}) + \gamma_1 I_t^- + \gamma_2 I_t^+ + \gamma_3 \Delta d_t + \gamma_4 \Delta sp_t$$

(3) $$q_t = \omega + \rho(q_{t-1} - \omega) + \varphi((\varepsilon^2_{t-1} - h_{t-1}) + \gamma_5 I_t^- + \gamma_6 I_t^+ + \gamma_7 \Delta d_t + \gamma_8 \Delta sp_t$$

where Δs_t is the (log) first-difference of the exchange rate (expressed in terms of local currency per US dollar and in log form), I_t^- (I_t^+) denotes sales (purchases) of foreign currency in millions of US dollars by the central bank for intervention purposes, d_t is the interest rate differential (domestic minus foreign), sp_t is the yield spread on a sovereign foreign currency bond over a comparable U.S. treasury bond. The log exchange rate, interest differential, and yield spreads are first differenced to obtain their stationary forms. The error term is the unexpected return which is used to model the conditional volatility of the exchange rate in the volatility equations (2) and (3).

Equation (1) of the empirical model (the "mean" equation) analyzes changes in the exchange rate return (depreciation or appreciation against the dollar) as a function of intervention, interest rate differentials, and yield spreads on a sovereign bond. The interest differential aims to capture the possible impact of monetary policy actions and local money market conditions on the exchange rate. Yield spreads on sovereign external debt over a comparable US Treasury bond are included as a measure of country risk and foreign investor sentiment, which are possibly key determinants of demand for local currency. It is hypothesized that a higher interest differential appreciates the domestic currency ($\Delta s_t < 0$), net purchases of foreign exchange depreciate the domestic currency, and higher yield spreads are associated with depreciations of the domestic currency.

In equation (2), h_t is the conditional volatility of the exchange rate (log returns), z_t is a dummy variable indicating *unexpected* exchange rate *appreciations* (i.e. if $\varepsilon_t < 0$, then $z_t > 0$). The model allows mean reversion of the short-term volatility, h_t, to a *time-varying* longer-term volatility, given by q_t, in contrast to the *constant* long-term volatility assumed in the standard GARCH model.[17, 18]

Equation (2) models the short-term conditional exchange rate volatility, h_t, as a function of a time-varying long-term volatility, q_t, lagged unexpected shocks relative to lagged long-term volatility, given by the term $(\varepsilon^2_{t-1} - q_{t-1})$, lagged volatility relative to lagged

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[17] Note that while h-q, the deviation of volatility from its long-term component, converges to 0 with powers of $\alpha+\delta$, the long run component converges to ω with powers of ρ. This model can be reparametrized as a non-linear restricted GARCH(2,2) model.

[18] The absolute value of the regressors is used in the variance equations.

long-term volatility, given by the term $(h_{t-1} - q_{t-1})$, and the set of regressors of explanatory variables that were included in the mean equation (intervention, interest rate differentials, and sovereign spreads). Lagged unexpected shocks and volatility are included to capture volatility clustering (as in standard GARCH-type models), since high volatility periods tend to be clustered over time. The equation also includes a term $((\varepsilon^2_{t-1} - q_{t-1})z_{t-1})$ that allows for asymmetric impacts of past shocks (relative to long-term volatility) on short-term volatility. If the estimated τ is less than zero, then unexpected depreciations increase short-term volatility.

The model departs from the standard GARCH representation by assuming that the long-term volatility is *not* constant. The long-term volatility equation is given by (3), and like its short-term counterpart, it depends on a set of explanatory variables (intervention, interest differentials, sovereign spreads), its own lagged value (q_{t-1}), and past shocks (ε^2_{t-1}). Unlike the short-term volatility, q_t converges to a constant ω.

Some general features of the model above are noteworthy. First, it allows for asymmetric shocks in the conditional (short-term) variance equation. In particular, if $\tau < 0$, then the impact of "negative" shocks (unexpected domestic currency depreciation, $\varepsilon_t > 0$) on short-term volatility is given by α, greater than the impact of "positive" shocks (unexpected appreciation), which is given by $(\tau + \alpha)$.[19] Second, the short-term impact of foreign exchange intervention on exchange rate volatility may differ from the long-term impact. The empirical model may also be augmented with other exogenous variables, such as sovereign spreads, market turnover, order flow, and other relevant variables. For instance, in the case of Mexico, futures market turnover (and open interest) are included in the exchange rate volatility equations.[20]

This paper also analyzes the effects of volatility on intervention, given the evidence in favor of reverse causation between exchange rate returns and intervention (policy reaction function). Following Dominguez (1998) and Baillie and Osterberg (1997), we apply the Probit model to evaluate whether *excessive* volatility, defined as the deviation of estimated volatility from its recent trend, increases the probability that the central bank will intervene in the foreign exchange market.[21] In addition to excessive volatility, the estimated Probit model also includes the deviation of the current exchange rate from its recent moving average. Although other variables could be included in the model, the estimated model appears to perform quite well and makes our analysis more comparable to previous work.

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[19] Note that for $\tau < 0$ and $\alpha > 0$, $\alpha > \tau + \alpha$.

[20] The number of outstanding contracts, measured in U.S. dollars. See also Jorion (1996) for the case of G-3 currency pairs

[21] The estimated volatility is based on a simple GARCH(1,1) model, although the same qualitative results obtain if the ACT-GARCH model is used.

The estimated model is given by:

$$\Pr\{|I_t| \neq 0\} = \Phi(\alpha_0 + \alpha_1(s_{t-1} - \sum_{j=1}^{k} s_{t-j} / k) + \alpha_2(\sqrt{h_t} - \sum_{j=1}^{k} \sqrt{h_{t-j}} / k))$$

where *Pr* denotes probability and $\Phi(.)$ denotes the standard normal transformation. If the estimated α_1 (α_2) is statistically significant (different from 0), then deviations from the k-day exchange rate trend (volatility) affect the probability of intervention.

C. Estimation Results

Mexico

The first set of regressions on Mexico (not reported here) highlight the importance of model specification and properly accounting for the simultaneity problem. The regressions also show that the effects of intervention on the exchange rate vary according to the sample period and whether intervention is lagged or contemporaneous.[22] For example, the regression of exchange rate returns on contemporaneous central bank *purchases* indicate that a US$100 million U.S. dollar purchase by the Banco de Mexico (BoM) *appreciates* the peso by 0.2 percent against the U.S. dollar, while an equivalent sale of U.S. dollars depreciates the peso by 1.4 percent (both statistically significant at the 1 percent level). This result could be *erroneously* interpreted as "leaning against the wind," but in fact, it is consistent with the rationale that investors tend to exercise their put options when the domestic currency appreciates. This, in turn, would make the error term correlated with the explanatory variable, which requires the application of instrumental variables/generalized method of moments or the use of lagged intervention to account for the correlation.[23]

In order to redress the simultaneity problem, the model was re-specified by using two-day lagged intervention. The estimates from the second set of regressions using lagged intervention are presented in Table 4. The upper half of the table shows the estimates for the *mean equation*.

The results indicate that the impacts of intervention on the level of the exchange rate are nontrivial. In particular, a two-day *lagged* US$100 million *sale appreciates* the peso (against the U.S. dollar) by 0.4 percent (statistically significant at the 5 percent level), but

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[22] The point estimates also differ significantly depending on whether sales and purchases of foreign exchange are considered separately or in conjunction. The error term is assumed to have a t-distribution to account for excess kurtosis in the data (fat tails). The estimates for the t parameter (degrees of freedom) are always significant at the 5 percent and indicate major departures from normality.

[23] Werner (1997) discusses this issue in detail.

purchases of foreign exchange do not have a statistically significant impact on the value of the peso.[24] The results also underscore the importance of estimating the impacts of sales and purchases of foreign exchange separately, particularly when there are systematic differences between purchases versus sales.

Table 4. Mexico and Turkey: Asymmetric Component GARCH Model Estimates

$$\Delta s_t = \beta_0 + \beta_1 I_t^+ + \beta_2 I_t^- + \beta_3 \Delta d_t + \beta_4 \Delta sp_t + \varepsilon_t$$

$$h_t - q_t = \alpha(\varepsilon^2_{t-1} - q_{t-1}) + \tau((\varepsilon^2_{t-1} - q_{t-1})z_{t-1} + \delta(h_{t-1} - q_{t-1}) + \gamma_1 I_t^+ + \gamma_2 I_t^- + \gamma_3 \Delta d_t + \gamma_4 \Delta sp_t$$

$$q_t = \omega + \rho(q_{t-1} - \omega) + \varphi((\varepsilon^2_{t-1} - h_{t-1}) + \gamma_5 I_t^+ + \gamma_6 I_t^- + \gamma_7 \Delta d_t + \gamma_8 \Delta sp_t$$

	Mexico	Turkey
Exchange rate level (mean) equation		
β_1 (Intervention-sale)	-0.4319**	-3.38E-05
β_2 (Intervention-purchase)	0.0122	7.15E-06
β_3 (Interest differential)	0.0369**	0.000203
β_4 (Spreads)	0.2163**	0.000172*
Short-term volatility equation		
τ (Negative shock)	-0.2363**	0.040596
γ_1 (Intervention-sale)	0.0595**	-0.011062***
γ_2 (Intervention-purchase)	0.0002	-2.08E-07
γ_3 (Interest differential)	0.0162	-1.25E-05
γ_4 (Spreads)	0.1886**	3.66E-07
Long-term volatility equation		
γ_5 (Intervention-sale)	0.0115**	0.011062***
γ_6 (Intervention-purchase)	-6.73E-05	2.72E-08
γ_7 (Interest differential)	-0.0211**	3.17E-06
γ_8 (Spreads)	0.0167	4.38E-07

Notes: An * denotes significant at 10 percent, and ** denotes significant at 5 percent. The results reported above are based on equations (1-3) after dropping the weekend dummy and the moving average parameter, which were insignificant in all specifications estimated. The coefficient on intervention in the mean equation gives the impact for a US$100 million purchase/sale of foreign exchange in percent. The sample sizes are respectively 1800 and 1278.

[24] When the sample period studied by Domac and Mendoza (2003)—August 1996 to June 2001—is used, the results are as follows. In the case of contemporaneous intervention both estimates remain significant at the 5 percent level, with the same patterns of signs and magnitude as those reported above, while in the case of lagged intervention the point estimates are also about the same (qualitatively and quantitatively) but only sales remain statistically significant at the 10 percent level. It is worth noting that the results may not be comparable to Domac and Mendoza (2003) since the econometric specifications are different, as well as some of the variables used in the estimations.

The effects of intervention on volatility are also significant and are shown in the lower half of Table 4. Several factors account for the time-varying nature of exchange rate volatility, including the yield spread on Brady Bonds, interest rate differential, and intervention. The impact of intervention on exchange rate volatility is also estimated separately for sales and purchases.

The model indicates that foreign exchange sales and changes in the Brady bond yield spread increase the *short-term* volatility of the exchange rate (h_t) at the 5 and 1 percent significance levels, respectively. The estimates indicate the existence of asymmetric shocks to the conditional variance (significant at the 10 percent level in both samples): Unexpected domestic currency depreciations have a larger effect on volatility than unexpected appreciations. By contrast, neither changes in the interest rate differential nor foreign exchange purchases affect short-term exchange rate volatility. Foreign exchange sales also increase the *long-term* component of exchange rate volatility (significant at the 5 percent level). The estimated effect of purchases is negative, but not statistically significant.[25] Changes in the Brady yield spread did not have a significant impact on long-term volatility, while changes in the interest rate differential has a negative effect (significant at the 5 percent level).

The main empirical findings for Mexico may be interpreted as follows.[26] First, intervention seems to have a non-negligible effect on exchange rate changes, with US$100 million *sale* of foreign exchange by the central bank estimated to *appreciate* the peso (against the U.S. dollar) by 0.4 percent. However, foreign exchange purchases, which constitute the bulk of interventions in Mexico during the period covered here, did not appear to have had a statistically significant impact on the value of the peso. This is consistent with the authorities' objective of accumulating international reserves in a floating exchange rate regime.

Nevertheless, intervention has a nontrivial impact on exchange rate volatility. The results indicate that foreign exchange sales increase both the short- and long-term volatility of the exchange rate, which in part may be because sales are seen as less credible.[27] Other

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[25] In the case of sales, one could argue that attempts by the monetary authorities to smooth volatility with discretionary sales were not fully credible, resulting in higher volatility.

[26] The model is also estimated under different assumptions about the error term, including the t distribution and the generalized exponential distribution (GED), see Baillie and Bollerslev (1992) and Nelson (1991), respectively.

[27] Generally, foreign exchange sales could be perceived as less credible because central banks often sell foreign exchange to prevent the domestic currency from depreciating, even if the ultimate objective is to smooth volatility (since depreciations and heightened uncertainty are highly correlated).

factors (e.g., interest rate differentials) also appear to be important in explaining exchange rate volatility at longer horizons. This finding has important implications for exchange rate policy, especially if (short-term) volatility-enhancing interventions can influence the expectations of market participants, as described by Hung (1997).

The probit estimations for Mexico indicate that "excessive" exchange rate volatility decreases the probability of intervention, in contrast with the findings of Dominguez (1998) and Baillie and Osterberg (1997b) (Table 5).[28] The estimations also reveal that exchange rate depreciations increase the probability of intervention. The results, which are based on a 21-day window (k=21) and the full sample, are generally *not* robust to the choice of k and the sample period. For instance, when the sample period 1996–2001 is considered, increases in volatility relative to its recent trend raise the probability of intervention. Nonetheless, the probit estimation results underscore the importance of controlling for simultaneity effects when estimating the impacts of intervention on the level and volatility of the exchange rate.

Table 5. Mexico and Turkey: Probit Model Estimates

$$\Pr\{|I_t| \neq 0\} = \Phi(\alpha_0 + \alpha_1(s_{t-1} - \sum_{j=1}^{k} s_{t-j}/k) + \alpha_2(\sqrt{h_t} - \sum_{j=1}^{k}\sqrt{h_{t-j}}/k))$$

Coefficients	Mexico 1996–2003	Turkey 2001–2003
α_0	-1.36**	-0.38***
α_1	8.58*	11.28
α_2	-0.03**	-2.42

Notes: *,**,and *** denote significance at 10, 5, and 1 percent levels. Huber-White standard errors are used. The results are based on k=21; s_t is the log of the nominal local currency-U.S. dollar rate, h_t denotes the estimated conditional volatility of the exchange rate return.

Turkey

In Turkey's case, regression estimates indicate that official intervention does not influence exchange rate levels (Table 4). Coefficients on the sale and purchase of foreign exchange carry the wrong sign (consistent with a "leaning against the wind" policy), but they are statistically insignificant. By contrast, sovereign spreads are highly significant. The regressions were also run on the entire sample as well as on the two subsamples in an attempt

[28] "Excessive" exchange rate volatility is defined as deviations from the annualized volatility from its 21-day moving average. The increase in volatility, which precedes intervention (i.e., exercising of put options) at time t_1, could be the result of dynamic hedging by market participants following the purchase of the options at t_0.

to distinguish the more volatile market conditions of the earlier subperiod from the more favorable conditions in the later subperiod. A second set of regressions with dummies for CBT's presence in the market were also run. A third set of regressions included lagged intervention. Finally, a dummy variable was used to account for the CBT discretionary interventions' in *unknown* amounts. None of the variants on the sample period, regressors, dummy variables or lags yielded results qualitatively different from the ones reported here. Regressions were also run under alternative GARCH specifications (not shown here) to illustrate the sensitivity of the results to model specification and the limitations of empirically modeling the intervention's effectiveness.[29]

The absence of evidence on the effectiveness of intervention in influencing the level of the exchange rate may reflect the nature of Turkey's intervention policies. The vast majority of official interventions were conducted in the context of *preannounced* foreign exchange sale (purchase) auctions, where the time and amounts were largely predetermined and known by market participants. Hence, the potential impact of interventions may have operated through the signaling channel well in advance of actual interventions themselves. Another interpretation of the results is that the authorities succeeded in their stated goal of maintaining a market-determined exchange rate by implementing a transparent, rules-based intervention policy.

The regression results suggest that intervention affects exchange rate volatility. Coefficients γ_1 and γ_5 on CBT foreign exchange sales in the short-term volatility equation are statistically significant at the 10 percent level. In particular, CBT foreign exchange sales appear to reduce short-term volatility (which is consistent with the findings of Domac and Mendoza (2003)), but over the long-term, sales increase volatility. Unlike in Mexico, unexpected depreciations do not appear to have asymmetric effects on volatility.

In Turkey's case, the Probit estimation finds no evidence that the probability of intervention increases in response to deviations of exchange rate volatility from its recent trend (Table 5). This result is consistent with Turkey's largely rules-based intervention policy during this period, where most interventions were preannounced. The results also show that exchange rate trends did not appear to have had an impact on the probability of intervention. Thus, the authorities rarely reacted to contemporaneous market conditions, with the possible exception of the few episodes of discretionary interventions.

[29] The findings contrast with those of Domac and Mendoza (2003), which concluded that CBT foreign exchange sales (but not purchases) have significant effects on exchange rate returns.

V. Conclusion

This paper finds mixed evidence on the effectiveness of intervention in Mexico and Turkey. In Mexico, foreign exchange sales (but not purchases) have a statistically significant, but small, impact on the exchange rate level, while neither foreign exchange sales nor purchases are significant in Turkey. In both cases these findings are broadly consistent with officially stated policy objectives, which generally aim to minimize the effect of intervention on the exchange rate. The results are also consistent with the empirical analyses on advanced economies, where intervention is generally found to have little, if any, effect on the exchange rate (Sarno and Taylor, 2001).

The evidence presented in this paper also shows that intervention may have nontrivial effects on exchange rate volatility. In the case of Mexico, sales of foreign exchange are usually associated with increases in exchange rate volatility, in contrast to the often stated intervention's objective of smoothing volatility. In Turkey's case, the evidence is more mixed, with only foreign exchange sales (but not purchases) reducing volatility in the short-term, but increasing it in the long term. In both cases, the results do not seem to substantiate claims that intervention is a useful tool to smooth volatility.

Intervention's apparently limited effectiveness highlights the need for central banks to use their scarce foreign reserves selectively and parsimoniously. The difficulty of identifying a strong link between intervention and exchange rate changes, however, may also stem from model misspecification and a failure to control for a variety of political and economic factors. We hope this paper serves to stimulate further research on the effectiveness of intervention—particularly by the staff of central banks—to ensure that international reserves are well spent when they are used for intervention purposes.

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Table 1. Analytical Methodologies of Empirical Studies on Intervention

Intervention Impact on Exchange Rate Level			
Sources	Econometric Specification	Data Requirements	Advantages & Disadvantages
Dominguez and Frankel (1993)	*OLS Regression of Mean Equation* $\Delta s_t = \alpha + \beta I_t + \gamma'\mathbf{X_t} + \varepsilon_t$ where Δs is the exchange rate change, I is intervention, and the X vector includes the interest differential, the country risk premium, and possible dummies, including on seasonality effects (e.g. Monday effect), news items, and reports of central bank presence in the market.	• Intervention, exchange rate, interest rate, country risk premium (e.g., spreads on sovereign bond) on a daily basis. • Compilation of news items, reports of central bank intervention, and other relevant information for dummy variables.	• Simple technique. • Simultaneity between exchange rate changes and intervention. • Analyzes only contemporaneous effects with no insight on long term effects. • Provides no insight on the channel of transmission.
Edison (1993) Dominguez and Frankel (1993a,b) Sarno and Taylor (2001)	*OLS Regression of Risk Premium Equation* $\rho_t = \theta_1 B_t + \theta_2 B^*_t$ where $\rho_t = r - r^* + E(s_{t+1}) - s_t$ where ρ_t is the risk premium, r domestic interest rates, r* foreign interest rates, B local currency denominated bonds, and B* foreign currency denominated bonds. The risk premium, ρ_t, is measured by deviations from uncovered interest parity, either assuming rational expectations or using survey data. If ρ_t is nonzero (in violation of interest rate parity) and systemically responds to the relative supplies of B and B* (i.e., imperfect substitutability), then the exchange rate necessarily changes in response to intervention and a change in the relative supplies of B and B*.	• Local and foreign currency bonds supplies, exchange rate, interest rate on a daily basis. • Daily survey data on exchange rate expectations (if rational expectations is not assumed). • In the absence of data on bond supplies, intervention may be used as a proxy for the change in relative bond supplies.	• Assuming rational expectations or the use of survey data has a number of problems. • Simultaneity between exchange rate changes and relative bond supplies (or intervention).

Table 1. Analytical Methodologies of Empirical Studies on Intervention (continued)

Intervention Impact on Exchange Rate Level (continued)			
Sources	Econometric Specification	Data Requirements	Advantages & Disadvantages
Evans and Lyons (2002)	*OLS Regression of Order Flow Equation* $\Delta s_t = \alpha + \beta\Delta r_t + \gamma x_t + \varepsilon$ where Δr_t is the change in the interest differential and x_t is interdealer order flow, which is defined as the net of buy-initiated and seller-initiated foreign exchange orders that are consummated.	• Daily data on interest rates, exchange rates, and interdealer order flow.	• Order flow data is not always available. • Effectiveness of order flow in impacting exchange rates is a indirect measure of the effectiveness of central bank-initiated order flow (intervention). • Simultaneity between exchange rate changes and order flow. • Measures the impact of private-sector generated order flow, which is equivalent to a sterilized secret intervention.
Fatum (2000) Fatum and Hutchison (2003a, 2003b) Hutchison (2003)	*Event Studies* An event window of 2, 5, 10, and 15 days is defined to include one or more intervention episodes (interspersed with nonintervention days), during which exchange rate changes are analyzed compared to the pre-event window.	• Intervention and exchange rate data on a daily basis.	• Simple and analytically sound technique. • Provides no insight on the channel of transmission • Analyzes only short-term effects (up to one month) with no insight on long term effects.
Guimarães (2004) Kim (2003)	Unified Approaches to Monetary Policy and Intervention *(Structural Vector Autoregression)* $B(L)y_t = u_t$ where B(L) contains the structural parameters, and the vector $\mathbf{y}_t$ contains the exchange rate, intervention, and monetary policy variables. The first two equations of the reduced form VAR can be expressed as: $s_t = c_1 + \alpha_1(L)s_{t-1} + \beta_1(L)I_{t-1} + \gamma_1(L)'\mathbf{X_t} + \varepsilon_{1,t}$ $I_t = c_2 + \alpha_2(L)s_{t-1} + \beta_2(L)I_{t-1} + \gamma_2(L)'\mathbf{X_t} + \varepsilon_{2,t}$	• Intervention, interest rate, trade-weighted exchange rate index (or bilateral exchange rate), money supply, inflation, industrial production, commodity prices on a monthly basis.	• Accounts for endogeneity of intervention, exchange rate, and interest rate movements. • Analyzes short term and long-term impact of intervention. • Estimated impact of intervention might not be robust to the identification scheme used to identify structural shocks

Table 1. Analytical Methodologies of Empirical Studies on Intervention (concluded)

Intervention Impact on Exchange Rate Volatility			
Sources	Econometric Specification	Data Requirements	Advantages & Disadvantages
Dominguez (1998)	*GARCH Approaches to Measuring Volatility* $\Delta s_t = \alpha + \beta I_t + \gamma_1'\mathbf{X_t} + \varepsilon_t$ $h_t = \beta_0 + \beta_1 \varepsilon^2_{t-1} + \beta_2 h_{t-1} + \beta_3 \lvert I_t \rvert + \gamma_2'\mathbf{X_t}$	• In addition to the exchange rate, intervention, the variables contained in the vector X, which would vary according to the case studied.	• Computationally simple. • Ignores market expectations embedded in option prices, but not subject to option pricing models known biases/problems
Dominguez (1998), Murray and others (1997)	*Implied Volatilities from Option Prices* $IV_t = \beta_0 + \beta_1 \lvert I_t \rvert + \beta_2'\mathbf{X_t}$ where IV is the measure of implied volatility calculated from option prices	• In addition to the above, FX option prices.	• Computationally more demanding and subject to data availability (especially in developing markets) • Subject to the option pricing model used • Subject to data problems related to option market (illiquid contracts, etc.)