Foreign Exchange Intervention Effectiveness: A Regression Discontinuity Design

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Abstract

This paper examines the effectiveness of the Sterilized Foreign Exchange Intervention in pushing changes in the exchange rate in the expected direction and curbing its volatility. Furthermore, we quantify the extent to which the effects of the intervention announcement differ from the actual intervention. To this end, we employ fuzzy and sharp Regression Discontinuity Designs that take advantage of exogenous variation from a rule-based intervention mechanism from the Central Bank of Colombia (CBoC). Specifically, we compare episodes in which the intervention rule was just missed with episodes in which it was barely triggered, leading to the purchase and sale of dollars. On the one hand, our findings suggest that, on average, 60 million dollar purchases depreciate the exchange rate by 1% and reduce its volatility by 1.2pp, and these effects last up to 20 days. By comparison, the announcement of purchases has lower effects, which disappear faster. On the other hand, CBoC dollar sales evidence a less consistent impact, indicating that only the intervention announcement is effective. Besides, the appreciation of the peso and the exchange rate volatility reduction appear several days after the intervention announcement.

JEL Classification: E58, F31, C22

Keywords: Foreign exchange intervention effectiveness; Regression Discontinuity Design; Fuzzy RDD; Sharp RDD; Exchange rate

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1 Introduction

Although ample literature has examined the effectiveness of Sterilized Foreign Exchange Intervention (SFXI)[1] in affecting the exchange rate or its volatility, there is still no consensus in terms of significance and duration of policy effects, at most times suggesting the lack of any relation (e.g., Sarno and Taylor 2001; Hillebrand and Schnabl 2003; Galati et al. 2005; Adler et al. 2014). Empirical surveys such as Menkhoff (2013), Villamizar-Villegas and Perez-Reyna (2017), and Arango-Lozano et al. (2020) show that almost half of the studies find non-significant effects. Conversely, other authors such as Dominguez and Frankel (1993), Fatum and Hutchison (2006), and Fatum and Hutchison (2010) find evidence that SFXI tends to be effective when intervention operations are large and infrequent.

Similarly, literature centered on emerging economies (EMEs) has also found mixed results. While Moura et al. (2013), Villamizar-Villegas (2016), and Marins et al. (2017) find no impacts on the exchange rate level, other authors have found significant effects (see Domaç and Mendoza 2004; Guimarães and Karacadag 2004; Echavarría et al. 2010; Echavarría et al. 2014; Chamon et al. 2017). At the same time, to the best of our knowledge, there is scant evidence related to the extent to which the effects of the intervention announcement differ from the actual intervention. Despite there is no conclusive evidence about several aspects of the intervention's effectiveness, SFXI remains a widely accepted policy tool by many central banks since it is generally believed that it is an effective instrument (Neely, 2008).

The absence of consensus is not surprising given the mixed goals and country heterogeneity, but also because assessing the SFXI effectiveness is empirically challenging. This is because of an inherent endogeneity problem well recognized in the literature (see, Kearns and Rigobon 2005; Kamil 2008; Chamon et al. 2019a). In particular, endogeneity arises because of four reasons mainly.

In the first place, SFXI does not occur at random; instead, the CBoC intervenes in the FX market to pursue specific macroeconomic goals and deal with exchange rate turmoil episodes, which yields a self-selection bias. Second, an omitted variable bias arises since all relevant information monetary authorities have when setting policy decisions is unknown.

[1] FXI can be sterilized or unsterilized, depending on whether or not the central bank offsets the monetary effects through open market operations. As Chamon et al. (2019a) point out, it is widely accepted that unsterilized interventions, which affect domestic liquidity conditions and the interest rate differential with foreign markets, have significant and durably effects on the exchange rate. Nevertheless, the effectiveness of sterilized interventions, which are intended to influence the exchange rate but without changing the monetary base or interest rates, is much less clear.

Third, there often exists a measurement error since data on intervention is scarce and numerous studies approximate intervention with changes in international reserves, incurring additional confounding factors. Finally, a simultaneity bias appears given that SFXI responds to macroeconomic conditions, and concurrently, the economy responds to central bank actions. More accurately, discerning the direction of causality between intervention and exchange rate is a demanding task as intervention may affect the exchange rate but the decision to intervene also depends on the behavior of the exchange rate.

Based on these concerns, this paper seeks to answer the following questions using an approach that appropriately copes with endogeneity issues previously described: Is the SFXI effective in pushing changes in the exchange rate in the desired direction and diminishing its volatility? Moreover, to what extent do the effects of the intervention announcement differ from the operative effects of the intervention?

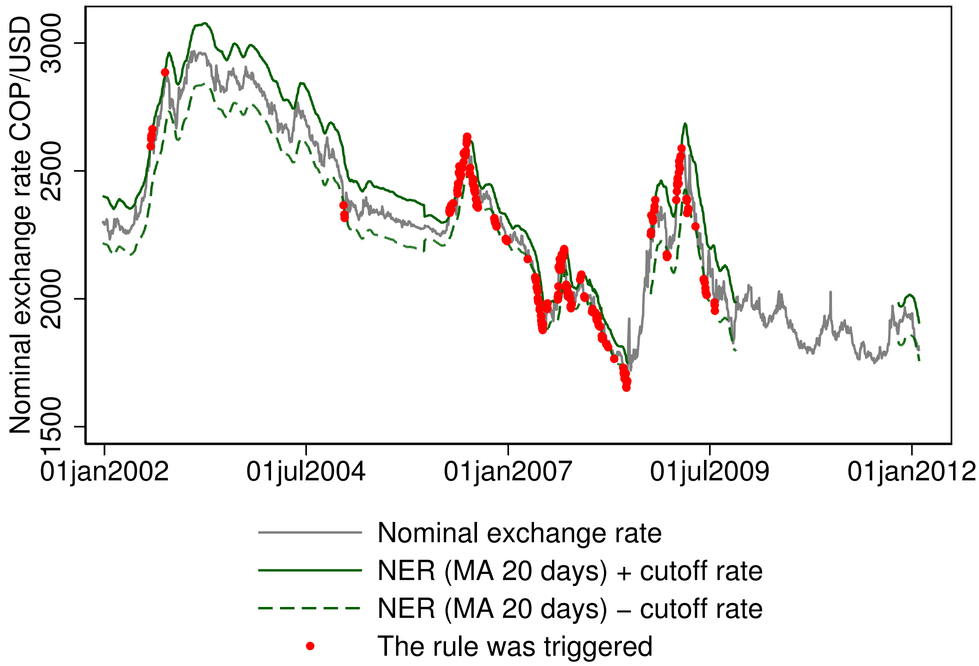
To answer previous questions and shed light on this long-lasting debate, we take advantage of a rule-based intervention mechanism from the Central Bank of Colombia (CBoC) that generates sales and purchases of currency to vary abruptly by exact triggering threshold. This discontinuity creates a localized quasi-experiment, which allows us to identify the effect of intervention by comparing days where the cut-off for triggering the rule was slightly met or missed. Formally, we apply a Regression Discontinuity Design (RDD) to pinpoint the surprise factor of rule-based interventions and use this exogenous variation to measure how they affect the exchange rate.

The rule-based intervention mechanism operated as follows; the CBoC publicly committed itself to offer put (call) options through auctions whenever the nominal exchange rate was below (above) its 20-day moving average minus (plus) 4 percent. The CBoC was committed only if the maturity of the last options had expired[2] or if no options were remaining. Also, the condition to exercise the options was the same as for the activation of the auction. This mechanism is partly explained by Figure 1, which depicts the nominal exchange rate and its 20-working day moving average plus/minus the specific threshold set by the CBoC. The rule-based intervention mechanism was triggered each time the exchange rate surpassed the band (represented by red dots).

We argue that treatment assignment (i.e., SFXI, either by issuance or exercise of options) within the immediate vicinity of the triggering thresholds is *as good as randomly assigned*.

[2] That is, one month has passed since the last emission.

Figure 1: Rule triggered to sell USD vs. Rule triggered to purchase USD



More precisely, under formal assumptions that guarantee comparability of treated and non-treated observations, the discontinuous change in the probability of treatment exposure can be used to infer the causal effects of treatment on outcomes of interest for observations neighboring the cutoff. This is because observations that were just about exceeding the band can be used as a comparison group for units that barely exceed the band.

In contrast with our approach, most of the existing literature that evaluate the FXI effectiveness is based on a selection-on-observables approach (see Chamon et al. 2019a,b), where a policy intervention rule is estimated (e.g., Kamil 2008; Rincón and Toro 2010; Echavarría et al. 2010, 2013; Villamizar-Villegas 2016). The main inconvenience with estimating a policy reaction function is that all relevant information monetary authorities have when setting policy decisions is unknown, entailing a potential problem of omitted variable bias.

The rule-based interventions have the advantage that the rule by which interventions are triggered is known to the public. Then, in our RDD, the exogeneity follows from traders' uncertainty on when the rule would be triggered, not on what the rule is. This strategy pays dividends over the related literature since we sidestep the need to estimate FX policy reaction functions. Thus, the concerns that arise in model-based approaches to identification, where FX policy rules need to be empirically estimated, do not emerge in our setting.

The contribution of this paper is twofold. First, the Colombian context, and more specifically the rule-based intervention mechanism carried out by the CBoC allow us to naturally distinguish between the operative effects of the intervention and its announcement. For that purpose, we explore the impact of the exercise (under a fuzzy RDD) and issuance (under a sharp RDD) of FX options, respectively. To the best of our knowledge, this is the first paper contrasting both types of effects using an RDD.

In particular, at the close of any business day, market participants gain information on whether the exchange rate would trigger the rule. If the rule is triggered, options are issued the next day.[3] Nonetheless, this does not necessarily imply the purchase or sale of dollars by the CBoC; rather, options issuance represents the amount of options to be adjudicated at the FX market. Then, the effects of options issuance can be interpreted as the effects of the intervention announcement. In contrast, we refer to the exercise of options as the operative effect of intervention since exercising options necessarily implies purchasing or selling dollars by the CBoC. Overall, this paper contributes by distinguishing the effects of the intervention announcement and the effects of the actual intervention.

Second, we quantify not only the effects on the exchange rate level but also the impact on its volatility. This last outcome is relevant since the rule-based intervention mechanism from the CBoC aimed to mitigate extreme short-term exchange rate movements. Furthermore, according to the meta-analysis conducted in 19 countries across five decades, Arango-Lozano et al. (2020) document that, in at least 70% of studies, central banks explicitly state the objective of influencing exchange rate volatility. Despite the impact of SFXI on this outcome has been widely examined in the literature (e.g., Echavarría et al. 2010; Berganza and Broto 2012; Kitamura 2017; Onder and Villamizar-Villegas 2018), to the best of our knowledge, this is the first time that the causal effects of SFXI on exchange rate volatility are explicitly explored using an RDD approach.

Furthermore, one feature that makes our study very novel and striking is the fact that we provide quasi-experimental evidence based on both fuzzy and sharp RDDs under the same setting. We employ a fuzzy RDD to quantify the effects of exercising options (i.e., operative effects of intervention) and a sharp RDD for measuring the effects of issuing options (i.e., announcement effects). As Villamizar-Villegas et al. (2021) points out in their comprehensive

[3] As long as there are no outstanding options or one month has passed since the most recent auction.

empirical survey about RDDs, studies that include simultaneously fuzzy and sharp RDDs under the same setting are very rare, and even more in the field of macroeconomics. While well developed in microeconomics, quasi-experimental methods have seen minimal application to macroeconomic questions.

In particular, the rule the CBoC employs to intervene in the FX market does not perfectly determine when market agents exercise options; then, we face a fuzzy discontinuity for measuring the effects of exercising options. Conversely, the conditions for issuing options allow constructing an assignment variable that deterministically determines when new options were issued by the CBoC, which yields a sharp discontinuity. Overall, this paper contributes by providing empirical evidence that contrasts the effects of the intervention announcement and the actual intervention.

Our findings provide evidence of the effectiveness of dollar purchases in depreciating the exchange rate and curbing its volatility.[4] Results indicate a 1% depreciation and a 1 pp volatility reduction in the spot rate in response to, on average, nearly 60 million US dollars purchased via put options. Similarly, we observe a 0.8% depreciation and a 0.8 pp volatility reduction in response to, on average, the announcement of 115 million US of put options.

In addition, we find that the effects of dollar purchases persist for up to 20 days, reaching a depreciation of nearly 4% and a 3.5 pp volatility reduction around the third week after the intervention. By comparison, the effect of the announcement of dollar purchases disappears after eight days the auction takes place, reaching a maximum depreciation of slightly 2%. Additionally, the effects of the announcement of purchases on volatility last around three weeks, with a maximum volatility reduction of 2.3 pp.

Regarding the dollar sales effectiveness, we document a less consistent effect compared to dollar purchases. In particular, the immediate response to the dollar sales announcement is a 0.3% depreciation, which is the opposite of expected. We attribute this initial effect to the CBoC's tendency to offset rule-based dollar sales with simultaneous purchases through discretionary mechanisms. However, we document that this effect rapidly reverses to the expected direction, and dollar sales generate a statistically significant appreciation between the second and third week after the announcement. This latter behavior is also observed in the exchange rate volatility. Namely, a volatility reduction occurs within the second and third

[4]The exchange rate is expressed as units of Colombian pesos per unit of United States dollars (COP/USD). Depreciation means the COP loses value, that is, COP/USD increases.

weeks after the intervention announcement. In contrast with the dollar sales announcement effects, we find that actual dollar sales are ineffective in appreciating the exchange rate level or reducing its implied volatility.

We document that our findings on the exchange rate level are quite similar to existing evidence in EMEs. For instance, in Colombia, Kamil (2008) estimates that a 100 million USD purchase depreciates the exchange rate by 0.76. On the other hand, Kuersteiner et al. (2018), find that the exercise of put options of about 100 million USD depreciates the exchange rate by as much as 2 percent. Like us, the authors do not find immediate effects from dollar sales. Regarding the effects on the exchange rate volatility, we observe that our findings are larger compared to what existing literature has encountered in EMEs. However, most of this literature has evaluated the effectiveness of dirty interventions. For example, in Colombia, Kamil (2008) finds that 100 million USD purchases lessen the exchange rate variance by 0.02 percent, while Villamizar-Villegas (2016) finds a volatility reduction by up to 0.5 percent after a 100 million USD intervention.

In terms of duration, Echavarría et al. (2010) find that FX purchases devaluated the exchange rate and reduced its volatility, not only in the short-term (1 day) but also in the medium-term (1 month, 3 months, and 6 months). Tobal and Yslas (2016) estimate the effect of interventions on the exchange rate level to last about two months in Mexico and one month in Brazil. Echavarría et al. (2014) find volatility options to be effective for up to 25 days in Colombia.

This paper is organized as follows: Section 2 details the empirical literature on SFXI effectiveness. Section 3 briefly describes the FXI policy carried out by the CBoC in terms of the exchange rate regime, objectives, and types of intervention. Section 4, describes the data sources and presents summary statistics. In Section 5, the identification strategy is detailed. Then, we present the main results in Section 6. In Section 7, the RDD assumptions are validated. Finally, Section 8 concludes.

2 Related work

It is well known that non-sterilized interventions influence the FX market through the transmission of monetary policy (Sarno and Taylor, 2001). However, concerning the sterilized FXI, the literature has not reached a definite conclusion on its effectiveness in affecting the exchange rate or its volatility. However, valuable progress has been made in synthesizing lessons learned. Surveys include Dornbusch (1980); Dominguez and Frankel (1993); Fatum and Hutchison (2003); Neely (2005); Menkhoff (2013); Villamizar-Villegas and Perez-Reyna (2017), and Arango-Lozano et al. (2020).

As for the Colombian case, findings from the empirical literature are mixed. Echavarría et al. (2010) find that FX purchases devaluated the exchange rate, not only in the short-term (1 day) but also in the medium-term (1 month, 3 months, and 6 months). Echavarría et al. (2018) document a significant price impact of preannounced interventions. Kuersteiner et al. (2018) confirm the effectiveness of SFXI, albeit effects are short-lived (2-3 weeks). In contrast, other studies fail to find an effect (e.g., Rincón and Toro 2010; Villamizar-Villegas 2016).

Regarding the impact on exchange rate volatility, findings are also diverse. For instance, Kamil (2008) shows that intervention lessened volatility when dollar purchases were made in periods of monetary easing, while interventions were ineffective during periods of monetary tightening. Similarly, Villamizar-Villegas (2016) and Echavarría et al. (2010) find that FX interventions reduced the exchange rate volatility. Conversely, Rincón and Toro (2010) find that FXI increases volatility no matter whether the use of capital controls accompanied the FXI policy. In this line, Murcia and Rojas (2014) report that intervention do not affect the exchange rate volatility after some minutes have passed. For additional details, in the Appendix the Table A.1 summarizes the results of several studies on the topic for Colombia.

Although the literature on FXI effectiveness is substantial, to the best of our knowledge, there is scant evidence on how much the effects of the intervention announcement differ from the actual intervention. Central banks usually presume that they can impact the exchange rate via their influence on expectations and through any direct effect on the composition of portfolio balances (i.e., signaling and portfolio channels, respectively). Still, few studies have elucidated their separate effects. With respect to this point, we intend to fill a gap in the literature. Specifically, we add to the literature by distinguishing to what extent these two types of effects differ.

Among the papers that have attempted this endeavor are Adler and Tovar (2014); Echavarría et al. (2014); Janot and Macedo (2016); Echavarría et al. (2018); and Luna Santos (2021), all of which compare discretionary with preannounced interventions. Nonetheless, a potential concern is that these two types of intervention differ in ways that can also affect the exchange rate, so treatment can ultimately reflect operational differences conveyed to the market. Additionally, this literature often employs different methodologies for each type of intervention, making the comparison of the effects much less straightforward.

Furthermore, the methodology presented in most of these articles is based on a selection-on-observables approach, where a policy intervention rule is estimated. The main inconvenience with estimating a policy reaction function appears since all relevant information that monetary authorities have when setting policy decisions is unknown, entailing a potential problem of omitted variable bias.

In contrast with existing literature, our paper exploits a rule-based intervention mechanism enacted by the CBoC during 2002-2012 that triggered either FX options or the ability to exercise these options under observable and deterministic conditions. This setting allows us to naturally distinguish between the announcement's effects and the intervention's operative effects. Notably, we take the issuance of options as central bank announcements since the rule and information that triggered the issuance of options was public. In contrast, we take the exercise of options as the actual intervention since the exercise of options necessarily implies the purchases and sales of foreign currency.

The rule-based interventions have the advantage that the rule by which interventions are triggered is known to the public. Then, in our RDD the exogeneity follows from traders' uncertainty on when the rule would be triggered, not on what the rule is. This strategy pays dividends over the related literature since we sidestep the need to estimate FX policy reaction functions. Thus, the issues that arise in model-based approaches to identification (e.g., Kamil 2008; Rincón and Toro 2010; Echavarría et al. 2010; Villamizar-Villegas 2016, among others), where explicit or implicit policy rules need to be empirically estimated do not emerge in our setting.

This article also relates to the small literature that applies quasi-experimental methods to macroeconomic questions. As Villamizar-Villegas et al. (2021) showed, while well developed in microeconomics, quasi-experimental methods like the RDD have seen minimal application in the field of macroeconomics. This may be somewhat explained by the inherent difficulty of finding institutional settings at the level of national economies where these methods can be applied.

3 Institutional setting: FXI policy of the CBoC

In this section, we briefly describe the FXI policy undertaken by the CBoC in three dimensions: the exchange rate regime, objectives and the mechanisms of FXI. Besides, we explain how the rule-based intervention mechanism carried out by the CBoC operates, which is the core of the identification strategy.

3.1 Exchange rate regime

According Cardozo (2019), the CBoCs' policy seeks to maintain low and stable inflation and output levels close to their target and potential value. Besides, the policy contributes to preserving the stability of the financial and payment systems. In doing so, the CBoC has adopted a flexible exchange rate regime since 1999. Exchange rate flexibility is fundamental for achieving those goals for three reasons mainly. First, adopting a flexible exchange rate regime let the exchange rate work as an adjustment variable against economic shocks, hence lessening the volatility of economic activity. Second, exchange rate flexibility allows for the autonomous use of the interest rate as an instrument to bring inflation and output closer to the target. Third, exchange rate flexibility diminishes agents' incentives for excessive exchange rate risk-taking, which is essential to maintain financial stability.

Nevertheless, the FXI carried out by the CBoC does not restrict the exchange rate flexibility, nor does it intend to achieve a specific level of the exchange rate. Instead, the FXI pursues aims compatible with the IT regime. To guarantee the compatibility of FXI and IT scheme, purchases and sales of dollars are sterilized, that is, the monetary expansion or contraction created by FX sales or purchases is offset to keep overnight interest rate (IBR/TIB in Spanish) aligned with the monetary policy interest rate and the output around its potential level. Then, sterilization is critical for central banks under an IT regime, allowing buying and selling reserves without compromising the inflation target.

3.2 Objectives

According, Uribe and Toro (2005), Vargas et al. (2013), Cardozo (2019), the CBoC has implemented a flexible exchange rate scheme that is governed by intervention rules with three purposes. First, FXI pursues to strengthen the international liquidity position of the economy by accumulating foreign reserves without jeopardizing the achievement of the inflation target or causing the exchange rate to deviate from its fundamental values. The CBoC seeks to maintain an adequate level of international reserves that lessen the economy's vulnerability to external shocks and improve access to foreign credit.

Besides that, FXI has been applied to limit the exchange rate's excessive volatility from its short-term trend. In this way, the CBoC avoids creating expectations of appreciation or depreciation, resulting in a significant deviation of the exchange rate from its fundamentals. Finally, FXI carried by the CBoC seek to diminish excessive fluctuations of the nominal exchange rate that could compromise the achievement of the inflation target, financial stability, and adequate functioning of the of the internal and external payments system.

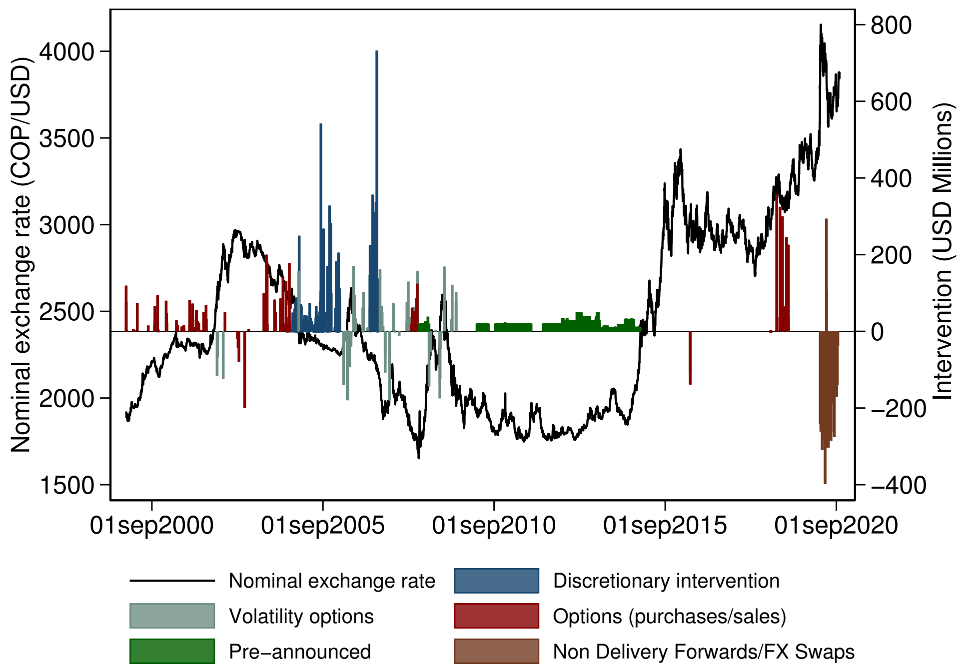
3.3 Mechanisms

In November 1999, right after the CBoC decided to shift to a flexible exchange rate regime, it introduced a rule-based intervention mechanism to jeopardise exchange rate volatility and provide coverage mechanisms to agents against extreme exchange rate movements. At that moment, the CBoC considered the market unprepared to offer hedges under extreme circumstances. This intervention mechanism, which is the core of the identification strategy, is detailed in the following subsection.

Two other mechanisms of FXI were established soon afterwards, which, as opposed to the rule-based mechanism, granted the board of directors complete discretion over when and how to intervene. Specifically, they consisted of options contracts aimed at accumulating/reducing international reserves (put in place in 1999), and direct interventions in the spot market intended to avoid excessive movements in output and the exchange rate (put in place in 2004). Furthermore, during the COVID-19 lockdown, the CBoC introduced new mechanisms to reinforce the liquidity on the payments system through non-delivery forwards and FX swaps auctions.

A graphic representation of the evolution of intervention mechanisms carried out by CBoC, and the nominal exchange rate behavior during 2000-2020 is presented in Figure 2, where the negative values represent sales, while positive represent purchases. At first sight, Figure 2 does not appear to depict whether dollar purchases and sales are followed by appreciation or depreciation episodes. Besides, the inconsistent use of a particular mechanism across the last two decades shows somehow that the CBoC does not have a definitive answer regarding the effectiveness of SFXI.

Figure 2: Nominal exchange rate and mechanisms of Intervention



3.4 Rule-based intervention mechanism

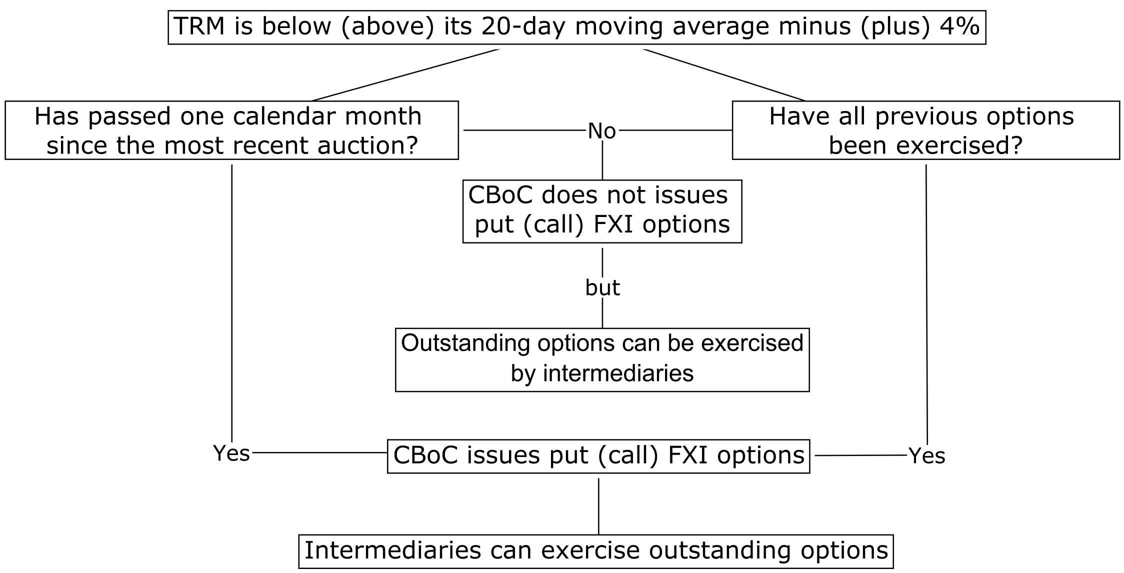
In 1999, the CBoC introduced the volatility options to mitigate extreme short-term exchange rate movements. The CBoC was committed to offering put (call) options to intermediaries whenever the daily nominal exchange rate (TRM for its acronym in Spanish) was lower (higher) than its 20-working day moving average minus (plus) 4 percent[5] and if the maturity of the last issued options had expired or no outstanding options were remaining. In particular, the options expire one month after the day of the auction.

During the one month after the CBoC issues new options, exchange rate fluctuations beyond the band would not trigger a new auction. Instead, they would allow market intermediaries to exercise the outstanding options. The CBoC could conduct a new auction if all options had been exercised. Considering that the objective was to mitigate an extreme fluctuation, the amount auctioned was large compared to the market. Specifically, the CBoC offered amount was typically set at 180 million USD.

[5]The rule was modified to have a cutoff of 2% from December 19, 2005, to June 24, 2008, and 5% from October 7, 2008, to October 27, 2009. Interventions were temporarily stopped from June 26, 2008, to October 6, 2008, and October 28, 2009, to October 30, 2011. The mechanism was permanently stopped on February 6, 2012.

Figure 3 details how this intervention instrument operates. Whenever the rule is triggered if one calendar month has passed since the most recent auction (i.e., previous options had expired) or if all options from the most recent auction have been exercised, the CBoC issues put or call FXI options. On that day, market intermediaries can exercise the options. On the contrary, if the rule is triggered but outstanding options exist from the previous auction, then, the CBoC does not issue new put or call options. Nonetheless, intermediaries can exercise outstanding options given that the rule is triggered.

Figure 3: The rule-based intervention mechanism



4 Data

To determine the causal effects of SFXI through the rule-based mechanism on the exchange rate, this paper relies on records from two sources, SET-ICAP FX S.A. and the CBoC. First, SET-ICAP FX S.A. is the authority in charge of managing the entire universe of FX operations in the Colombian stock market. Data from this source include all minute-by-minute FX operations between 2001 and 2012. Second, the CBoC, through the Market Operations and Development Department, offers data about the daily TRM, the timing and amount issued of every auction held by the CBoC, and the amount exercised each time the rule was triggered.

Table 1: Summary Statistics

Variable	Mean	Sum	St. Dev.	Min	Max	Obs.
Exchange rate	2,257	-	348.0	1,652.4	2,968.9	2,433
Put options issued	179.1	3,760.4	4.1	161	180	21
Call options issued	180	3,059.3	0.1	179.8	180	17
Put options exercised	57.9	2,373.1	51.9	0.5	170	41
Call options exercised	68.5	2,330.3	59.7	1.0	179.9	34

Note: author's calculations using daily data from December 24, 2001, to February 3, 2012. Last four rows present calculations for non-zero observations.

From these sources, we document that the rule was triggered 231 times between December 2001 and February 2012. In particular, the rule was triggered 91 times for call options, while it was triggered on 140 occasions for put options. Table 1 shows there were 38 auctions during this period: 17 auctions for call options and 21 auctions for put options. Moreover, options were exercised on 75 occasions: call options were exercised 34 times, while put options were exercised 41 times.

While the rule-based intervention mechanism was active, purchases via put options totaled 2,373 million dollars, and sales through call options totaled USD 2,330 million. Furthermore, the CBoC issued 3,059 million dollars through call options and 3,760 million dollars via put options. Average sales reached 68.5 million dollars, while average purchases equaled 57.9 million dollars. We also observe that the average daily exchange rate during this period was 2,257 COP/USD. Finally, in the Appendix, we include tests describing the time series' statistical properties.

5 Identification Strategy

RDDs were introduced by Thistlethwaite and Campbell (1960) as a way of estimating treatment effects in a non-experimental setting where treatment is determined by whether an observed assignment variable exceeds a known cutoff point. Intuitively, observations just above the threshold are very similar to the units just below the cutoff. As Lee (2008) pointed out, in an RDD setting where the score can be influenced by the subjects' decisions and unobservable characteristics, the treatment status can be interpreted to be *as good as randomly assigned* in the immediate vicinity of the threshold, as long as individuals lack the ability to precisely define the value of the score they hold, that is, as long as their score contains a random component. In other words, exogeneity arises just around the cutoff, where random chance similar to a flip-coin experiment determines whether the score exceeds the threshold or not.

The CBoC rule-based intervention mechanism is the core of the identification strategy. Figure 1 exhibits the nominal exchange rate and its 20-working day moving average plus/minus the specific threshold set by the CBoC. As explained before, the intervention was triggered whenever the exchange rate surpassed this band. This situation allowed the CBoC to auction new options (as long as there are no outstanding options) and entitle the redemption of existing options. In Figure 1, the red dots represent each time the rule was triggered, and periods with no band around the nominal exchange rate correspond to periods when the intervention mechanism was temporarily suspended. Mathematically, this condition can be expressed as follows,

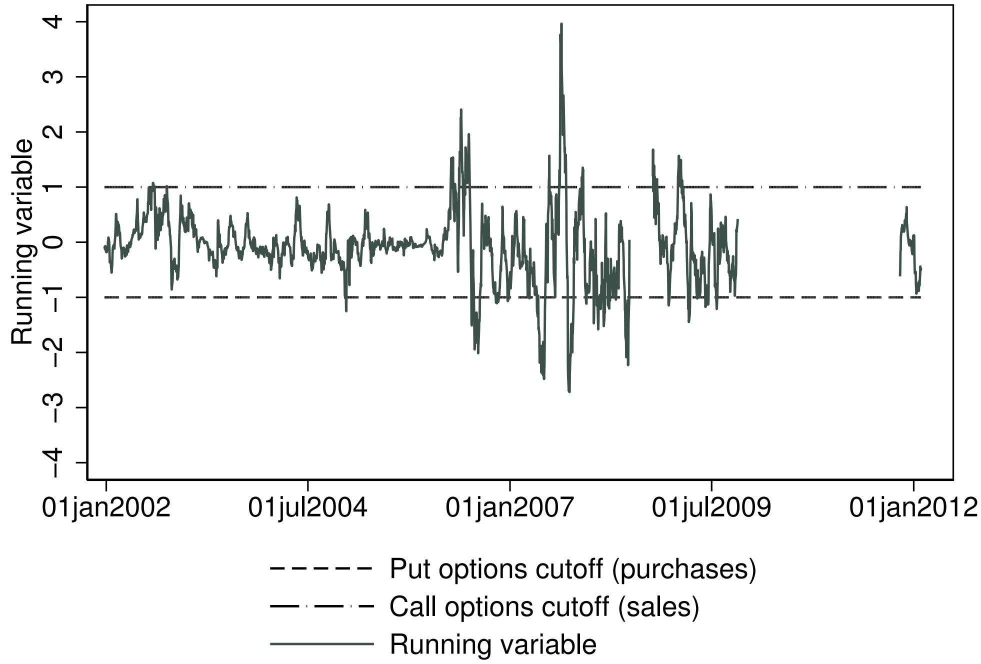
$$X_{i,t} = \frac{1}{r_t}\frac{e_t - \bar{e}_t}{\bar{e}_t} \qquad i = S, P \tag{1}$$

where i denotes either sales (S) or purchases (P). e_t denotes the nominal exchange rate, $\bar{e}_t$ is its 20-day moving average, and r_t is the cutoff generally set at 4%. Under this definition, the rule was triggered whenever its absolute value exceeded unity. The graphical representation of the policy rule represented by Equation 1 is depicted in Figure 4. Namely, whenever the running variable exceeds 1, the rule is triggered to sell dollars (call options). Conversely, each time the exceeds the -1, the rule triggered to purchases dollars (put options). This condition for triggering intervention is the start line for identifying the effects of issuing and exercising options on the exchange rate level and volatility.

Intuitively, this paper compares episodes in which the intervention rule was just missed with episodes in which it was barely triggered, leading to purchases or sales of dollars by CBoC. The day before trading opens, uncertainty among market agents about whether the rule is triggered or missed leads to random deviations of central bank actions from market expectations. We exploit this variation to identify the effects of SFXI on exchange rates. Consequently, exchange rate variation within the immediate vicinity of the triggering threshold is *as good as randomly assigned* and forms the base for identifying the SFXI causal effects either through the issuance or exercise options.

Comparing outcomes locally around the triggering threshold supports the assumption

Figure 4: The running variable and the cutoffs



that observable and unobservable cofounders do not vary with the policy rule. The latter implies that tiny movements in the exchange rate when the running variable is slightly around the triggering threshold are not linked with macroeconomic fundamentals driving the exchange rate and cannot be influenced by intermediaries trying to benefit from the CBoC positions. This occurs because, despite market agents know the policy rule, they are not able to predict with certainty whether the rule will be triggered or not until the end of the trading day.

RDD have some advantages compared to conventional methodologies applied in the field based on selection-on-observables approach (e.g., Toro and Julio 2005; Kamil 2008; Echavarría et al. 2010; Villamizar-Villegas 2016; Echavarría et al. 2018). In the first place, in our setting, the rule that triggers interventions is known to the public. Then, the exogeneity follows from traders' uncertainty on when the rule would be triggered, not on what the rule is. This strategy pays dividends over the related literature since we sidestep the need to estimate FX policy reaction functions. Hence, the concerns that arise in model-based approaches to identification, where FX policy rules need to be empirically estimated, do not emerge in our setting.

Second, Lee and Lemieux (2010) point out that one reason for the popularity of this method is the belief that RDDs are not just another evaluation strategy and that causal inference from RDDs are potentially more credible and transparent than those from other strategies, such as instrumental variables, which has been heavily employed in the literature assessing the SFXI effectiveness (see Chamon et al. 2019a). This notion has a theoretical justification supported by Lee (2008). The author formally shows that one need not assume the RDD isolates treatment variation that is *as good as randomized*; instead, such randomized variation is a consequence of agents' inability to precisely manipulate the forcing variable just around the known threshold.

The following subsections detail why the Colombian context allows distinguishing the operative effects of intervention from the effects of intervention announcement. We also explain how we simultaneously deal with fuzzy and sharp discontinuities to measure the impact of exercising and issuing options, respectively.

5.1 Sharp RDD: effects of issuing options

In this subsection, we explain why the issuance of options can be interpreted as the vocal effect of the intervention and why we face a sharp RDD for measuring the effects of issuing options. First, market participants gain information on whether the exchange rate would trigger the rule at the close of any business day. If the rule is triggered and no outstanding options remain, then options are emitted by the CBoC the following day. Consequently, the issuance of options can be interpreted as the announcement of the amount of options to be offered and permits finding the effect of the intervention announcement (we will use the terms "issuing effects" and "announcement effects" interchangeably, hereafter).

Second, as discussed above, there were two necessary conditions for the CBoC to issue FX options. In the first place, the rule needs to be triggered, that is, each time Equation 1 passed 1 or -1. In the second place, there must be no outstanding options from the last auction; this condition holds if one month has passed since the most recent auction. Both conditions can be implemented under a unique definition of running variable that deterministically determines whether the CBoC issued options or not, as follows

$$\tilde{X}_{i,t} = \frac{1}{r_t}\frac{e_t - \bar{e}_t}{\bar{e}_t}(1 - I_{i,t}) \qquad i = S, P \tag{2}$$

where the first two terms of Equation 2 are as in Equation 1, and $I_{i,t}$ are dichotomic variables that take the value of one whenever put (P) or call (S) options from the most recent auction remain outstanding at date t. These two definitions of running variables perfectly describe when the CBoC issued new either put or call options. In other words, the probability of receiving the treatment (i.e., options issuance) jumps from 0 to 1 once the running variable described by Equation 2 crosses either -1 for call options or 1 for put options. Hence, the two conditions for issuing new options fit into a sharp RDD.

Given the sharp nature of the discontinuity in the probability of issuing options, for estimating the effect of issuing new options on the exchange rate level and its volatility, we implement the following specification

$$y_{t+j} = \gamma_0 + \gamma_1 \boldsymbol{I}(\tilde{X}_{S,t} \geq 1) + \gamma_2 f(\tilde{X}_{S,t} - 1) + \gamma_3 f(\tilde{X}_{S,t} - 1) \times \boldsymbol{I}(\tilde{X}_{S,t} \geq 1) + \epsilon_{S,t} \tag{3}$$

where y_{t+j} are the outcomes of interest j periods ahead. $\boldsymbol{I}(\tilde{X}_{S,t} \geq 1)$ is a dummy equal to one if the running variable described by Equation 2 is above the threshold for each day t. Besides, $f(\tilde{X}_{S,t} - 1)$ is a polynomial re-scaled to be zero at the threshold. Also, we allow the function to vary across the threshold by including the linear-interaction term $f(\tilde{X}_{S,t} - 1) \times \boldsymbol{I}(\tilde{X}_{S,t} \geq 1)$. Note this is the specification for measuring the effects of issuing call options. For put options is very similar but redefining equations based on the normalized cutoff for put options (-1).

Under the sharp discontinuity setting $\hat{\gamma}_1$ is the estimate of the issuance of options on outcomes. Focusing on average treatment effects, the fundamental identifying assumption is that the regression functions $E[y_{t+j}(0)|\tilde{X}_{S,t} = x]$ and $E[y_{t+j}(1)|\tilde{X}_{S,t} = x]$ are continuous in x at the threshold. This assumption captures the idea that observations slightly below and above the cutoff would show the same average response if their treatment status did not change. Thus, any difference between the average response of treated and control units at the threshold can be interpreted as a causal effect of issuing options for units with score variable $\tilde{X}_{S,t} = 1$, that is, at the threshold. Formally, the sharp RDD treatment effect is

$$\gamma_1 = \lim_{x \downarrow 1} E[y_{t+j}|\tilde{X}_{S,t} = x] - \lim_{x \uparrow 1} E[y_{t+j}|\tilde{X}_{S,t} = x] = E[y_{t+j}(1) - y_{t+j}(0)|\tilde{X}_S = 1] \tag{4}$$

5.2 Fuzzy RDD: effects of exercising options

In this subsection, we explain why the exercise of options can be interpreted as the operative effect of the intervention and why we face a fuzzy RDD for measuring the effects of exercising options. Once issued, intermediaries may exercise the options during the following calendar month. Since the exercise of options necessarily implies the purchase or sale of dollars by the CBoC, we refer to the exercise of options as the operational effects of the intervention (we will use the terms "exercising effects" and "operative effects of intervention" interchangeably, hereafter).

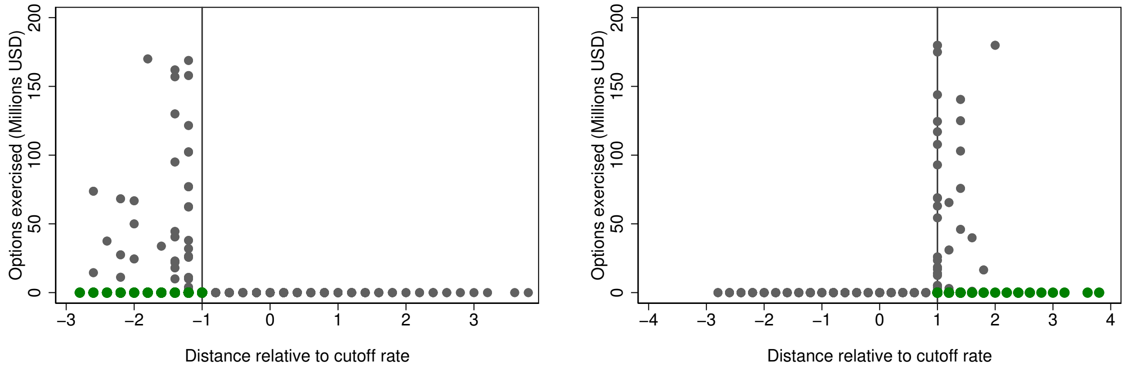
For determining the effects of exercising options, it is critical to remember that whenever the rule is triggered, this does not necessarily imply the exercise of options, mainly because it is up to intermediaries whether to exercise her options or not. In other words, a trader could have chosen (but was not obligated) to exercise the option in the following days after options were issued. Consequently, for measuring the effects of exercising options, we face a fuzzy RDD given that passing the threshold described by Equation 1 (i.e., the rule is triggered) does not perfectly determine the treatment exposure, that is, exercising options. Instead, it creates a discontinuity in the probability of receiving the treatment.

The Figures 5(a) and 5(b) illustrate why we face a fuzzy design when we seek to quantify the effects of exercise options. The Figures portray the exercised amount for put and call options and the running variable described by Equation 1. Note that in the case of put options (Figure 5(a)) there are days under which despite the rule being triggered for purchases ($X_{P,t} \leq -1$) no amount was exercised, which means, there were not purchases of US dollars by the CBoC (represented by the green dots). This is also the case for call options (See Figure 5(b)).

Since we are facing a fuzzy discontinuity, a two-stage least square approach is implemented. Intuitively, we estimate the discontinuity in the probability of exercising FX options, and use it to re-scale the discontinuity in the specification of the outcome variables [6]. In other words, we re-scale the estimate of the intent-to-treat of receiving the treatment by the estimate of the treatment take-up at the discontinuity. In doing so, we begin estimating the predicted probability of exercising options at t with the following first stage regression

[6]That is, the reduced-form $y_{t+j} = \rho_1 \boldsymbol{I}(X_{S,t} \geq 1) + \rho_2 f(X_{S,t} - 1) + \rho_3 f(X_{S,t} - 1) \times \boldsymbol{I}(X_{S,t} \geq 1) + \delta_m + v_{S,t}$

Figure 5: Options exercised when the rule was triggered



(a) Put options

(b) Call options

Note: the plots show the average amount of exercised options on days when the rule was triggered and days when the rule was not triggered. The plotted points show averages of the dependent variable for 0.2 width bins. The green dots represent untreated units.

$$p(SFXI_{S,t} = 1) = \theta_1 \boldsymbol{I}(X_{S,t} \geq 1) + \theta_2 f(X_{S,t} - 1) + \theta_3 f(X_{S,t} - 1) \times \boldsymbol{I}(X_{S,t} \geq 1) + \varepsilon_{S,t} \quad (5)$$

where $p(SFXI_{S,t})$ is a dummy that indicates whether in the day t the CBoC sell US dollars through the exercise of call options. $\hat{\theta}_1$ is the estimate of the discontinuity in the probability of exercising call options at the threshold. $\boldsymbol{I}(X_{S,t} \geq 1)$ is a dummy equal to 1 if the running variable for exercising options is above the threshold for each day t. Besides, $f(X_{S,t} - 1)$ is a polynomial re-scaled to be zero at the threshold. Also, as in the sharp setting, we allow the function to vary across the cutoff by including linear-interaction term of $f(X_{S,t} - 1) \times \boldsymbol{I}(X_{S,t} \geq 1)$.

The effect of the SFXI through the exercise of call options is captured by the estimator of δ_1 from the following second stage equation in which $\boldsymbol{I}(X_{S,t} \geq 1)$ works as an instrument for the probability $p(SFXI_{S,t} = 1)$. Then,

$$y_{t+j} = \delta_1 p(\widehat{SFXI}_{S,t} = 1) + \delta_2 f(X_{S,t} - 1) + \delta_3 f(X_{S,t} - 1) \times \boldsymbol{I}(X_{S,t} \geq 1) + u_{S,t} \quad (6)$$

where y_{t+j} are the outcomes of interest j periods ahead (i.e., changes in the exchange rate and its volatility). Also, note that the effect of SFXI through sales, δ_1, is the result of re-scaling the discontinuity in the outcomes (say ρ_1, as depicted in footnote 5) by the discontinuity of the SFXI probability $\hat{\theta}_1$. By substituting Equation 5 into 6 leads to $\theta_1\delta_1 = \rho_1$ and thus $\delta_1 = \frac{\rho_1}{\theta_1}$. Formally, the fuzzy RD estimand is

$$\delta_1 = \frac{\lim_{x\downarrow 1} E[y_{t+j}|X_{S,t} = x] - \lim_{x\uparrow 1} E[y_{t+j}|X_{S,t} = x]}{\lim_{x\downarrow 1} E[SFXI_{S,t}|X_{S,t} = x] - \lim_{x\uparrow 1} E[SFXI_{S,t}|X_{S,t} = x]} \tag{7}$$

The coefficients δ_1 and γ_1 identify the causal operative effects of intervention and the causal effect of the intervention announcement if two assumptions are satisfied: (i) there is no manipulation of the running variable around the cutoff, and (ii) no potential confounders are also changing discontinuously at the cutoff. In other words, unobservable macroeconomic exchange rate fundamentals vary smoothly nearby the cutoff. If the conditional mean of unobservables, $E[u_{S,t}|X_{S,t} = x]$ and $E[\epsilon_{S,t}|\tilde{X}_{S,t} = x]$, are continuous in the running variable locally at the cutoff, then the approach proposed in previous subsections identify the effect of exercising (δ_1) and issuing options (γ_1), even when $X_{S,t}$ and $u_{S,t}$ are correlated. The plausibility of these assumptions is evaluated empirically in Section 7.

Note that we already defined the scheme for estimating the effects of SFXI through the exercise of call options). Estimating the effect of exercising put options is almost the same but redefining equations based on the normalized cutoff for put options (-1).

6 Results

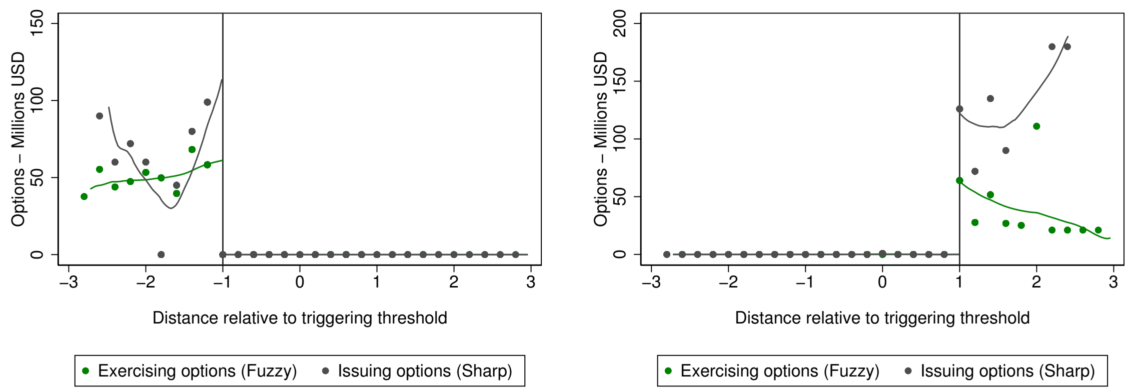
6.1 Same-day effects

This section details whether CBoC's intervention in the FX market affects the spot rate level and its volatility. To this end, we contrast the effects of the issuance of options offered by the CBoC and the exercise of options undertaken by the market intermediaries. As explained before, the issuance of options can be interpreted as vocal effects of interventions, while the exercise of options is taken as the operative effects of intervention.

To begin with, Figures 6(a) and 6(b) present the rule for issuing (exercising) put and call options. Both Figures present the average amount of put and call options issued (exercised) for different values of the assignment variables. Note that when the exchange rate is depreciating or appreciating at a slower rate than the cutoff rate, making either $\tilde{X}_{P,t} > -1$ ($X_{P,t} > -1$) or $\tilde{X}_{S,t} < 1$ ($X_{S,t} < 1$), the CBoC does not purchase or sell of dollars.

Contrariwise, once the triggering threshold is surpassed, this yields the issuance or exercise of put or call options. These jumps in the probability of intervention occurrence at the cutoff represent the exogenous variation exploited to identify the causal effects of vocal and operative effects of SFXI.

Figure 6: Cutoff rule for exercising and issuing options



(a) Put options

(b) Call options

Note: the plotted points show averages of the dependent variable for 0.2 width bins. Fitted curves result from a local linear regression of options exercised on the running variable.

More accurately, Table 2 shows the effects of exercising options, while Table 3 presents the effects of issuing options. On the one hand, column 1 from Table 2 reveals that once the rule is triggered for put options, this leads to the purchase of nearly 23.6 million dollars. Once we re-scale this discontinuity by the probability of exercising options (ρ_1/θ_1), results from the second stage indicate that, on average, the CBoC purchased around 61.3 million dollars in the FX market each time options were exercised. Besides, each time the CBoC intervened through call options, it sold about 65.6 million dollars.

On the other hand, column 1 from Table 3 portrays the average amount issued when the rule was triggered. Results indicate that the rule triggers the issuance of nearly 115.7 million dollars in put options by the CBoC. Besides, triggering the rule yields the issuance of nearly 122.2 million dollars in call options.

Table 2 also quantifies the effect on the level and volatility of the exchange rate on the day the options are exercised. Column 2 measures the effects on the exchange rate level. Notably, the outcome variable is the difference between the log average daily exchange rate on the day of the intervention and the day before the intervention. This log difference can be interpreted as the percent change in the exchange rate. Thus, results from Table 2 suggest

Table 2: Same day exercising effects: fuzzy estimates

Treatment effects	Main outcomes				Placebos	
	(1)	(2)	(3)	(4)	(5)	(6)
	Exercised amount	$\log(e_t/e_{t-1})$	$\text{Vol}_t - \text{Vol}_{t-1}$	GARCH(1,1)	$\log(e_{t-1}) - \log(e_{t-2})$	$\text{Vol}_{t-1} - \text{Vol}_{t-2}$
Purchases of US dollars						
Second stage estimates	61.26***	0.0101*	-0.0115**	-9.81e-05**	0.00413	0.00327
Exercising effects	(12.72)	(0.00538)	(0.00542)	(4.86e-05)	(0.00351)	(0.00315)
First stage estimates	-0.385***	-0.388***	-0.346***	-0.335***	-0.348***	-0.383***
Disc. P(SFXI)	(0.0768)	(0.0761)	(0.0507)	(0.0766)	(0.0512)	(0.0772)
Reduced-form estimates	-23.59***	-0.00393**	0.00399**	3.29e-05**	-0.00144	-0.00125
Triggering rule (ITT)	(6.800)	(0.00169)	(0.00162)	(1.48e-05)	(0.00116)	(0.00112)
Sales of US dollars						
Second stage estimates	65.66***	0.00252	0.000928	3.29e-05	0.000188	-0.000807
Exercising effects	(4.012)	(0.00272)	(0.00304)	(8.44e-05)	(0.00316)	(0.00424)
First stage estimates	0.642***	0.650***	0.577***	0.669***	0.650***	0.493***
Disc. P(SFXI)	(0.0887)	(0.0904)	(0.0756)	(0.125)	(0.0906)	(0.0615)
Reduced-form estimates	42.13***	0.00164	0.000536	2.20e-05	0.000122	-0.000398
Triggering rule (ITT)	(10.45)	(0.00184)	(0.00177)	(6.33e-05)	(0.00205)	(0.00209)
BW-purchases	0.7562	0.7754	0.7783	0.1626	0.7499	0.7433
BW-sales	1.0407	0.9521	0.949	0.29635	0.9424	0.9484
Observations	1,867	1,866	1,866	1,867	1,866	1,866

Method: fuzzy RD estimation (2SLS). Robust standard errors in parentheses. Bandwidth is chosen optimally following Imbens and Kalyanaraman (2012). *** p<0.01, ** p<0.05, * p<0.1 .
Specification: linear flexible polynomial following Equations 5 and 6.
Dependent variables: column 1 shows the quantity of exercised options. Column 2 shows the effects on the difference between the log average daily exchange rate on the day of the intervention and the day before. Column 3 measures the effects on the difference between the exchange rate volatility on the day of the intervention and the day before. Column 4 shows the effects on the exchange rate variance predicted from a GARCH(1,1) model. Column 5 shows the effects on the difference between log average daily exchange rate the day before the intervention and two days before. Finally, column 6 presents the effects on the difference between exchange rate volatility the day before intervention and two days before the intervention.
Running variable: the forcing variable is described by Equation 1.
Sample: daily data from the period when the rule-based intervention mechanism was in place in Colombia: December 24, 2001 to February 3, 2012.

that the exercise of put options depreciates the spot rate by 1% on the day of the intervention. More precisely, findings indicate a 1% depreciation in the spot exchange rate in response to, on average, 61 million US dollars purchased via put options. Besides, Table 3 presents the effects of issuing options on the exchange rate level and its volatility. We document a 0.8% increase in the spot exchange rate in response to, on average, the issuance of 116 million US of put options.

Relative to the effects of call options. From theory, it is expected that if selling dollars had an impact, it would appreciate the nominal exchange rate. However, Table 3 indicates an inconsistent effect after the announcement of dollar sales, suggesting a 0.3% depreciation

Table 3: Same day issuing effects: sharp estimates

Treatment effects	Main outcomes				Placebos	
	(1)	(2)	(3)	(4)	(4)	(5)
	Issued amount	$\log(e_t) - \log(e_{t-1})$	$\text{Vol}_t - \text{Vol}_{t-1}$	GARCH(1,1)	$\log(e_{t-1}) - \log(e_{t-2})$	$\text{Vol}_{t-1} - \text{Vol}_{t-2}$
Purchases of US dollars						
Issuing effects	115.7***	0.00860***	-0.00877***	-4.06e-05*	-0.00107	-0.00179
	(24.09)	(0.00316)	(0.00317)	(2.16e-05)	(0.00185)	(0.00184)
Sales of US dollars						
Issuing effects	122.2***	0.00326*	0.00260	-4.42e-05	6.90e-05	-0.000283
	(31.38)	(0.00173)	(0.00185)	(4.31e-05)	(0.00318)	(0.00314)
BW - purchases	0.5731	0.8379	0.7766	0.1569	0.6991	0.743
BW -sales	1.02285	1.13065	1.1013	0.29925	0.91505	0.88905
Observations	1,867	1,866	1,866	1,867	1,866	1,866

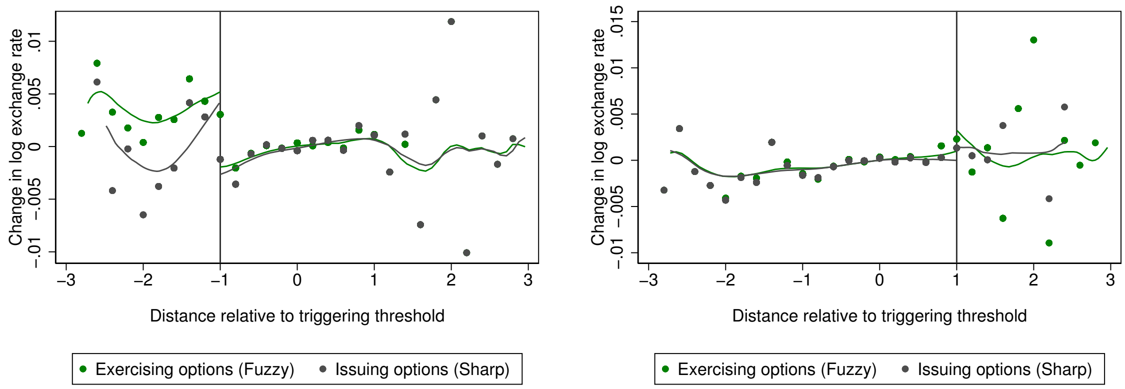
Method: parametric sharp RD estimation. Robust standard errors in parentheses. Bandwidth is chosen optimally following Imbens and Kalyanaraman (2012). *** p<0.01, ** p<0.05, * p<0.1 .
Specification: linear flexible polynomial following Equation 3.
Dependent variables: Column 1 shows the quantity of issued options. Column 2 shows the effects on the difference between the log average daily exchange rate on the day of the intervention and the day before. Column 3 measures the effects on the difference between the exchange rate volatility on the day of the intervention and the day before. Column 4 shows the effects on the exchange rate variance predicted from a GARCH(1,1) model. Column 5 shows the effects on the difference between log average daily exchange rate the day before the intervention and two days before. Finally, column 6 presents the effects on the difference between exchange rate volatility the day before intervention and two days before the intervention.
Running variable: the forcing variable is described by Equation 2.
Sample: daily data from the period when the rule-based intervention mechanism was in place in Colombia: December 24, 2001 to February 3, 2012.

due to the issuance of nearly 122.2 million dollars via call options. As Kuersteiner et al. (2018) argue, this unexpected behavior stems because purchases via discretionary intervention mechanisms a few days before and after offset the sales issuance effect. Despite this being the opposite of what theory anticipates, we will show in the following subsections that after several days the CBoC intervenes through dollar sales, the exchange rate begins depicting an appreciation trend.

Previous findings of the effects on the exchange rate level are presented graphically in Figures 7(a) and 7(b). The dependent variable is the difference in the log spot exchange rate between the start of the trading day (8:00 a.m.-8:15 a.m.) and the average spot rate for the entire day before the intervention, where each plotted point represents averages for the dependent variable for different values of the assignment variables.

On the one side, Figure 7(a) presents the effects of dollar purchases. Results reveal that the exchange rate tends to depreciate more when the rule is barely triggered (i.e., crossing the (-1) threshold to the left). This behavior is depicted for both the issuance and the exercise of

Figure 7: Same day effects on the exchange rate level



(a) Put options (b) Call options

Note: The outcome is the difference between the log average spot rate from 8:00 a.m. to 8:15 a.m. on the day the rule was triggered and the log average spot rate on the entire day before. The plotted points show averages of the dependent variable for 0.2 width bins. Fitted curves result from local linear regression of the outcome variable on the running variable.

FX options. On the other side, Figure 7(b) illustrates the effects of dollar sales. As discussed previously, the Figure shows an unexpected behavior, indicating the exchange rate increases when the rule is triggered for dollar sales (i.e., crossing the (1) threshold to the right). This effect is observed for both the exercise and issuance of call options.

We now turn attention to the effects on the exchange rate volatility. We define volatility as deviations of the exchange rate from its last 20-day moving average as depicted in Equation 8, where each term is as in Equation 1. In other words, we measure the exchange rate volatility as the running variable for exercising options. We define the volatility under this definition since this was the measure from the CBoC to assess episodes of unconventional volatility (i.e., the rule was triggered). Additionally, we also measure the effects on the exchange rate volatility using a GARCH(1,1) model.[7] We will show later that findings are somehow sensitive depending on the embraced volatility definition.

$$Vol_t = \frac{e_t - \bar{e}_t}{\bar{e}_t} \tag{8}$$

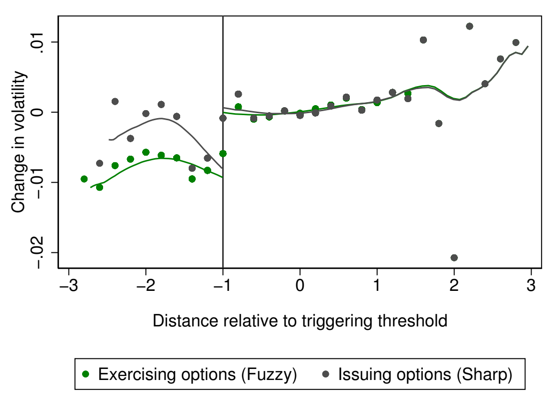
Column 3 from Table 2 shows the effects of exercising options on the exchange rate volatility. When the CBoC purchases dollars, findings suggest a reduction in the exchange

[7]Often, empirical literature applies a GARCH(1,1) specification since this capture the main features of financial series, as long as the unconditional variance is constant.

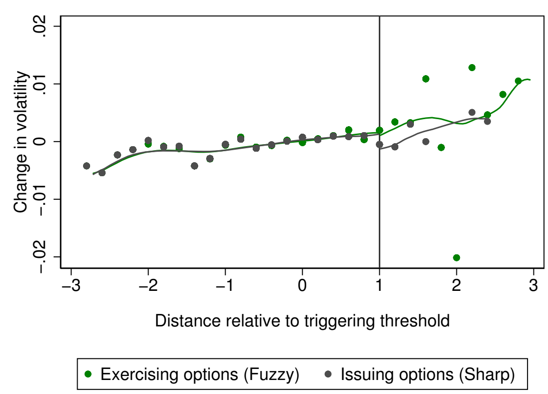
rate volatility of about 1 pp on the day of the SFXI. Similarly, Column 3 of Table 3 exhibits a 0.9 pp reduction in response to the issuance of put options. We also document significant reductions when we measure volatility predicted from a GARCH(1,1). By comparison, regarding the effects of dollar sales, we find non-statistically significant effects from the issuance or exercise of call options (See columns 3 and 4 from Tables 2 and 3).

Previous results on the volatility effects are presented graphically in Figures 8(a) and 8(b). On the one side, Figure 8(a) supports the effectiveness of the intervention mechanism in curbing the exchange rate volatility via put options, implying volatility reductions after SFXI. On the other hand, the small jumps reported in Figure 8(b) once the threshold is surpassed explains why we find non-significant effects on the exchange rate volatility in response to the sale of dollars.

Figure 8: Same day effects on the exchange rate volatility



(a) Put options



(b) Call options

Note: The outcome is the difference between the spot rate volatility on the day the rule was triggered and the spot rate volatility on the entire day before. The plotted points show averages of the dependent variable for 0.2 width bins. Fitted curves result from local linear regression of the outcome variable on the running variable.

Our findings are consistent with what literature has found in EMEs. For instance, in Colombia, Echavarría et al. (2014) found that preannounced interventions move the exchange rate by about 0.55 percent per 100 million of intervention. Similarly, Kamil (2008) finds that a 100 million USD purchase depreciates the exchange rate by 0.76 percent. Meanwhile, Echavarría et al. (2018) find that 1 million USD through daily auctions (discretionary purchases) depreciates 0.004 percent (0.001 percent). In contrast, Domaç and Mendoza (2004) find that a sale of 100 million USD appreciates the exchange rate by 0.9 percent in México. Also, Lahura and Vega (2013) find that a sale of 25 million USD appreciates the exchange rate by 0.1 percent in Perú. Kuersteiner et al. (2018), that directly evaluate the rule-based intervention mechanism in Colombia, estimate that the exercise of put options of about 100 million USD depreciates the exchange rate by as much as 2 percent, which is quite similar to what we found. Like us, the authors do not find immediate effects of call options.

Regarding the volatility effects, our findings are quite large compared to what existing literature has found in emerging markets. Nevertheless, most of the literature has evaluated dirty interventions. For example, in Colombia, Kamil (2008) shows that intervention reduced volatility when purchases were made during a period of monetary easing. Specifically, the author finds that 100 million USD purchases lessen the exchange rate variance by 0.02 percent. Furthermore, although Villamizar-Villegas (2016) finds no effect on exchange rate level, the author's results suggest a 100 million USD purchase reduces realized volatility, measured by a squared log change in the daily exchange rate, by up to 0.5 percent.

Finally, if the empirical strategy correctly measures the effect of CBoC intervention, then the intervention should not affect the previous day's spot rate level nor its volatility. Intuitively, non-significant effects on the lagged outcomes supports the assumption that around the threshold, no other factors are affecting the exchange rate level or its volatility different from the SFXI. This validates the fact that there is no noticeable baseline difference between days on which new auctions are triggered and those on which they are not.

Column 5 from Table 2 shows the effects of exercising options on the exchange rate level on the day before the intervention (i.e., placebo). Namely, the dependent variable is defined as the difference between the log average daily exchange rate the day before the exercise of put options and two days before the intervention. As depicted in Table 2, the coefficient for both sales and purchases is non-significant. This lack of variation across the cutoff is consistent with the RDD assumptions that such conditional expectations are continuous without intervention.

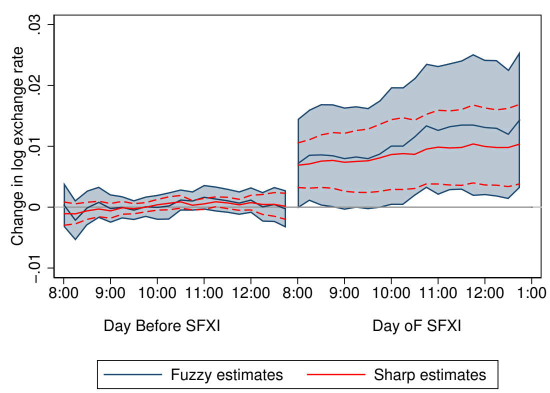
Moreover, in column 5 of Table 3, we also test whether the issuance of options that have not occurred yet have effects on today's exchange rate level. The non-significant coefficient suggests no covariates imbalance just around the triggering threshold for the issuance of options. Similarly, column 6 from Tables 2 and 3 test whether the spot rate volatility responds to the exercise or issuance of options that have not yet been triggered. Given that the estimated coefficients are non-significant, the results imply no noticeable confounding factors affecting exchange rate volatility around the triggering cutoff.

6.2 Intra-day effects

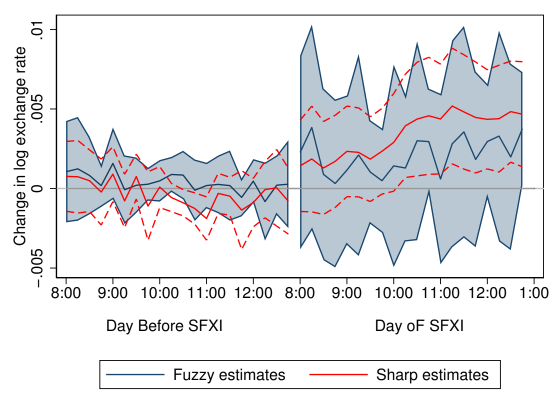
In the following subsections, we seek to quantify the effects of SFXI t periods after the CBoC has intervened in the FX market. In doing so, we propose an Impulse Response Function (IRF) analysis. We follow the method suggested by Jordá (2005) of local projections to estimate the implied IRFs. Essentially, we estimate sequential regressions in which the outcome variables y_t (i.e., change in the exchange rate level and volatility) are shifted ahead at each forecasting period. Then, the figures plot the vector of γ_1 and δ_1 of Equations 3 and 6 across different time horizons.

We first quantify the tick-by-tick effects of issuing and exercising options on the day the intervention occurs. After, we present the effects one month after the intervention. Figures 9(a) and 9(b) show the IRF moving in 15-minute segments from the beginning of the trading day (8:00 a.m.) on the day previous to the intervention until the close of the trading day (1:00 p.m.) on the day of the intervention. The Figures show the effects of the issuance (sharp estimates) and exercise (fuzzy estimates) of FX options, where the dependent variable is the difference between the log exchange rate at the listed time and the average spot rate for the entire previous day.

Figure 9: Intra-day effects on the exchange rate level



(a) Put options



(b) Call options

Note: The outcome is the difference between the log average spot rate in 15-min increments on the day the rule was triggered and the TRM on the day before. The solid curves present a series of RD estimates. The bands display 90% confidence intervals.

Figure 9(a) show that the SFXI effect through purchases lasts for the entire day after the auction, rising slightly to a roughly 1% depreciation of the spot rate. Furthermore, the magnitudes of the estimates along the trading day are very similar for both the issuance and exercise of put options. The preceding is consistent with the coefficients reported in Column 2 from Tables 2 and 3, which present the average effects on the whole day following the auction.

In comparison, the effects of the issuance of call options presented in Figure 9(b) exhibit an inconsistent effect implying a depreciation pattern. As mentioned, this is partly explained by the simultaneous purchases that occurred through other discretionary intervention mechanisms. However, we go in-depth into the explanation of this unexpected behavior in the next subsection. Besides, note that the effect of the exercise of call options is non-significant during the entire day of the intervention, which is compatible with the coefficient reported in Column 2 Table 2. Finally, the IRFs also show that the intervention is not affecting the previous day's spot rate, which supports the idea of covariates baseline balance.

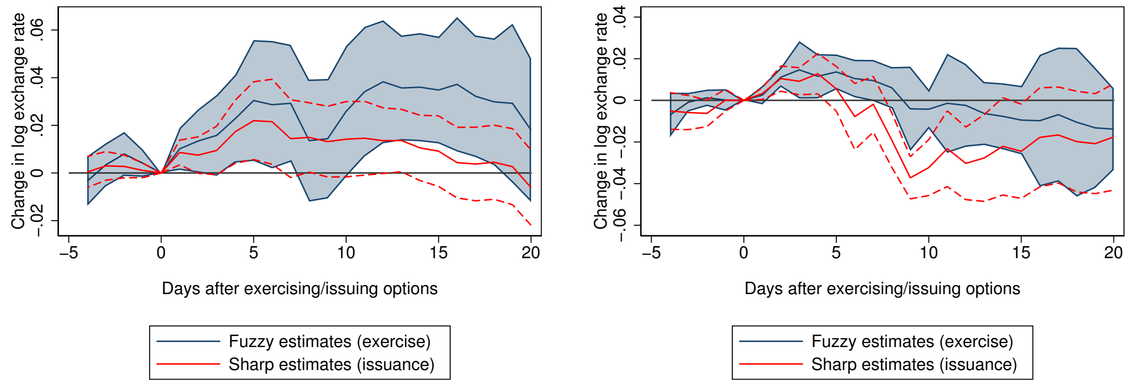
6.3 One-month effects

In this section, we measure the effects on the level and volatility of the exchange rate one month after the CBoC intervenes in the FX market. Figures 10(a) and 10(b) present the effects on the exchange rate level t days after the issuance (sharp estimates) and exercise (fuzzy estimates) of FX options. Figure 10(a) shows that after CBoC purchases US dollars via the exercise of put options, significant effects persist up to twenty days and rise to a maximum depreciation of nearly 4%. After day twenty, the exchange rate returns to its pre-intervention level. These effects are presented more accurately in Table 4.

By comparison, the issuance of put options exhibits a slightly lower effect. Particularly, the estimated coefficients on the day of the auction are quite similar as Tables 2 and 3 display. Nonetheless, after the first day, exercising options seem to have a broad and long-lasting effect compared to the issuance of options. Indeed, the maximum effect from put options issuance is a depreciation of about 2%. Also, the IRF displays that the effects of issuing options disappear around eight days after the announcement.

On the other side, Figure 10(b) shows the one-month effects of the issuance and exercise of call options. From theory, we might expect sales of dollars to have a negative impact. Nevertheless, we observe that the exchange rate tends to depreciate immediately after the CBoC intervenes via dollar sales, and this effect lasts about one week. The preceding occurs for the issuance and exercise of options. Nevertheless, we observe that the depreciation effect after the call options issuance rapidly reverses to the expected direction, and the dollar sales generates an appreciation effect that is statistically significant between the second and third

Figure 10: One-month effects on the exchange rate level



(a) Put options

(b) Call options

Note: Impulse Response Function: Exchange rate level effects 20 calendar days after the intervention. The dependent variable is the difference between the log daily average spot rate t days after the SFXI and the log average spot rate the day before the SFXI. The central solid curves present the fuzzy/sharp regression discontinuity estimates. The upper and lower lines display 90% confidence intervals.

week.

While our study focuses only on the CBoC's rule-based intervention mechanism, we assert there are potential correlations and overlap with the other CBoC FX mechanisms. We argue that this delayed reaction of dollar sales may occur because other intervention mechanisms sometimes offset sales through dollar purchases. In particular, the CBoC's use of discretionary mechanisms could explain the asymmetry between purchases and sales on the days when the auction takes place. Figure 11 shows that, in general, call options were immediately preceded or followed by purchases via discretionary mechanisms. Also, in almost all the cases, purchases from discretionary mechanisms were considerably higher relative to sales.

From 2000 to 2012, the CBoC used discretionary mechanisms to purchase dollars totaling 28.1 billion dollars but only sold 0.3 billion dollars. This great propensity in the use of discretionary mechanisms for purchasing dollars partly explains why rule-based sales were likely to be offset. At the same time, it is not reasonable to think that sales through discretionary mechanisms affected rule-based purchases, given the low frequency and amount of sales.

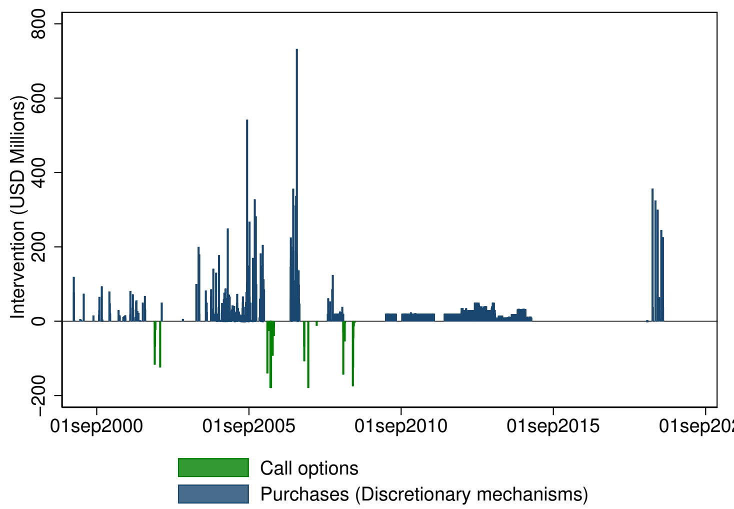
For instance, 143.9 million dollars were exercised via call options on October 7, 2008, while the prior week (September 29, 2008 – October 03, 2008), 100.1 million dollars were

Table 4: One-month SFXI effects

	(1) Level	(2) Volatility	(3) GARCH(1,1)	(4) Level	(5) Volatility	(6) GARCH(1,1)
	Purchases of US dollars			Sales of US dollars		
Exercising effects: fuzzy estimates						
1 day	0.0101*	-0.0115**	-9.81e-05**	0.00252	0.000928	3.29e-05
	(0.00538)	(0.00542)	(4.86e-05)	(0.00272)	(0.00304)	(8.44e-05)
5 days	0.0255*	-0.0248**	0.000136	0.0137***	0.00678*	0.000496
	(0.0133)	(0.0124)	(0.000692)	(0.00510)	(0.00408)	(0.000307)
10 days	0.0217	-0.0240	-0.000587	-0.00424	-0.0127	-6.80e-06
	(0.0141)	(0.0158)	(0.000805)	(0.00572)	(0.00865)	(0.000696)
15 days	0.0418***	-0.0359**	-0.00135	-0.00948	-0.0131	-0.000856
	(0.0161)	(0.0141)	(0.00116)	(0.01000)	(0.0108)	(0.000646)
20 days	0.0149	-0.0114	-0.00372**	-0.0138	-0.0187	-0.000589
	(0.0152)	(0.0142)	(0.00184)	(0.0119)	(0.0162)	(0.000846)
Issuing effects: sharp estimates						
1 day	0.00860***	-0.00877***	-4.06e-05*	0.00326*	0.00260	-4.42e-05
	(0.00316)	(0.00317)	(2.16e-05)	(0.00173)	(0.00185)	(4.31e-05)
5 days	0.0219**	-0.0228**	0.000335	0.00553	0.00159	-1.27e-05
	(0.00992)	(0.00913)	(0.000438)	(0.00655)	(0.00674)	(0.000295)
10 days	0.0142	-0.0132	8.52e-05	-0.0323***	-0.0319***	-0.00102**
	(0.00960)	(0.00961)	(0.000429)	(0.00815)	(0.00639)	(0.000508)
15 days	0.00917	-0.0104	-0.000355	-0.0245*	-0.0141	-0.000777
	(0.00899)	(0.00743)	(0.000553)	(0.0138)	(0.00899)	(0.000968)
20 days	-0.00615	0.00422	-0.00109	-0.0176	-0.0150**	-0.000976
	(0.00960)	(0.00751)	(0.00103)	(0.0155)	(0.00737)	(0.00109)

Method: fuzzy RD estimation (2SLS) for the exercise of options and sharp RD estimation for the issuance of options. Robust standard errors in parentheses. Bandwidth is chosen optimally following Imbens and Kalyanaraman (2012). *** p<0.01, ** p<0.05, * p<0.1 .
Specification: linear flexible polynomial following Equations 3 and 6.
Dependent variables: columns 1 and 4 show the effects on the difference between the log average daily exchange rate t days after the SFXI and the day before SFXI. Columns 2 and 5 measure the effects on the difference between the exchange rate volatility t days after the SFXI and the exchange rate volatility the day before SFXI. Columns 3 and 6 quantify the effects on the exchange rate variance predicted from a GARCH(1,1).
Running variable: the forcing variables are described by Equations 1 and 2.
Sample: daily data from the period when the rule-based intervention mechanism was in place in Colombia: December 24, 2001 to February 3, 2012.

Figure 11: Rule-based sales vs. Discretionary purchases



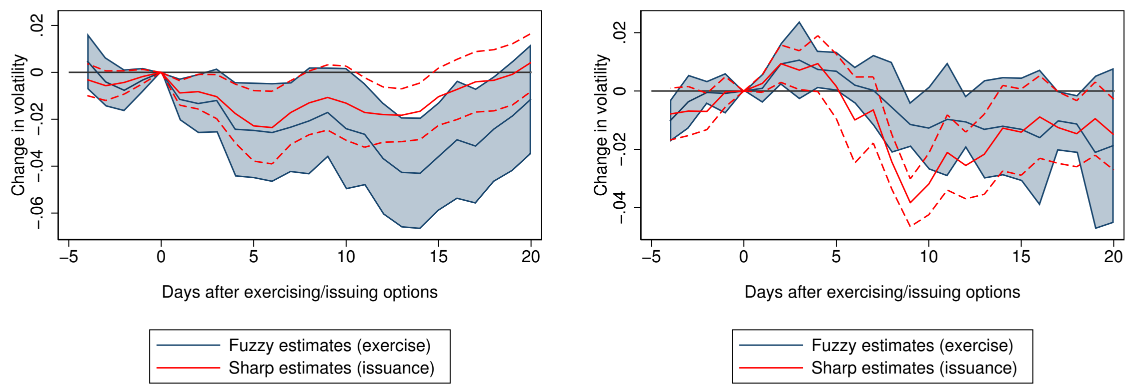
purchased through a discretionary auction. As another example, 124.5 million USD was exercised through call options on October 2, 2002. Then, on October 21, 2002, the CBoC purchased 50 million USD through discretionary put options.

Kuersteiner et al. (2018) show that, on average, the CBoC used discretionary purchases after call auctions. In contrast, the CBoC used discretionary mechanisms to reinforce rule-based purchases. The authors argue that this preference for employing discretionary intervention mechanisms to buy rather than sell dollars could induce asymmetric uncertainty regarding the CBoC's commitment to rule-based interventions. Consequently, this uncertainty could make interventions temporarily ineffective in the days immediately after intervention via call options until the uncertainty resolves.

We now focus attention on the volatility effects. In Figures 12(a) and 12(b), we explore whether intervention is an effective mechanism for curtailing exchange rate volatility 20 working days after the SFXI. Figure 12(a) shows the effectiveness of intervention through dollar purchases in reducing the exchange rate volatility. The IRF displays that the exercise of options curbs the exchange rate volatility to a greater extent than the issuance of options. Indeed, the IRF shows that the exercise of put options reduces the spot rate volatility up to nearly 4 pp, and the volatility reduction endures almost three weeks after the auction. In contrast, results indicate that the issuance of put options reduces volatility up to about 2 pp (see column 2 from Table 4).

On the other hand, Figure 12(b) shows the effects of issuing and exercising call options on exchange rate volatility. The IRF show an increase in volatility during the first week after the issuance of options. However, hereafter, the issuance of call options reduces exchange rate volatility, and the effects persist for two weeks, reaching nearly a 3 pp reduction. Besides, we document no significant impact on the exchange rate volatility from the exercise of call options (see column 4 from Table 4).

Figure 12: One-month effects on the exchange rate volatility



(a) Put options

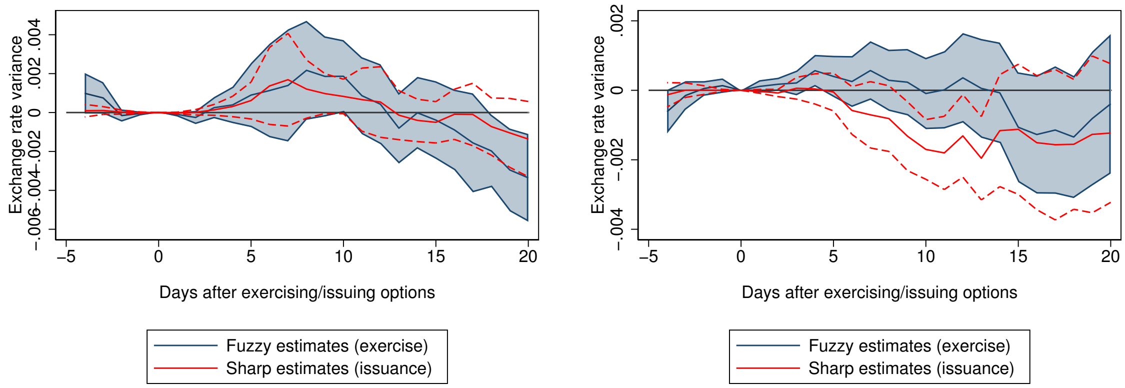
(b) Call options

Note: effects on the exchange rate volatility 20 calendar days after the intervention. The dependent variable is the difference between the exchange rate volatility t days after the SFXI and the exchange rate volatility the day before the SFXI. The central solid curves present the fuzzy/sharp RD estimates. The upper and lower lines display the 90% confidence intervals.

We also quantify the effects on the exchange rate variance obtained from a GARCH(1,1), and the IRFs are displayed in Figures 17(a) and 17(b). We identify that findings are somehow sensitive depending on the volatility definition adopted. On the one hand, regarding the dollar purchases, we observe that even though the IRF evidence a volatility reduction, the effects are significant almost four weeks after the dollar purchases. Moreover, we dont observe significant effects from the issuance of put options. On the other hand, regarding the sales of dollars, as under the previous definition of volatility (i.e., the running variable for exercising options), only the issuance of options effectively reduces the volatility, and these effects appear within the second and third week after the announcement.

Likewise, Figures 14(a) and 14(b) empirically show that FXI undertaken by the CBoC through the rule-based intervention mechanism is sterilized, implying no effects on the monetary base or interest rates. The IRFs displayed in Figures 14(a) and 14(b) exhibit the response of the overnight rate when SFXI has occurred either by the issuance or exercise of FX options. The Figures depict no statistically significant effects on the overnight rate

Figure 13: One-month effects on the exchange rate variance predicted from a GARCH(1,1)



(a) Put options

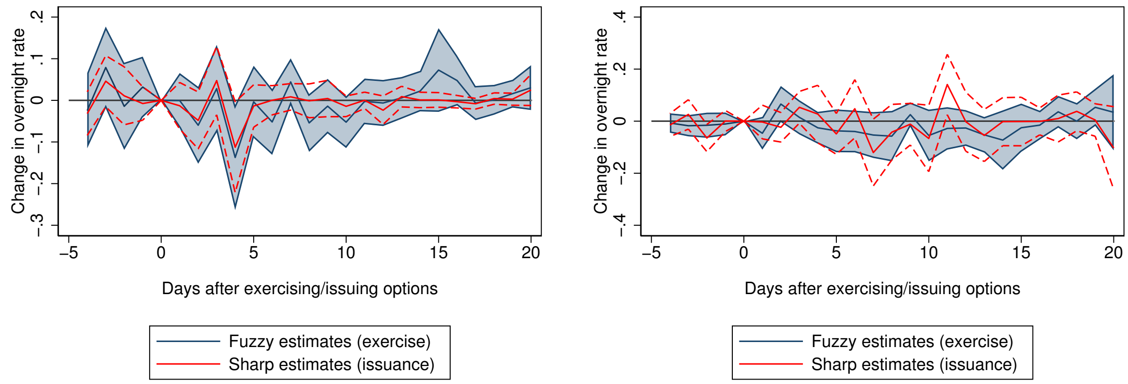
(b) Call options

Note: effects on the exchange rate volatility 20 calendar days after the intervention. The dependent variable is the exchange rate variance t days after the SFXI. The central solid curves present the fuzzy/sharp RD estimates. The upper and lower lines display the 90% confidence intervals.

in response to intervention via put and call options over 20 days. Therefore, results suggest that the intervention is sterilized.

Finally, note that all presented IRFs present the estimates before intervention happens ($t < 0$). By all means, the reported coefficients must be non-significant, indicating that intervention that has not occurred yet has any significant effects on the exchange rate level or its volatility. Once more, this validates the fact that there is no noticeable baseline difference between days on which new auctions are triggered and those on which they are not.

Figure 14: One-month effects on the overnight rate



(a) Put options

(b) Call options

Note: effects on the overnight rate 20 calendar days after intervention. The dependent variable is the difference between the overnight rate t days after the SFXI and the overnight rate the day before the SFXI. The central solid curves present the fuzzy/sharp RD estimates. The upper and lower lines display the 90% confidence intervals.

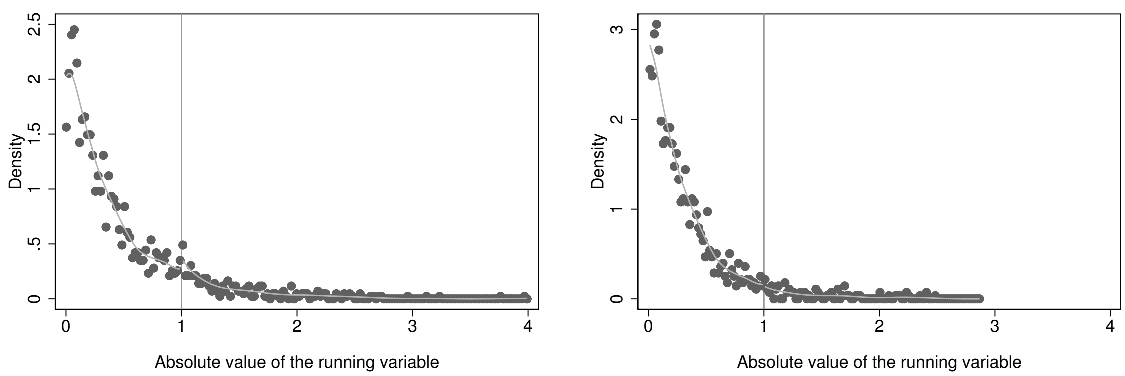
7 Validity of RDD assumptions

The fundamental identification assumption for RDD is that assignment nearby the cutoff, which determines the treatment exposition (i.e., issuing/exercising options), is locally random. The local randomness condition may be violated if the market intermediaries can accurately predict and manipulate the assignment variable to surpass the thresholds that trigger new auctions or allow the exercise of previously purchased options. Nevertheless, despite traders knowing the policy rule, it seems credible to think that they cannot predict with certainty whether the rule will be triggered or not. Instead, the exchange rate is locally determined by random factors that market participants cannot predict or manipulate around the threshold.

We test the validity of this assumption in three ways. First, the local randomness condition implies no manipulation near the threshold. We follow the test proposed by McCrary (2008) to assess whether there exists manipulation. The author presented a density test, where the null hypothesis implies that the density function of the running variable is continuous at the threshold. In principle, a discontinuity would indicate that agents can manipulate the exchange rate around the cutoff resulting in an unbalanced number of days when the rule was triggered and days when the rule was not triggered.

Results for manipulation for issuing (sharp RDD) and exercising (fuzzy RDD) options are displayed in Figures 15(a) and 15(b), respectively. The line represents the estimated density of each running variable on either side of the cutoff. It is observed that the cutoff does not generate an apparent discontinuity for both distributions. Moreover, we find no evidence of manipulation with p-values of 0.83 and 0.72 for the fuzzy and sharp designs, respectively. Hence, the null hypothesis of continuity at the threshold is not rejected. Thus, results suggest exchange rates are randomly allocated around the cutoff, and there is no evidence of manipulation by market agents.

Figure 15: Density test around the triggering threshold



(a) Exercising options - fuzzy

(b) Issuing options - sharp

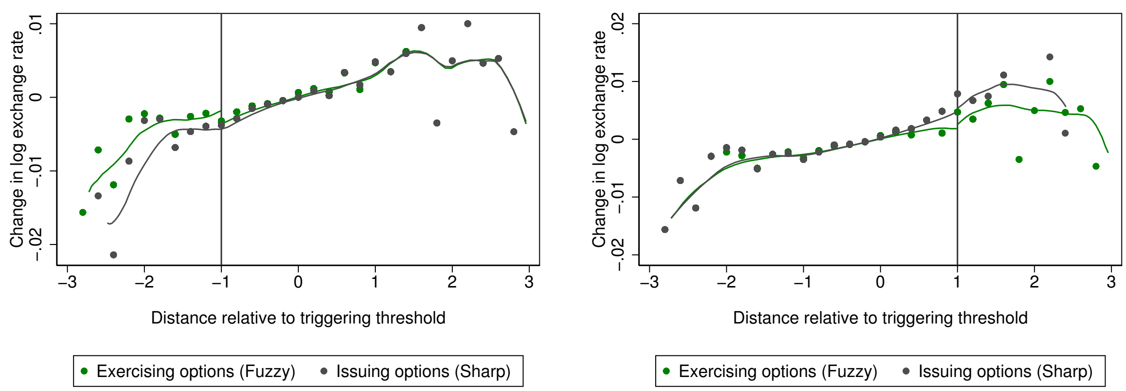
Note: the plotted points show the frequency of the running variable for exercising and issuing options in bins of width 0.02. The solid curve is a local linear fit of the density of the absolute value of the running variable on either side of the cutoff.

A second test for local random assignment of the treatment relies on the fact that if the values of the assignment variable in the immediate neighborhood of the threshold are as good as randomly assigned, then the values of baseline covariates should have a smooth behavior across the threshold. This is analogous to a test for the balance of background characteristics in an experimental study. The latter condition implies that covariates should be balanced between treatment and control groups. Consequently, the treatment effects are not attributable to other factors different from the intervention.

As explained in the previous section, column 5 of Tables 2 and 3 examine whether the level of lagged spot rates appears to respond to policy interventions. Namely, we examine the difference between the log of the average exchange rate the day before the auction and the log exchange rate two days before the auction. The coefficient is non-significant, suggesting that no other factors influence the exchange rate around the threshold different from the intervention. Thus, there is no detectable baseline difference between days where the CBoC carried out an intervention and those on which no intervention occurred.

Previous results are also presented graphically in Figures 16(a) and 16(b). Specifically, each point of the graph represents the mean difference between the log average spot rate from 8:00 a.m. to 8:15 a.m. on the day before the rule was triggered and the log average spot rate two days before the intervention. Figures show no clear jump around the threshold for put or call options indicating that today's intervention does not affect the lagged exchange rate level, but also, there are no other factors affecting the exchange rate around the threshold.

Figure 16: Exchange rate level effects one day before intervention



(a) Put options

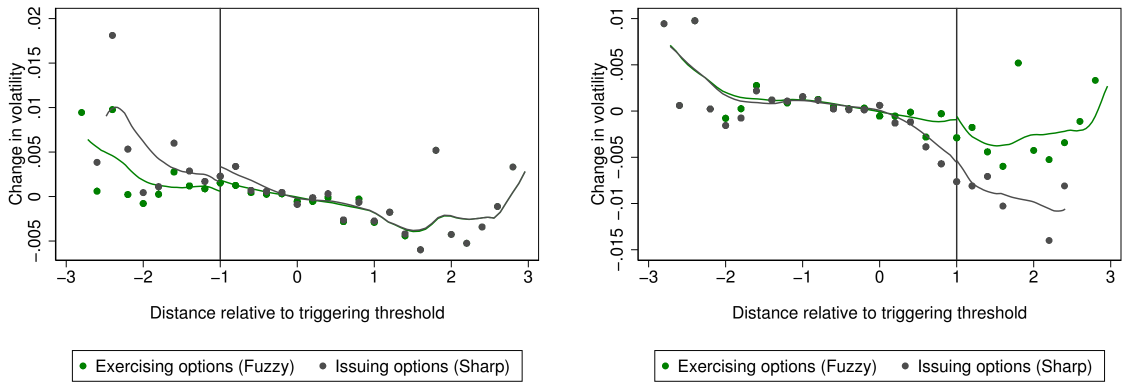
(b) Call options

Note: the outcome is the difference between the log average spot rate from 8:00 a.m. to 8:15 a.m. on the day before the SFXI and the log average spot rate two days before the SFXI. The plotted points show averages of the dependent variable for 0.2 width bins. Fitted curves result from local linear regression of the outcome variable on the running variable.

All previous analysis is also done for exchange rate volatility (see Column 6 of Tables 2 and 3, and Figures 17(a) and 17(b)) and results indicate that lagged spot rate volatility seem not to respond to policy interventions that have not occurred. Overall, results suggest a continuous baseline covariates behavior around the threshold.

Finally, we test whether there is correlation between underlying fundamentals and the probability of exercising/issuing options. In doing so, we follow the approach proposed by Kuersteiner et al. (2018) and we perform a regression of a dummy variable switched on each time options are issued/exercised on one lagged day macroeconomic fundamentals (i.e., one-day exchange rate trends, appreciation built into forward contracts on that day, the interbank interest rate, credit default swap spread). Intuitively, if the CBoC's rule intervention mechanism generates random variation in interventions just around the triggering treshold,

Figure 17: Exchange rate volatility effects one day before intervention



(a) Put options

(b) Call options

Note: The outcome is the difference between the spot rate volatility the day before the SFXI and the spot rate volatility two days before the SFXI. The plotted points show averages of the dependent variable for 0.2 width bins. Fitted curves result from local linear regression of the outcome variable on the running variable.

then, the probability of issuing/exercising options must be uncorrelated with fundamentals near the cutoff, conditional on the running variable.

Table 5 demonstrates whether this assumption holds empirically. Columns 1 and 3 show that intervention is correlated with fundamentals when the regression is done using the entire sample. Almost all independent variables are predictors of the probability of issuing/exercising put or call options. Moreover, the joint F-tests reject the null hypothesis that all fundamentals are jointly non-significant. Conversely, when the sample is being restricted to observations just around the cutoff, the correlation between issuing/exercising options and macroeconomic fundamentals start to disappear (see Columns 2 and 4 from Table 5). Indeed, all fundamentals become insignificant once the regression is performed within a small bandwidth, and this behavior is true for both purchases and sales of US dollars.

Additionally, conditional to the running variable and focusing on observations around the triggering threshold, we can not reject the null hypothesis that fundamentals are jointly statistically different from 0. Further, note that the low predictive power of fundamentals is not solely explained because of the restricted sample. In fact, the running variable itself remains a strong predictor of intervention, as the significance of its coefficients and the F tests exhibit. Hence, previous results demonstrate no correlation between underlying fundamentals and the probability of exercising/issuing options.

Table 5: Correlation of intervention on fundamentals

	(1) All	(2) BW = 0.5	(3) All	(4) BW = 0.5
	Purchases of US dollars		Sales of US dollars	
Exercising options - Fuzzy RDD				
Lag log change in spot rate	-3.619*	1.707	-1.279	3.229
	(1.847)	(4.404)	(2.513)	(4.612)
Lag exercised forward rate	-608.2***	-491.3	-270.0***	583.7
	(137.1)	(707.8)	(66.71)	(487.0)
Lag interbank rate	0.0571***	0.0401	0.0484***	0.0158
	(0.00981)	(0.0392)	(0.00966)	(0.0266)
Lag EMBI spread	6.24e-05	0.000200	-9.02e-05*	-0.000184
	(5.28e-05)	(0.000265)	(5.32e-05)	(0.000143)
Running var.	-0.237***	-1.420***	0.207***	1.271***
	(0.0245)	(0.0902)	(0.0230)	(0.102)
Constant	-0.286***	-1.216***	-0.212***	-0.866***
	(0.0711)	(0.301)	(0.0758)	(0.189)
Observations	554	74	554	72
Fundamentals, F test	11.73	0.341	11.69	1.746
Fundamentals, Prob > F	3.76e-09	0.849	4.07e-09	0.150
Running var., F test	93.34	247.8	81.09	155.4
Running var., Prob > F	0	0	0	0
Issuing options - Sharp RDD				
Lag log change in spot rate	-1.857	0.392	-1.968*	-7.408
	(1.424)	(7.487)	(1.063)	(6.323)
Lag exercised forward rate	-190.1**	748.2	-102.4**	259.6
	(76.72)	(590.2)	(45.30)	(545.6)
Lag interbank rate	0.0274***	0.000521	0.0122**	0.0137
	(0.00687)	(0.0754)	(0.00591)	(0.0261)
Lag EMBI spread	2.77e-05	-9.44e-05	-5.81e-05*	-0.000128
	(3.08e-05)	(0.000374)	(3.42e-05)	(0.000152)
Running var.	-0.143***	-1.205***	0.0897***	1.059***
	(0.0300)	(0.205)	(0.0263)	(0.149)
Constant	-0.146***	-0.812	-0.0247	-0.735***
	(0.0477)	(0.544)	(0.0413)	(0.192)
Observations	554	32	554	46
Fundamentals, F test	4.520	1.529	1.910	0.818
Fundamentals, Prob > F	0.00134	0.223	0.107	0.521
Running var., F test	22.54	34.64	11.66	50.44
Running var., Prob > F	2.63e-06	3.31e-06	0.000687	1.35e-08

Using daily data, each column presents an OLS regression of macroeconomic fundamentals and the running variable on a treatment dummy (i.e., exercising/issuing options). The first F-statistic and p-value provide a joint test of the null that coefficients on the macroeconomic fundamentals are zero. The second F-statistic and p-value does the same for the running variable. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

8 Concluding remarks

Foreign Exchange Interventions (FXI) are the standard instrument available to central banks to manage FX markets by purchasing or selling dollars. Also, FXI remains an essential instrument for the monetary authorities to stabilize the domestic economy and cover it from external shocks. Currently, literature has struggled to reach a definite conclusion regarding the significance and duration of intervention effects. Also, there is scant evidence related to the extent to which the effects of the intervention announcement differ from the actual intervention.

To shed light on this debate, this paper applies a Regression Discontinuity Design (RDD), taking advantage of a discontinuous policy rule used by the Central Bank of Colombia. By exploiting the exogenous component of the rule-based intervention mechanism, this article measures the effects of sterilized interventions on the exchange rate level and its volatility. Most importantly, we quantify the extent to which the effects of the intervention announcement (under a sharp RDD) differ from the actual intervention (under a fuzzy RDD). To the best of our knowledge, this is the first document distinguishing these two types of effects using an RDD approach.

Our findings provide evidence of the effectiveness of dollar purchases in depreciating the exchange rate and curbing its volatility. Results indicate a 1% depreciation and a 1.2 pp volatility reduction in the spot rate in response to, on average, nearly 60 million dollars purchased via put options. Similarly, we observe a 0.8% depreciation and a 0.8 pp volatility reduction in response to, on average, the announcement of the purchase of 115 million dollars through put options.

In addition, we find that the effects of dollar purchases persist for up to 20 days, reaching a depreciation of nearly 4% and a 3.5 pp volatility reduction. By comparison, the impact of the announcement of dollar purchases disappears after eight days, depreciating the exchange rate by as much as 2%. Likewise, the effects of the announcement of purchases on volatility last around three weeks, with a maximum volatility reduction of 2.3 pp.

Regarding the dollar sales effectiveness, we document a less consistent effect. In particular, the immediate response to the dollar sales announcement is a 0.3% depreciation, which is the opposite of expected. We attribute this initial effect to the CBoC's tendency to offset rule-based dollar sales with simultaneous purchases through discretionary mechanisms. However, we document that this effect rapidly reverses to the expected direction, and the dollar sales announcement generates a statistically significant appreciation between the second and third week after the announcement. This latter behavior is also observed in the exchange rate volatility. Namely, a volatility reduction occurs within the second and third weeks after the intervention announcement. In contrast with the dollar sales announcement effects, we find that actual dollar sales are ineffective in appreciating the exchange rate level or reducing its implied volatility.

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Appendix A. Empirical Literature in Colombia

Author(s)	Period	Evaluated mechanism(s)	Methodology	Effectiveness		Duration	
				Level	Volatility	Level	Volatility
Durán-Vanegas (2015)	2008-2013, daily	Volatility options and purchases through daily auctions	Two-stage model, AR-GARCH	Yes, purchases of 100 million USD generates a 0.02 percent depreciation.	-	Contemporary	-
Echavarría (2009)	2000-2008, monthly	Discretionary interventions, options, and rule-based interventions	SVAR	Yes	-	1 month	-
Echavarría et al. (2010)	1999-2008, daily	Discretionary interventions and options	2S-IV, TOBIT, EGARCH	Yes	Yes	The authors find effects in the short-term (1 day) and the medium-term (1 month, 3 months, and 6 months).	The authors find effects in the short-term (1 day) and the medium-term (3 months, 6 months and 1 year).
Echavarría et al. (2014)	2000-2012, daily	Options, rule-based intervention, and discretionary intervention	Event study	All types of interventions were successful according to the smoothing criterion. In particular, volatility options had the most substantial effect (successful according to the direction, smoothing, reversion and matching criteria).	-	All intervention mechanisms were successful under the smoothing criteria and for window sizes of less than 12 days.	-
Echavarría et al. (2018)	2004-2012, daily	Discretionary and preannounced interventions	TOBIT-GARCH and PGARCH	Preannounced interventions of 100 million USD depreciate domestic currency by 0.55 percent, 3.3 times more than discretionary interventions.	-	Contemporary	-
Fuentes et al. (2014)	2007-2011, intraday	Daily purchases through auctions	Event study	No	No		-
Kamil (2008)	2004-2007, daily	Discretionary interventions and options	2S-IV, TOBIT, GARCH	- Intervention was effective during 2004-2006. A 30 million USD purchase depreciated the domestic currency by 0.23 percent. - In 2007, the intervention was ineffective in reversing the domestic currency appreciation.	- During 2004-2006, results indicate that CBoC's discretionary intervention had the unintended consequence of dampening the volatility of exchange rate returns.G13 - In 2007, the discretionary intervention had no discernible impact on exchange rate volatility.	Contemporary	Contemporary
Kuersteiner et al. (2018)	2001-2012, intraday	Rule-based interventions	Regression Discontinuity Design	Yes, purchases of 115 million USD depreciate the exchange rate by as much as 2 percent, while sales of 122 million USD generate a 3 percent appreciation after two weeks.	-	3 weeks for purchases and 2 weeks for sales (from day 5 to day 15).	-
Mandeng (2003)	2002, daily	Rule-based interventions	Event study and an analysis-of-variance model	-	- Moderately successful (options sold in July and October 2002) - Unsuccessful (2002)	-	Short-lived
Rincón and Toro (2010)	1993-2010, daily	Options and Discretionary and preannounced interventions	GARCH	Capital controls nor FXI used separately were successful in depreciating the exchange rate. Nonetheless, during 2008-2010, when both policies were used simultaneously, they effectively produced an average daily depreciation.	When capital controls and FXI are applied separately, they have the side effect of augmenting the exchange rate volatility. During 2008-2010, when both policies were used simultaneously, they effectively generated a depreciation without increasing its volatility.	Contemporary	Contemporary
Uribe and Toro (2005)	2002-2003, daily	Volatility options and discretionary options	Event study	- Rule based intervention: Yes - Discretionary options: Yes	-	- Rule-based intervention: effective in moving the exchange rate in the short-term (during the intervention) and in the long-term (21 days after intervention). - Options: in the short-term, the options were effective in 2 of 3 events, while in the long-term, the options were effective in 3 of the 3 events analyzed.	-
Villamizar-Villegas (2016)	1999-2012, daily	Spot and discretionary options	BI-TOVIT	No	A 100 million USD intervention decreases volatility by 0.5 percent.		3 weeks

Appendix B. Time Series Properties

B.1. Stationarity

Table 7: Test for Stationarity

	(1) $\log(e_t) - \log(e_{t-1})$	(2) $\text{Vol}_t - \text{Vol}_{t-1}$	(3) GARCH(1,1)	(4) Run. Var.
Test statistic	-37.008	-36.712	-3.603	-2.803
P-value	0.000	0.000	0.0057	0.0579

Notes: H_0: Random walk without drift. The test is performed on different variables. Column 1 refers to the difference between the log average daily exchange rate. Column 2 refers to the difference between the exchange rate volatility. Column 3 presents results for the exchange rate variance predicted from a GARCH(1,1) model. Column 4 refers to the rule that triggered either the issuance or exercise of FX options.

B.2. Heteroskedasticity

Table 8: Test for Heteroskedasticity

	(1)	(2)	(3)	(4)	(5)	(6)
	$\log(e_t) - \log(e_{t-1})$		$\text{Vol}_t - \text{Vol}_{t-1}$		GARCH(1,1)	
	Put	Call	Put	Call	Put	Call
Test statistic	7.937	15.894	7.873	12.792	2.004	0.214
P-value	0.0473	0.0012	0.0487	0.0051	0.5715	0.9753

Notes: H_0: Disturbance is homoskedastic. Each column performs the test following the specification from Equation 6 either by sales or purchases of dollars, for different outcomes.