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The Relative Effectiveness of Spot and Derivatives Based Intervention

Abstract

This paper studies the relative effectiveness of foreign exchange intervention in spot and derivatives markets. We make use of Brazilian data where spot and non-deliverable futures based intervention have been used in tandem for more than a decade. The analysis finds evidence in favor of a significant link between both modes of intervention and the Real/Dollar exchange rate return. In line with theory, the impact of spot market intervention is strikingly similar to that achieved through futures based intervention worth an equivalent amount in notional principal when convertibility risk is limited. We show that both types of interventions also affect the level and the price of hedging risk in the foreign exchange market.

JEL-Codes: F310, G100, E500.

Keywords: FX intervention, derivatives, exchange rates.

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1. Introduction

Unconventional monetary policies in advanced economies and volatile capital flows in and out of emerging markets have brought foreign exchange intervention (FXI) back to the forefront of the policy debate in recent years. While flexible exchange rate regimes have facilitated more orderly currency adjustments in the aftermath of the global financial crisis than was often the case in the past, both spot and derivatives-based FXI have been important elements of the policy response.[2] Despite the burgeoning literature on the effectiveness of FXI, little is known, either theoretically or empirically, about the relative effectiveness of different FXI instruments.

This paper studies the relative effectiveness of FXI in spot and derivatives markets in a common empirical framework. We focus our analysis on the case of Brazil which is perhaps unique in that it provides the necessary elements for such a study. The Brazilian authorities have used both spot and non-deliverable futures based FXI since the early 2000s and, importantly, often alongside each other. This variation in the choice of FXI instruments over a significant time period allows for a direct empirical comparison between the two modes of intervention, in particular since any changes in agents' behaviors or central bank policy during this period are conditional on the existence of both instruments. The authorities also publish detailed data not only on the two modes of intervention but also on variables that may drive policy decisions and thus allow identifying distinct reaction functions for each policy instrument. Finally, the non-deliverable futures contracts the BCB employs are particular in that they settle in local currency and thus offer an interesting opportunity to determine whether the effectiveness of this mode of FXI may be conditional on the absence of convertibility risk (e.g. the risk that capital controls are introduced).[3]

The empirical approach we take in this paper is straightforward. We estimate instrumental variables regressions using daily data to explain changes in the BRL-USD exchange rate. Our explanatory variables of interest are spot intervention - in billions of US Dollars - and futures intervention - in billions of US Dollar equivalent of notional principal – defined such that positive values imply that the BCB takes a long Dollar position. We also analyze the impact of both modes of intervention on measures of the quantity and the price of hedging foreign exchange volatility derived from the options market.

[2] In the 1990s, several Latin American countries intervened in foreign exchange markets by issuing debt denominated in, or indexed to, foreign currencies. Since then, FXI in markets for swaps, options and forwards has become part of the policy toolkit in a number of countries (e.g. in Brazil, Mexico, South Africa and Thailand).

[3] The central banks of both Mexico and Peru have more recently begun using similar instruments.

We find strong evidence in favor of a significant link between intervention through both spot and derivatives markets and changes in the Real/Dollar exchange rate. Both spot and futures intervention enter the regression significantly and with the expected signs. What is more, the impact of $1 billion in net spot market intervention changes the Real/Dollar exchange rate by about 0.73 percent, an impact that is statistically indistinguishable from the 0.67 percent change achieved through auctions of non-deliverable futures worth $1 billion in notional principal. This main result of the paper is in line with the theoretical work of Eaton and Turnovsky (1983) who show that spot and forward market intervention have equivalent effects on the spot exchange rate in the absence of elevated convertibility risk (e.g. risk of prohibitive capital control tightening).[4] In contrast, when convertibility risk rises, hedging local positions through futures contracts becomes incomplete, giving rise to a wedge between covered foreign and domestic interest rates and implying that intervention in the futures market no longer equally impacts the spot exchange rate. Our results thus suggest that such convertibility risk has been too limited in our baseline sample to drive a significant wedge between the relative effectiveness of spot and futures market intervention.[5] [6] Nevertheless, in an extended sample we find evidence that futures intervention is ineffective in the presence of non-negligible convertibility risk.

Our options based volatility regressions suggest similar conclusions. Both modes of intervention have statistically significant and indistinguishable effects on both implied volatility and the cost of hedging foreign exchange uncertainty (the volatility risk premium). These results are consistent with the idea that FXI can have a signalling effect that affects the dispersion of beliefs of foreign exchange market participants, and can thereby impact both implied foreign exchange volatility and the volatility risk premium (for anecdotal evidence of the Japanese interventions, see Beber et al., 2010). In addition, the results from the volatility risk premium (VRP)

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[4] Eaton and Turnovsky (1983) use the broader term “political risk” which encompasses the risk of capital control introduction as well as the risk of debt repudiation.

[5] There are at least two additional factors that could limit the relative effectiveness of futures based intervention in moving spot exchange rates. First, there may be limits to arbitrage arising, inter alia, from a potential unwillingness on the part of arbitrageurs (e.g. commercial banks) to take large short (long) futures positions in the foreign exchange market that are only imperfectly covered by long (short) spot positions in the same currency (see Garcia and Volpon, 2014 and Kang and Saborowski, 2014). Second, the finite nature of the futures contracts may render them less effective than spot intervention which is, ex ante, permanent in nature. Our finding that the two modes of intervention have very similar impacts may suggest that (i) any potential limits to arbitrage were not reached in the baseline sample and (ii) that the length of the contracts was sufficient not to reduce the effectiveness of the futures based intervention.

[6] Persistent deviations from covered interest rate parity that occurred over the post-crisis period in major currencies are discussed in e.g., Buraschi et al. (2015) and Du et al. (2018). For a more detailed account of frictions related to persistent deviations from the law of one price in the literature see Gromb and Vayanos (2010).

regressions indicate that FXI can be effective in counter-balancing net price pressures in the options market which may arise in the presence of limits to arbitrage (Acharya et al., 2014, Della Corta et al., 2016).[7]

Finally, the analysis also detects significant differences in reaction function estimates between the two instruments. The BCB appears to use spot FXI, more so than futures based intervention, in reaction to daily movements in the exchange rate and to resist capital flow pressures. Conversely, it is more likely to use futures based intervention to smooth trend movements in the exchange rate and to react to changes in risk aversion in global financial markets.

The idea that sterilized FXI can be effective in moving exchange rates has been widely covered in the literature. Sterilized intervention should affect neither prices nor interest rates but can drive exchange rates through signaling (Mussa, 1981; Vitale, 1999) and coordination (Taylor and Sarno, 2001) channels as well as when frictions cause agents not to be indifferent between holding assets denominated in different currencies (Branson and Henderson, 1985; Kumhoff, 2010; Gabaix and Maggiori, 2015).[8] While the effectiveness of FXI would depend on country circumstances – such as whether domestic and foreign assets are reasonably good substitutes (Bayoumi and Saborowski, 2014; Bayoumi et al, 2015), recent studies (Adler et al 2015; Blanchard et al 2015; Fratzscher et al, 2018) find rather strong support for a causal link between FXI and exchange rates at the cross-country level.[9] Similarly, several recent studies of emerging economies confirm that spot FXI may not only impact the exchange rate but also its volatility (Scalia, 2008; Dominguez et al, 2013).

The relatively scarce empirical literature on derivatives based intervention similarly finds evidence to support the effectiveness of FXI. It includes Kohlscheen and Andrade (2014) who find that auctions of Brazilian non-deliverable FX futures settled in local currency had a

[7] The literature also provides strong empirical evidence of a link running from changes in volatility hedging costs to the spot exchange rate (Della Corta et al., 2016; Londono and Zhou, 2017), which in our context provides another channel through which FXI can affect the spot exchange rate.

[8] In addition, the market microstructure literature shows that new information released through FXI can also lead market participants to revise their beliefs in the presence of different types of frictions at the micro level (Lyons, 2006).

[9] The results in an earlier literature focused mostly on developed economies were more mixed (Dominguez and Frankel, 1993; Humpage, 1999). The literature on market microstructure in turn finds supportive evidence for the effectiveness of FXI (Dominguez, 2003; Payne and Vitale, 2003). For a comprehensive survey of the literature see Sarno and Taylor (2001), Neely (2005), Lyons (2006) and Menkhoff (2013).

significant effect on intra-day exchange rate changes.[10] Chamon et al. (2017) show that a program of pre-announced interventions using the same instruments was effective although it appeared not to affect exchange rate volatility. Relatedly, Keefe and Rengifo (2015) show in an event study that FX options based intervention conducted by the Central Bank of Colombia was effective in reducing daily exchange rate volatility. While the literature on derivatives based intervention thus finds evidence supporting the effectiveness of such policies, to our knowledge, there is no study that directly compares the effectiveness of spot and non-spot FXI.

Our results contribute to the literature in several ways. First, this is the first study analyzing empirically the relative effectiveness of spot and derivatives based FXI in a common framework. Our main contribution is thus to provide evidence of the theoretical prediction that FXI in forward markets should be similarly effective as spot FXI in the absence of convertibility risk. From a policy perspective, the result highlights the potential advantages of a broader central bank toolkit. Second, we provide empirical evidence that both types of FXI affect not only the level, but also the price of hedging risk in the foreign exchange market. Third, our study allows comparing central bank reaction functions for spot and derivatives based intervention, allowing us to draw conclusions, both on the types of factors that incentivize FXI more generally, and on those that affect the use of one mode of FXI versus the other.

The remainder of this paper is organized as follows: Section 2 briefly discusses the data and the features of the Brazilian FXI policy framework, before laying out our empirical specification. Section 3 outlines the results of the empirical analysis, Section 4 provides additional specification checks and Section 5 concludes.

2. CONTEXT AND EMPIRICAL SPECIFICATION

FX Intervention in Brazil

Intervention in markets for currency derivatives has become part of the policy toolkit in a number countries around the globe. The growing popularity of derivatives based FXI can be traced to some of its notable advantages (Blejer and Schumacher, 2000; Domanski et al 2016): first, the provision of innovative instruments may aid in developing nascent or illiquid markets and thus reduce volatility; second, FXI in derivatives markets may not require explicitly committing reserves, or at least not immediately (as is the case for the Brazilian futures contracts discussed in this paper); third, in the absence of arbitrage between spot and forward markets, derivatives based FXI could represent an additional policy tool in managing liquidity in forward

[10] In addition, Garcia and Volpon (2014) discuss the mechanisms through which the derivative interventions provide hedging instruments for market participants and limits to such strategy in the Brazilian context.

markets during episodes of market segmentation; fourth, specific tools such as at-the-money put options can act as automatic stabilizers for the foreign exchange market, allowing the central bank to accumulate reserves when the exchange rate appreciates and selling them when it depreciates. Finally, there can be circumstances in which a central bank may prefer derivatives based FXI over sterilized spot FXI either because of concerns over the supply of sterilization instruments or because it perceives sterilized FXI as too costly relative to its expectation of the net cost of the derivatives transaction.

The Brazilian central bank has intervened frequently in foreign exchange markets since the adoption of its floating exchange rate regime in January 1999, including through the use of derivatives instruments. Brazil's derivatives markets have developed to rank among the largest in the world amid demand for hedging instruments to cover interest and exchange rate risk given Brazil's history of high inflation, devaluations and high nominal interest rates. Trading volumes in Brazil's derivatives markets are around four times larger than those in its spot market for foreign exchange (Kang and Saborowski, 2014); relatedly, it appears that derivatives markets lead the spot market in price discovery (Garcia et al, 2014).[11] It is further important to note that the Brazilian exchange regime prohibits financial instruments traded in Brazilian markets from settling in foreign currency with a few exceptions.[12] As a result, policymakers can make use of a highly liquid market for FX derivatives that settle in local currency.

The derivatives instruments most frequently used by policymakers are the so-called Brazilian FX Swaps and Reverse FX Swaps.[13] The instruments were first used in March 2002 and soon replaced Dollar linked treasury notes as the preferred mode of non-spot FXI (Bevilaqua and Azevedo, 2005). Brazilian FX swap contracts are structured similar to non-deliverable forwards or futures. Importantly, any proceeds from the contracts are paid out only at maturity such that

[11] Access to Brazil's spot market is restricted to chartered banks, laws preclude trading the *real* offshore, and domestic bank accounts denominated in foreign currency are forbidden by law.

[12] Brazilian law (Decree-Law No. 857) states that every contract, security, document or obligation, in order to be fulfilled in Brazil, can't stipulate payment in gold or foreign currency, or, in any form, restrict or refuse fulfillment in the Brazilian currency. The exceptions to that law are: currency exchange operations, import/export contracts, export financing (when a Brazilian bank buys, paying in reais, in advance, the amount of foreign currency to be received by an exporter in an export operation) or loans or any obligations in which the creditor or debtor is domiciled outside Brazil.

[13] Brazilian FX Swaps and Reverse FX Swaps are typically auctioned. The BCB announces detailed information prior to each auction, such as the exact time of the auction, the maximum quantity of contracts that the BCB offers, and the maturity. Bidders are allowed to place up to five bids, specifying the quantity and price quotation for the bids. However, every bid-winner pays the same SELIC rate and receives the same cupom cambial and exchange rate variation. The BCB has its discretion to accept any volume of contracts up to the maximum that is on offer.

the contracts do not have a direct impact on reserve money at the time of intervention and can thus be directly compared to sterilized spot FXI. At maturity, the BCB pays its counterparts the observed exchange rate variation against the Dollar plus the ex-ante Cupom Cambial and receives the ex-post SELIC rate in return.[14] [15] In other words, it makes a positive return if the observed exchange rate depreciation falls short of initial expectations and makes a loss otherwise. By offering a quantity of FX swaps, the BCB thus takes a short Dollar position in the markets and expands the availability of hedge to investors with open *Real* positions, potentially bidding down the forward exchange rate.[16] The Brazilian Reverse FX swap is structured in an equivalent way except that the BCB takes the long Dollar position.

The discussion highlights that the name Brazilian FX swap is somewhat misleading since the instruments are more similar to non-deliverable futures; unlike conventional cross-currency swaps, they do not involve an exchange of notional principal; the crucial difference to conventional non-deliverable futures is that they settle in local currency.[17] One major advantage of intervening via these instruments is thus that the operation does not directly impact the BCB's stock of foreign exchange reserves. From the BCB's counterparts' perspective, however, the fact that the instrument settles in local currency represents a risk to the extent that immediate conversion to hard currency at maturity is less than certain. As a result, using auctions of FX swaps in place of spot Dollar sales is likely to be ineffective if convertibility risk is non-negligible. The reason is that investors are unlikely to purchase the derivative contract if they cannot be sure that its proceeds can be converted into Dollars at maturity as needed. In what follows we refer to FX swaps and Reverse FX swaps as futures based intervention for simplicity.

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[14] The Selic rate is the BCB overnight rate; the Cupom Cambial is a highly liquid instrument that serves as the onshore Dollar interest rate and is priced in basis points equal to the spread between the overnight interbank deposit rate and the expected exchange rate variation.

[15] The net gain of $1 in FX swap contracts is thus very similar to the net gain from purchasing $1 in the spot market. As part of the spot market purchase, the BCB would forgo the dollar interest rate as well as the exchange rate gain on $1 of reserves while avoiding having to pay the Selic rate on $1 of reserve money. However, there are two differences: first, the exchange rate gain/loss is realized in the case of the FX swap but potentially unrealized in the case of the spot market operation; second, the cupom cambial could differ from the dollar interest rate on reserve assets.

[16] In addition, the instruments not only transmit price signals but also fill a market gap as futures contracts tend to have shorter maturities and OTC markets offering derivative products with longer maturities are not sufficiently liquid (Kang and Saborowski, 2014).

[17] Another frequently used instrument is the Brazilian FX repo which is akin to a conventional FX swap, resembling a Dollar credit line. It has traditionally been used to provide FX liquidity to the market during periods of seasonal shortages.

For the purpose of comparing the effectiveness of the two modes of FXI empirically, two conditions are key: first, developments triggering spot FXI as opposed to futures FXI need to be sufficiently distinct in order to allow for identification when included jointly in a regression; second, the two modes of FXI need to have been used during broadly the same time period in order to minimize the possibility that agents adapt their actions to the prevailing mode of FXI. Figure 1 illustrates that these conditions are generally in place in our sample. The chart shows, for instance, that the BCB used both spot purchases and auctions of Reverse FX swaps during the period of 2005-11, presumably to tame appreciation pressures and accumulate reserves; in turn, both spot sales of Dollars and auctions of FX swaps were used to stabilize markets during the crisis episodes of 2002/03 and 2008/09. Only during the market turmoil following the taper tantrum in May 2013 did the central bank use FX swaps alone.[18]

[Insert Figure 1]

Data and Empirical Approach

The sample period used for our baseline regression ranges from September 3rd 2008 to August 21st 2013. The beginning of the period is determined by data availability. The end point is chosen to be one day before the announcement of the central bank's 2013/14 intervention program. We exclude this most recent episode because the heavy interventions conducted at the time were largely pre-announced months in advance (with rollover rates as the only discretionary factor). Including the episode would have required a distinct empirical approach compared to the one taken in this paper as auctions were likely priced in at the time they occurred (Chamon et al, 2017).

We estimate different variants of a standard intervention model:

$$\Delta y_t = \alpha_i + \sum_{i=1}^{p} \phi_i \Delta y_{t-i} + \sum_{i=0}^{q} \delta_i FI_{t-i} + \sum_{i=0}^{l} \beta_i SPI_{t-i} + X_t' \gamma + \varepsilon_t \tag{1}$$

$$INT_t = \alpha_i + \sum_{i=1}^{p} \phi_i \Delta y_{t-i} + X_t' \varphi + Z_t' \theta + u_t \tag{2}$$

[18] The motivation for this choice may have been twofold: first, futures based intervention allowed the BCB not to directly commit its reserves in a volatile international environment for emerging markets. Second; the BCB may have perceived futures based intervention as relatively less costly than sterilized spot intervention in an environment in which interest differentials were very high, perhaps due to a more bullish expectation of exchange rate developments.

where Δy_t is the dependent variable defined as: i) the daily percentage change in the nominal BRL/USD exchange rate; ii) the daily percentage change in the implied BRL/USD volatility; iii) the daily change in the BRL/USD volatility risk premium, depending on the regression. The specification includes lagged values of the dependent variable, a measure of futures FXI, FI_{t-i}, a measure of spot FXI, SPI_{t-i}, and a vector of control variables, including year dummies, X_t. All of these variables are defined in Table A1 in the Appendix.

The exchange rate is defined in units of local currency such that higher values imply a depreciation of the Real. The measure of implied volatility is derived from three months ahead at-the-money (ATM) currency options. In specification checks, we assess the robustness of our results to using shorter (one month) and longer (six months and one year) maturities. The currency volatility risk premium is defined as the difference between the risk-neutral (Q) and physical (P) expectations of the future realized currency volatility:

$$VRP_{t,t+h} = E_t^Q\left[RV_{t,t+h}\right] - E_t^P\left[RV_{t,t+h}\right] \quad (3)$$

As is common in the literature, we use our measure of implied volatility as a measure of the risk neutral expectation Q. We approximate the physical expectation with the lagged realized volatility (Bollerslev et al, 2009, Della Corta et al., 2016), computed as the square root of the sum of the current and the past *h-1* daily squared log Real/$ returns. In specification checks we also follow Drechsler and Yaron (2011) and Bekaert and Hoerova (2014) in using the forecast of the realized volatility from simple linear models as an alternative measure of one-month and three-month realized volatilities. Note that we define VRP such that positive values indicate higher risk premia (the opposite of what is typically done in the literature), to make the results more easily comparable to the ones from our implied volatility regressions. We use the same three months ahead maturity in the baseline specification, and shorter and longer maturities in the specification checks.

For the remainder of the paper, spot FXI is defined as spot Dollar purchases minus spot Dollar sales in billions of US Dollars. The BCB publishes data on spot sales and purchases at a daily frequency since May 2009 and at a monthly frequency since 2000. In order to allow extending our daily sample back to include earlier episodes of heavy interventions, we construct an estimate of both variables based on daily data the BCB publishes under the heading “Factors conditioning the Monetary Base – External Sector Operations” in combination with the monthly data on spot FXI. In particular, we set the daily spot FXI variable to zero in months during which no FXI took place according to the monthly data; in months during which spot FXI was non-zero, we set the variable equal to the composite of external sector operations, namely the sum of spot, forward, FX repo and FX loan operations. While the variable is thus not a fully clean proxy for spot FXI in the earlier data, it would provide the best possible option for extending the sample.[19]

Detailed data on FX swap and FX Reverse swap auctions is available from the BCB at a daily frequency since 2002. We define the futures FXI term as the notional principal entailed in auctions of Reverse FX swaps minus that entailed in announcements of FX swap auctions in billions of US Dollars.[20] In other words, in line with the spot FXI term, futures FXI takes positive values when the BCB takes long Dollar positions and negative values when it takes short Dollar positions. Importantly, the magnitudes of the two variables are comparable in the following sense: $1 of negative spot FXI (spot sales) takes $1 of Brazilian Real exposure off of investors' books; similarly, $1 of futures FXI takes $1 of Brazilian Real exposure off of investors' books, although only temporarily and conditional on the absence of convertibility risk.

The main empirical challenge in studying the effectiveness of FXI is the endogeneity of the FXI terms to contemporaneous movements in the exchange rate. To estimate a causal relationship between the both types of FXI and the dependent variable of interest we rely on the continuously updated generalized method of moments estimator (CUE, Hansen et al., 1996). The estimator uses a vector of instruments Z_t for the vector of endogeneous variables given in Equation (2), where INT_t is a two-dimensional vector of the two modes of FXI. CUE estimates allow for conditional heteroscedasticity and serial correlation in the data and tend to perform better than the standard two-stage least squares (2SLS) and GMM estimators in finite samples as well as in the presence of weak instruments (Hansen et al., 1996, Hahn et al., 2004).

Finding appropriate instruments for the two FXI terms is particularly challenging in our setup as candidate terms not only need to fulfill standard requirements for instruments; it is also essential that they allow identifying separate reaction functions that are sufficiently distinct to permit including the two modes of FXI jointly in our regressions. In part following the literature on spot FXI (see, inter alia, Ito and Yabu, 2007, Fatum and Hutchison, 2010), we include the following terms in our vector of instruments: (i) lagged one year moving average of the exchange rate, (ii) lagged exchange rate deviation from two week moving average (time-varying target), (iii) lagged average exchange rate volatility over previous two weeks, (iv) lagged change in the monetary

[19] When aggregating our spot intervention proxy at monthly frequency, it has a correlation of 97 percent with the monthly spot market intervention data available from the BCB in the baseline sample period. In the extended sample (going back to 2001), the correlation is 86 percent.

[20] We exclude FX swaps and reverse FX swaps auctioned to roll over existing swap contracts. The reason is that these could drive the exchange rate in either direction, depending on whether the roll-over rate surprised the market on the up- or the downside.

policy rate, (v) lagged spot and futures FXI, and (vi) lagged net FX flows. The latter three variables are defined as averages over a one-week window to smooth out irregular behavior.

The first three terms capture the hypothesis that central banks react to exchange rate developments in various forms. The lagged change in the local policy rate, in turn, allows for potential linkages between monetary and foreign exchange intervention policies (Gnabo et al, 2010). The two lagged FXI terms account for persistence in FXI, for instance during periods of trend appreciation. The intuition behind the final instrument, the net foreign exchange flows into Brazil, is similar to that of the 'exchange rate deviation from the moving average' term.[21] That said, we include the FX flows term separately in order to better distinguish flow pressures on the exchange rate from pure price pressures, based on the hypothesis that the BCB may have a higher propensity to react to what it perceives as flow pressures using spot rather than derivatives based FXI. The term indeed turns out to be particularly important in distinguishing the reaction functions for spot and futures FXI. Our instruments pass a battery of validity and weak exogeneity tests.

An intriguing question is whether there are instances in which the BCB chooses one mode of FXI over the other because it believes that it will be relatively more effective in the present environment. For example, one may consider that the central bank would refrain from using futures based FXI when it either perceives convertibility risk to be high or arbitrage between futures and spot markets to be limited for other reasons. One variable that may proxy for such situations of incomplete arbitrage is the onshore-offshore spread in the dollar interest rate. Consequently, we experiment with including the lagged spread between the Dollar Libor rate and the onshore Dollar rate (cupom cambial) as well as the lagged difference between the onshore and offshore forward rate in the first-stage regressions in the robustness section. In addition, we add several alternative instruments such as local macroeconomic news surprises and regional news indicators and vary the window over which the instruments are defined with no impact on our results.

In selecting the vector of control variables X_t we follow the literature while trying to keep the specification parsimonious. In particular, our benchmark choice of controls includes: (i) the daily percent change in the Thomson Reuters Core Commodity (CRB) price index (both current and lagged), (ii) the daily percent change in the Chicago Board Options Exchange Market Volatility Index (VIX, both current and lagged), (iii) the lagged average change in the expected exchange

[21] The net FX flow includes all daily FX transactions into Brazil, excluding interbank operations and the BCB's external operations, as published by the BCB.

rate depreciation over the coming 3 months (based on spot and forward rate differentials) and (iv) the lagged daily percentage change in the five year sovereign CDS spread for Brazil. The first two controls capture the importance of commodity prices (see also Kohlscheen and Andrade, 2014) and global uncertainty (Forbes and Warnock, 2012; Rey, 2013). The latter two control for the impact of changes in depreciation expectations and changes in investor perceptions of country risk (Della Corte et al, 2015); they enter the regression only in lags to avoid potential endogeneity concerns. We also explicitly allow for interactions between spot and options FX markets (Della Corta et al., 2016; Londono and Zhou, 2017) and include lagged values of changes in either the volatility risk premium or implied volatility in the FX returns regressions and vice versa. In the robustness section, we add several alternative controls (day of the week effects, local macroeconomic news surprises, regional and EM news sentiment, actual interest rate differential) with no meaningful impact on our results.

3. ESTIMATION RESULTS

The estimation section is divided into three parts: the first shows estimates of reaction functions for both types of FXI; the second presents estimates for regressions that use changes in the Real/Dollar exchange rate as the dependent variable; the third runs a similar set of regressions but uses the implied volatility and the volatility risk premium as dependent variables. In the two latter sections, we ask whether or not one or both of the two modes of FXI are effective in the sense that we can establish a causal link to the dependent variable. Assuming that this first question can be answered with the affirmative, we ask whether one mode is more effective than the other.

3.1. Reaction function estimates

We begin our analysis by estimating central bank reaction function for both types of FXI. The instruments and control variables are those discussed in the previous section and defined in Table A1. The estimates of the reaction functions are reported in Table 1. The first two columns show the estimated reaction functions for spot and futures based FXI using the OLS estimator with Newey-West (1987) heteroscedasticity and autocorrelation (robust) standard errors (first stage). The top panel reports estimated coefficients for explanatory variables included in the vector X, while the bottom panel shows the results for the instruments.[22]

[Insert Table 1]

[22] Estimated coefficients for further lags of the control variables were not statistically significant in the joint estimation and are dropped from the analysis.

Estimated coefficients for the instruments generally carry the expected signs throughout the regressions in Table 1 and are statistically significant for at least one of the two modes of FXI. Moreover, the model diagnostics at the bottom of Table 1 suggest that the instruments are valid. Kleibergen and Paap's (2006) rank LM statistic strongly rejects the null hypothesis that the model is unidentified. In addition, the instruments pass weak identification tests. Kleibergen and Paap's (2006) Wald F statistic significantly exceeds the Stock and Yogo (2005) threshold of maximum size distortions.[23] We also compute Sanderson and Windmeijer's (2016) conditional F-test which additionally controls for cross-effects of multiple endogenous regressors. The results from the test reject the weak instrument hypothesis.

We now move to discussing the first-stage coefficient estimates in detail. The estimates in Table 1 would suggest that the two modes of FXI react to short-term trends in the nominal exchange rate and excessive FX volatility in the expected direction: the BCB would take short dollar positions when the Real is depreciating or when volatility is elevated and long dollar positions in the opposite case. In contrast, the response to the remaining variables differs notably between the two modes of FXI.

First, spot FXI appears to be used more in response to short-term movements in the exchange rate, as suggested by the signs and the significance of the coefficients on the daily change in the exchange rate and the expected depreciation term; futures FXI, in turn, appears to be used to smooth medium-term exchange rate trends (see one year moving average term). Second, the BCB responds to changes in country risk and global risk aversion through futures based intervention. Third, the lagged change in the monetary policy rate is significantly positively associated with spot FXI, suggesting that spot rather than futures FXI tends to be used to attempt to offset the exchange rate effects of tighter/looser monetary policy. [24] Fourth, the lagged trend FX transactions variable enters the spot regressions significantly with a positive coefficient while its coefficient is not significant in the futures regressions. This suggests that spot FXI is the mode of choice when responding to actual currency outflows rather than purely price based pressures on the exchange rate. Finally, there is evidence that both spot and futures FXI tend to cluster as illustrated by the positive and significant coefficient on their lagged moving averages.

[23] The Wald F statistic results may not be fully accurate as the critical values are tabulated under the assumption of conditional homoscedasticity in the regression errors. Nevertheless, the strong rejection of the null hypothesis as well as the results from the Sanderson and Windmeijer (2015) conditional F-test imply that these concerns should be small.

[24] While using FXI as additional instrument may yield a welfare improvement within an inflation targeting regime in models with imperfect capital mobility (Ghosh et al, 2016), the offsetting effects can potentially provide mixed signals to market participants and undermine the credibility of the inflation-targeting framework.

Conversely, the relationship between spot (futures) FXI and lagged futures (spot) FXI is, if anything, negative, although rarely significantly so.

In sum, the BCB appears to react to daily movements in the foreign exchange market and perceived flow pressures using spot FXI. On the other hand, futures FXI appear to be primarily used in reaction to trend movements in the exchange rate as well as to changes in country and global risk perceptions.

We perform several robustness checks of the reaction function results. Table OA1 in the Online Appendix presents the estimates of the reaction functions when additional instruments are included and when the window over which the short-term trend variables are calculated varies. Although some of the additional instruments are significant in the first stage regressions, this does not change the significance or the magnitudes of the coefficients of the baseline regressors. In particular, while the onshore-offshore spread enters with the expected sign, it is statistically insignificant in both reaction functions. In addition, Tables OA2-OA4 show that changes in the instrument set do not impact the second stage results. Another potential concern is that the multiple zeros in the dependent variables in the reaction function regressions may bias the linear regression estimates. To assess the importance of this potential bias, Columns 3 and 4 of Table 1 report estimates from an Ordered Probit model (Ito and Yabu, 2007).[25] While the magnitudes of the estimated coefficients are not directly comparable to the linear regression estimates, we confirm that neither the significance of the key variables nor their signs change significantly.[26]

3.2. Intervention and exchange rate changes

The second stage results of our baseline regressions for equation (1) are summarized in Table 2. Columns 1 to 3 report our baseline estimates, Column 4 shows how the results change when using simple OLS, and Columns 5 to 8 report extensions of the baseline specification. In order to allow for delayed impacts of our control variables, we include them either as moving averages or with both their contemporaneous and lagged values.[27]

[Insert Table 2]

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[25] Ito and Yabu (2007) show that the ordered probit specification can be interpreted as a linearized version of the general friction model of central bank intervention (Almekinders and Eijffinger, 1996).

[26] The only relevant difference among the instruments is that the Ordered Probit model reduces the importance of the FX volatility in the spot intervention regressions.

[27] Estimated coefficients for further lags of the control variables were not statistically significant in the joint estimation and are dropped from the analysis.

We begin by including the FXI terms separately in the regressions. The first regression in Table 2 shows that the spot FXI term is highly significant and carries the expected positive coefficient. Taken at face value, the coefficient of 0.97 suggests that $1 billion of spot purchases (sells) would depreciate (appreciate) the exchange rate by 0.97 percent. Similarly, Regression 2 would suggest that futures FXI is a highly significant determinant of the Real/Dollar exchange rate, with futures FXI worth $1 billion in notional equivalent moving the exchange rate by some 1.5 percent. The third regression in Table 2 includes both FXI terms in the regression simultaneously. Of crucial importance at this point is the fact that our instruments identify central bank reaction functions that are sufficiently distinct to permit including the two variables jointly in a single regression. The results in Column 3 confirm those from the first two regressions: while both coefficients are now somewhat smaller, they are still quite similar at 0.73 and 0.67 respectively, and the two variables remain highly significant. Indeed, the Wald-test statistic given in the last row cannot reject the null hypothesis that the two coefficients are equal.

The estimated coefficients on the control variables are in line with theory, and they are frequently significant at conventional levels. Across Table 2, we find that the lagged volatility risk premium is a significant predictor of future FX returns in the expected direction. The commodity price index and its lag both carry the expected negative coefficient, indicating that rising commodity prices are associated with an appreciating Real, but only the lagged term is consistently significant. The VIX term carries a positive contemporaneous coefficient, but is not statistically significant. Lagged depreciation expectations and a rise in the country risk are, as we would expect, associated with Real depreciation.

The bottom three rows of Table 2 show that the baseline specification passes the J-test of overidentifying restrictions. Stock and Wright's (2000) S statistic, in addition, verifies that the impact of the FXI is significant even if we allow for the case of weak instruments. The C-test for endogeneity confirms that both types of FXI are endogenous to contemporaneous movements in the exchange rate. This can also be observed in Column 4 where we depart from the use of instruments and run a simple OLS regression of the percentage change in the exchange rate on the two FXI terms and controls. The coefficients on both terms become substantially smaller and turn negative in the case of futures FXI. This is in line with the results from the endogeneity test since theory would predict that the OLS regression without instruments would likely introduce a negative bias in the estimated coefficients.[28]

[28] A negative bias would result if the BCB responds to a depreciating (appreciating) exchange rate by taking short (long) Dollar positions.

We extend our baseline specification in several directions in Columns 5 to 8. *First*, we extend the sample to 2002, the first year for which the futures FXI data is available. As we move the start date back to 2002 we lose the FX transactions instrument (which plays an important role in ensuring that the reaction function for the two modes of FXI are sufficiently distinct) as well as the implied volatility term due to lack of data availability (we also lose the volatility risk premium among the second-stage covariates). In place of the lagged trend exchange rate volatility we now include an alternative forward-looking proxy of uncertainty in the FX market, namely the lagged trend difference between the onshore and offshore forward rate. The data for this variable is available from 2002, and is highly correlated with the volatility series (sample correlation 0.47 over the period).[29] The Column 5 shows that our main findings continue to hold in that both modes of FXI appear to be significant drivers of the exchange rate with only somewhat different coefficients than before (0.69 for spot FXI and 0.57 for futures FXI).[30]

Second, an important advantage of extending the sample period back to 2002 is that it allows us to test whether futures FXI loses its effectiveness in the presence of non-negligible convertibility risk. As discussed earlier, FX futures contracts settle in local currency. As such, they only provide effective hedge against currency movements to the extent that their holder is able to convert the proceeds at the time of maturity. In other words, we would expect futures FXI to be ineffective in the presence of non-negligible convertibility risk. In order to test this prediction, we define a dummy variable denoted "Convertibility Risk" that takes the value 1 on days on which the spread between the three-month onshore Dollar interest rate (cupom cambial) and the offshore Dollar Libor rate was 1.5 standard deviations above its sample mean.[31] Including this variable alongside its interaction with futures and spot FXI in Regression 6, we indeed find tentative evidence for the hypothesis: the interaction term for futures FXI is highly significant with a negative coefficient, indicating that futures FXI becomes less significant when convertibility risk is high.[32] In fact, the combined coefficient of futures FXI and the interaction term turns negative, suggesting that futures FXI moves the exchange rate *with the wind* in such

[29] The variable also passes the instrument redundancy test. In addition, we also exclude the potentially problematic instrument (the long-run trend in the exchange rate) – as suggested by the J-test. The results when this instrument is included are nevertheless similar.

[30] The results from individual intervention regressions are also in line with the findings in the baseline regressions.

[31] It is important to note that changes in the cupom cambial do not necessarily reflect convertibility risk, although large shifts relative to offshore Dollar interest rates are likely attributable to it. The results do not change if we use a higher or lower threshold (2 instead of 1 standard deviation). Figure A1 in the Appendix shows that the period of heightened convertibility risk broadly matches the crisis episode of 2002/03.

[32] We interact the instruments with the convertibility risk dummy to obtain instruments for the interaction term.

an environment. In contrast, the coefficient for the interaction term with spot FXI is not statistically significant.

Third, our baseline specification implicitly assumes that the impact of both types of FXI is symmetric. To allow for asymmetric effects we interact our intervention variables with a dummy variable denoted "Spot (Futures) Long" that takes the value one on days when the BCB takes long Dollar positions. We use the interaction of "Spot (Futures) Long" with all significant first stage instruments from Table 1 as additional instruments for the interaction terms.[33] In Regression 7, which includes both interaction terms, we find that the term is not significant in the case of spot FXI and it is excluded from Regression 8. The coefficient on the interaction term is negative and significant for futures FXI in both regressions. We interpret this finding as tentative evidence suggesting that futures FXI are more effective when the BCB takes short Dollar positions. This tentative evidence of asymmetry in the effect of futures FXI would corroborate the findings of Kohlscheen and Andrade (2014) who show that FX swap auctions ("Futures Short") have stronger impacts than Reverse FX swaps ("Futures Long"). The result is in line with the fact that local currency liabilities to Dollar investors in Brazil, as is the case in many other EMs, grossly exceed foreign currency denominated assets held by Brazilian investors. In such case, local currency depreciations constitute a more significant downside risk to the universe of private investors than appreciations. By intervening in response to depreciation pressures, the central bank may thus have a larger role to play in limiting tail risks for investors with open positions than in the case of long Dollar FXI.

In sum, we find that spot and futures based FXI have very similar impacts on the exchange rate. This main result of the paper is in line with the theoretical work of Eaton and Turnovsky (1983) who show that spot and futures market FXI have equivalent effects on the spot exchange rate in the absence of convertibility risk. Our finding suggests that episodes of non-negligible convertibility risk are rare and have thus only a limited impact on the regression coefficients (Figure A1). [34] Similarly, the finite nature of the futures contracts does not seem to weaken the

[33] Additional instruments enter the first stage regressions of the interaction terms significantly and pass the instrument validity tests.

[34] Figure A1 suggests that convertibility risk as defined by the spread between the onshore dollar interest rate and the US Libor rate has been limited during the baseline sample period. Large spreads would suggest that a dollar borrowed onshore is costlier than a dollar borrowed offshore. While a limited positive spread could simply reflect country risk, a large deviation would signal that the risk that cannot be repatriated in the future has become non-negligible for investors (perhaps due to a risk that capital controls may be severely tightened). Another reason for an elevated spread could be constraints on the part of arbitrageurs that prevent them from engaging in bringing dollars onshore to benefit from an appreciated forward exchange rate (Garcia and Volpon, 2014).

relative effectiveness of futures based FXI in Brazil significantly, suggesting that the maturities are sufficiently long to limit the associated roll-over risk for FX investors.[35]

3.3. Implied exchange rate volatility and volatility risk premium

The second part of the empirical analysis examines a potential role for the two modes of FXI in influencing foreign exchange volatility and the price of hedging foreign exchange risk. Indeed, containing foreign exchange volatility was named a prime motive for FXI in a recent BIS survey of EM central banks (Mohanty and Berger, 2013).

The dependent variable in the first set of regressions in this section is the three-month at-the-money implied volatility in the Real/Dollar exchange rate. We use the same set of instruments and similar control variables as in the previous section (we exclude the lagged forward exchange rate differential and the change in the CDS spread from the regressions as none of the lags of the two variables was statistically significant), allowing us to focus our discussion on the second stage results. The first three regressions in Table 3 present the results from estimating our baseline specification and including the two FXI terms individually and jointly. Column 4 shows the results from estimating the same specification as in Regression 3 using OLS in place of the CUE. Column 5 extends the sample period back to October 2003 (when the volatility data start becoming available). Regression 6 tests for asymmetric effects of FXI.[36]

As in the previous sub-section, we find that the control variables in Table 3 are often significant and their coefficients generally carry the expected signs. The lagged dependent variable is significant in most regressions, in line with certain persistence in implied volatility movements. Higher commodity prices are significantly negatively associated with implied volatility in the Real/Dollar exchange rate as expected, and the impact is primarily contemporaneous. The VIX, in turn, enters the regression with a positive coefficient in all regressions and is always highly significant. Intuitively, higher uncertainty in global financial markets implies higher volatility in emerging market exchange rates.

Regressions 1 and 2 in Table 3 contain the results from estimating the baseline specification when including one FXI term at a time. We note that both FXI terms enter the regression with the expected positive coefficient and are significant. When including the two terms jointly in Regression 3, the coefficients fall to some extent but remain within a close range of 1.9 to 2.1.

[35] It may also reflect market participants' experience that the central bank has varied the availability of the stock of hedge only very slowly, generally rolling over the bulk of its portfolio.

[36] Data unavailability unfortunately prevents us from examining the impact of elevated convertibility risk period (which ends in early 2003) on the options market effects of FXI.

The Wald test fails to reject the null hypothesis of coefficient equality. Taken at face value, these findings imply that $1 billion in short Dollar spot FXI or short Dollar futures FXI reduces implied volatility in the Real Dollar exchange rate by some 2 percent. Regression 4, in turn, shows that the coefficient on the FXI term drops significantly in the absence of instruments, signaling that these were important in attenuating a likely negative bias. Regression 5 extends the sample period to 2003-13. Compared to the baseline specification in Regression 3, we find that the coefficient on spot FXI increases somewhat while futures FXI loses its significance and carries a somewhat lower coefficient than before. The Wald test nevertheless fails to reject the null hypothesis that the two coefficients are equal. Regression 6 tests for asymmetric effects of FXI by adding interaction terms with a dummy variable indicating long Dollar FXI. The estimated coefficients for both interaction terms are negative, but not statistically significant, indicating no significant evidence of asymmetry in the implied volatility response. This finding is in line with the signalling effect of FXI that can affect the dispersion of beliefs of foreign exchange market participants in both directions, leading to symmetric effects of FXI on implied foreign exchange volatility (Beber et al., 2010). In addition, potential symmetric effects on volatility may also arise if the credibility of central bank's commitment to reduce volatility vis-a-vis achieving other intervention goals differs across the interventions (Dominguez, 1998).

[Insert Table 3]

To examine whether FXI affect not only uncertainty, but also the price of hedging FX uncertainty, we use the volatility risk premium in the Real/Dollar exchange rate at the three month horizon as an additional dependent variable of interest. The results are summarized in Table 4. The coefficients on the control variables, as before, generally carry the expected signs, and the reported tests confirm the validity of our instruments. We thus proceed directly to discussing the coefficients of interest.

Regressions 1 and 2 in Table 4 show that coefficients for both FXI terms are statistically significant with the expected positive sign when included individually in the regressions. In the joint estimation (Column 3), the coefficient estimates are strikingly similar, ranging between 0.57 and 0.58. The Wald test once again fails to reject the null hypothesis of coefficient equality. Taken at face value, these findings imply that $1 billion in short Dollar spot FXI or short Dollar futures FXI reduces the volatility risk premium in the Real Dollar exchange rate by 0.57. The effect is also economically important as the estimated response roughly equals the 85^{th} percentile of the volatility risk premium empirical distribution. The results are confirmed in the extended sample where we obtain very similar estimates (Column 5). Finally, Regression 6, similarly to implied volatility regression, does not find any evidence in favor of asymmetry in the impact of FXI on the volatility risk premium.

[Insert Table 4]

In sum, the results in this section suggest that both spot and futures FXI have important effects on volatility and currency risk premia. As in the previous section, we also find that these impacts are strikingly similar for spot and futures FXI of a comparable magnitude. The estimated similarity in the effectiveness of the two modes of FXI indicates that the finite maturity of futures contracts and/or the prevalence of convertibility risk were negligible to limit the ability of futures FXI to reduce private sector FX risk. The results from the volatility risk premium (VRP) regressions, in addition, indicate that both types of FXI also affect the price of hedging foreign exchange uncertainty in the expected direction. To the extent that the changes in the hedging price reflect shocks in the availability of arbitrage capital (of the liquidity providers) or in the net demand for volatility protection (e.g. companies), the results suggest that by providing spot dollars and directly altering the supply of hedging opportunities, spot and futures based FXI can contribute to loosening limits to arbitrage constraints. Given the strong empirical evidence in favor of spot price effects resulting from changes in volatility hedging costs (Della Corta et al., 2016; Londono and Zhou, 2017), this provides an additional channel through which the FXI can impact the spot exchange rate.

4. SPECIFICATION CHECKS

In this Section, we provide various additional specification checks. Some of the results are relegated to an Online Appendix and only briefly discussed in the main text.

We start with alternative estimators of the regressions of interest. We perform two sets of alternative estimations reported in Table 5 and Table OA6. *First*, we re-estimate our baseline specification using the bi-variate system CUE estimator. Our results in the previous section allowed for dependencies between spot and derivatives markets via the inclusion of lagged terms in the specifications. In the generalized method of moments context this is equivalent to assuming a block diagonal moment weighting matrix in the joint estimation of spot and options equations. However, in the presence of cross-equation correlations between the spot and options moment conditions, such an estimator would not be fully efficient. To assess the importance of potential cross-equation correlations for the results, we re-estimate our baseline specification using the system CUE estimator. The results for jointly estimated FX returns and implied volatility equations are reported in the first two columns of Table 5; Columns 3-4 report estimates from the joint estimation of FX returns and VRP equations. Both sets of estimates fully confirm our earlier results derived under diagonal weighting. *Second*, we consider alternative definitions of the effectiveness of FXI to the ones implied by the regressions. In particular, we follow Humpage (1999) and Fratzscher et al. (2018) and implement an event study type of analysis. We first construct FXI episodes by defining the last day of an FXI episode as a day which is either followed by an FXI in the opposite direction or by no similar FXI for at least 5 days.[37] We then calculate four types of criteria that measure FXI effectiveness. The so-called "event criterion" is computed for each FXI episode such that FXI is regarded as successful when the exchange rate moves in the intended direction (depreciates during long Dollar FXI and vice versa) during the episode and the 5 days thereafter (Column 1 in Table OA5). The "smoothing criterion" is defined such that success is achieved when the exchange rate change during and for five trading days after the FXI is smaller than during the five trading days leading up to the FXI (Column 2 in Table OA5). As alternative indicators of success in affecting foreign exchange volatility, we also compute the event criterion for changes in the implied volatility (Column 3 in Table OA5; success is achieved when volatility falls in case of short dollar FXI) and in the VRP (Column 4 in Table OA5; success is achieved when the risk premium falls in case of short dollar FXI). Our findings are presented in Table OA5. In all four cases, we also calculate the success rates of "placebo" FXI episodes which are calculated by creating FXI days in random directions on actual non-FXI days. In short, spot FXI generally performs strongly against all success criteria: except in the case of the implied volatility event criterion, its success rates are not only high, but also consistently higher than the placebo success rates. In the case of futures FXI, the evidence is somewhat less strong, but the success rates are always higher than the placebo success rates. Finally, note that by design both types of criteria evaluate the effectiveness of one type of FXI in isolation, ignoring the presence of other types of FXI, which may potentially impact the obtained results.[38]

[Insert Table 5]

Next, we assess the sensitivity of the results to using alternative instruments and controls sets. Tables OA2-OA4 in the Online Appendix show that changes in the instrument set do not impact the second stage results meaningfully. Table 6 includes a battery of specification checks of our baseline specification for spot returns, including one additional covariate at a time. Regression 1 includes Brazilian macroeconomic announcement surprises (for inflation, unemployment and industrial production). Regressions 2 and 3 include the Citi EM Economic Surprise Index and the Citi Latin America Economic Surprise Index, respectively. Neither variable appears to add much to the regressions' explanatory power and neither variable changes our results in a notable way.

[37] Using a longer event window (10 days) significantly reduces the number of events, especially in the case of futures FXI which often occurred almost daily for extended periods of time (with small amounts).

[38] Excluding the events with overlapping spot and futures interventions would further reduces the number of available events.

The same is the case when we add additional lags of the dependent variable (Regression 4).[39] Regression 5 adds the actual interest rate differential and once again our results are unchanged. Finally, Regression 6 drops all remaining insignificant variables from the regression without affecting our findings.

[Insert Table 6]

Table 7 repeats the same exercise for implied volatility and VRP regressions. We only report a subset of these results. Regression 1 (for implied volatility, 4 for VRP) adds the three announcement surprise terms to the regression, Regression 2(5) adds the EM Economic Surprise Indexes, Regression 3(6) adds additional lags of the dependent variable, while Regression 4(8) includes the lagged change in the CDS spread.[40] The results remain robust to all these additions.

[Insert Table 7]

Next, we consider alternative maturities for implied volatility and the volatility risk premium. We also construct alternative measures of VRP based on forecasts for realized volatility. These are obtained from a linear model in which we regress the (ex-post) realized volatility computed over the $[t,t+h]$ period, $RV_{t,t+h}$, either i) on the realized volatility estimated over the $[t-h-1,t-1]$ period $RV_{t-h-1,t-1}$, or ii) using a broader model that, in addition to $RV_{t-h-1,t-1}$, includes the maturity h implied volatility at time $t-1$, IV_{t-1}, and a measure of negative foreign exchange returns RET_{t-1}.[41] The latter term, suggested by Corsi and Reno (2013) and Bekaert and Hoerova. (2014), captures a potential leverage effect and appears significantly in our RV regressions. The empirical RV models at one month horizon perform relatively well, with an R^2 of around 0.4, but their performance worsens at longer maturities (Table OA10). The results for alternative maturities of implied volatility and measures of VRP are reported in Tables OA6 and OA7. In short, the results are mainly consistent with the baseline. The only exception is that the estimated coefficient for spot FXI in the one-year regressions is not statistically significant, and the Wald test weakly rejects the null hypothesis that the two intervention coefficients are equal in the VRP equation.

Finally, we consider whether our results may reflect the fact that FXI is not sterilized, such that changes in interest rates and/or the monetary base would be the main drivers of the exchange rate response. To address these concerns we look more closely into interest rate and base money

[39] We report coefficient only for the second lag but the regression includes up to five lags which were all insignificant. We also included day-of-the-week dummies and lags of intervention variables (not reported), with no effect on our results.

[40] We report only the coefficients for the lags that are statistically significant; the regressions include up to five lags.

[41] The variable takes a positive value for days when the Real/$ exchange rate depreciates and zero otherwise.

developments surrounding the incidences of both types of FXI in our baseline sample. More concretely, we calculate daily changes in the interbank rate targeted by monetary policy (the Selic rate) and daily changes in base money. We then run simple regressions of both variables on spot FXI, similar to Fratszcher et al. (2018). We experiment with day-of-the-week and year fixed effects to assure that we capture the impact of FXI on liquidity correctly. We also estimate regressions with two-day changes in the monetary base that allow for some degree of smoothness in the liquidity reaction and obtain the same result. Note that by definition of the underlying contracts, futures based FXI does not impact reserve money directly at the time of FXI; we thus do not show regressions of the monetary base on futures FXI. The results are summarized in Tables OA8 and OA9. We do not find any systematic evidence in favor of either a positive correlation between net spot market purchases and base money movements nor of a negative link between the FXI and the changes in the interbank (or official) rates. In short, the evidence of FXI effectiveness does not appear to be driven by non-sterilization concerns.

5. CONCLUSION

This paper studies the relative effectiveness of foreign exchange intervention in spot and derivatives markets. We focus on the case of Brazil where spot and non-deliverable futures based intervention have been used alongside each other since the early 2000s, making it a unique case study for the analysis at hand.

In particular, we compare the effectiveness of the Brazilian Central Banks's purchases and sales of spot Dollars to its auctions of non-deliverable futures settled in local currency. We use instrumental variable regressions that seek to explain changes in the BRL-USD exchange rate and in measures of volatility as well as the price of hedging it. Our set of instruments for the two intervention terms makes use of a rich data set and succeeds at identifying distinct reaction functions that permit including the two modes of intervention jointly in our regressions.

The analysis finds strong evidence in favor of a significant link between intervention through both spot and derivatives markets and changes in the Real/Dollar exchange rate. What is more, the impact of $1 billion in net spot market intervention is statistically indistinguishable to that achieved through auctions of non-deliverable futures worth $1 billion in notional principal. The effect is economically important and survives a battery of robustness checks including extending the length of the sample period. The same result holds for the impact of the two modes of FXI on the volatility risk premium and the implied exchange rate volatility at different horizons.

The analysis also detects significant differences in reaction functions for the two instruments. The BCB appears to use spot intervention more so than derivatives based intervention in reaction to daily movements in the exchange rate and to capital flow pressures. Conversely, it is more likely to use futures based intervention to smooth trend movements in the exchange rate and when price pressures dominate.

Our analysis provides the first set of empirical results on the relative effectiveness of spot market and derivatives based forms of FXI in driving spot and options market exchange rate changes. Future work can extend the analysis in at least two directions. First, while we analyze the price effects of FXI on spot and derivatives markets, further analysis could consider their broader effects on market liquidity and the formation of market participants' beliefs. Second, while our volatility risk premium results can be interpreted in the context of the growing limits to arbitrage literature, further theoretical work on the channels through which foreign exchange interventions influence derivative and spot markets is warranted.

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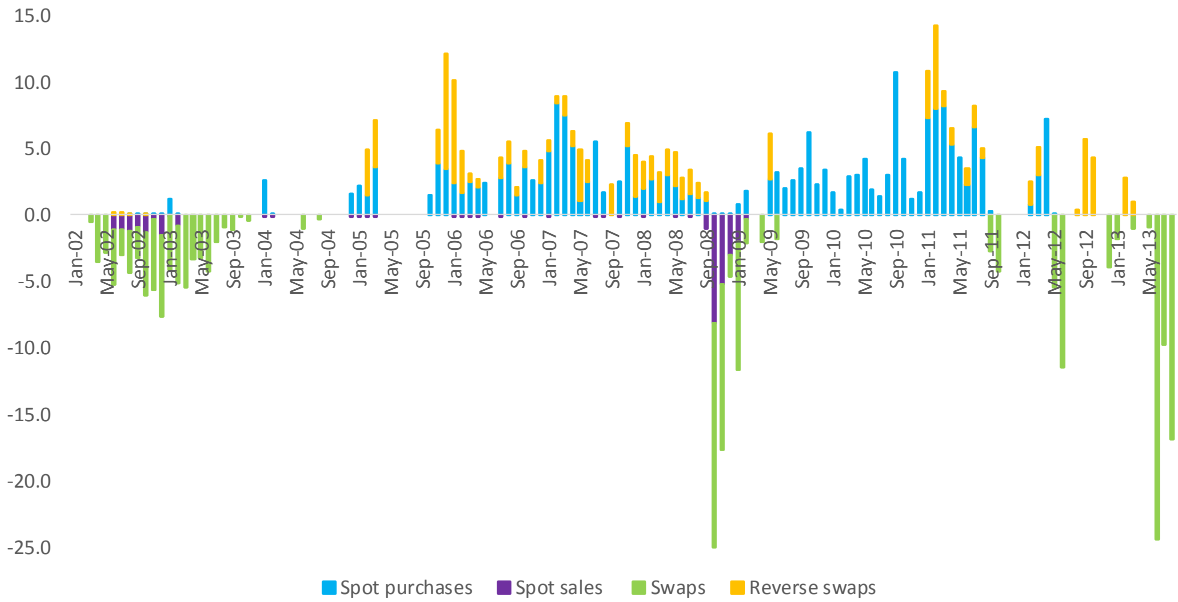
Figure 1: Spot and Brazilian (Reverse) Futures based intervention in Billions of US$ or Notional Principal Equivalent



Notes: The chart shows the evolution of spot and futures based FX intervention. The variables shown are Spot market purchases (*Spot purchases*), spot market sales (*Spot sales*), Short-dollar futures intervention (*Swaps*) and Long-dollar futures intervention (*Reverse swaps*) in billions of US dollars and aggregated at monthly frequency. The futures based intervention variables exclude auctions for roll-over.

Table 1: First-Stage Regressions:

Controls	Spot	Futures	Spot	Futures
Lagged daily pct change in FX	-0.019**	0.014	-0.007	0.001
	(0.01)	(0.01)	(0.07)	(0.05)
Change in VRP, lag	0.00	-0.045**	0.08	(0.06)
	(0.01)	(0.02)	(0.08)	(0.06)
CRB index, % change	0.027	0.019	-0.164	0.125
	(0.02)	(0.02)	(0.12)	(0.12)
CRB index, % change, lag	-0.024	-0.038	-0.044	0.006
	(0.03)	(0.03)	(0.14)	(0.11)
VIX, % change	0	-0.004**	-0.003	-0.016*
	(0.00)	(0.00)	(0.01)	(0.01)
VIX, % change, lag	0.002	0.001	0	0
	(0.00)	(0.00)	(0.01)	(0.01)
Spot forward differential, lag	-0.047**	0.009	-0.419**	0.089
	(0.02)	(0.01)	(0.20)	(0.06)
5Y sovereign CDS return, lag	-0.002	-0.013*	-0.026	-0.047***
	(0.00)	(0.01)	(0.02)	(0.02)
Instruments				
FX deviation from moving average, lag	-1.084	-3.070***	-11.061**	-17.075***
	(0.70)	(0.88)	(5.29)	(3.35)
Medium-run FX trend	-0.247	-0.819**	-0.269	-2.817***
	(0.24)	(0.37)	(0.58)	(1.00)
Lagged average FX volatility	-0.929***	-1.448***	1.831	-3.437***
	(0.26)	(0.37)	(1.30)	(0.94)
Lagged net FX flows	0.075***	0.035	0.289***	0.173
	(0.02)	(0.02)	(0.11)	(0.13)
Lagged policy rate change	0.615***	0.005	3.688***	-1.007
	(0.19)	(0.31)	(0.99)	(1.48)
Lagged spot intervention	0.168*	-0.120**	2.484***	0.454***
	(0.09)	(0.06)	(0.16)	(0.14)
Lagged futures intervention	-0.024	0.416***	0.223	2.423***
	(0.04)	(0.14)	(0.34)	(0.35)
Constant	0.287	0.551**		
	(0.18)	(0.25)		
N	1100	1100	1100	1100
Kleibergen-Paap rk Wald F	6.4	6.4		
Sanderson-Windmeijer F test	10.0 (0.00)	6.4 (0.00)		
Kleibergen-Paap rk LM	27.9 (0.00)	27.9 (0.00)		
Mc Fadden's R^2			0.49	0.41

Notes: The dependent variable in columns 1 is *spot intervention* - in billions of US Dollars – while the dependent variable in columns 2 is *futures intervention* - in billions of US Dollar equivalent of notional principal – defined such that positive values imply that the BCB takes a long Dollar position. The dependent variable in columns 3 (spot) and 4 (futures) takes the value +1 when the BCB takes a long Dollar position, -1 for when it takes a short Dollar position; and 0 in the absence of intervention. Explanatory variables are defined in Table A1. The first two columns report OLS estimates, the last two columns report estimates from an ordered probit. Robust standard errors in parentheses (Newey-West HAC in Column 1-2, heteroscedasticity robust in Column 3-4). *. *, ** and *** denote statistical significance at 10%, 5% and 1% level. For test statistics p-values are reported in parentheses. Stock-Yogo critical value for the weak instrument test with 10% maximal LIML size is: 4.18.

Table 2: Second-Stage Regressions: Exchange rate changes

	1	2	3	4	5	6	7	8
% change in FX rate, lag	-0.178***	-0.169**	-0.177***	-0.174***	-0.086*	-0.066	-0.133**	-0.130**
	(0.06)	(0.07)	(0.07)	(0.06)	(0.05)	(0.05)	(0.07)	(0.06)
change in VRP, lag	0.433***	0.401***	0.378***	0.395***			0.329***	0.314***
	(0.08)	(0.10)	(0.09)	(0.10)			(0.10)	(0.09)
CRB index, % change	-0.107	-0.170*	-0.160*	-0.09	-0.155**	-0.160**	-0.152	-0.149
	(0.09)	(0.10)	(0.09)	(0.08)	(0.08)	(0.08)	(0.10)	(0.10)
CRB index, % change, lag	-0.324***	-0.381***	-0.370***	-0.354***	-0.348***	-0.337***	-0.375***	-0.379***
	(0.08)	(0.08)	(0.08)	(0.09)	(0.06)	(0.08)	(0.08)	(0.07)
VIX, % change	0.006	0.010*	0.007	0.008	0.006	0.006	0.007	0.007
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
VIX, % change, lag	-0.014***	-0.014**	-0.015***	-0.011**	-0.002	0	-0.013**	-0.013**
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Spot forward differential, lag	0.157***	0.142***	0.154***	0.070*	0.168***	0.165***	0.140***	0.137***
	(0.04)	(0.05)	(0.04)	(0.04)	(0.04)	(0.04)	(0.05)	(0.04)
5Y sovereign CDS return, lag	0.076***	0.082***	0.081***	0.072***	0.100***	0.097***	0.083***	0.082***
	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)
Spot intervention	0.977***		0.733*	0.185	0.697*	0.724**	0.24	0.512*
	(0.36)		(0.39)	(0.17)	(0.36)	(0.35)	(0.81)	(0.31)
Futures intervention		1.490***	0.670**	-0.103*	0.575*	0.532*	0.636*	0.544*
		(0.40)	(0.32)	(0.06)	(0.30)	(0.29)	(0.34)	(0.31)
Conv. Risk * Futures Int.						-2.090*		
						(1.25)		
Conv. Risk * Spot Int.						1.48		
						(4.98)		
Convertibility Risk						-0.008		
						(0.78)		
Spot Long * Spot Int.							0.30	
							(0.94)	
Futures Long * Fut. Int.							-0.918***	-0.822**
							(0.35)	(0.32)
Constant	0	0.111	0.078	0.234	0.102	0.091		
	(0.05)	(0.11)	(0.09)	(0.29)	(0.09)	(0.09)		
N	1,100	1,100	1,100	1,100	2,218	2,218	1,100	1,100
Hansen's J stat.	9.1 (0.17)	9.3 (0.16)	7.9 (0.16)		5.5 (0.14)	7.5 (0.19)	11.5 (0.40)	11.4 (0.41)
Stock-Wright S stat	16.4 (0.02)	16.4 (0.02)	16.4 (0.02)		20.2 (0.00)	24.7 (0.00)	25.8 (0.04)	25.8 (0.03)
C test for endogeneity	15.9 (0.03)	15.9 (0.03)	15.9 (0.03)		15.2 (0.01)	19.2 (0.02)	26.6 (0.03)	26.5 (0.02)
Wald statistic	()	()	0.01 (0.91)		0.05 (0.82)	0.13 (0.71)		0.00 (0.95)
Wald statistic – short US$							0.16 (0.69)	
Wald statistic – long US$							4.78 (0.03)	

Notes: The dependent variable is the percent daily change in the Real/$ rate. Explanatory variables are defined in Table A1. The *Convertibility Risk* variable takes the value one on days on which the spread between 3M local interest rate (cupom cambial) and Dollar Libor was 1.5 standard deviations above its sample mean. The *Spot* (*Futures*) *Long* dummy takes the value one on days when the BCB takes a long Dollar position via the respective mode of intervention. Regressions 1-3 and 5-7 report estimates using CUE, regression 4 reports OLS estimates. Newey-West HAC standard errors in parentheses. *, ** and *** denote statistical significance at 10%, 5% and 1% level. For test statistics p-values are reported in parentheses. Wald statistic tests the null hypothesis of equality of the spot and futures intervention coefficients. Wald statistic – short USD tests the null hypothesis of equality of the spot and futures intervention coefficients. Wald statistic – long USD tests the null hypothesis of equality of the sum of the level and interaction term coefficients for spot and futures intervention.

Table 3: Second-Stage Regressions: Implied Volatility:

	1	2	3	4	5	6
% change in IV, lag	0.135***	0.208***	0.174***	0.128**	0.054	0.170***
	(0.04)	(0.05)	(0.05)	(0.06)	(0.03)	(0.05)
% change in FX rate, lag	-0.034	0.20	0.19	0.17	0.297**	0.096
	(0.15)	(0.17)	(0.17)	(0.21)	(0.14)	(0.21)
CRB index, % change	-1.439***	-1.591***	-1.543***	-1.312***	-1.063***	-1.590***
	(0.29)	(0.30)	(0.30)	(0.31)	(0.28)	(0.28)
CRB index, % change, lag	-0.018	-0.08	-0.209	-0.333	-0.522**	-0.311
	(0.29)	(0.34)	(0.33)	(0.33)	(0.23)	(0.27)
VIX, % change	0.176***	0.206***	0.199***	0.203***	0.171***	0.197***
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
VIX, % change, lag	0.040**	0.043**	0.038*	0.040**	0.052***	0.037**
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Spot intervention	2.415**		1.892*	1.000**	2.337**	4.660*
	(1.02)		(1.06)	(0.39)	(1.04)	(2.65)
Futures intervention		3.219***	2.107**	-0.208	1.379	1.916*
		(1.13)	(1.07)	(0.31)	(0.95)	(1.17)
Spot Long * Spot Int.						-3.394
						(2.92)
Futures Long * Fut. Int.						-1.045
						(1.27)
Constant	0.361	0.990**	0.836**	0.383	0.716*	0.780**
	(0.26)	(0.39)	(0.37)	(0.99)	(0.38)	(0.38)
N	1,100	1,100	1,100	1,100	1,979	1,100
Hansen's J stat.	5.4 (0.49)	4.7 (0.58)	2.0 (0.84)		3.7 (0.45)	6.4 (0.85)
Stock-Wright S stat	23.3 (0.00)	23.3 (0.00)	23.3 (0.00)		20.1 (0.00)	31.3 (0.01)
C test for endogeneity	16.7 (0.02)	16.7 (0.02)	16.7 (0.02)		16.2 (0.01)	31.7 (0.01)
Wald statistic	()	()	0.01 (0.90)		0.33 (0.56)	
Wald statistic – short US$						0.70 (0.40)
Wald statistic – long US$						0.16 (0.69)

Notes: The dependent variable is the percent daily change in the three month Real/$ at-the-money implied volatility. Explanatory variables are defined in Table A1. The *Spot* (*Futures*) *Long* dummy takes the value one on days when the BCB takes a long Dollar position via the respective mode of intervention. Regressions 1-3 and 5-7 report estimates using CUE, regression 4 reports OLS estimates. Newey-West HAC standard errors in parentheses. *, ** and *** denote statistical significance at 10%, 5% and 1% level. For test statistics p-values are reported in parentheses. Wald statistic tests the null hypothesis of equality of the spot and futures intervention coefficients. Wald statistic – short USD tests the null hypothesis of equality of the spot and futures intervention coefficients. Wald statistic – long USD tests the null hypothesis of equality of the sum of the level and interaction term coefficients for spot and futures intervention.

Table 4: Second-Stage Regressions: Volatility Risk Premium:

	1	2	3	4	5	6
change in VRP, lag	0.074*	0.176***	0.149***	0.148*	0.149**	0.135***
	(0.04)	(0.05)	(0.05)	(0.08)	(0.06)	(0.05)
% change in FX rate, lag	-0.06	0.04	0.01	0.04	-0.01	0.035
	(0.05)	(0.06)	(0.05)	(0.08)	(0.05)	(0.07)
CRB index, % change	-0.336***	-0.340***	-0.351***	-0.359***	-0.293***	-0.308***
	(0.09)	(0.09)	(0.09)	(0.10)	(0.07)	(0.09)
CRB index, % change, lag	-0.165**	-0.104	-0.161*	-0.093	-0.145**	-0.075
	(0.08)	(0.10)	(0.09)	(0.12)	(0.06)	(0.09)
VIX, % change	0.030***	0.037***	0.036***	0.037***	0.028***	0.038***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.00)	(0.01)
VIX, % change, lag	0.004	0.006	0.004	0.004	0.005	0.009
	(0.01)	(0.01)	(0.01)	(0.01)	(0.00)	(0.01)
Spot intervention	0.720***		0.574**	0.288**	0.581*	1.759**
	(0.26)		(0.26)	(0.13)	(0.30)	(0.89)
Futures intervention		0.889***	0.581*	-0.001	0.610**	0.724**
		(0.32)	(0.30)	(0.08)	(0.26)	(0.35)
Spot Long * Spot Int.						-1.426
						(0.95)
Futures Long * Fut. Int.						-0.591
						(0.37)
Constant	0.025	0.225**	0.159**	-0.568	0.171**	0.199**
	(0.03)	(0.09)	(0.08)	(0.36)	(0.07)	(0.09)
N	1,100	1,100	1,100	1,100	1,989	1,100
Hansen's J stat.	7.9 (0.25)	8.5 (0.20)	4.1 (0.54)		6.3 (0.18)	12.0 (0.37)
Stock-Wright S stat	30.9 (0.00)	30.9 (0.00)	30.9 (0.00)		39.7 (0.00)	49.5 (0.00)
C test for endogeneity	26.1 (0.00)	26.1 (0.00)	26.1 (0.00)		20.8 (0.00)	51.2 (0.00)
Wald statistic	()	()	0.00 (0.99)		0.00 (0.95)	
Wald statistic – short US$						0.94 (0.33)
Wald statistic – long US$						0.75 (0.39)

Notes: The dependent variable is the daily change in the three-month Real/$ volatility risk premium (VRP). The VRP is defined as the difference between the implied volatility and realized volatility at the corresponding horizon. Explanatory variables are defined in Table A1. The *Spot* (*Futures*) *Long* dummy takes the value one on days when the BCB takes a long Dollar position via the respective mode of intervention. Regressions 1-3 and 5-7 report estimates using CUE, regression 4 reports OLS estimates. Newey-West HAC standard errors in parentheses. *, ** and *** denote statistical significance at 10%, 5% and 1% level. For test statistics p-values are reported in parentheses. Wald statistic tests the null hypothesis of equality of the spot and futures intervention coefficients. Wald statistic – short USD tests the null hypothesis of equality of the spot and futures intervention coefficients. Wald statistic – long USD tests the null hypothesis of equality of the sum of the level and interaction term coefficients for spot and futures intervention.

Table 5: Second-Stage Regressions: System estimator

	1	2	3	4
% change in FX rate, lag	-0.164***	0.177	-0.09*	0.017
	(0.06)	(0.17)	(0.05)	(0.05)
% change in IV, lag	0.102***	0.174***		
	(0.02)	(0.04)		
change in VRP, lag			0.374***	0.151***
			(0.08)	(0.05)
CRB index, % change	-0.126	-1.486***	-0.158**	-0.350***
	(0.09)	(0.30)	(0.07)	(0.09)
CRB index, % change, lag	-0.349***	-0.22	-0.368***	-0.158*
	(0.08)	(0.31)	(0.07)	(0.09)
VIX, % change	0.01	0.193***	0.01	0.034***
	(0.01)	(0.02)	(0.01)	(0.01)
VIX, % change, lag	-0.021***	0.035*	-0.013***	0.004
	(0.01)	(0.02)	(0.01)	(0.01)
Spot forward differential, lag	0.162***		0.155***	
	(0.05)		(0.04)	
5Y sovereign CDS return, lag	0.088***		0.080***	
	(0.01)		(0.01)	
Spot intervention	0.763**	1.801*	0.743**	0.567**
	(0.38)	(1.04)	(0.37)	(0.25)
Futures intervention	0.592**	2.058*	0.616**	0.59**
	(0.28)	(1.05)	(0.28)	(0.28)
Constant	0.06	0.876**	0.08	0.162**
	(0.09)	(0.38)	(0.08)	(0.08)
N	1,100	1,100	1,100	1,100
Hansen's J stat.	14.9 (0.13)	14.9 (0.13)	17.3 (0.07)	17.3 (0.07)
Wald statistic	0.1 (0.75)	0.0 (0.88)	0.1 (0.81)	0.0 (0.95)

Notes: The dependent variable in Column 1 and 3 is the percent daily change in the Real/$ rate. The dependent variable in Column 2 is the percent daily change in the three month Real/$ at-the-money implied volatility The dependent variable in the Column 4 is the daily change in the three-month Real/$ volatility risk premium (VRP). The VRP is defined as the difference between the implied volatility and realized volatility at the corresponding horizon. Explanatory variables are defined in Table A1. Columns 1 and 2 report estimates from the joint estimation of returns and implied volatility equations by CUE. Columns 3 and 4 report estimates from the joint estimation of returns and volatility risk premium equations by CUE. Newey-West HAC standard errors in parentheses. *, ** and *** denote statistical significance at 10%, 5% and 1% level. For test statistics p-values are reported in parentheses. Wald statistic tests the null hypothesis of equality of the spot and futures intervention coefficients.

Table 6: Second-Stage Regressions: Exchange rate changes: Alternative control variables

	1	2	3	4	5	6
% change in FX rate, lag	-0.176***	-0.176***	-0.172***	-0.184***	-0.173***	-0.180***
	(0.07)	(0.06)	(0.07)	(0.07)	(0.07)	(0.07)
change in VRP, lag	0.380***	0.370***	0.363***	0.366***	0.376***	0.388***
	(0.09)	(0.09)	(0.09)	(0.09)	(0.09)	(0.09)
CRB index, % change	-0.159*	-0.155	-0.154	-0.169**	-0.154	-0.201**
	(0.09)	(0.09)	(0.10)	(0.09)	(0.10)	(0.10)
CRB index, % change, lag	-0.369***	-0.371***	-0.372***	-0.373***	-0.380***	-0.363***
	(0.08)	(0.08)	(0.08)	(0.08)	(0.08)	(0.08)
VIX, % change	0.007	0.006	0.006	0.008	0.008	
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	
VIX, % change, lag	-0.015***	-0.014***	-0.014**	-0.015***	-0.015***	-0.016***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Spot forward differential, lag	0.154***	0.159***	0.160***	0.160***	0.131***	0.156***
	(0.04)	(0.04)	(0.05)	(0.04)	(0.04)	(0.05)
5Y sovereign CDS return, lag	0.081***	0.080***	0.080***	0.079***	0.082***	0.081***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Spot intervention	0.654**	0.519*	0.600**	0.351	0.692**	0.791**
	(0.31)	(0.29)	(0.30)	(0.26)	(0.33)	(0.34)
Futures intervention	0.738*	0.867**	0.829**	0.813**	0.658*	0.719*
	(0.39)	(0.40)	(0.42)	(0.37)	(0.40)	(0.40)
Inflation surprise	0.342					
	(1.57)					
Unemployment surprise	(0.00)					
	(0.37)					
Industrial Prod. surprise	-0.017					
	(0.08)					
Citi EM surprise index		-0.065				
		(0.08)				
Citi LATAM surprise index			-0.01			
			-0.114			
% change in FX rate, lag 2				-0.043		
				-0.045		
Interest rate differential, change					-0.119	
					(0.37)	
Constant	0.077	0.029	0.073	0.069	0.094	0.078
	(0.09)	(0.09)	(0.09)	(0.08)	(0.09)	(0.09)
N	1,100	1,093	1,094	1,100	1,079	1,101
Hansen's J stat.	7.9 (0.16)	7.6 (0.18)	8.1 (0.15)	5.4 (0.37)	6.9 (0.22)	7.8 (0.17)
Stock-Wright S stat	16.3 (0.02)	16.6 (0.02)	15.9 (0.03)	13.6 (0.06)	16.4 (0.02)	17.2 (0.02)
C test for endogeneity	15.7 (0.03)	16.0 (0.02)	15.3 (0.03)	14.2 (0.05)	14.2 (0.05)	16.8 (0.02)
Wald statistic	0.02 (0.88)	0.37 (0.54)	0.15 (0.70)	0.83 (0.36)	0.00 (0.96)	0.01 (0.91)

Notes: The dependent variable is the % daily change in the Real/$ rate. Explanatory variables are defined in Table A1. Newey-West HAC standard errors in parentheses. *, ** and *** denote statistical significance at 10%, 5% and 1% level. For test statistics p-values are reported in parentheses. Wald statistic tests the null hypothesis of equality of the spot and futures intervention coefficients. Only the coefficients for the second lag of the dependent variable is reported (all statistically insignificant).

Table 7: Second-Stage Regressions: Implied volatility and volatility risk premium: Alternative control variables

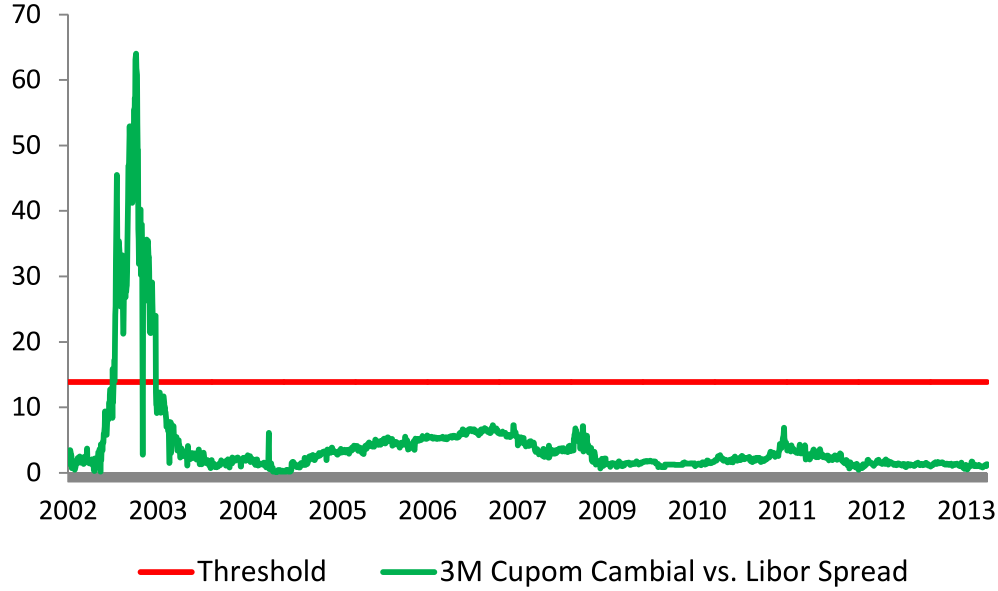
	1	2	3	4	5	6	7	8
% change in IV, lag	0.173***	0.173***	0.157***	0.161***				
	(0.05)	(0.05)	(0.05)	(0.04)				
% change in FX rate, lag	0.19	0.20	0.23	0.16	0.01	0.02	0.138*	(0.01)
	(0.17)	(0.17)	(0.20)	(0.17)	(0.05)	(0.06)	(0.07)	(0.05)
CRB index, % change	-1.548***	-1.603***	-1.636***	-1.531***	-0.353***	-0.376***	-0.420***	-0.337***
	(0.31)	(0.31)	(0.31)	(0.31)	(0.09)	(0.09)	(0.10)	(0.10)
CRB index, % change, lag	-0.217	-0.231	-0.167	-0.13	-0.162*	-0.169*	-0.124	-0.102
	(0.33)	(0.34)	(0.32)	(0.32)	(0.09)	(0.10)	(0.10)	(0.10)
VIX, % change	0.199***	0.198***	0.192***	0.198***	0.036***	0.036***	0.038***	0.035***
	(0.02)	(0.02)	(0.02)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)
VIX, % change, lag	0.038*	0.037*	0.034*	0.027	0.003	0.003	0.001	-0.005
	(0.02)	(0.02)	(0.02)	(0.03)	(0.01)	(0.01)	(0.01)	(0.01)
Spot intervention	2.126**	2.101*	1.608*	2.145**	0.582*	0.657**	0.967***	0.592**
	(1.07)	(1.07)	(0.97)	(1.08)	(0.30)	(0.31)	(0.36)	(0.30)
Futures intervention	1.886*	2.158*	2.632**	1.788*	0.577**	0.660**	0.763***	0.493*
	(1.06)	(1.13)	(1.12)	(1.05)	(0.26)	(0.29)	(0.29)	(0.26)
Inflation surprise	2.233				1.018			
	(4.64)				(1.01)			
Unemployment surprise	-0.561				-0.079			
	(1.26)				(0.27)			
IP surprise	(0.11)				(0.02)			
	(0.23)				(0.05)			
Citi EM surprise index		-0.412				-0.228***		
		(0.29)				(0.07)		
% change in IV, lag 4			-0.101**					
			-0.041					
5Y Sov. CDS return, lag				0.048				0.035
				-0.073				-0.024
change in VRP, lag					0.148***	0.151***	0.147***	0.108**
					-0.046	-0.048	-0.057	-0.051
change in VRP, lag 4							-0.140**	
							-0.07	
change in VRP, lag 5							-0.152**	
							(0.07)	
Constant	0.842**	0.537	0.774**	0.823**	0.159*	0.01	0.253**	0.146*
	(0.38)	(0.39)	(0.36)	(0.38)	(0.08)	(0.08)	(0.10)	(0.08)
N	1,100	1,093	1,100	1,100	1,100	1,093	1,100	1,100
Hansen's J stat.	2.0 (0.85)	2.2 (0.82)	1.5 (0.92)	2.0 (0.85)	4.1 (0.54)	4.6 (0.47)	1.1 (0.95)	3.7 (0.59)
Stock-Wright S stat	24.0 (0.00)	24.2 (0.00)	25.1 (0.00)	23.1 (0.00)	31.3 (0.00)	32.2 (0.00)	37.8 (0.00)	33.0 (0.00)
C test for endogeneity	16.8 (0.02)	17.7 (0.01)	17.1 (0.02)	16.4 (0.02)	26.2 (0.00)	29.5 (0.00)	24.5 (0.00)	24.5 (0.00)
Wald statistic	0.02 (0.89)	0.00 (0.97)	0.35 (0.55)	0.04 (0.84)	0.00 (0.99)	0.00 (1.00)	0.16 (0.69)	0.05 (0.83)

Notes: The dependent variable is the percent daily change in the three month Real/$ implied volatility (Column 1-4) and the daily change in the three month Real/$ volatility risk premium (Column 5-8). The VRP is defined as the difference between the implied volatility and realized volatility at the corresponding horizon. Explanatory variables are defined in Table A1. Newey-West HAC standard errors in parentheses. *, ** and *** denote statistical significance at 10%, 5% and 1% level. For test statistics p-values are reported in parentheses. Wald statistic tests the null hypothesis of equality of the spot and futures intervention coefficients. Only the coefficients for statistically significant lags of the dependent variable are reported.

Table A1: Variable Definitions and Sources

Variable Name	Definition	Source
Dependent Variables		
Exchange rate	Percent Daily Change in Real/$	Bloomberg; authors' calculations
Implied Volatility	Percent Daily Change in at-the-money implied Real/$ volatility at 1M, 3M, 6M and 1Y horizons.	Bloomberg; authors' calculations
Volatility Risk Premium	The difference between Implied Volatility and Realized Volatility at selected horizons. Realized Volatility measured using past daily FX returns and through model predictions.	Bloomberg; authors' calculations
Intervention Terms		
Spot intervention	Spot purchases net of Spot sales	BCB and authors' calculations
Futures intervention	Reverse FX swaps net of FX swaps	BCB and authors' calculations
Spot purchases	In billions US$	BCB and authors' calculations
Spot sales	In billions US$	BCB and authors' calculations
Reverse swaps	In billions of notional outstanding principal in US$	BCB and authors' calculations
Swaps	In billions of notional outstanding principal in US$	BCB and authors' calculations
Instruments		
Lagged FX deviation from moving average	The difference between the exchange rate and the two week moving average of the exchange rate in log terms.	Bloomberg; authors' calculations
Lagged FX volatility	Two week moving average of 1M implied volatility	Bloomberg; authors' calculations
Medium-run FX trend	One year moving average of the log of the exchange rate	Bloomberg; authors' calculations
Lagged net FX flows	One-week average of net daily FX flows in billions US$	BCB and authors' calculations
Lagged spot intervention	One week moving average of the spot interventions	BCB and authors' calculations
lagged futures intervention	One week moving average of the futures interventions	BCB and authors' calculations
Lagged policy rate change	One week change in the Selic target rate	Bloomberg; authors' calculations
Difference between the onshore and offshore forward rate	One-week moving average percent difference between offshore and onshore NDF	Bloomberg; authors' calculations
Control Variables		
5Y sovereign CDS return	Percent daily change in 5Y sovereign CDS spread	Bloomberg; authors' calculations
CRB index	Thomson Reuters Core Commodity (CRB) price index	Haver; authors' calculations
VIX	Chicago Board Options Exchange Market Volatility Index	Haver; authors' calculations
Lagged FX forward differential	One-week average percent difference between spot and forward rate	Bloomberg; authors' calculations
Inflation surprise	The difference between actual announcement and Bloomberg expectations	Bloomberg; authors' calculations
Unemployment surprise	The difference between actual announcement and Bloomberg expectations	Bloomberg; authors' calculations
Industrial production surprise	The difference between actual announcement and Bloomberg expectations	Bloomberg; authors' calculations
Citi EM surprise	Citi EM surprise Index	Haver; authors' calculations
Citi LATAM surprise	Citi Latam surprise Index	Haver; authors' calculations
Interest rate differential	Difference between Selic and Fed Funds rate	Bloomberg and Haver.
Other		
Convertibility Risk	Value 1 on days when cupom cambial-Dollar libor spread is 1.5 std above sample mean	Bloomberg; authors' calculations
Cupom cambial	Three-month onshore dollar interest rate	Bloomberg; authors' calculations

Figure A1: Convertibility Risk



Notes: The graph shows the evolution of *Convertibility Risk* proxied by the spread between three month Cupom Cambial rate and the Dollar Libor rate. The threshold is equal to one sample standard deviation above the sample mean. The cupom cambial is priced in basis points equal to the spread between the overnight interbank deposit rate and the expected exchange rate variation and serves as the onshore Dollar interest rate.

Online Appendix

to accompany

The Relative Effectiveness of Spot and Derivatives Based Intervention

Table OA1: First-Stage Regressions: Alternative instruments:

Controls	Spot	Futures	Spot	Futures	Spot	Futures	Spot	Futures
Lagged daily pct change in FX	-0.019**	0.014	-0.020**	0.014	-0.018*	0.014	-0.019*	0.013
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Change in VRP, lag	0.004	-0.045**	0.005	-0.045**	0.007	-0.045**	0.007	-0.042**
	(0.01)	(0.02)	(0.01)	(0.02)	(0.01)	(0.02)	(0.01)	(0.02)
CRB index, percent change	0.027	0.019	0.027	0.02	0.03	0.019	0.029	0.022
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
CRB index, lagged percent change	-0.024	-0.039	-0.024	-0.039	-0.023	-0.04	-0.021	-0.033
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
VIX, percent change	0	-0.004**	0	-0.004**	0	-0.004**	0	-0.003**
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
VIX, lagged percent change	0.002	0.001	0.002	0.001	0.001	0.001	0.002	0.001
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
FX forward differential, lag	-0.048**	0.007	-0.047**	0.008	-0.048**	0.01	-0.049**	0.003
	(0.02)	(0.01)	(0.02)	(0.01)	(0.02)	(0.01)	(0.02)	(0.01)
5Y sovereign CDS return, lagged	-0.002	-0.013*	-0.002	-0.012*	-0.002	-0.013*	-0.003	-0.013*
	(0.00)	(0.01)	(0.00)	(0.01)	(0.00)	(0.01)	(0.00)	(0.01)
Instruments								
FX deviation from moving level, lag	-1.082	-3.067***	-1.074	-3.048***	-1.018	-3.078***	-1.012	-2.805***
	(0.70)	(0.88)	(0.70)	(0.87)	(0.70)	(0.88)	(0.74)	(0.92)
Medium-run FX trend	-0.257	-0.835**	-0.269	-0.815**	-0.33	-0.843**	-0.196	-0.606
	(0.25)	(0.37)	(0.25)	(0.37)	(0.25)	(0.39)	(0.25)	(0.39)
Lagged average FX volatility	-0.941***	-1.468***	-0.917***	-1.457***	-0.867***	-1.484***		
	(0.25)	(0.39)	(0.25)	(0.38)	(0.25)	(0.37)		
Lagged net FX flows	0.075***	0.035	0.074***	0.035	0.071***	0.035	0.073***	0.034
	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
Lagged policy rate change	0.622***	0.016	0.621***	0.012	0.501***	0.016	0.644***	0.073
	(0.19)	(0.31)	(0.19)	(0.31)	(0.15)	(0.32)	(0.19)	(0.31)
Lagged spot intervention,	0.168*	-0.120**	0.170*	-0.125**	0.160*	-0.121*	0.188**	-0.064
	(0.09)	(0.06)	(0.09)	(0.06)	(0.09)	(0.06)	(0.09)	(0.06)
Lagged swap intervention	-0.026	0.413***	-0.023	0.415***	-0.025	0.413***	0.003	0.473***
	(0.03)	(0.14)	(0.03)	(0.13)	(0.04)	(0.14)	(0.04)	(0.13)
3M Cupom cambial-Libor spread	-0.009	-0.016						
	(0.02)	(0.02)						
Inflation surprise			0.635	-0.15				
			(0.83)	(0.87)				
Unemployment surprise			0.076	0.246*				
			(0.07)	(0.13)				
IP surprise			0.022*	-0.008				
			(0.01)	(0.02)				
Citi LATAM surprise index					0.044	-0.003		
					(0.03)	(0.04)		
Lagged average FX volatility, 1M							-0.724***	-0.847**
							(0.24)	(0.35)
Constant	0.303	0.578**	0.300*	0.548**	0.351*	0.569**	0.236	0.353
	(0.19)	(0.26)	(0.18)	(0.25)	(0.19)	(0.27)	(0.18)	(0.27)
N	1100	1100	1094	1094	1100	1100	1100	1100
Kleibergen-Paap rk Wald F	5.7	5.7	4.52	4.52	5.8	5.8	6.3	6.3
Sanderson-Windmeijer F test	8.6 (0.00)	5.9 (0.00)	6.8 (0.00)	4.4 (0.00)	8.6 (0.00)	5.6 (0.00)	10.5 (0.00)	5.1 (0.00)
Kleibergen-Paap rk LM	28.9 (0.00)	28.9 (0.00)	29.0 (0.00)	29.0 (0.00)	29.6 (0.00)	29.6 (0.00)	27.0 (0.00)	27.0 (0.00)

Notes: The dependent variables in all columns are spot intervention - in billions of US Dollars - and futures intervention - in billions of US Dollar equivalent of notional principal – defined such that positive values imply that the BCB takes a long Dollar position. The instrument set is enlarged to include lagged offshore-onshore spread (Columns 1-2), macro-news surprises (Columns 3-4), the regional news index, *Citi LATAM* (Columns 5-6). Columns 7-8 use the one month moving average of the implied volatility to approximate short-term trends. Newey-West HAC standard errors in parentheses. *, ** and *** denote statistical significance at 10%, 5% and 1% level. For test statistics p-values are reported in parentheses. Stock-Yogo critical value for the weak instrument test with 10% maximal LIML size is: 4.18.

Table OA2: Second-Stage Regressions, Exchange rate changes: Alternative instruments:

	1	2	3	4
% change in FX rate, lag	-0.119**	-0.180***	-0.172***	-0.143**
	(0.07)	(0.06)	(0.07)	(0.07)
change in VRP, lag	0.383***	0.381***	0.365***	0.391***
	(0.09)	(0.09)	(0.09)	(0.09)
CRB index, % change	-0.136*	-0.159*	-0.153	-0.128
	(0.08)	(0.09)	(0.09)	(0.10)
CRB index, % change, lag	-0.355***	-0.369***	-0.372***	-0.346***
	(0.08)	(0.08)	(0.08)	(0.08)
VIX, % change	0.006	0.007	0.006	0.007
	(0.01)	(0.01)	(0.01)	(0.01)
VIX, % change, lag	-0.014***	-0.015***	-0.014**	-0.014**
	(0.01)	(0.01)	(0.01)	(0.01)
Spot forward differential, lag	0.147***	0.157***	0.159***	0.150***
	(0.04)	(0.04)	(0.05)	(0.05)
5Y sovereign CDS return, lag	0.086***	0.081***	0.080***	0.084***
	(0.01)	(0.01)	(0.01)	(0.01)
Spot intervention	0.746**	0.598**	0.602**	0.763**
	(0.35)	(0.29)	(0.30)	(0.37)
Futures intervention	0.54*	0.779**	0.815**	0.448*
	(0.28)	(0.36)	(0.40)	(0.28)
Constant	0.069	0.075	0.076	0.087
	(0.08)	(0.09)	(0.09)	(0.11)
N	1,100	1,100	1,094	1,100
Hansen's J stat.	9.8 (0.13)	8.0 (0.43)	8.1 (0.23)	9.3 (0.10)
Stock-Wright S stat	15.8 (0.04)	16.9 (0.08)	17.0 (0.03)	15.2 (0.03)
C test for endogeneity	16.0 (0.04)	16.7 (0.08)	16.8 (0.03)	15.8 (0.03)
Wald statistic	0.15 (0.69)	0.11 (0.74)	0.13 (0.71)	0.35 (0.55)

Notes: The dependent variable is the percent daily change in Real/$. Explanatory variables are defined in Table A1. Regression 1 reports the second-stage results when lagged offshore-onshore spread is added to the instrument set. Regression 2 reports the second-stage results when macro-surprise news are added to the instrument set. Regression 3 adds the regional news index (*Citi LATAM*) to the instruments. Regression 4 uses one month moving average of implied volatility to approximate short-term trends in volatility. Newey-West HAC standard errors in parentheses. *, ** and *** denote statistical significance at 10%, 5% and 1% level. For test statistics p-values are reported in parentheses. Wald statistic tests the null hypothesis of the equality of the spot and futures intervention coefficients.

Table OA3: Second-Stage Regressions, Implied volatility: Alternative instruments:

	1	2	3	4
% change in IV, lag	0.173***	0.172***	0.175***	0.172***
	(0.04)	(0.04)	(0.05)	(0.05)
% change in FX rate, lag	0.18	0.18	0.19	0.20
	(0.16)	(0.16)	(0.17)	(0.17)
CRB index, % change	-1.541***	-1.519***	-1.592***	-1.507***
	(0.30)	(0.30)	(0.30)	(0.31)
CRB index, % change, lag	-0.209	-0.231	-0.159	-0.213
	(0.33)	(0.32)	(0.32)	(0.35)
VIX, % change	0.199***	0.197***	0.199***	0.199***
	(0.02)	(0.02)	(0.02)	(0.02)
VIX, % change, lag	0.038*	0.039*	0.040*	0.040*
	(0.02)	(0.02)	(0.02)	(0.02)
Spot intervention	2.074**	2.053**	2.036*	2.255**
	(1.01)	(1.03)	(1.07)	(1.12)
Futures intervention	1.909*	1.963*	1.940*	1.910*
	(1.04)	(1.03)	(1.08)	(1.07)
Constant	0.833**	0.836**	0.817**	0.866**
	(0.37)	(0.37)	(0.37)	(0.38)
N	1,100	1,100	1,094	1,100
Hansen’s J stat.	2.0 (0.92)	2.7 (0.95)	2.3 (0.89)	2.5 (0.78)
Stock-Wright S stat	23.5 (0.00)	24.5 (0.01)	23.5 (0.00)	23.4 (0.00)
C test for endogeneity	17.0 (0.03)	17.6 (0.06)	17.5 (0.02)	17.4 (0.01)
Wald statistic	0.01 (0.92)	0.00 (0.96)	0.00 (0.96)	0.04 (0.85)

Notes: The dependent variable is the percent daily change in the three month Real/$ implied volatility. Explanatory variables are defined in Table A1. Regression 1 reports the second-stage results when lagged offshore-onshore spread is added to the instrument set. Regression 2 reports the second-stage results when macro-surprise news are added to the instrument set. Regression 3 adds the regional news index (*Citi LATAM*) to the instruments. Regression 4 uses one month moving average of implied volatility to approximate short-term trends in volatility. Newey-West HAC standard errors in parentheses. *, ** and *** denote statistical significance at 10%, 5% and 1% level. For test statistics p-values are reported in parentheses. Wald statistic tests the null hypothesis of the equality of the spot and futures intervention coefficients.

Table OA4: Second-Stage Regressions, Volatility Risk Premium: Alternative instruments:

	1	2	3	4
change in VRP, lag	0.172***	0.147***	0.134***	0.148***
	(0.05)	(0.05)	(0.05)	(0.05)
% change in FX rate, lag	0.05	0.01	0.01	0.01
	(0.05)	(0.05)	(0.05)	(0.06)
CRB index, % change	-0.351***	-0.344***	-0.402***	-0.360***
	(0.09)	(0.09)	(0.09)	(0.09)
CRB index, % change, lag	-0.161*	-0.174*	-0.136	-0.159*
	(0.10)	(0.09)	(0.09)	(0.10)
VIX, % change	0.036***	0.036***	0.035***	0.036***
	(0.01)	(0.01)	(0.01)	(0.01)
VIX, % change, lag	0.003	0.003	0.005	0.003
	(0.01)	(0.01)	(0.01)	(0.01)
Spot intervention	0.771**	0.564**	0.525*	0.564*
	(0.30)	(0.28)	(0.30)	(0.30)
Futures intervention	0.493*	0.622**	0.581**	0.574**
	(0.25)	(0.26)	(0.27)	(0.26)
Constant	0.187**	0.154**	0.137*	0.154*
	(0.09)	(0.08)	(0.08)	(0.08)
N	1,100	1,100	1,094	1,100
Hansen's J stat.	5.5 (0.48)	5.2 (0.73)	6.3 (0.40)	4.3 (0.51)
Stock-Wright S stat	34.0 (0.00)	33.3 (0.00)	32.5 (0.00)	29.3 (0.00)
C test for endogeneity	29.2 (0.00)	27.8 (0.00)	28.9 (0.00)	25.1 (0.00)
Wald statistic	0.38 (0.54)	0.02 (0.89)	0.01 (0.91)	0.00 (0.98)

Notes: The dependent variable is the daily change in the three month Real/$ volatility risk premium. The VRP is defined as the difference between the implied volatility and realized volatility at the corresponding horizon. Explanatory variables are defined in Table A1. Regression 1 reports the second-stage results when lagged offshore-onshore spread is added to the instrument set. Regression 2 reports the second-stage results when macro-surprise news are added to the instrument set. Regression 3 adds the regional news index (*Citi LATAM*) to the instruments. Regression 4 uses one month moving average of implied volatility to approximate short-term trends in volatility. Newey-West HAC standard errors in parentheses. *, ** and *** denote statistical significance at 10%, 5% and 1% level. For test statistics p-values are reported in parentheses. Wald statistic tests the null hypothesis of the equality of the spot and futures intervention coefficients.

Table OA5: Event and smoothing criterion of FXI effectiveness:

	1	2	3	4
Spot intervention	0.67	0.78	0.47	0.53
Placebo Rates	0.51	0.49	0.51	0.50
Number of episodes	46	46	46	46
Futures intervention	0.54	0.52	0.57	0.61
Placebo Rates	0.49	0.48	0.52	0.50
Number of episodes	15	15	15	15

Notes: Rows 1 and 5 show success rates for the set of intervention episodes in the sample, respectively for spot intervention (Row 1) and futures intervention (Row 4). Rows 2 and 5 show the respective success rates for placebo episodes while Rows 3 and 6 show the number of intervention episodes in the sample. Column 1 shows the success rate according to the Event Criterion; Column 2 shows the success rate according to the Smoothing Criterion; Column 3 shows the success rate when the Event criterion is applied to the three month at-the money foreign exchange implied volatility rather than to the exchange rate; Column 4 shows the success rate when the Event criterion is applied to the three month volatility risk premium rather than to the exchange rate.

Table OA6: Second-Stage Regressions, Implied volatility: Alternative maturities:

	1M	3M	6M	1Y
% change in IV, lag	0.106***	0.174***	0.146**	0.124
	(0.04)	(0.05)	(0.06)	(0.08)
% change in FX rate, lag	0.21	0.19	0.17	0.14
	(0.17)	(0.17)	(0.16)	(0.15)
CRB index, % change	-2.065***	-1.543***	-1.208***	-0.932***
	(0.39)	(0.30)	(0.27)	(0.24)
CRB index, % change, lag	-0.314	-0.209	-0.234	-0.193
	(0.38)	(0.33)	(0.26)	(0.25)
VIX, % change	0.282***	0.199***	0.145***	0.104***
	(0.03)	(0.02)	(0.02)	(0.01)
VIX, % change, lag	0.074**	0.038*	0.038*	0.034*
	(0.03)	(0.02)	(0.02)	(0.02)
Spot intervention	3.198*	1.892*	1.441*	0.694
	(1.66)	(1.06)	(0.83)	(0.67)
Futures intervention	2.869**	2.107**	1.698*	1.372*
	(1.39)	(1.07)	(0.95)	(0.79)
Constant	1.058**	0.836**	0.702**	0.580**
	(0.53)	(0.37)	(0.30)	(0.24)
N	1,100	1,100	1,094	1,100
Hansen's J stat.	3.8 (0.57)	2.0 (0.84)	1.3 (0.93)	2.3 (0.80)
Stock-Wright S stat	22.8 (0.00)	23.3 (0.00)	21.7 (0.00)	19.1 (0.01)
C test for endogeneity	23.2 (0.00)	16.7 (0.02)	13.5 (0.06)	9.0 (0.26)
Wald statistic	0.02 (0.90)	0.01 (0.90)	0.03 (0.86)	0.32 (0.57)

Notes: The dependent variables are: the percent daily change in the one month Real/$ implied volatility (Column 1), three month Real/$ implied volatility (Column 2), six month Real/$ implied volatility (Column 3) and one year Real/$ implied volatility (Column 4). Explanatory variables are defined in Table A1. Newey-West HAC standard errors in parentheses. *, ** and *** denote statistical significance at 10%, 5% and 1% level. For test statistics p-values are reported in parentheses. Wald statistic tests the null hypothesis of the equality of the spot and futures intervention coefficients.

Table OA7: Second-Stage Regressions, VRP: Alternative maturities and measures:

	1M	3M	6M	1Y	1M	1M	3M
change in VRP, lag	0.06	0.149***	0.161***	0.131*	0.143***	-0.316***	-0.391***
	(0.05)	(0.05)	(0.06)	(0.08)	(0.05)	(0.06)	(0.07)
% change in FX rate, lag	-0.036	0.01	0.01	0.05	0.08	0.16	0.124*
	(0.09)	(0.05)	(0.05)	(0.04)	(0.09)	(0.12)	(0.07)
CRB index, % change	-0.531***	-0.351***	-0.258***	-0.240***	-0.623***	-0.687***	-0.566***
	(0.18)	(0.09)	(0.07)	(0.06)	(0.16)	(0.21)	(0.16)
CRB index, % change, lag	-0.216	-0.161*	(0.06)	(0.10)	0.06	-0.334*	-0.348***
	(0.15)	(0.09)	(0.07)	(0.07)	(0.13)	(0.17)	(0.13)
VIX, % change	0.049***	0.036***	0.023***	0.018***	0.055***	0.060***	0.033***
	(0.01)	(0.01)	(0.00)	(0.00)	(0.01)	(0.01)	(0.01)
VIX, % change, lag	0.00	0.00	0.01	0.01	0.016*	0.031***	0.019**
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Spot intervention	0.16	0.574**	0.298*	0.09	0.981**	1.424**	0.71
	(0.48)	(0.26)	(0.18)	(0.16)	(0.42)	(0.64)	(0.51)
Futures intervention	0.954*	0.581*	0.465*	0.693***	0.815**	1.180**	0.836*
	(0.53)	(0.30)	(0.25)	(0.25)	(0.39)	(0.53)	(0.43)
Constant	0.310**	0.159**	0.118*	0.120*	0.198*	0.233	0.279**
	(0.15)	(0.08)	(0.07)	(0.07)	(0.11)	(0.16)	(0.12)
N	1,100	1,100	1,094	1,100	1,100	1,100	1,100
Hansen's J stat.	5.4 (0.37)	4.1 (0.54)	5.5 (0.36)	6.9 (0.23)	3.5 (0.63)	4.1 (0.54)	2.9 (0.72)
Stock-Wright S stat	20.7 (0.00)	30.9 (0.00)	28.4 (0.00)	23.5 (0.00)	36.2 (0.00)	31.9 (0.00)	22.3 (0.00)
C test for endogeneity	17.6 (0.01)	26.1 (0.00)	18.2 (0.01)	13.1 (0.07)	27.5 (0.00)	28.2 (0.00)	14.9 (0.04)
Wald statistic	0.92 (0.34)	0.00 (0.99)	0.21 (0.64)	3.01 (0.08)	0.07 (0.80)	0.07 (0.79)	0.03 (0.87)

Notes: The dependent variables are: the percent daily change in the one month Real/$ volatility risk premium (Column 1), three month Real/$ VRP (Column 2), six month Real/$ VRP (Column 3), one year Real/$ VRP (Column 4), one month Real/$ VRP based on the forecast of realized volatility from the regression of realized volatility (RV) on its one month lag (Column 5), one month Real/$ VRP based on the forecast of RV from the regression of RV on one month lags of RV, implied volatility and foreign exchange leverage (Column 6), three month Real/$ VRP based on the forecast of RV from the regression of RV on three month lags of RV, implied volatility and foreign exchange leverage (Column 7). Results from these regressions are reported in Table OA10. Explanatory variables are defined in Table A1. Newey-West HAC standard errors in parentheses. *, ** and *** denote statistical significance at 10%, 5% and 1% level. For test statistics p-values are reported in parentheses. Wald statistic tests the null hypothesis of the equality of the spot and futures intervention coefficients.

Table OA8: FX Interventions and domestic interest rates:

	1	2	3
Spot Intervention	0.005	0.006	0.008
	(0.01)	(0.01)	(0.01)
Futures Intervention	-0.003	-0.003	0
	(0.00)	(0.00)	(0.00)
Constant	-0.006	-0.005	0.004
	(0.00)	(0.01)	(0.01)
Day fixed effects	N	Y	Y
Year fixed effects	N	N	Y
N	1,100	1,100	1,100
R^2	0.00	0.01	0.02

Notes: The dependent variable in all regressions is the daily change in the Selic (Special Clearance and Escrow System) rate (the overnight interest rate targeted by monetary policy). Newey-West HAC standard errors in parentheses. *, ** and *** denote statistical significance at 10%, 5% and 1% level.

Table OA9: FX Interventions and monetary base:

	1	2	3
Spot Intervention	0.005*	0.004	0.005
	(0.00)	(0.00)	(0.00)
Constant	0.00	0.005***	0.005**
	(0.00)	(0.00)	(0.00)
Day fixed effects	N	Y	Y
Year fixed effects	N	N	Y
N	1,100	1,100	1,100
R^2	0	0.21	0.21

Notes: The dependent variable in all regressions is the daily change in the monetary base (daily data from Haver Analytics). Newey-West HAC standard errors in parentheses. *, ** and *** denote statistical significance at 10%, 5% and 1% level.

Table OA10: Realized volatility forecasting regressions:

	1M	1M	3M	3M
Realized vol, 1M lag	0.540***	0.231***		
	(0.07)	(0.08)		
Implied vol, 1M lag		0.476***		
		(0.15)		
FX leverage, 1M lag		1.625*		
		(0.87)		
Realized vol, 3M lag			0.318***	0.046
			(0.07)	(0.14)
Implied vol, 3M lag				0.362
				(0.28)
FX leverage, 3M lag				1.683*
				(0.91)
Constant	6.477***	3.125**	10.115***	7.909***
	(0.96)	(1.58)	(1.34)	(2.92)
N	3,012	2,118	2,970	2,076
R^2	0.29	0.37	0.11	0.12

Notes: The dependent variables are: the Real/$ realized volatility calculated as the square root of the sum of the current and past 20 daily squared log Real/$ returns (Column 1 and 2) and the Real/$ realized volatility calculated as the square root of the sum of the current and past 62 daily squared log Real/$ exchange returns (Column 3 and 4). Explanatory variables enter with lag of 21 (Column 1 and 2) and 63 days (Column 3 and 4). Foreign exchange leverage variable is defined as in Bekaert and Hoerova (2014): it takes positive value for the days when Real/$ exchange rate depreciates and zero otherwise. Newey-West HAC standard errors in parentheses. *, ** and *** denote statistical significance at 10%, 5% and 1% level.