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Interventions and Expected Exchange Rates in Emerging Market Economies*

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Abstract: We study variations in the risk-neutral distributions of the exchange rates in Brazil, Chile, Colombia, Mexico, and Peru due to interventions implemented by these countries. For this purpose, we first estimate the risk-neutral densities of the exchange rates based on derivatives market data, for one-day and one-week horizons. Second, using a linear regression model, we assess possible effects on the distributions of the expected exchange rates due to these interventions. We find little evidence of an effect on the expected exchange rates' means, volatilities, skewness, kurtoses, risk premia, and tails' parameters. In the few cases for which we do find some statistical evidence of an effect, it tends to be short-lived or not economically significant. On the other hand, we find evidence that interventions which objective is to restore and/or assure the proper functioning of exchange rate markets have a higher probability of success. This probability increases as the amount of resources to intervene at the disposal of the central bank increases. Needless to say, there are limits to the methodology we use.
Keywords: Interventions, Exchange Rates, Risk-Neutral Distributions, Generalized Extreme Value Distributions.
JEL Classification: E5, F31, G12, C58.

Resumen: Estudiamos las variaciones en las distribuciones neutrales al riesgo de los tipos de cambio de Brasil, Chile, Colombia, México y Perú debido a las intervenciones implementadas por estos países. Para dicho fin, primero estimamos las densidades neutrales al riesgo de los tipos de cambio con base en datos del mercado de derivados, con horizontes de un día y una semana. Segundo, utilizando un modelo de regresión lineal, consideramos posibles efectos en la distribución del tipo de cambio esperado debido a dichas intervenciones. Encontramos poca evidencia de un efecto en las medias, las volatilidades, los sesgos, las curtosis, las primas por riesgo y los parámetros de las colas de los tipos de cambio esperados. En los pocos casos en los cuales encontramos evidencia estadística de un efecto, éste tiende a durar poco o a no ser económicamente significativo. Por otro lado, encontramos evidencia de que las intervenciones cuyo objetivo es restaurar y/o asegurar el funcionamiento apropiado de los mercados del tipo de cambio tienen una mayor probabilidad de éxito. Esta probabilidad se incrementa conforme el monto de los recursos disponibles para que el banco central intervenga aumenta. Sobra decirlo pero existen límites a la metodología que utilizamos.
Palabras Clave: Intervenciones, Tipos de Cambio, Distribuciones Neutrales al Riesgo, Distribuciones Generalizadas de Valor Extremo.

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*The views in this paper are those of the authors and do not necessarily reflect those of the Banco de México.

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Introduction

As part of the Great Recession and its aftermath, the unprecedented monetary policy stances in advanced economies have provided leeway for upsurges in capital flows. Concurrently, variations in the risk appetite of investors and in global financial volatility have had a significant impact on the rate at which capital flows have entered and exited emerging market economies. Such flows have been a matter of concern for policy makers.

In effect, although capital flows provide ample benefits to the recipient countries, e.g., supplementary financing, improved Sharpe ratios, and a lower cost of capital, they also entail potential costs, e.g., sudden stops, abrupt currency depreciation, asset price bubbles, and potential risk mispricing. In this context, some policymakers have responded by intervening in their exchange rate markets, having different specific aims, along with implementing other policy measures.

The effects of interventions and their measurement are key policy issues. Yet, they have been a matter of debate. To assess their effects a plethora of methods has been proposed (see, e.g., Sarno and Taylor [2001]). Albeit data availability and innovative approaches in more recent years have generally allowed for a more thorough analysis, the debate has not been settled.

By and large, direct comparisons of interventions are difficult to make since interventions in different countries are seldom analyzed jointly. This is partially explained as interventions are implemented in different ways, both across time and countries. Thus, it seems worthy to assess interventions in various emerging countries under a common methodology. Naturally, doing so implies making some simplifying assumptions.

Against this backdrop, we assess the potential effects on the expected exchange rates in Brazil, Chile, Colombia, Mexico, and Peru due to interventions implemented by the authorities in these countries. With this end in view, we proceed as follows. First, we extract the risk-neutral densities from options data on the individual exchange rates for two horizons, one-day and one-week. Second, we estimate key statistics based on these densities, including some associated with the distributions' tails. Third, using a linear regression model, we analyze how these statistics might have changed as a result of interventions in the corresponding spot exchange rate market.

We generally find little statistical evidence of an effect on the exchange rates risk-neutral densities given an intervention and, when we do, it tends to be short-lived or not economically significant. Nonetheless, it is essential to acknowledge the scope and limitations of our methodology and results. The implementation of an intervention and its effects depend on several factors, some of which we have not considered.

More generally, interventions aimed at affecting an exchange rate varying due to an adjustment in economic fundamentals will very likely be a futile effort with close to nil probability of success. The exchange rate will eventually move based on such adjustment. Nonetheless, there are cases in which interventions may have better chances of succeeding. One such case is when non-fundamental phenomena, such as herd-like behavior, is responsible for large variations in the exchange rate. Perhaps the most important case would be when an economy with relatively shallow financial markets, including the foreign exchange one, suffers a large sized external shock. Under these conditions, the operability in the foreign exchange rate market can be compromised, which can lead to bad expectations equilibria with potentially large disruptions in economic activity. In such cases, we believe that interventions which objective is to maintain the functioning of financial markets through the proper provision of liquidity have better chances of succeeding.[1] Clearly, the more reserves a central bank has to do this, the higher the probability of the intervention's success. We further comment on the limitations and scope of our work in the final remarks of our paper.

The rest of the paper is divided into four sections. The second section provides a brief discussion on interventions, and includes a description of the main features of the interventions we consider. The third section describes our data and the methodology we use. The fourth presents and comments on our results. In addition, it includes a subsection where the dynamics of the risk-neutral exchange rate are examined after some selected episodes, such as the announcement of the Swap Line between the Federal Reserve Board and some Central Banks in the region. The last section offers some final remarks. An appendix provides supplementary material.

Interventions

Whether an intervention is sterilized or not is fundamental to its potential effects. On the one hand, if there is no sterilization then the effects of an intervention are similar to those of an open market operation. This is so since the monetary base changes in both cases. The key difference though is that in an unsterilized intervention a central bank only uses foreign assets, while in an open market operation it only uses domestic assets.

On the other hand, for sterilized interventions, the literature has considered mainly two potential channels through which an intervention might have an effect on the exchange rate. These are the portfolio balance and the expectations or signaling channel, which we explain in turn in more detail. It is worth mentioning that all of the interventions we consider in this paper are in principle sterilized. Thus, given an intervention, we would not expect to see an effect on

[1] Actually, one could argue that evidence of their very success is the fact that in many instances the intervention mechanism, although in force, is not triggered. As an example, in Mexico since 1997, a rules-based intervention mechanism has been in place for long stretches, whereby the Central Bank auctions off dollars to banks if the exchange rate depreciates by more than 2% on any single day. The last time this mechanism was in force was from November 2011 through April 2013, and auctioned off dollars only on three occasions. In none of them was the full allotment reached. Evidently, although it is difficult to gauge in a precise way this type of mechanisms' effectiveness, they have been able to successfully avoid the referred bad equilibria, specially early on, that is, before the foreign exchange market deepened considerably in Mexico. In fact, the Mexican peso moved from the 14th to the 8th place in the most traded currencies ranking, in 2010 and 2013, respectively, as documented in the BIS Triennial Central Bank surveys (BIS[2010] and BIS[2013]).

the short-term interest rate, a piece of data that is embedded in the risk-neutral distribution of an exchange rate.

In the portfolio balance channel, if an intervention takes place, e.g., when financial institutions buy dollars from the central bank, then in the sterilization process the central bank buys domestic bonds from the public. Thus, the relative supply of domestic to foreign bonds decreases. If domestic and foreign bonds are imperfect substitutes, then their relative price changes. Thus, leading -in our example- to an appreciation of the exchange rate. The converse effect takes place when financial institutions sell dollars to the central bank, since in the sterilization process the central bank sells domestic bonds to the public.

The expectations or signaling channel has an effect if market participants perceive an intervention as signaling the central bank's intentions with regards to its future policy, e.g., its monetary stance (Mussa [1981]). In this channel, it is inconsequential if domestic and foreign bonds are substitutes or not. Thus, interventions are seen as a prelude to a policy change and, thus, albeit possibly indirectly, might affect the exchange rate.

A closely related issue is whether an intervention should be public, rules-based, and transparent, or private, discretionary, and opaque.[2] We do not distinguish between these issues and consider an intervention as the same one irrespective of whether it is rules-based or discretionary.

Different countries have had diverse aims when intervening in their exchange rate market. Some typical aims have been, among others, to (implicitly or explicitly) target the nominal or the real exchange rate, to reduce the volatility, to provide liquidity, to procure orderly conditions, all in the exchange rate market, etc. We leave the countries' stated aims aside and only make a distinction if the authority sells or buys dollars in the spot market. This same comment applies to those interventions which are used as controls in the regressions.

Our sample includes five emerging market economies, namely, Brazil, Chile, Colombia, Mexico, and Peru.[3] Central to our analysis are two common characteristics of these economies. First, they are small open economies. Thus, for each, its exchange rate is a fundamental price in its economy. Second, they all essentially have floating exchange rate regimes, which imply that, *at least in most cases nominally*, none of these countries targets its exchange rate.

The following country-specific descriptions refer to our database. Brazil is probably one of the most active countries in terms of intervening in the exchange rate market. We only consider those interventions directly implemented in the spot market (i.e., spot net interventions). In addition, Brazil intervenes in other related markets. Hence, in some of our model specifications

[2] On the one hand, paraphrasing Kenen [1988], the rules of the exchange rate market need to be as transparent as possible to maintain credibility. Thus, in this case the authorities have an incentive to openly and clearly convey their rationale and intentions for the expectations channel to render more effective. On the other hand, Dominguez and Frankel [1993] consider cases in which the authorities might have the incentive to minimize the effects of an intervention and, thus, make it private and discretionary.

[3] A paper related to ours is Broto [2012] in which by fitting a GARCH-type model the author analyzes the effect of interventions in the exchange rate market in Chile, Colombia, Mexico, and Peru. While she studies the effect on the actual exchange rates, we look at the expectations. Thus, any comparison is not direct.

we control for three interventions not implemented in the spot market (i.e., in the swaps, reverse swaps, and forwards markets).

Chile has had some activity intervening in the exchange rate market. We consider Chilean interventions involving the selling and buying of US dollars through auctions. The most recent Chilean intervention activity can be characterized by buying and selling periods. In addition, Chile implemented some interventions in the swap market, for which we control for, but has not done so recently.

Colombia has been relatively active when it comes to intervening in the exchange rate market in recent years. Their economic authorities have, for the most part, done so buying dollars in the spot market through auctions. Yet, Colombia has also implemented other types of interventions (specifically, those implemented with call and put options for volatility control, and call and put options for reserves management). One of our specifications has these latter interventions as controls.

For the Mexican case, we similarly consider interventions implemented in the spot market in recent years, except for the one case of a discrete intervention.[4] It is worth mentioning that Mexico has for the most part intervened by selling US dollars through auctions. The one exception is an intervention aimed at increasing the rate of reserves accumulation, which involves the sale to banks of US dollar put options.[5] Similarly, we have considered a specification in which we control for this type of interventions.

[4]For the discrete intervention detailed data are not publicly available. It took place for seven days, namely, on September 10, 1998, and in a second period on February 4, 5, 6, 20, 23, and 27, 2009.

[5]In the period considered there have been five types of intervention mechanisms implemented in the spot market: i) mechanism to reduce the international reserves' accumulation rate (active from May 2003 to July 2008, but for our purposes it is relevant it was active as of January 2007 onwards); ii) extraordinary dollar auctions (active in October 2008); iii) auctions with a minimum price (active from October 2008 to April 2010, and from November 2011 to April 2013); iv) auctions with no minimum price (active from March 2009 to September 2009); and, v) auctions in which the resources from the swap line between the Bank of Mexico and the Federal Reserve Board were made available (active from April 2009 to February 2010). The resources from the swap line could be used for dollar credit auctions among credit institutions in Mexico. The first dollar credit auction took place on April 21, 2009, with the final aim of providing finance to those private sector participants who faced pressure to obtain dollar-denominated resources in the short term. In addition, the mechanism to accumulate international reserves through the sale of US dollar put options was active from February 2010 to November 2011. As mentioned in the main text, there is an extension of our model that controls for this type of interventions.

For their part, on October 29, 2008, the Federal Reserve and the Central Bank of Brazil agreed on a swap facility that expired on 30 April 2009. This facility was used to improve the Bank's ability to provide US dollar liquidity to bank funding markets (source: www.bcb.gov.br).

Two other Central Banks from Emerging Market Economies that participated in similar facilities were the Central Banks' of Korea and Singapore. Specifically, the Bank of Korea entered into a US dollar swap arrangement with the Federal Reserve on October 30, 2008, to "strengthen the backstop blocking the risk of the global financial market turmoil spreading into the domestic economy." The arrangement with the Federal Reserve was later extended to October 30, 2009. On the other hand, on October 30, 2008, the Monetary Authority of Singapore (MAS) established a reciprocal swap line with the Federal Reserve. The swap facilities allowed the Federal Reserve to "provide US dollar liquidity to financial institutions through central banks [...] to help to improve liquidity conditions in global financial markets and to mitigate the spread of difficulties in obtaining US dollar funding." Later on, the Federal Reserve and the MAS extended their swap lines to October 30, 2009 (sources: www.bok.or.kr and www.mas.gov.sg).

Peru has intervened in the exchange rate market by typically selling and buying dollars in the spot market. Nonetheless, it has also intervened in other closely related markets. Again, we control for other types of interventions different from those implemented in the spot market (i.e., swaps and repo-type transactions).

All in all, we are considering broadly similar interventions. This is with the view of making comparisons as direct as possible. In addition, in emerging market economies the most common market in which interventions take place is the spot market, with Brazil being an exception.

Data and Methodology

Data

Our database can be divided into five: the interventions, the options, the interest rates, the exchange rates, and what we refer as the rest of the data. We describe them in turn. First, much of the details about the interventions have been already described above.

Second, for the countries in our database we obtain the daily options data on the respective exchange rates. We consider two horizons for the options data, one-day and one-week. This allows for examining the effects of the interventions for two horizons. Although the options data are available for longer ones, we thought it was unlikely that there would be an effect on longer horizons. This is in line with what we later found in our estimations. As will be seen, in the estimated models below the effects in general fade away swiftly. We describe the options data in more detail in Appendix A.

Third, we use daily data on the one-month risk-free rate of each country, and the one-month risk-free rate in the US. Since one of our aims is to compare the effects across countries, we choose comparable rates across them. We found that comparable risk-free rates associated to shorter horizons are not available for some countries in our sample. Yet, since interest rates with small differences in maturity (i.e., close to a month) have high and significant correlations, we believe that the rates we use are representative of shorter term rates.[6] The US risk-free rate is needed for pricing the options since they have the US dollar as their underlying asset.

Fourth, the exchange rates are in terms of the local currencies per US dollar.

We face some restrictions on the data, as we explain next. First, in some cases we were unable to gain access to all the data we needed, forcing us to drop some countries out of the sample. Second, although it is desirable to consider the complete periods for each country where interventions take place, the linear regressions we estimate have a common component that requires the time series *for the same periods and for all the countries in the sample*. Thus,

[6] We could have also used target rates that are more generally available. Yet, these rates commonly do not measure the markets' daily frequency information, but rather are associated to lower frequency economic phenomena.

for instance, Peru's data on options does not start until August, 2008. Thus, for a first period from January 1, 2007 to July 31, 2008 we only consider Brazil, Chile, Colombia, and Mexico. For a second period, starting August 1, 2008, we consider the full country sample.

Thus, bearing the above in mind, the specific period we use for our estimation goes from January 1, 2007 to November 11, 2013. In addition to those mentioned above, our sample has other advantages. For instance, it has episodes of capital inflows and, on the other hand, of capital outflows. Indeed, it has episodes of heightened uncertainty and others of relative lull (more generally, so-called risk-on, risk-off episodes). It includes the pre-crisis, crisis, and post-crisis periods, which provide a rich sample of interventions.

We have the following comments, regarding the rest of the data we use, namely, the volume of dollars traded in the spot market, the GDP's, and the international reserves. First, we use the volume of dollars traded in the spot market since, precisely, we have focused on interventions in the spot market. In addition, we want to have a common unit of standardization and using the spot market volume seems as a reasonable benchmark. Second, the measures used for the volume of dollars traded in the spot market changes due to data availability. While for Brazil, Colombia, and Peru we use the volume traded in the interbank spot market, for Chile and Mexico we use a broader measure, namely, the volume traded in the spot market among all financial institutions, not only the banks. Of course, these are all proxies to the volume of US dollars traded in their respective spot markets. The working assumption is that they are each reliable measures of the respective spot market's size. Third, we consider the nominal GDP in US dollars for each country. Third, the international reserves' reporting frequency varies across countries. More generally, different data frequency is an issue for some time series. For instance, some international reserves have a monthly frequency, while essentially all of our time series have daily frequencies. Thus, our convention is that, for example, the value of an international reserve that is only reported once a month is kept constant throughout the referred month.

Methodology

First, we estimate the risk-neutral densities of the exchange rates of each country in our sample. The intuition is that by considering the prices of several options on the same underlying asset and the same horizon, one is able to extract the implied risk-neutral density. Next, we provide a general explanation, albeit we describe this procedure in more detail in Appendix A.

We collect the implied volatilities on several derivatives on an exchange rate all sharing the same expiration horizon. Next, we obtain the implied volatilities as a function of the strike prices. Then we use a spline interpolation to obtain a denser set of strike prices, each one being associated to a level of implied volatility. In turn, we find the prices of various calls and puts based on strike prices and their implied volatilities. Finally, we make use of the formulas due to Breeden and Litzenberger [1978] to extract the risk-neutral density as a function of the calls' and puts' second partial derivative with respect to the underlying asset. Based on these densities, the mean, volatility, skewness, kurtosis, risk premium, and right and left tail parameters, are estimated for each period and horizon.

Second, we estimate the following three specifications, exploring the interventions' effects through slightly different approaches. For instance, while the first two specifications see an intervention as an event, and thus use a dummy, the third uses the intervention quantity standardized by the volume of dollars traded in the spot market. As another difference, note the last two specifications do control for interventions other than those implemented in the spot market and for the level of international reserves (standardized). Thus, we have for our benchmark specification:

$$s_{t,c,i} = \beta_{0,c,i} + \beta_{1,c,i} D_{t-1,c} + \beta_{2,c,i} CF_{t,-c,i} + \sum_{k=1}^{n_{c,i}} \beta_{k+2,c,i} s_{t-k,c,i} + \varepsilon_{t,c,i} \tag{1}$$

and for the other two specifications, we control for the interventions not implemented in the exchange rate spot market and the size of international reserves:

$$s_{t,c,i} = \beta_{0,c,i} + \beta_{1,c,i} D_{t-1,c} + \beta_{2,c,i} CF_{t,-c,i} + \sum_{k=1}^{n_{c,i}} \beta_{k+2,c,i} s_{t-k,c,i} + \gamma'_{1,c,i} CD_{t-1} + \gamma_{2,c,i} CSR_{g,t,c} + \varepsilon_{t,c,i} \tag{2}$$

$$s_{t,c,i} = \beta_{0,c,i} + \beta_{1,c,i} SQ_{t-1,c} + \beta_{2,c,i} CF_{t,-c,i} + \sum_{k=1}^{n_{c,i}} \beta_{k+2,c,i} s_{t-k,c,i} + \gamma'_{1,c,i} CSQ_{t-1} + \gamma_{2,c,i} CSR_{v,t,c} + \varepsilon_{t,c,i} \tag{3}$$

where t is the time period (day), c is the country ($c =$ Brazil, Chile, Colombia, Mexico, or Peru), and i is the type of statistic based on the risk-neutral density. The term $s_{t,c,i}$ stands for statistic i (where $i =$ mean, volatility, skewness, kurtosis, risk premium, right, or left tail parameters) of the risk-neutral distribution on day t, and for the exchange rate of country c. While obtaining any of the first four statistics is direct from a density function, we explain how we do so for the risk premium, and the right and left tails parameters further below.

$D_{t-1,c}$ is the intervention dummy variable, which equals one if there is an intervention that involves buying dollars on day $t-1$ in country c, minus one if the intervention involves the sale of dollars, and it is zero in any other case. We use this definition for specifications (1) and (2) and thus see an intervention as an event. In contrast, in specification (3), we instead consider the quantity of dollars involved in each intervention divided by the volume of dollars traded in the spot market, denoted by $SQ_{t-1,c}$ (i.e., (S)tandardized (Q)uantity). Similarly, if such quantity is positive, it involves buying dollars, if it is negative, it involves selling dollars, and zero otherwise.[7] Thus, we think of the intervention's size in terms of the spot market's size.

[7]By buying we specifically mean that the central banking obtains the dollars and, conversely, by selling we

We use intervention variables associated with period $t-1$ to mitigate potential simultaneity in our regressions. In this context, simultaneity might be an issue as the variable $D_{t,c}$ might depend on $s_{t,c,i}$. Thus, the information used to decide whether to intervene (in $t-1$) takes place before the exchange rate option data is fixed (in t), in the discretionary case. Similarly, the information the triggering rule depends on (in $t-1$) takes place before the exchange rate option data is decided (in t), in the rules-based case.

$CF_{t,-c,i}$ is a common factor or component. Following Abarca, Ramírez, and Rangel [2012], we construct this factor as the average of the percentage changes in $s_{t,c,i}$ for all the countries in the sample except for c, hence the notation $-c$. Specifically, we have that:

$$CF_{t,-c,i} = (\%\Delta s_{t,1,i} + ... + \%\Delta s_{t,c-1,i} + \%\Delta s_{t,c+1,i} + ... + \%\Delta s_{t,C,i})/(C-1)$$

where $\%\triangle x$ denotes the percentage change of x, and C is the number of countries in the sample. Thus, this factor aims to control for the common macroeconomic and financial effects that affect the exchange rates jointly.

The lagged terms account for the possible presence of autocorrelation in the error term. Since the data frequency is daily, the presence of autocorrelation in the error term is likely. We choose the lag based on the BIC criteria in specification (1). In particular, we estimate the models with sequential lags and choose the first lag that minimizes the BIC statistic.[8] Note that the number of lags depend on the country, denoted by c, and the statistic, denoted by i, at hand. Hence, we denote the number of lags as $n_{c,i}$, which reflects that fact that it depends on the country and the statistic. To be able to compare across specifications, we set the same number of lag terms in (2) and (3) as in (1).

The terms $CD_{c,t-1}$, $CSQ_{c,t-1}$, and $CSR_{c,t-1}$ denote a set of variables used as controls. Thus, we have considered three type of controls. In the first and second cases, we control for a number of interventions that take place in markets different from the spot one. Thus, the terms $CD_{c,t-1}$ and $CSQ_{c,t-1}$ stand for vectors. Each entry refers to a different intervention in country c. Note, however, that the first entry in CD_1 is not generally the same type of intervention as the first entry of CD_2, and so forth. The interpretation of their signs is maintained, nonetheless. For these interventions we either use a dummy, denoted by $CD_{c,t-1}$ (i.e., (C)ontrol (D)ummy) or the intervention quantity standardized by the volume of dollars traded in the spot market, denoted by $CSQ_{c,t-1}$ (i.e., (C)ontrol (S)tandardized (Q)uantity). In the third case, the other control is the level of international reserves standardized. Thus, for specification (2) we posit the international reserves as a proportion of the GDP, denoted $CSR_{g,c,t-1}$, hence the subscript g for gdp. For specification (3) we set it as a proportion of the volume of dollars traded in the respective spot market, denoted $CSR_{v,c,t-1}$, hence the subscript v, for volume.

mean that the central bank provides the dollars.

[8]This means that such lag might be a local minimum with respecto to the BIC criteria.

Finally, $\varepsilon_{t,c,i}$ is the error term associated to time period t, country c, and statistic i.

Next, we explain how we construct the risk premium, and the right and left tail parameters. We incorporate them in the linear model as we do with the other statistics.

A common way of defining a(n) (expected) risk premium is to consider the percentage change of the (objective or real) probability density's mean against the risk-neutral density's mean (over the latter). Yet, as known, it is problematic to accurately estimate the (objective or real) probability density of the exchange rate or its mean for that matter. Thus, we approximate the expected risk premium using the *realized* value of the exchange rate, as follows:

$$Risk\ Premium_{t,T} = \frac{E_t(S_T) - E_t^*(S_T)}{E_t^*(S_T)} \approx \frac{S_T - E_t^*(S_T)}{E_t^*(S_T)}$$

where * denotes that the expectation is taken with respect to the risk-neutral probability, S_T is the value of the exchange rate at time T, and $E_t(S_T)$ is the expected value of the exchange rate at time T taken with respect to the (objective or real) probability at time t, where it is assumed that $t < T$.[9]

The dynamics of the distributions' tails are also of keen interest to our analysis. To estimate them we follow Figlewski [2008]. He proposes incorporating the generalized extreme value distribution (GEVD) to the estimated risk-neutral distribution (RND) at both ends to account for events in the tails. The main rationale behind the use of the GEVD is the Fisher-Tipper Theorem, akin to the Central Limit Theorem but for the tails of the distribution. The Fisher-Tipper Theorem states that under some regularity conditions the maximum in a sample of independently drawn random variables from an unknown distribution will converge to the GEVD.

The idea is to adjoin the GEVD to the extremes of the RND keeping the combined functions as a *bona fide* probability distribution. The GEVD is determined by the following three parameters: ξ, σ, and μ.

$$F_{GEVD}(z) = exp(-(1 + z\xi)^{-1/\xi})$$

where $z = (x - \mu)/\sigma$. Thus, the parameter μ determines the location and σ the scale. The parameter ξ defines whether the distribution is Fréchet ($\xi > 0$), Gumbel ($\xi = 0$) or Weibull ($\xi < 0$). If the referred parameter is negative, the distribution is bounded from above and as it becomes (negatively) larger, the tail is relatively slimmer. If it is zero, it behaves similarly to a normal distribution's tail. Finally, as it becomes (positively) larger, the tail becomes relatively fatter. In short, a larger ξ assigns a greater probability to extreme events. We thus focus on

[9] This differs from the one used by Abarca, Ramírez, and Rangel [2012]. It is also worth mentioning that we do not assume that the exchange rate is a random walk, as they do. Using such assumption is problematic since a variation due to an intervention is in principle permanent.

the dynamics of ξ.

The values α_{0R} and α_{1R} are parameters that serve as anchors to the adjoining process. Although there is some flexibility in their selection, we set $\alpha_{0R} = 0.92$ and $\alpha_{1R} = 0.95$, as in Figlewski [op. cit.]. As a next step, $K(\alpha_{0R})$ and $K(\alpha_{1R})$ are defined as $F_{RND}(K(\alpha_{0R}))= \alpha_{0R}$ and $F_{RND}(K(\alpha_{1R})) = \alpha_{1R}$, where F_{RND} is the risk-neutral probability function. Then Figlewski [op. cit.] proposes the following three conditions to determine ξ, σ, and μ.

$$\begin{aligned}
F_{GEVD}(S(\alpha_{0R})) &= \alpha_{0R} \\
f_{GEVD}(S(\alpha_{0R})) &= f_{RND}(S(\alpha_{0R})) \\
f_{GEVD}(S(\alpha_{1R})) &= f_{RND}(S(\alpha_{1R}))
\end{aligned}$$

We numerically minimize the sum of the quadratic differences of these three equations to estimate $\xi_{t,R}$, $\sigma_{t,R}$, and $\mu_{t,R}$, now annotated with a t, the time period, and an R, for right tail.

The parameters for the left tail are estimated in a similar way. The distribution of the GEVD follows from the distribution of the maximum value of independently drawn variables, as briefly explained above. On the left tail, one is concerned about the distribution of the minimum value of independently drawn variables. Thus, to obtain the GEVD for the left tail one then has to introduce a change of variable to the ordinary GEVD. [10]

The values α_{0L} and α_{1L} are set $\alpha_{0L} = 0.05$ and $\alpha_{1L} = 0.02$, again as in Figlewski [op. cit.]. As a next step, $K(\alpha_{0R})$ and $K(\alpha_{1R})$ are similarly defined as $F_{RND}(K(\alpha_{0L}))= \alpha_{0L}$ and $F_{RND}(K(\alpha_{1L})) = \alpha_{1L}$. Then he proposes the following three conditions to determine $\xi_{t,L}$, $\sigma_{t,L}$, and $\mu_{t,L}$. [11]

$$\begin{aligned}
F_{GEVD-L}(S(\alpha_{0L})) &= \alpha_{0L} \\
f_{GEVD-L}(S(\alpha_{0L})) &= f_{RND}(S(\alpha_{0L})) \\
f_{GEVD-L}(S(\alpha_{1L})) &= f_{RND}(S(\alpha_{1L}))
\end{aligned}$$

Similarly, we numerically minimize the sum of the quadratic differences of these three equations to estimate $\xi_{t,L}$, $\sigma_{t,L}$, and $\mu_{t,L}$.

Next, we estimate our linear model with the time series of $\xi_{t,L}$, measuring the possible effects an intervention might have on the exchange rate distribution's left tail, and with the time series $\xi_{t,R}$, similarly, measuring the possible effects an intervention might have on the exchange rate distribution's right tail. Note that our notation makes a distinction on whether the parameter is from the right or the left tail. We also use the acronyms LTP and RTP to refer, respectively, to $\xi_{t,L}$ and $\xi_{t,R}$.

Before moving on to our main results we consider some interpretations on the statistics and, on the other hand, the statistics' averages and standard deviations for the countries in our sample (Exhibit 1). On the interpretation of the statistics, we consider the following comments relevant.

[10] Note that the maximum of a set of variables equals minus the minimum of the referred variables multiplied by minus one.

[11] The interested reader can refer to Figlewski [op. cit.] for further details.

We generally consider, ceteris paribus, an increase in the statistic at hand. First, one should interpret a change in the mean with some care. Under the risk-neutral density, the expected growth of the exchange rate is the interest rate minus the US interest rate.[12] Thus, in general, a change in the mean does not imply a change in the expected depreciation or appreciation. This is so since the expected exchange rate under the risk-neutral density is $S(t)(1+r-r^*)$. Of course, this would be the correct interpretation if one believes there has been a change in the objective mean, since in such case the expected exchange rate is $S(t)(1+\mu)$. Second, an increase in volatility implies an increment in the probability of a movement in either direction, i.e., a depreciation or an appreciation. As it is commonly interpreted, the volatility measures the risk in the exchange rate variations. Third, an increase in skewness augments the probability of an abrupt depreciation. On the other hand, a decrease in the skewness increases the probability of an abrupt appreciation. Yet one should also consider the following. An increase in skewness also implies that, in tandem, the probability mass of the distribution tends to move towards the left of the mean, thus assigning greater probability to small appreciations. A similar result holds when the skewness decreases, it increases the probability of a small depreciation. A skewness of zero implies symmetrical probabilities of a depreciation or an appreciation. Fourth, an increase in kurtosis implies an increase in the probability of an abrupt movement in either direction. In effect, the kurtosis measures the tails' fatness. In tandem, an increase in kurtosis involves an increase in the density's peakedness, increasing the probability of a mild movement in either direction. Fifth, an increase in the LTP ($\xi_{t,L}$) implies an increase in the probability of an extreme appreciation, and not much can be said about the rest of the density based on changes in the LTP. On the other hand, an increase in the RTP ($\xi_{t,R}$) implies an increase in the probability of an extreme depreciation, but similarly not much can be said about the rest of the density based on changes in the RTP.

On the averages and standard deviations of the statistics for the countries in our sample there are a few comments in order. First, as the horizon increases, the volatility increases, as one would expect to observe. Second, for all five countries skewness are positive and increase with the horizon. This implies that the exchange rates' distributions have a right tail that is somewhat fatter, indicating proportionally a greater probability of a depreciation. Third, with respect to the kurtosis, all values are around three and have a similar level as the horizon increases. Fourth, as for the average risk premium, all of the estimates are close to zero. Given the horizons considered, this is as expected. The largest absolute values are associated with Brazil, regardless of the horizon.[13] Fifth, regarding the right and left tails' parameters, their magnitudes are similar between countries and horizons. Their standard deviations point to important variability in all cases.[14]

[12]This result is similar to the uncovered interest parity.

[13]Note that a negative risk premium entails an appreciation of the local currency or a higher local short-term rate compared to the one in the US.

[14]These statistics are useful to get a grasp of the data's magnitudes. More specifically, the standard deviations

Finally, it is worth mentioning that the economic fundamentals of a country are conceivably relevant to the effects an intervention might have. Yet, we are not considering them in our exercises and leave this important issue for future research.

Results

As explained, we posit and estimate three specifications of our linear model (i.e., equations 1, 2 and 3). The selected estimates are respectively in Exhibits 2, 3 and 4. Each one takes a somewhat different approach. In what follows we provide several comments regarding the significance, both statistically and economically, of the coefficients associated to the interventions in the spot markets.[15] For space reasons we do not include all the estimates and statistics for all the regressions. Rather, we focus on the coefficients associated to the interventions in the spot market, and refer to each as a case. Thus, note we have 210 cases (i.e., five countries, seven statistics, two horizons, and three specifications).

First, with respect to the mean, almost all cases have coefficients that are not statistically significant. There are, however, four cases that are statistically significant but which are not economically significant. Thus, interventions, on average do not seem to be affecting the first moment of the risk-neutral distribution. Based on what was previously discussed, these results are expected. The mean of these distributions are determined by the interest rates differentials (local minus US). In addition, considering that these interventiones are sterillized, no change in the interest rate would be expected.

Second, none of the coefficients associated to the volatility are statistically significant.

Third, as for the skewness, in general, specifications do not have statistically significant coefficients. There are, nonetheless, four exceptions. Three are not economically significant and only the case of Mexico, for the one-day horizon, (specification (3)) is somewhat economically significant. If dollars are sold in the intervention, its skewness increases, raising the probability of an large depreciation and the probability of a slight appreciation. Note, however, it is for the one-day horizon and, thus, a short-lived effect.

The case of kurtosis differs somewhat from the dynamics of the three first moments. We have eight cases with a statistically significant coefficient, from which only three have somewhat

provide a yardstick to assess the economic significance of the expected exchange rates' variations due to the interventions. These will be quite useful when we comment on the estimates of the linear models.

[15]To assess the economic significance of the coefficients we use the following conventions. First, when we consider a coefficient associated with a dummy, we take a look at the ratio $\beta_{1,c,i}/std(s_{c,i})$. Second, when we consider a coefficient related to an intervention quantity (standardized), we analyze the following ratio: $\beta_{1,c,i} max\{E(SQ_c|SQ_c > 0), E(SQ_c|SQ_c < 0)\}/std(s_{c,i})$. In general, taking the normal distribution as a benchmark, if the ratio is below 0.10 then we interpret it as not being economically significant. In effect, 92% of the changes in the referred statistic are greater (in absolute value) than $\beta_{1,c,i}$. If the ratio is greater than 0.10 but lower than 0.25 we interpret it as somewhat economically significant. In effect, 80% of the variations in the statistic at hand are greater (in absolute value) than $\beta_{1,c,i}$. If it is above 0.25, then we take it to be economically significant.

economically significant coefficients. Peru stands for having the greatest impact, in terms of the standard deviation of its kurtosis. In this case, a sale of dollars implies an increae in the kurtosis, and thus a higher probability of an large depreciation or appreciation.

The risk premium has a different behavior. We have fifteen cases with a statistically significant coefficient. Out of this set, eight are somewhat economically significant and only one economically significant. This last case is Peru (specification (3)) with a one-week horizon. In effect, the variation of the risk premium after an intervention stands for more than a quarter of its standard deviation. If the authorities sell dollars they reduce the risk premium. Conversely, if they purchase dollars they augment the risk premium.

On the other hand, the cases of the left tail and right tail parameters are different from the results above. Regarding the LTP, we have eleven cases with statistically significant coefficients. Three are not economically significant, one is only somewhat, and the rest are all economically significant. There is no uniform effect regarding the direction that an intervention has in the LTP. For example, while a sale of dollars leads to an increase in the LTP for Mexico, it implies a decrease in the LTP for Peru (for specification (1) and the one-day horizon). Also, except for three cases, all of the economically significant coefficients are for the one-day horizon, and thus short-lived effects. These exceptions are related to the case of Peru. Based on specification (3), if the authorities in Peru sell dollars, the probability of an abrupt appreciation increases. From the economic point of view, this is reasonable, as more dollars makes the Sol relatively less abundant.

Finally, the right tail parameter presents a similar behavior to the left one. There are nine cases having a statistically significant coefficient, six are somewhat economically significant and three are economically significant. Similarly, of those that are economically significant only two are for a one-week horizon. These are associated to Peru (Specifications 1 and 2), and to Mexico in specification 3. In both cases, if the authorities sell dollars the probability of an abrupt depreciation is reduced. This makes economic sense to the extent that more dollars in the exchange rate market imply that the local currency is -in relative terms- less abundant and thus more valuable. Note as well that this keeps some consistency with the results found for the LTP.

Several further comments are in place. First, it seems that those parameters, i.e., the LTP and RTP, trying to measure the probability of extreme changes in the exchange rates are the most affected by interventions. These effects are plausibly unintended consequences of the interventions. Moreover, it is important to bear in mind that these are the most challenging to measure. The risk premium and the kurtosis also tend to be moderately affected, while the rest of the statistics in general stay put. Second, comparing our three specifications, we have that specification (3) tends pick up the effects of these interventions. Third, Peru seems to be the country which has the most notable effects in terms of the statistics we have considered. This result is consistent with the fact that Peru has by a long shot the biggest interventions in terms of its spot market's size.

Selected episodes

In this subsection, we consider some episodes that are germane to our analysis. These are, first, those associated to the Dollar Swap Line between the Fed and the Central Bank of Brazil, and on a separate basis, the Fed and the Bank of Mexico and, second, to the Flexible Credit Line (FCL) setup between the IMF and Colombia, and on a separate basis, between the IMF and Mexico.[16] In some cases, such as Mexico's, the Dollar Swap Line did lead to an intervention. Yet, the sole fact of gaining access to such amount of resource might as well be considered an intervention itself. On the other hand, the FCL can be considered as a contingent reserve.

Against this backdrop, we think it is worth exploring the behavior of the respective exchange rates' probability density functions on the days associated to these episodes. As an additional remark, note that it is particularly challenging to measure the effects on the exchange rate given that they all are unique episodes.[17]

We specifically consider the day before the relevant event (identified by T-1) and the day of the event (identified by T). We focus on the one-week horizon PDF as we believe it should best capture any possible effect. Needless to say, our analysis is based on the visual inspection of the PDF's, and their changes can be due to other, and perhaps, unrelated events. The specific events, dates, and the countries we consider are as follows.

1. The Fed's announcement of the Dollar Swap Line between this institution and the Central Bank of Brazil on October 29, 2008.

2. The Fed's announcement of the Dollar Swap Line between this institution and the Bank of Mexico on October 29, 2008.

3. The Bank of Mexico announces that the mechanism to allocate part of the resources of the Fed's Swap Line would be activated, April 3, 2009.

[16]The Flexible Credit Line (FCL) is a credit line provided by the International Monetary Fund (IMF). One of its distinctive features is that countries qualify for a FCL *ex-ante*.

It is designed to meet the demand for crisis-prevention and crisis-mitigation lending for countries with very strong policy frameworks and track records in economic performance. This tool was created as part of the process of reforming how the IMF lends money to countries that find themselves in a cash crunch, with the idea of tailoring its lending instruments to the diverse needs and circumstances of member countries. Hitherto, Colombia, Mexico, and Poland have obtained a FCL. While none of these countries have so far drawn down on these lines, their FCLs have provided them valuable insurance and helped boost market confidence during the period of heightened risks (Source: IMF). The exercises presented in this section provide evidence favorable to the latter.

[17]In effect, for example, one can see a common intervention as an event that takes place several times. Thus, one is able to measure the average effect through a regression model, as we have done so. Nonetheless, unique episodes by their own nature take place one or perhaps a couple of times. In addition, there is no natural counterfactual to the day a unique episode took place.

4. The Bank of Mexico summons an auction to allocate part of the resources of the Fed's Swap Line on April 21, 2009.

5. The IMF announces the Flexible Credit Line (FCL) for Mexico on November 30, 2012.

6. The IMF announces the Flexible Credit Line (FCL) for Colombia on June 24, 2013.

In the plots, each of these days is identified by T. Thus, accordingly, day T-1 is the working day immediately prior to T. So, for example, for the Fed's announcement, we have that October 29, 2008 is day T, and October 28, 2008 is day T-1 (provided that October 28, 2008 was a working day).

For event 1, the Fed's announcement of the Dollar Swap Line between this institution and the Central Bank of Brazil, we have that the corresponding PDF's mode shifts perceptively towards the left, i.e., an appreciation, volatility diminishes marginally, its skewness perhaps increases slightly, and its kurtosis increases. These mainly imply a slight increase in the probability of a significant depreciation or appreciation. Yet, again, these changes do not seem to be particularly prominent (Exhibit 5, graph on the left). For event 2, the Fed's announcement of the Dollar Swap Line between this institution and the Bank of Mexico, we observe in the corresponding PDF's, a similar effect to the one we have just described (Exhibit 5, graph on the right). Also, we think that these changes are not particularly protuberant. All in all, it seems that the announcement of the Dollar Swap Lines did not affect the PDF of the exchange rates of Brazil and Mexico, respectively. This could have been simply because the markets had previously priced in the referred events.

For event 3, The Bank of Mexico announces that the mechanism to allocate part of the resources of the Fed's Swap Line would be activated, there are more notable changes. The PDF's mean moves to the left, perhaps reflecting an appreciation. It seems that its variance decreases and its kurtosis increases. For event 4, the Bank of Mexico summons an auction to allocate part of the resources of the Fed's Swap Line, there are some similar changes to those seen in event 3. Of course, event 4 can be seen as a development to event 3 (events 3 and 4's PDF's are depicted in Exhibit 6). The PDF's mean shifts leftwards, and its kurtosis increases somewhat. In addition, note the drastic difference between the PDF's variance for the Mexican peso-US dollar exchange rate on the day event 2 took place vs. the variance it had on the days of the other events related to Mexico. This could reflect conditions of stress in the exchange rate market at the time.

For events 5 and 6, whereby the IMF announces the Flexible Credit Line (FCL) for Colombia, and on a different date for Mexico, a possible effect is less direct (Exhibit 7). We see modests decreases in their kurtosis taking place in both cases. Nonetheless, their means seem to stand still. Note, however, that our analysis assumes that the implementation's announcement of the mechanism at hand comes as a complete surprise in period T. Admittedly, this is not generally the case as the information that an economy is being considered for such a facility is generally known. Thus, agents can assess the possibilities that an economy will obtain such resources ahead of period T. Accordingly, it is difficult to exactly determine the exact time the exchange rate market prices in such information. We believe this is the case with the FCLs.

All in all, it stands that the events associated to the Swap Line between the Fed and the Bank of Mexico brought about the most significant changes in the respective risk-neutral density function, particularly so in the days associated to the intervention. This is in line with the sheer size of the associated resources.

Final Remarks

It is essential to put our results in perspective. Although these are interesting in their own right, it is important to acknowledge that we have left out of the analysis several factors that could have a role determining the effects of an intervention. For instance, the overall macroeconomic situation of the country at hand may very likely play an important role too.

More broadly, we would like to make several remarks. First and foremost, if there is a shift in an economic fundamental causing a movement in the real exchange rate, then an intervention under such setting will have a low probability of success. The exchange rate will eventually end up being determined by the corresponding economic fundamentals. Indeed, it is unlikely that an intervention will do well if it attempts to go against economic fundamentals, even more so if the intervention is not part of other policy measures. We believe that these results are well-known.

Second, in the few cases in which we do find an effect, some appear to be unintended. Arguably, it is unlikely that a central bank would have as an objective of selling dollars some of the effects we observe, e.g., increasing the probability of an abrupt depreciation. One possible explanation is that the authority -with an informational advantage- if that were the case, could try to intervene and have a head start to attenuate or compensate an external shock. In this type of situations, although plausible, the intervention will probably not be successful and as a consequence, at the end of the day, the referred shock would be what ends up affecting the exchange rate. However, it could also be the case that without the intervention the depreciation could have been worse. However, in trying to prove or disprove this, as usual, it is difficult to obtain counterfactuals.

Third, nonetheless, intervening might be certainly warranted under certain cases. One such case is when the central bank acts as a "market maker," e.g., to facilitate an exchange rate transition between two equilibria in an orderly fashion. Another such case might be justified given the sheer size of some external shocks, both when these lead to large capital inflows (e.g., in tight relative monetary policy stances episodes) or large outflows (e.g., in flight to safety episodes), considering the relative size of exchange rates markets in some emerging economies. In this case, intervening should aim to provide liquidity, assuring the operability of the exchange rate market. This, in effect, might avoid bad equilibria that could otherwise prove to be very costly for the economy.

What is more, there are perhaps cases in which interventions might have aims we have not considered and may not even be explicitly stated by the authorities. One such possibility could entail political economy considerations, for example, not standing idle under the presence of large external shocks. Although the analysis of these aims is beyond the scope of this paper, we believe they should not be left unexplored.

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Appendices

A. Extracting the Risk-Neutral Densities

In this appendix we explain in some detail our procedure to extract the risk-neutral densities from the options data. To set the stage, first consider the following classic problem in option pricing. Namely, the determination of the value of an option having as an underlying a given financial asset. To fix ideas, suppose that this option gives its holder today, i.e., t, the option but not the obligation to buy the referred financial asset at the expiration period, T, at a fix price, K, the strike price. Such option goes by the name of European Call. Its price in T is given by $C(S(T),T) = max\left\{S(T)-K,0\right\}$. Thus, the price of the option in T will trivially depend on the financial asset price in T.

Yet, the problem at hand is to determine the price of the option in the present period, $C(S(t),t)$, considering that the price of the underlying asset at expiration is yet unknown. The Fundamental Theorem of Asset Pricing states that under the absence of arbitrage, there exists a probability density such that: $C(S(t),t) = E_t^*(exp(-r(T-t))max\left\{S(T)-K,0\right\})$. This probability density is the risk-neutral density, also known as the Equivalent Martingale Measure. The * denotes that the expectation has been taken with respect to the risk-neutral density, which is different from the objective or real probability density. One of the insightful and powerful aspects of this theorem is that the risk-neutral density prices *any* option. This is relevant to understand why the extraction of a risk-neutral density is feasible, each option on the *same* underlying asset and expiration date carries a piece of information regarding their *common* risk-neutral distribution.

Thus, one would like to estimate the risk-neutral density of a financial asset based on a set of options which have as an underlying this same asset. It turns out that this is possible. Breeden and Litzenberger (1978) derived some general formulas (shown below) to do this. These formulas relate the prices of put and call options to the risk-neutral density of the underlying asset. An intuitive way to understand one of the formulas is to consider a discrete state-space and then obtain the differences of the differences of the adjacent call options prices and realize that these are the prices of the state-contingent assets, which are proportional to the risk-neutral probabilities. The case for the other formula is similar but involves put options prices.[18]

In what follows we explain how we obtained the prices of the put and call options from the options data in order to apply the formulas by Breeden and Litzenberger (1978). Thus, next, we briefly explain what is meant by implied volatility in the context of options. Recall that the theoretical price of an option is a function of several parameters,

$$C(t, T, S(t), \sigma, r, K),$$

[18] The state-contingent assets are also known as Arrow-Debreu assets.

the current period t, the maturity period T, the current price of the underlying $S(t)$, the volatility of the underlying asset return's distribution, σ, the risk-free interest rate, r , the strike price K, among possibly others. All of the parameters are *observable* except for the volatility, σ.

The implied volatility is such that the option's theoretical price equals its market price having plugged in all the other parameters (i.e., $t, T, S(t), r$, and K) except for the volatility (σ) into the formula. In short, if P is the market price of the option in question, the implied volatility is $\sigma_{implied}$ such that the following equality holds:

$$P = C(t, T, S(t), \sigma_{implied}, r, K)$$

Similarly, some options' characteristics such as the delta (δ), the partial derivative of the value of the option with respect to the underlying asset, are a function of a set of parameters, including the volatility.

It is customary for exchange rates options data to be provided in terms of the implied volatilities of specific positions. Thus, let $V_{position,x}$ denote the implicit volatility of the *position* associated to a delta value of x. For example, $V_{Call,10}$ is the implied volatility of a call with a delta of 0.10, while $V_{Put,10}$ corresponds to the implied volatility of a put option with a delta of -0.10. Furthermore, the data is provided in terms of portfolio positions of different options (see, e.g., Reiswich and Wystup (2010)). So for example, a Risk Reversal (RR) refers to a portfolio of a long position in a call and a short position in a put, i.e., RR = Call - Put. Thus, the piece of data is provided as the difference between the call's implied volatility and the put's implied volatility, e.g., $V_{RR,10} = V_{Call,10} - V_{Put,10}$.

Thus, we use daily data on the implied volatilities of 10 and 25 risk reversals, 10 and 25 butterflies (BF), and at the money (ATM) options. For example, the 10 risk reversal implied volatility is the difference between the 10 delta call and the 10 delta put implied volatilities.

$$V_{RR,10} = V_{Call,10} - V_{Put,10}$$

In this case, the underlying asset is the US dollar. The 10 butterfly is defined as:

$$V_{BF,10} = (V_{Call,10} + V_{Put,10})/2 - V_{ATM}$$

Likewise for the 25 risk reversals, 25 butterfly, and ATM options we have: $V_{RR,25} = V_{Call,25} - V_{Put,25}$ and $V_{BF,25} = (V_{Call,25} + V_{Put,25})/2 - V_{ATM}$. The convention is that V_{ATM} is associated with the strike price, K, for which $\delta_{Call} = -\delta_{Put}$.

This set of equations implies, in terms of implied volatilities, that:

$$
\begin{aligned}
V_{Put,25} &= V_{BF,25} + V_{ATM} - \tfrac{1}{2}V_{RR,25} \\
V_{Put,10} &= V_{BF,10} + V_{ATM} - \tfrac{1}{2}V_{RR,10} \\
V_{Call,10} &= V_{BF,10} + V_{ATM} - \tfrac{1}{2}V_{RR,10} \\
V_{Call,25} &= V_{BF,25} + V_{ATM} - \tfrac{1}{2}V_{RR,25}
\end{aligned}
$$

This provides us with five (delta, implied volatility) data points for each day.[19] We reckon that the number of data points per day is limited. Yet, to the best of our knowledge other databases which have more data points per day are not available for options with a one-day horizon.

Next, we describe our method in more detail. To fix ideas, we consider a one-week horizon. Thus, for every period t, we proceed with the following steps.

1. From the data in terms of the 10 and 25 risk reversals, the 10 and 25 butterflies, and the at the money option, we calculate the implied volatilities associated to the 10 call and put, the 25 call and put, and at the money call, as a function of the associated deltas, i.e., data points in the (deltas, implied volatilities) space.

2. Then, we estimate the implied volatilities as a function of the strike prices, i.e., data points in the (strike prices, implied volatilities) space. Note that if the current exchange rate, the interest rates (local and US), the implied volatility and the maturity are known, there is a one-to-one correspondence between deltas and strikes prices.

3. We obtain a denser set of strike prices using spline interpolation on the options and strike prices. Each interval is constructed considering the historical behavior of the exchange rates to completely include the historical densities' supports.

4. Using Breeden and Litzenberger [1978] formulas, we then obtain the probability density function of the underlying asset, in this case the exchange rates:[20]

   $$f(K) = exp(rT)\frac{\partial^2 C}{\partial K^2} = exp(rT)\frac{\partial^2 P}{\partial K^2}$$

   where C and P are the value of the call and the put, respectively. As in Figlewski [op. cit.], their discrete counterparts are used to approximate the partial derivatives.

   $$f(K) \approx exp(rT)\frac{C_{n+1} - 2C_n + C_{n-1}}{(dK)^2} \approx exp(rT)\frac{P_{n+1} - 2P_n + P_{n-1}}{(dK)^2}$$

   where $n = K_1, ..., K_N$.

[19] For the few days on which there is no piece of data available, the nearest previous one is used.

[20] See Figlewksi [op. cit.] for a formal derivation.

5. Finally, from the risk-neutral density function, $f(K)$, we estimate various statistics, the mean, the volatility, the skewness, the kurtosis, the risk premium, and the parameters describing the right and left tails.

Several comments are in place. The formulas proposed by Breeden and Litzenberger [op. cit.] are quite general. In particular, they do not assume the same volatility for different strike prices, thus, the so-called volatility surface as observed in the data is accounted for. This is essential to our results, as strictly assuming the Black and Scholes framework would remove much flexibility from our analysis.

This approach has the clear advantage of being based on market information and not merely on survey expectations. Although there is a reputational aspect to surveys, market information is based on prices that agents use to take buying and selling decisions. Of course, it hinges on having an adequate pricing model and data. Centrally, using market-based expectations allows for having daily frequency and short horizons data, which is considered a key aspect in the analysis of interventions.

Derivatives are commonly priced based on their associated so-called risk-neutral density, the use of which greatly simplifies many asset pricing problems.[21] Yet, interpreting the risk-neutral probabilities should be made cautiously. For example, an increase in the risk-neutral probability must be either due to an increase in the (real or objective) probability of the underlying asset having a set of values or to an increase in the marginal utility of the representative agent in the states of nature associated to the referred set of values.[22]

Extracting the risk-neutral distribution from options prices to see how it is affected by economic events is a remarkable application of asset pricing. The approach we use provides much flexibility in terms of the amount of information one can extract from market data. For example, Figlewski and Birru [2010] study how the risk-neutral distribution of the S&P 500 index changed through the fall of 2008, period in which the recent global financial crisis erupted in full force. In particular, they analyze some parameters describing the distributions' tails. In the same vein, Abarca, Benavides, and Rangel [2012] analyze how the risk-neutral distribution of the peso/dollar exchange rate might vary with monetary policy announcements in Mexico, while Abarca, Ramírez, and Rangel [2012] analyze how the implementation of capital controls and banking regulations might affect the risk-neutral distribution of the exchange rate in a

[21] Its name can be considered a misnomer, as no agent is risk-neutral in the option pricing model. The pricing equation under the risk-neutral probability looks *as if* it was derived from a risk-neutral agent.

[22] In a mathematical finance setup, one commonly assumes that the real probability distribution and the risk-neutral distribution are absolutely continuous measures with respect to each other. Then, as a result of the Girsanov Theorem, these densities differ only in their means. Thus, under the referred assumption, we are able to take the risk-neutral distributions' moments as *bona fide* moments, except for the first one. Moreover, in a macroeconomics setup, given the short horizons the stochastic discount factor might be taken approximately as constant. Thus, in this sense, a risk-neutral distribution can be taken as a close approximation to the objective distribution.

group of emerging market economies.[23]

Gnabo and Teiletche [2008] and Roger and Siklos [2001] analyze the expected exchange rate using methods similar to the ones we have used in this paper. The former paper studies how announcements impact the US dollar/Japanese Yen exchange rate's risk-neutral density. The latter paper considers the interventions of the Bank of Canada and the Reserve Bank of Australia in their respective exchange rate markets. Here, volatility is measured using the implied volatility, and uncertainty is approximated with the kurtosis obtained from the risk-neutral probability density.

Ours is similar to the paper by Miyajima and Montoro's [2013], since both analyze the effects of interventions on exchange rate expectations. Yet ours differs in some key aspects. First, while we consider market-based expectations, they consider survey-based expectations. Second, we have access to daily data and short-term horizons options. In contrast, surveys typically entail data with lower frequencies, e.g., biweekly, monthly, and longer horizons. Third, in a survey there is typically the issue of when exactly a piece of data was collected from each forecaster, which is not necessarily the same date as when the survey was published. Our data do not have this problem. It has been a matter of debate whether professional forecasters or market based predictions perform better (see, e.g., Ang, Bekaert and Wei [2006]).

B. Variants to our model

We believe there are at least two additional variants to our model that might be relevant. First, one always worries about possible non-stationarity in the time series involved, in particular for the mean. To entertain such possibility, one could also estimate a similar model but using the differences of the means, an adjust the other statistics accordingly, such as the common factor.

$$\triangle s_{t,c,i} = \beta_{0,c,i} + \beta_{1,c,i} D_{t-1,c} + \beta_{2,c,i} CF_{t,-c,i} + \sum_{k=1}^{n_{c,i}} \beta_{k+2,c,i} s_{t-k,c,i} \triangle s_{t-j,c,i} + \varepsilon_{t,c,i}$$

It can be argued that higher order moments have less of a chance of presenting non-stationarity.

Second, we have used what can be considered common statistics, except perhaps for the parameters associated to the distribution's tails. We think it is worth considering taking a look to a more general measure of the PDF's such as its entropy. Likewise, the use of some benchmark to impose a preference order on the PDF's might be useful as well.

[23]Bayoumi and Saborowski [2012] have recently underscored the importance of analyzing interventions and capital controls jointly to adequately measure the effectiveness of interventions. Thus, a natural step in our study would be to consider how interventions and capital controls together (and perhaps with other macroprudential policies) might have affected the expected distribution of exchange rates. This is where our paper and that of Abarca, Ramírez, and Rangel [2012] intersect. We leave this important topic for future research.

C. Further Data Details

As mentioned in the main text, our database can be divided into five: the interventions, the options, the interest rates, the exchange rates, and the rest of the data. Here we describe our data sources in more detail.

The interventions data are essentially based on information obtained from the Central Banks' websites. For Brazil we use the spot net interventions time series. Brazil reports its swap operations in their Open Market Press Releases. To construct these series we have followed the Notes column to determine if an entry refers to a dollar sale or a purchase. On the other hand, Gabriela Fernandes (2013) generously provided us with her database on Brazilian interventions. It is worth mentioning it has some discrepancies with ours. Thus, as a robustness check, we reestimate all our models for the Brazilian case but using her database. In sum, although the point estimates do not coincide, these results tell the same story as with our database.

All of the options data, i.e., the implicit volatilities as described in detail in appendix A, the interest rates, i.e., the all one-month generic government rates, and the exchange rates are all from Bloomberg.

The other data term refers to the GDPs, the international reserves, and the volume of US dollars traded in the spot market. The GDPs are all taken from Haver Analytics (in US dollars, quarterly frequency). The international reserves' data are taken from the Central Banks' websites. Their frequencies vary, so e.g., Peru presents a daily frequency, while Mexico presents a weekly one. The volumes of dollars traded in their respective spot markets are also taken from the Central Banks' website. As mentioned, they differ in their exact construction. Brazil, Colombia and Peru's data account for the volume of dollars in the interbank spot market. Chile and Mexico's data account for the volume in the spot market among financial institutions. Naturally, these are proxies to the size of their respective spot markets.

Horizon	Brazil One day	Chile One day	Colombia One day	Mexico One day	Peru One day	Brazil One week	Chile One week	Colombia One week	Mexico One week	Peru One week
Mean	1.9211	513.2112	1952.412	12.4363	2.8707	1.9239	513.4868	1953.033	12.445	2.8722
	[0.2193]	[42.4599]	[173.066]	[1.0878]	[0.1830]	[0.2195]	[42.4888]	[173.362]	[1.089]	[0.1829]
Volatility	0.0211	5.8965	18.5247	0.1167	0.0186	0.0421	10.4150	34.5256	0.2301	0.0344
	[0.0147]	[3.6182]	[11.8250]	[0.0815]	[0.0086]	[0.0290]	[6.0467]	[20.9312]	[0.1658]	[0.0203]
Skewness	0.0333	0.0414	0.0266	0.0313	0.0219	0.0841	0.0786	0.0676	0.0687	0.0466
	[0.0380]	[0.0298]	[0.0176]	[0.0396]	[0.1964]	[0.0587]	[0.0364]	[0.0377]	[0.0556]	[0.0305]
Kurtosis	2.9840	2.9986	2.9954	2.9919	2.9893	3.0193	3.0141	3.0112	3.0140	2.9851
	[0.0650]	[0.0130]	[0.0116]	[0.0648]	[0.6644]	[0.0437]	[0.0147]	[0.0177]	[0.0353]	[0.0780]
Risk Premium	-0.0082	-0.0054	-0.0054	-0.0053	-0.0072	-0.0093	-0.0059	-0.0059	-0.0055	-0.0080
	[0.0106]	[0.0068]	[0.0076]	[0.0082]	[0.0032]	[0.0222]	[0.0172]	[0.0184]	[0.0175]	[0.0077]
Left Tail P.	-0.0912	0.0020	0.0116	-0.1154	0.0040	-0.1946	-0.0881	-0.0440	-0.1480	-0.0577
	[0.2290]	[0.2283]	[0.1162]	[0.2077]	[0.1399]	[0.2726]	[0.1676]	[0.0842]	[0.2280]	[0.1380]
Right Tail P.	-0.1178	-0.0711	-0.0228	-0.1394	-0.0280	-0.1935	-0.1564	-0.0862	-0.1839	-0.1021
	[0.2051]	[0.2129]	[0.1297]	[0.2089]	[0.1302]	[0.2305]	[0.1541]	[0.0866]	[0.1833]	[0.1574]

EXHIBIT 1. AVERAGES AND STANDARD DEVIATIONS OF THE STATISTICS FOR THE EXPECTED (RISK-NEUTRAL) DISTRIBUTION OF THE EXCHANGE RATES.

The mean and volatility are in local currency per USD. The risk premium is in percentage for the respective horizon, i.e., one-day or one-week. Standard deviations are in brackets.

Specification	1									
	Brazil	**Chile**	**Colombia**	**Mexico**	**Peru**	**Brazil**	**Chile**	**Colombia**	**Mexico**	**Peru**
Horizon	**One day**	**One day**	**One day**	**One day**	**One day**	**One week**	**One week**	**One week**	**One week**	**One week**
Mean	-0.00106	0.0497	0.587	0.00665	-0.000709	-0.00105	0.0517	0.589	0.00667	-0.000708
	(0.000872)	(0.177)	(0.756)	(0.00611)	(0.000454)	(0.000873)	(0.177)	(0.759)	(0.00612)	(0.000455)
Volatility	-0.000205	-0.00226	0.127	-0.00175	-6.16e-05	-5.37e-05	0.0159	-0.0865	0.000719	-4.64e-05
	(0.000146)	(0.0308)	(0.0883)	(0.00147)	(4.68e-05)	(0.000123)	(0.0342)	(0.107)	(0.00149)	(7.41e-05)
Skewness	-0.000762	-0.000605	-0.000258	0.000799	-0.00259	-0.000133	0.000115	9.65e-05	0.000115	-0.00263***
	(0.000646)	(0.000631)	(0.000251)	(0.00117)	(0.0109)	(0.000309)	(0.000263)	(0.000224)	(0.000444)	(0.000894)
Kurtosis	0.000137	-8.78e-05	-0.000859**	0.00944**	0.00657	-0.000209	4.10e-05	1.14e-05	2.83e-05	-0.0183***
	(0.00301)	(0.000136)	(0.000386)	(0.00438)	(0.0368)	(0.000146)	(0.000104)	(9.56e-05)	(0.000365)	(0.00659)
Risk Premium	-0.00143***	0.000219	0.000683*	0.00130***	-0.000522***	-0.000661	0.000458	0.00107**	0.000794	-0.000244
	(0.000475)	(0.000313)	(0.000352)	(0.000429)	(0.000159)	(0.000542)	(0.000387)	(0.000420)	(0.000575)	(0.000221)
Left Tail P.	0.00302	-0.00200	0.0214	-0.0938***	0.0499***	-0.00453	0.0186	-0.00417	0.0362***	0.0412***
	(0.0108)	(0.0148)	(0.0148)	(0.0142)	(0.0151)	(0.0152)	(0.0128)	(0.0127)	(0.0133)	(0.0115)
Right Tail P.	0.00496	0.0123	0.00897	-0.0443***	0.0188**	-0.0187	-0.00962	-0.00373	-0.0218*	0.0431***
	(0.0103)	(0.00892)	(0.0109)	(0.0111)	(0.00834)	(0.0122)	(0.00768)	(0.00899)	(0.0114)	(0.00862)

EXHIBIT 2. THE ESTIMATED COEFFICIENT ($\beta_{1,c,i}$) ASSOCIATED TO THE INTERVENTIONS IN THE SPOT MARKET FOR EACH COUNTRY AND EACH HORIZON FOR SPECIFICATION 1: $s_{t,c,i} = \beta_{0,c,i} + \beta_{1,c,i} D_{t-1,c} + \beta_{2,c,i} CF_{t,-c,i} + \sum_{k=1}^{n_{c,i}} \beta_{k+2,c,i} s_{t-k,c,i} + \varepsilon_{t,c,i}$. Robust Standard Errors in Parentheses: *** p<0.01, ** p<0.05, * p<0.1

Specification	2									
	Brazil	**Chile**	**Colombia**	**Mexico**	**Peru**	**Brazil**	**Chile**	**Colombia**	**Mexico**	**Peru**
Horizon	**One day**	**One day**	**One day**	**One day**	**One day**	**One week**	**One week**	**One week**	**One week**	**One week**
Mean	-0.00102	0.0390	0.470	0.0106	-0.000605	-0.00101	0.0407	0.472	0.0107	-0.000606
	(0.000871)	(0.171)	(0.775)	(0.00689)	(0.000475)	(0.000872)	(0.171)	(0.778)	(0.00689)	(0.000476)
Volatility	-0.000235	0.00298	0.117	-0.00174	-6.30e-05	-8.25e-05	0.0473	-0.0794	0.00139	-3.70e-05
	(0.000152)	(0.0360)	(0.0920)	(0.00202)	(4.83e-05)	(0.000133)	(0.0386)	(0.109)	(0.00228)	(7.75e-05)
Skewness	-0.000989	-0.000221	-0.000296	0.00228	-0.00251	-0.000130	0.000341	3.29e-05	0.000593	-0.00232***
	(0.000608)	(0.000670)	(0.000239)	(0.00140)	(0.0103)	(0.000324)	(0.000283)	(0.000241)	(0.000687)	(0.000842)
Kurtosis	0.00149	9.26e-06	-0.000983**	0.0112**	0.0120	-0.000170	0.000156	-2.64e-05	0.000400	-0.0147**
	(0.00282)	(0.000153)	(0.000436)	(0.00454)	(0.0341)	(0.000157)	(0.000116)	(9.74e-05)	(0.000692)	(0.00606)
Risk Premium	-0.00129***	0.000329	0.000722**	0.00182***	-0.000446***	-0.000612	0.000395	0.00110***	0.00152*	-0.000230
	(0.000474)	(0.000356)	(0.000343)	(0.000629)	(0.000150)	(0.000553)	(0.000433)	(0.000423)	(0.000881)	(0.000218)
Left Tail P.	0.00127	-0.0310*	0.0245	-0.0612***	0.0445***	-0.00147	0.0129	-0.00162	-0.00445	0.0401***
	(0.0110)	(0.0163)	(0.0155)	(0.0179)	(0.0146)	(0.0157)	(0.0148)	(0.0133)	(0.0164)	(0.0111)
Right Tail P.	0.00353	-0.00457	0.00968	-0.0234*	0.0134	-0.0133	0.00124	-0.00317	-0.0274**	0.0429***
	(0.0106)	(0.00989)	(0.0114)	(0.0135)	(0.00819)	(0.0125)	(0.00927)	(0.00960)	(0.0138)	(0.00935)

EXHIBIT 3. THE ESTIMATED COEFFICIENT ($\beta_{1,c,i}$) ASSOCIATED TO THE INTERVENTIONS IN THE SPOT MARKET FOR EACH COUNTRY AND EACH HORIZON FOR SPECIFICATION 2: $s_{t,c,i} = \beta_{0,c,i} + \beta_{1,c,i} D_{t-1,c} + \beta_{2,c,i} CF_{t,-c,i} + \sum_{k=1}^{n_{c,i}} \beta_{k+2,c,i} s_{t-k,c,i} + \gamma'_{1,c,i} CD_{t-1} + \gamma_{2,c,i} CSR_{g,t,c} + \varepsilon_{t,c,i}$.Robust Standard Errors in Parentheses: *** p<0.01, ** p<0.05, * p<0.1

Specification	3									
	Brazil	**Chile**	**Colombia**	**Mexico**	**Peru**	**Brazil**	**Chile**	**Colombia**	**Mexico**	**Peru**
Horizon	**One day**	**One day**	**One day**	**One day**	**One day**	**One week**	**One week**	**One week**	**One week**	**One week**
Mean	0.00272	2.201	18.80*	1.255	-0.00358**	0.00269	3.054	19.08*	1.252	-0.00358**
	(0.00247)	(117.4)	(10.42)	(0.903)	(0.00181)	(0.00248)	(117.4)	(10.32)	(0.902)	(0.00182)
Volatility	-0.000471	-2.125	2.574	0.420	6.35e-06	-0.000123	9.763	-0.609	-0.115	-7.89e-05
	(0.000431)	(23.00)	(2.083)	(0.321)	(8.17e-05)	(0.000400)	(22.90)	(1.593)	(0.316)	(0.000216)
Skewness	-0.000112	-0.305	0.00229	0.868**	0.00135	0.000734	0.0761	0.000804	-0.298	-0.00169*
	(0.00182)	(0.402)	(0.00378)	(0.396)	(0.01000)	(0.00133)	(0.185)	(0.00313)	(0.211)	(0.000974)
Kurtosis	-0.00805	-0.0441	-0.00642	4.132**	0.0184	-4.73e-05	0.0309	0.000466	-0.0463	-0.0124**
	(0.00710)	(0.0864)	(0.00443)	(1.981)	(0.0280)	(0.000557)	(0.0708)	(0.00137)	(0.0730)	(0.00572)
Risk Premium	-0.00191	0.0934	0.0125**	0.196*	-0.00133*	0.00138	0.166	0.0137**	0.175	-0.00126
	(0.00172)	(0.220)	(0.00607)	(0.108)	(0.000805)	(0.00184)	(0.272)	(0.00642)	(0.142)	(0.00125)
Left Tail P.	0.0113	-13.37	-0.0246	-18.99***	0.0462*	-0.0416	11.24	-0.180	5.751	0.0449**
	(0.0375)	(9.917)	(0.211)	(4.295)	(0.0276)	(0.0726)	(8.205)	(0.210)	(6.656)	(0.0198)
Right Tail P.	0.0492	1.381	0.0483	-9.265***	-0.00659	-0.00789	-1.466	-0.303*	-9.634	0.0290
	(0.0336)	(5.899)	(0.137)	(3.457)	(0.0217)	(0.0525)	(4.964)	(0.166)	(7.521)	(0.0201)

Exhibit 4. The estimated coefficient ($\beta_{1,c,i}$) associated to the interventions in the spot market for each country and each horizon for specification 3: $s_{t,c,i} = \beta_{0,c,i} + \beta_{1,c,i}SQ_{t-1,c} + \beta_{2,c,i}CF_{t,-c,i} + \sum_{k=1}^{n_{c,i}} \beta_{k+2,c,i}s_{t-k,c,i} + \gamma'_{1,c,i}CSQ_{t-1} + \gamma_{2,c,i}CSR_{v,t,c} + \varepsilon_{t,c,i}$. Robust Standard Errors in Parentheses: *** p<0.01, ** p<0.05, * p<0.1

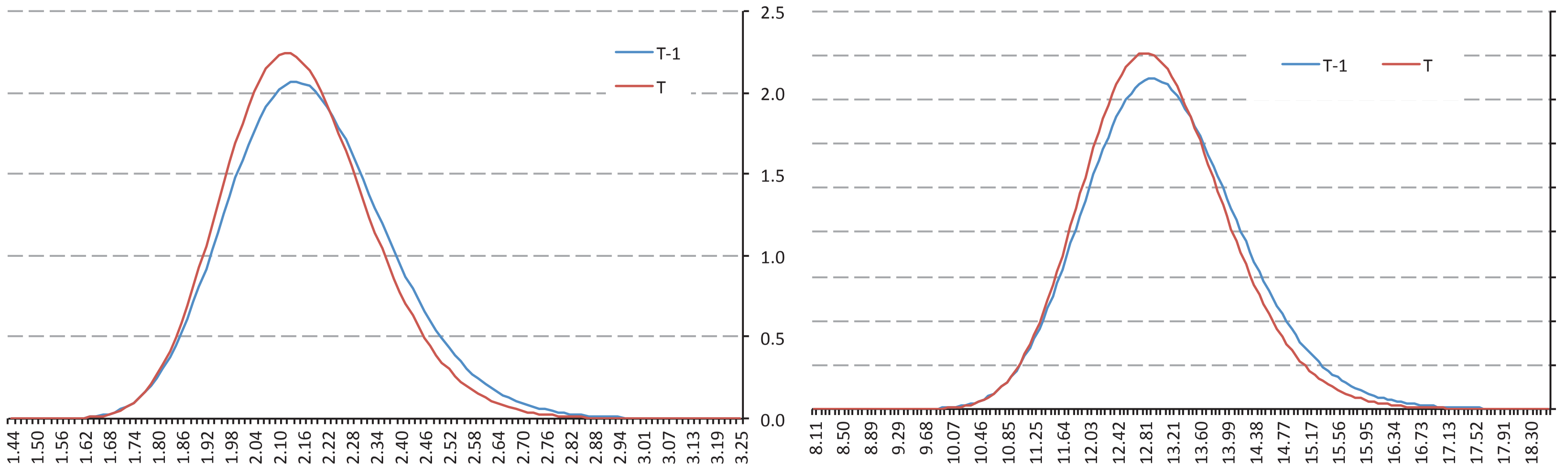


Exhibit 5. Risk-Neutral Densities for Real-US Dollar and Peso-US Dollars Exchange Rates. These densities are from the Fed's Announcement on the Dollar Swap Lines. T-1 indicates the Risk-Neutral Density a Day Before the Announcement. T Indicates the Risk-Neutral Density On the Day of the Announcement.

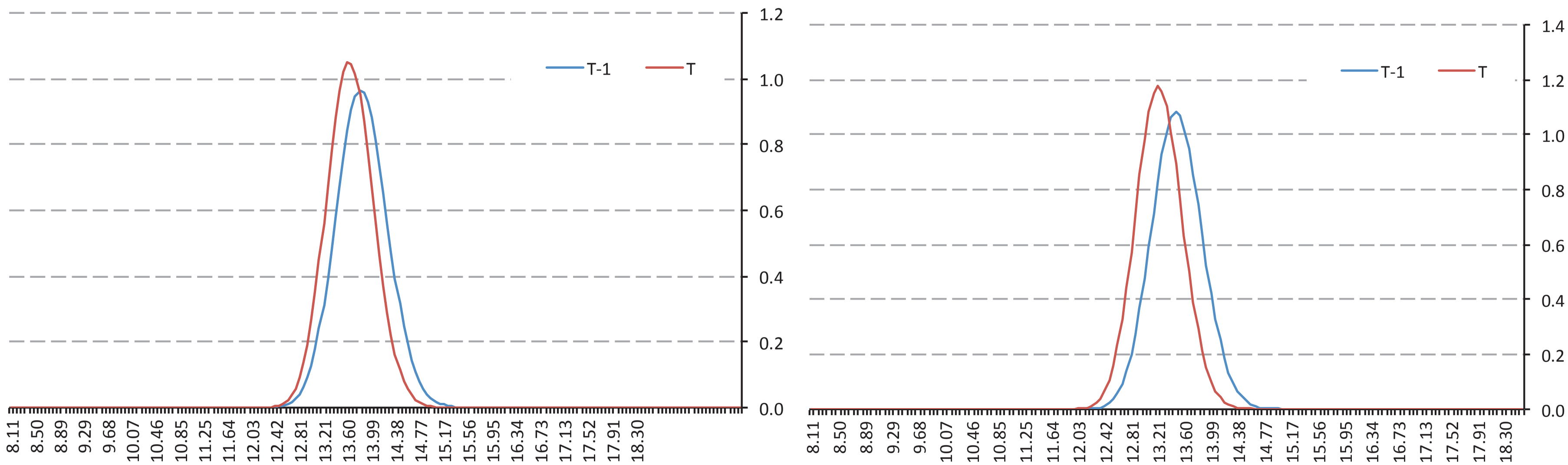
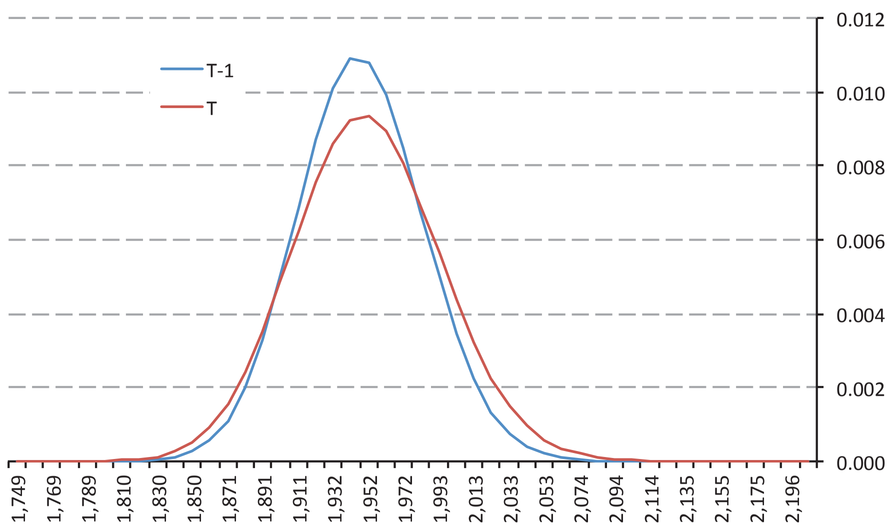


Exhibit 6. Risk-Neutral Density For The Mexican Peso-US Dollar Exchange Rate. Graph on the Left Side: The Bank of Mexico announces its intention to use part of the resources provided by the Dollar Swap Line. Graph on the Right Side: The Bank of Mexico implements the auctions using part of the resources associated to the Dollar Swap Line. In each, T-1 indicates the Risk-Neutral Density a Day Before the Announcement/Implementation. T Indicates the Risk-Neutral Density On the Day of the Announcement/Implementation.



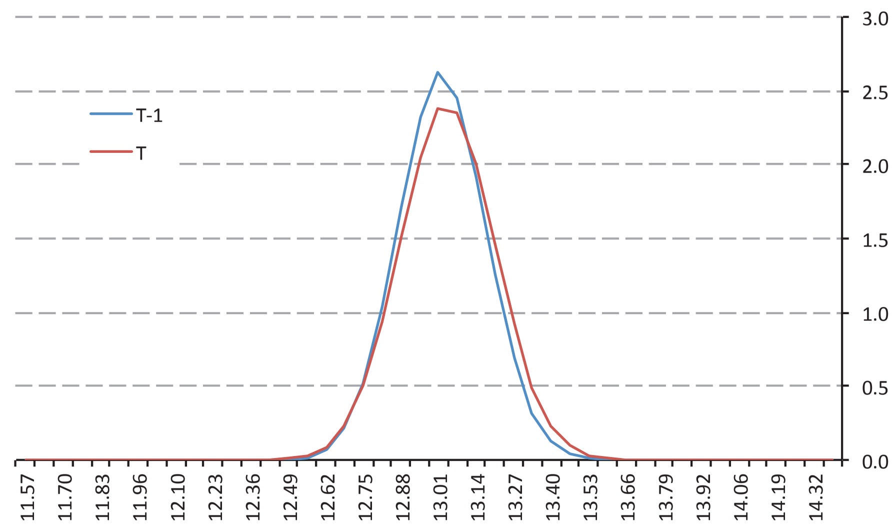


Exhibit 7. Risk-Neutral Densities Colombian Peso-US Dollar and Mexican Peso-US Dollar Exchange Rates. Graph on the left: IMF's Announcement on the Flexible Credit Line for Colombia. Graph on the Right: IMF's Announcement on the Flexible Credit Line for Mexico. T-1 indicates the Risk-Neutral Density a Day Before the Announcement. T Indicates the Risk-Neutral Density on the Day of the Announcement.