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# Options and central bank currency market intervention: The case of Colombia ☆

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ABSTRACT

Many central banks in emerging economies are concerned with excessive volatility in foreign exchange markets, especially those with inflation-targeting regimes. Historically, many have intervened using foreign exchange reserves in directly the spot market. However, these are not the only strategies available for intervention. The Colombian central bank implemented various intervention strategies while maintaining its inflation-targeting goals. In this paper we analyze the strategies employed by Colombia, with a special focus on the volatility option strategy. We argue that the abandonment of the currency options program for intervention was premature and that its success was not fully appreciated in previous literature.



## 1. Introduction

In several emerging market economies, policy makers intervene into currency markets to exert control over exchange rates.[2] Some intervene to calm disorderly markets and relieve liquidity shortages, while others

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[2] Emerging markets are economies where some market segments are developed, while others are still not developed or underdeveloped.

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try to correct misalignment and stabilize volatile exchange rates.[3] According to a Bank of International Settlements survey of 19 central banks in emerging markets, two-thirds reported conducting some type of currency market intervention and found it to be an effective tool for controlling exchange rate volatility (Mihaljek, 2004). All policy makers surveyed stated that interventions which influence future expectations and signal a future stance of monetary policy are the most effective ones. Moreover, these interventions are understood to primarily have a short-term influence on currency markets. Since currency markets are very dynamic, especially in emerging markets, the most effective intervention strategies will be the ones that are consistent.

In this paper, we analyze the Colombian central bank intervention strategies, with a specific focus on the central bank's use of currency options to mitigate exchange rate volatility.[4] Historically, currency interventions have consisted of using foreign exchange reserves to purchase and sell foreign currency directly in the spot market. However, these spot market interventions are not the only type of intervention available for central banks. The Colombian central bank has implemented various strategies to intervene into currency markets to smooth volatility, build reserves, and influence the direction of the exchange rate. Moreover, it has been one of the only economies to auction options as a tool for smoothing exchange rate volatility. This intervention technique was abandoned in favor of daily discretionary interventions in the spot market.

In this paper, we argue that the abandonment of options was premature. Past analyses of currency options as a central bank intervention mechanism lacked the data to support the conclusion that options were only moderately successful in curbing volatility. Using event study methodologies, we find that in fact in 80 to 90% of the cases the currency options auctioned by the central bank were successful in lowering volatility and countering persistent appreciation or depreciation of the currency. With this research, we contribute to the literature by reexamining the success of the use of options to curb drastic exchange rate movements and revisiting the discussion of the use of options as a viable alternative to continual or excessive reserve accumulation for the purpose of foreign exchange market intervention using all available data on options in Colombia.

The remaining sections of the paper are structured as follows. Section 2 presents a review of past literature on central bank intervention, linkages between policy goals and exchange rates, and macroeconomic fundamentals of currency markets. Section 2.1 illustrates the current macroeconomic situation in Colombia. Section 3 describes Colombia's central bank currency intervention strategies, and section 2.2 discusses the historical use of options as an intervention mechanism. Section 4 details the methodology used for analysis and section 5 presents the results of the analysis for the case of Colombia. Section 6 discusses implications of the findings and future extensions of the research.

## 2. Literature review

This section summarizes the literature on central bank interventions in foreign exchange markets. First, we address the main macroeconomic fundamentals that influence exchange rate movements as well as the linkages between inflation-targeting goals and exchange rates in emerging markets. Then, we present central banks' interventions in currency markets and describe their goals and the transmission mechanisms to lower volatility and provide liquidity to currency markets.

### *2.1. Macroeconomic fundamentals, inflation-targeting and exchange rates*

The value of a country's currency reflects the market's expectation about its current and future macroeconomic conditions, as well as its political and social climate. In this paper, we concentrate on the former. Many theoretical models have linked exchange rate movements to changes in macroeconomic conditions.[5] Among them, the *monetary model* presented in Dornbusch (1976) determines that changes in the domestic money supply that affect the domestic interest rate relative to the foreign interest rate will translate into adjustments in nominal exchange rates. For example, an increase in the domestic money supply will require a decrease in

[3] Such volatility can cause banking crises, economic instability, slowing growth and decrease in trade.

[4] The central bank of Colombia used currency options as a tool for both controlling volatility as well as adjusting international reserves. We focus our analysis on the former strategy and the impact of volatility options on the Colombian peso–US dollar exchange rate.

[5] A currency's value will react to changes in macroeconomic fundamentals including trade, monetary policy, balance of payments, aggregate demand and supply (Obstfeld and Rogoff, 1999).

the domestic interest rate to adjust for the excess supply of real money balances with no change in the foreign interest rate. The relative decrease in the domestic interest rate to foreign interest rate will translate to a depreciation in the nominal exchange rate as foreign investors move their money out of the country.

In another model, the *portfolio balance model* presented in Dornbusch and Fischer (1980), exchange rates determine the equilibrium between domestic money, domestic bonds and foreign bonds. Changes in domestic money supply or supply of bonds will drive changes in the exchange rate to maintain equilibrium. An increase in the supply of domestic bonds,[6] an increase in foreign interest rate,[7] or expectation of future depreciation[8] will result in a depreciation of the domestic currency. An increase in the supply of foreign bonds[9] or an increase in the domestic interest rate[10] results in an appreciation of the domestic currency in this channel.

The impact of exchange rates on inflation targets and on monetary policy goals has been a concern for many emerging economies due to their weaker financial system and their susceptibility to external shocks. Inflation-targeting has been adopted by a number of both emerging and advanced economies over the last two decades. Even though it has been considered advantageous as a framework for monetary policy, the macroeconomic effects of inflation-targeting in empirical terms have been limited (Levin et al., 2004). In industrialized economies, inflation-targeting has been most effective in controlling long run inflation expectations and lowering the persistence of inflation. On the other hand, Fraga et al. (2003) argue that emerging markets face more acute trade-offs when choosing the design of their inflation-targeting monetary policy, including higher output and inflation volatility. Moreover, due to a more volatile macroeconomic environment, the implementation and commitment to inflation-targeting become more difficult in emerging markets than in developed economies.

The use of exchange rates as a policy tool for inflation-targeting has been found to be more important for emerging markets than for their industrialized counterparts for a number of reasons (Stone et al., 2009): First, in emerging markets the presence of a high exchange rate pass-through[11] could signal lower policy credibility and translates to a closer link between price and exchange rate movements. Additionally, less developed financial systems in these countries correspond to more rigidity in currency markets, which amplifies the impact of exchange rate shocks on the domestic economy. In this sense, intervention reflects the desire of central banks in emerging markets to mitigate the impact of short-term currency fluctuations on output. Finally, active management of the exchange rate with international reserves is seen as a way to promote financial stability and minimize the negative effects on the domestic economy of sudden stops or reversals in foreign currency inflows.

A high exchange rate pass-through in emerging markets makes it more difficult for central banks to target low inflation rates and maintain price stability (Minella et al., 2003; Fraga et al., 2003). Acosta-Ormaechea and Coble (2011) find that in emerging markets with high levels of dollarization and a strong exchange rate pass-through, inflation-targeting is more effective through policies that target exchange rates rather than interest rates. Reyes (2013) finds that the implementation of inflation-targeting paired with currency market interventions may aid in decreasing the degree of pass-through, and that the exchange rate pass-through effect is on the decline in emerging markets. Though the effects of nominal exchange rate fluctuations on inflation rates can still be felt in these economies, he argues that the decline in the pass-through is a natural result of the implementation of inflation-targeting policies. Through a correlation analysis, he finds that countries that adopted inflation-targeting while continuing direct or indirect interventions into currency markets

[6] An increase in the supply of domestic bonds will lead to a decrease in the domestic interest rate and foreign investors will move their money elsewhere, in turn increasing the relative demand for foreign currency to domestic currency, which will lead to a depreciation of the domestic currency.

[7] An increase in the foreign interest rate relative to the domestic interest rate will lead to an outflow of foreign investment from the domestic economy, which in turn causes an increase in the demand for foreign currency and a depreciation of the nominal exchange rate.

[8] Through the signaling channel, the anticipation of a future depreciation by investors will trigger a sell off of domestic currency and lead to a depreciation in the current time.

[9] An increase in the supply of foreign bonds will lead to an increase in the relative domestic interest rate and increase in the demand for domestic currency relative to foreign currency, which will lead to an appreciation of the domestic currency.

[10] An increase in the domestic interest rate relative to the foreign interest rate will lead to an inflow of foreign investment into the domestic economy, which in turn causes an increase in the demand for domestic currency and an appreciation of the nominal exchange rate.

[11] The exchange rate pass-through effect relates movements in the exchange rate to changes in domestic prices. For example, an increase in the relative price of imports will translate to higher domestic prices. Therefore, in emerging markets with high exchange rate pass-through, changes in exchange rate values will also affect inflation rates.

experienced a decline in the pass-through between currency depreciation and inflation. The interventions in these countries are now justified by the adoption of the inflation-targeting regime, and in turn lower the correlation between exchange rate and inflation movements. In a related issue, Sek (2008) finds that the reaction of monetary policy[12] to exchange rate shocks in three inflation-targeting East Asian economies has declined after the East Asian crisis.[13] However, if the pass-through effect is on the decline due to the implementation of inflation-targeting with a complimentary intervention strategy, as argued by Reyes (2013), this explains why Sek (2008) finds a lower reaction of monetary policy to exchange rate shocks after the Asian crisis.

According to Taylor (2001), an appreciation of the domestic currency can lead to lower output and inflation in future periods due to expenditure switching and because import prices will not rise as quickly with the appreciation. It is also important to note that the reaction of interest rates to an appreciation is indirect because interest rates react to changes in inflation and real GDP rather than directly to fluctuations in the exchange rate. Taylor concludes that policy makers' reactions to changes in the exchange rate by adjusting interest rates may not improve performance because this mechanism is already indirectly built into the policy rule, and because the reaction in real output and inflation can create swings that can worsen the economic situation of a country. Additionally, changes in exchange rates under floating exchange rate regimes may indicate changing productivity and should not be ignored.

### *2.2. Foreign exchange market intervention by central banks*

The central bank's main goals when intervening in currency markets are to smooth exchange rate volatility, supply liquidity into foreign exchange markets and to control the amount of foreign exchange reserves (Moreno, 2005). The broad motives for intervention are driven by macroeconomic goals, such as inflation-targeting, maintaining economic stability and competitiveness, preventing crises and boosting growth.

There are four main channels through which the central bank can intervene into currency markets (Archer, 2005). First, in the *monetary channel*, a change in the domestic money supply will alter the domestic interest rate relative to the foreign interest rate, as discussed above. This change in relative interest rates will alter the value of the domestic currency as investors react to the change and alter their demand for foreign and domestic currency. Second, in the *portfolio balance channel*, the issuance of domestic bonds and the relative scarcity of domestic assets to foreign assets will lead investors to reallocate their portfolios in a way that can change relative prices, including the value of the exchange rate. Third, through the *signaling and expectations channel*, the central bank can shape expectations on future monetary and exchange rate policy. Influencing expectations through the promise of future intervention can curb speculative behavior and coordinate the direction of the currency value towards equilibrium. As usual, the credibility of the signal is also critical. However, it has been observed that signals to control appreciation tend to be more credible than those to curb depreciation. Lastly, in the *order flow channel*, the central bank tracks order flows in foreign exchange markets to predict subsequent price action. Central bankers can intervene by altering the order flow with their own orders. Their intervention must be large relative to the total market turnover to have an impact. Because the relative size of the intervention to total market turnover is crucial for this channel to be effective, Archer argues that it may be more productive in emerging economies where there is less liquidity in currency markets.

In emerging markets and developing economies, 82% of interventions take place in the spot market due to the fact that this is the main or only currency market in the economy (Canales-Kriljenko, 2003). If the intervention is unsterilized, effectively changing the domestic money supply, it can directly influence the nominal exchange rate. Craig and Humpage (2001) note that unsterilized interventions can conflict with price stabilization due to the possible change of the relative price of foreign goods to local goods.[14] To counteract the effect of an appreciation and to maintain exchange rate stability, the central bank can increase the domestic money supply by purchasing foreign currency in the spot market, leading to inflation while influencing the nominal

[12] The monetary policy measures used by the author include money demand (M1), short-term interest rates, output gap, and inflation.

[13] The three economies are Thailand, Korea and Philippines.

[14] Such an effect can occur when there is an excess supply of foreign goods. For example, an increase in the supply of foreign goods will decrease their price in foreign currency, in turn decreasing the demand for foreign currency and effectively leading to an appreciation of the domestic currency.

exchange rate. Therefore, Craig and Humpage (2001) argue that such unsterilized interventions can impact nominal exchange rates but at the cost of price stability.

On the other hand, sterilized spot market intervention by the central bank does not change the country's monetary base when it involves buying and selling of domestic and foreign bonds (Weber, 1986). If sterilized, the intervention will affect volatility through expectations and by attempting to curb speculative behavior. The primary purpose of sterilized interventions has been to counter appreciation of the domestic currency in fixed or managed float exchange rate regimes without impacting real exchange rates to diminish inflationary pressure coming from changes in foreign currency inflows (Agenor, 2004). From a theoretical perspective, sterilized interventions can influence exchange rates if bonds denominated in different currencies are not perfect substitutes (Weber, 1986). The success of sterilized interventions in lowering volatility has been questionable (Breuer, 1999). Craig and Humpage (2001) suggest that such sterilized interventions have been ineffective in the US because they do not affect macroeconomic fundamentals. Instead, these interventions influence expectations and perceptions, which we believe are equally valuable in determining exchange rate movements in emerging markets.

In terms of the size, frequency and timing of intervention, Mihaljek (2004) cites that when the goal of the intervention is to influence the exchange rate, central banks find larger and less frequent interventions to be more effective. In contrast, when the goal is to reserve accumulation, frequent but smaller interventions are more successful. In addition, he finds that many emerging market central banks view currency market intervention as an effective tool to use within their monetary policy framework, but the success of the intervention is related to what is happening both in financial markets and with macroeconomic fundamentals. With weak fundamentals, central banks are aware that intervention will not be effective in stabilizing exchange rate markets, and other measures must be considered to strengthen fundamentals along with attempts to stabilize currency markets.

## 3. Central bank currency intervention strategies in Colombia

Colombia has experimented with many different intervention tools in its recent history. The Colombian central bank began systematic currency market interventions following the introduction of a floating exchange rate regime and the adoption of inflation-targeting monetary policy in 1999 (Uribe and Toro, 2005). They were the first to introduce the use of currency options for reserve accumulation and later, to control for volatility. From 2002 to 2009, the average yearly purchase of US dollars by the Colombian Central Bank was US$ 2.7 billion,[15] representing an average of 1.7% of total domestic market transactions (Echavarria et al., 2013). From 2005 to 2007, the purchase of US dollars by the central bank was much larger, the latter reflecting a change in policy to daily discretionary purchases. The intervention activity of the central bank has been illustrated in Fig. 1.

From 2002 to 2009, the Colombian peso experienced a number of volatile periods. The top panel in Fig. 2 illustrates the market bid and ask prices along with the official exchange rate in Colombia from 2002 to 2009. The middle panel illustrates the spread between the bid and ask prices. The bottom panel depicts the midquote 20-day volatility, which is calculated as the standard deviation of the percent change in the midquote value of the COPUSD over a 20-day rolling window.[16] High volatility in the Colombian peso corresponds to the period prior to the introduction of a managed float. From 2004 onward, volatility in the mid-quote reached very low levels, corresponding to the central bank's interventions to stabilize the exchange rate starting in 2004. In response to the appreciation experienced that started in 2003, the Colombian central bank began intervening much more frequently and in larger positions than ever before, switching the currency regime to a managed float. This strategy was used to supplement the inflation-targeting policies that the central bank had adopted (Vargas, 2005).

From a global perspective, in 2013 Colombia's currency trading represented approximately 0.05% of all currencies traded on a net-gross basis,[17] representing a daily average trade of US$ 3.34 billion. Foreign

[15] Sales were smaller at US$ 382 million.

[16] We have used Bloomberg to construct this figure as this data is the industry benchmark. However, it is important to note that there are significant discrepancies with another industry providers, like OANDA, which require further research and analysis. We plan to pursue this in future research.

[17] Net-gross basis adjusts for only local inter-dealer double-counting. Data were taken from the Bank of International Settlements.

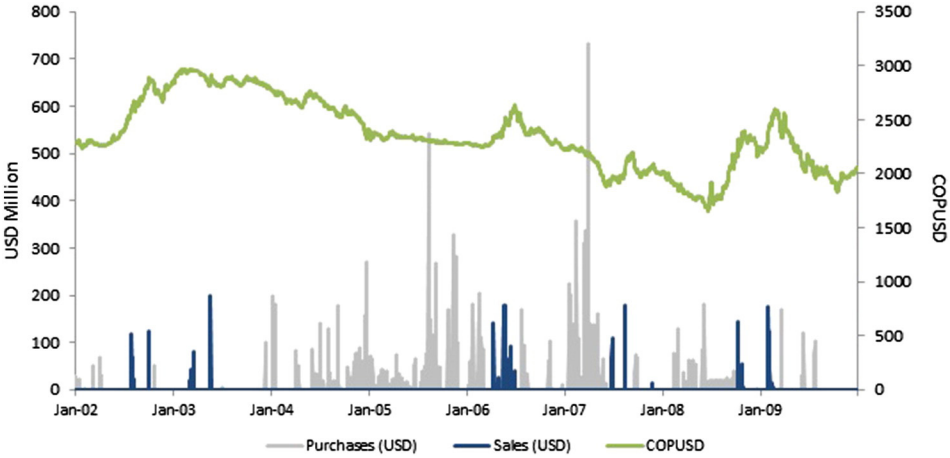



**Fig. 1.** Central bank interventions. The figure represents the volume and frequency of Colombia's central bank interventions into its domestic foreign exchange market. The purchase and sale of US Dollars are represented by the bar graph, including both spot market interventions (discretionary interventions) and auctioning of options contracts. The purchase of US dollars happened more frequently, and at a larger volume, than the sale of USD by the central bank over this period.

exchange markets in Chile and Peru have similar characteristics, as can be seen in Table 1. On a global scale, the foreign exchange trading of these currencies is low relative to all global spot market transactions, which in 2013 reached a daily average volume of US$ 6.7 trillion according to the Bank of International Settlements.

Colombia is one of the few countries to date that have auctioned call and put options to mitigate exchange rate volatility and adjust reserve holdings. Colombia's central bank stated clearly that when issuing options contracts, its main objectives were not only to avoid excessive volatility in the exchange rate but also to do it in a way that would uphold inflation targets, strengthen the international liquidity position domestically and smooth any deviations of the exchange rate from its long run trend. The auctions of options contracts in Colombia were fully transparent and the benefits of these auctions were derived from the hedging operations of market participants (Uribe and Toro, 2005).

Table 2 summarizes each type of options contract by providing details on the action taken by the owner of the contract, purpose of auction, amount auctioned, and conditions for auction by the central bank of Colombia. Recall that Colombia's central bank was the issuer or seller of the option contracts. The strike prices for all options were set as the official exchange rate as reported by Tasa Representativa de Mercado at the close of the day prior to auction.

For the purposes of reserve accumulation and decumulation, the central bank auctioned options contracts on a monthly basis. To accumulate reserves, the central bank auctioned put options with a maturity of 30 days, which give the buyer of the contract[18] the right to sell US dollars at a given price (strike price) to the central bank at maturity. The central bank was obligated to fulfill this contract, and therefore accumulated US dollars when the contract was exercised. To decumulate reserves, call options with a maturity of 30 days were auctioned. The owner of the call option had the right to buy US dollars at a given price (strike price) from the central bank, and in turn, by fulfilling its contractual obligations, the central bank decreased the amount of foreign reserves that it held. The options were exercised when the exchange rate appreciated or depreciated with respect to the 20-day moving average mean.

Volatility options with 30-day contract maturity were auctioned whenever the exchange rate changed more than a given percentage variation with respect to the 20-day moving average. Until December 2001, the maximum percentage variation was set to 5%; 4% from December 2001 to February 6, 2006; 2% from February 6, 2006 to June 24, 2008; and 5% from June 24, 2008 to October 13, 2011. The volatility option

[18] The buyer of the contract is in the long position, whereas the seller or issuer is in the short position.

could be exercised at any time within contract period when COPUSD appreciated or depreciated more than the established percentage variation with respect to the 20-day moving average.[19] In many cases, the option was auctioned and immediately exercised on the same day or the following day, as can be seen in Tables 3 and 4, which detail the date and amount of auction, frequency and amount of exercise, the option premium and the corresponding change in COPUSD relative to the 20-day moving average.

During periods when the COPUSD appreciated by more than the given percentage variation, volatility put options were auctioned to mitigate the appreciation pressure. By auctioning put options, the central bank was obligated to buy US dollars (or equivalently, to sell pesos) from the owners of the contract at maturity or at the exercise date. Through the expectations or signaling channel, this action was aimed to show the central bank's commitment to increasing the relative supply of Colombian pesos to US dollars through the purchase of US dollars (or sale of Colombian pesos) at contract maturity or exercise date. By doing so, the volatility put options created depreciationary pressure to counteract the appreciation over the 20-day moving average.

During periods when the COPUSD depreciated by more than the set percentage change with respect to the 20-day moving average, volatility call options were auctioned to counter the depreciation. By auctioning call options, the central bank was obligated to sell US dollars (or equivalently, to buy pesos) to the owners of the contract at maturity or at the exercise date. This action was aimed to show the central bank's commitment to decreasing the relative supply of Colombian pesos to US dollars in the market through the sale of US dollars (or purchase of Colombian pesos) at contract maturity or date of exercise. By doing so, the volatility call options introduced appreciationary pressure to counter the depreciation over the 20-day moving average.

For the volatility options contracts, the maximum amount exercised was US$ 180 million. In addition, the amount to be auctioned in the subsequent month was determined at the end of each contract. From 1999 to 2009, there were a total of 38 volatility options contracts auctioned by the Colombian central bank, consisting of 21 volatility put options and 17 volatility call options. The options intervention strategy was abandoned when the central bank switched intervention strategies to a daily discrete intervention plan, where the central bank purchases an average of US$ 20 million per day.

From Tables 3 and 4, it is evident that in the majority of cases, the options were exercised almost immediately after they were auctioned. In only six out of 38 cases was the last date of exercise more than 10 days after auction. Additionally, the persistence of appreciation or depreciation were the main drivers of the premium in each case. When we compare the premiums in Tables 3 and 4 to the corresponding changes in the COPUSD 20 days prior to the auction date presented in Figs. 3 and 4, there is a drastic and persistent appreciation (for puts) or depreciation (for calls) for options with the highest premiums, indicating that risks can be understood by both the spreads (see Fig. 2) and premiums.

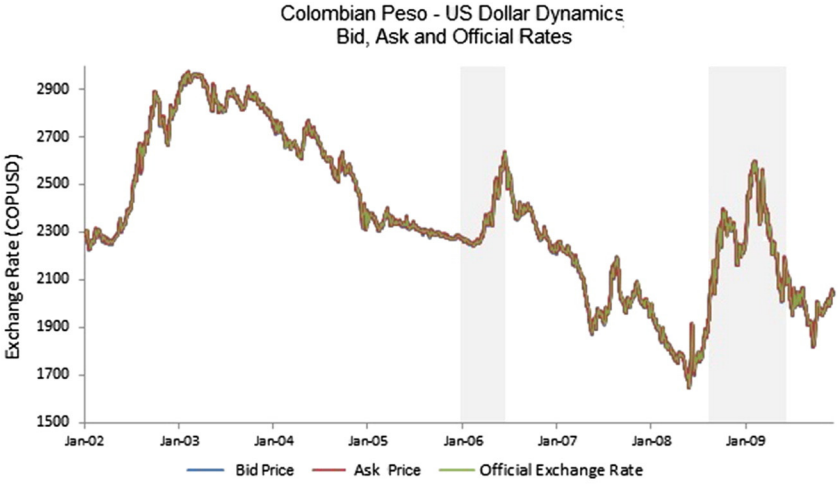
Fig. 5 illustrates intervention with volatility put options and volatility call options and the corresponding exchange rate volatility of the COPUSD from 2002 to 2009, the duration of the option-based intervention strategy of the Colombian central bank. The auctioning of the volatility options was sporadic and dictated by any drastic movements of the exchange rate in the spot market.[20]

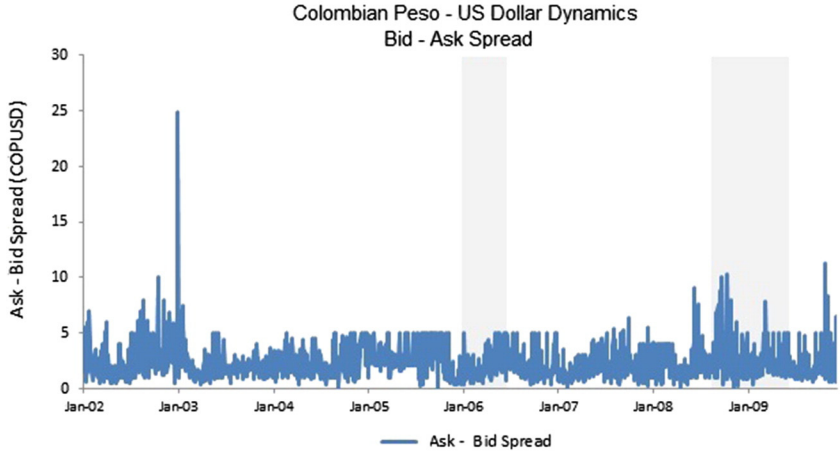
Starting in 2008, the Colombian central bank began purchasing US$ 20 million daily, first for two months in 2008, then for five months in 2010, for six months in 2011, and every month since 2012. The daily discretionary intervention of US$ 20 million in average was selected to mimic the policies adopted by Chile and Israel (Echavarria et al., 2013). From August 2012, the amount purchased varied from US$ 20 million to US$ 50 million daily. The average intervention represents 3.7% of total US dollars traded in the Colombian foreign exchange market, with a maximum intervention that totaled 33.6% of the market volume. As mentioned before, Colombia abandoned the use of options-based intervention once it began the daily purchase of US dollars. The change in policy has been considered a good mechanism for accumulating reserves without promoting speculative behavior because it is a consistent and transparent intervention.

At this point, it is important to mention that there have been some studies conducted on the use and effectiveness of options contracts by the Colombian central bank. Mandeng (2003) finds that volatility call

[19] For example, in July 2006, the COPUSD appreciated more than 2% of the 20-day moving average, and US$ 180 million in volatility put options were auctioned. In the subsequent 3 business days after auction, the COPUSD continued to be over 2% of the moving average and the contracts were exercised, totaling US$ 180 million. See Table (3).

[20] Although the rule to trigger an auction of volatility options was established as described above, there were times when the central bank did not immediately auction options. Especially during periods with high variation when auctions already occurred, the central bank chose to wait to see how the market would react to the previously auctioned options before selling more.


Colombian Peso - US Dollar Dynamics
Bid, Ask and Official Rates
Exchange Rate (COPUSD)
2900
2700
2500
2300
2100
1900
1700
1500
Jan-02
Jan-03
Jan-04
Jan-05
Jan-06
Jan-07
Jan-08
Jan-09
Bid Price
Ask Price
Official Exchange Rate


Colombian Peso - US Dollar Dynamics
Bid - Ask Spread
Ask - Bid Spread (COPUSD)
30
25
20
15
10
5
0
Jan-02
Jan-03
Jan-04
Jan-05
Jan-06
Jan-07
Jan-08
Jan-09
Ask - Bid Spread

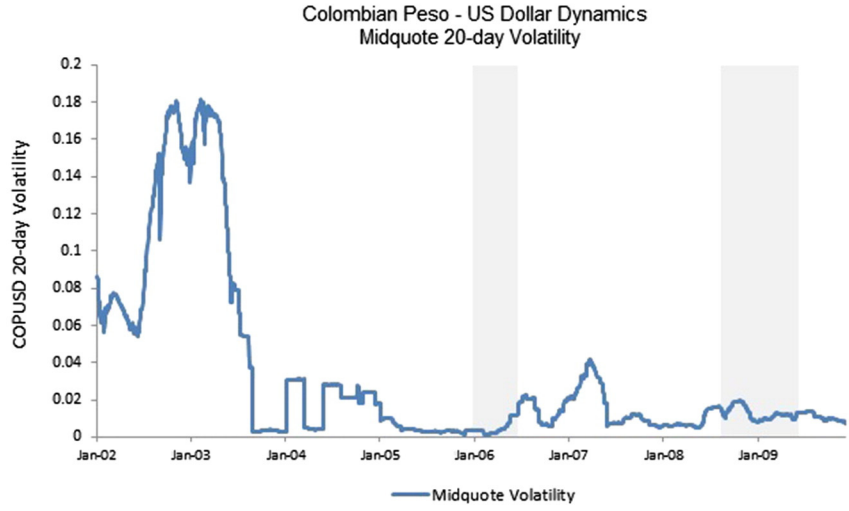

Colombian Peso - US Dollar Dynamics
Midquote 20-day Volatility
COPUSD 20-day Volatility
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-02
Jan-03
Jan-04
Jan-05
Jan-06
Jan-07
Jan-08
Jan-09
Midquote Volatility

**Table 1**
Foreign exchange markets: Global vs. domestic.

| | | 2004 | 2007 | 2010 | 2013 |
|---|---|---|---|---|---|
| *Colombia* | | | | | |
| Global transactions | Daily average traded volume (USD Mil), % of global daily trades | 802<br>0.03% | 1860<br>0.04% | 2794<br>0.06% | 3343<br>0.05% |
| Domestic interbank transactions | Total interbank traded volume (USD Mil), daily average traded volume (USD Mil), % of daily average global traded volume | 107,660<br>476<br>59.4% | 199,590<br>821<br>44.1% | 256,514<br>1056<br>37.8% | 219,670<br>904<br>27.0% |
| *Chile* | | | | | |
| Global transactions | Daily average traded volume (USD Mil), % of global daily trades | 2462<br>0.09% | 4003<br>0.09% | 5544<br>0.11% | 11,956<br>0.18% |
| Domestic interbank transactions | Total interbank traded volume (USD Mil), daily average traded volume (USD Mil), % of daily average global traded volume | 323,975<br>1295<br>52.6% | 419,576<br>1698<br>42.4% | 379,433<br>1518<br>27.4% | 617,102<br>2488<br>20.8% |
| Domestic spot market | Total spot market volume (USD Mil), interbank trades (% total spot volume) | 496,175<br>65.3% | 712,086<br>58.9% | 745,207<br>50.9% | 1,196,890<br>51.6% |
| *Peru* | | | | | |
| Global transactions | Daily average traded volume (USD Mil), % of global daily trades | 306<br>0.01% | 805<br>0.02% | 1425<br>0.03% | 2171<br>0.03% |
| Domestic interbank transactions | Total interbank traded volume (USD Mil), daily average traded volume (USD Mil), % of daily average global traded volume | 18,602<br>71<br>23.2% | 30,294<br>116<br>14.4% | 93,378<br>356<br>25.0% | 177,431<br>677<br>31.2% |

This table presents data on global and domestic foreign exchange trading in three economies: Colombia, Chile and Peru. The global transactions illustrate the average daily foreign exchange transactions for each currency on global markets, as well as the ratio to the total transactions in all currencies. Data for global transactions comes from the Bank of International Settlements. The domestic interbank transactions capture the total annual volume of interbank foreign exchange trading, as well as the average daily volume of interbank foreign exchange transactions. Data for interbank foreign exchange transactions comes from the central banks. For Chile, we also present the total spot market transaction volume for banks, which includes foreign exchange purchases from third parties, sales to third parties and interbank transactions. Data is provided by the central bank of Chile. Colombia and Peru do not have comparable datasets publicly available.

options issued until 2003 were only moderately successful in decreasing short term exchange rate volatility. On the other hand, Uribe and Toro (2005) states that from 1999 to 2002 reserve adjustment put options were successful in the accumulation of reserves. They also find that Colombia's intervention policies have been largely consistent with its inflation-targeting goals. As such, changes in monetary policy came first through interest rates and then through intervention in currency markets. It is important to note that both studies were made using data of only the first years of the interventions. In this paper, we concentrate on the effects of options used to manage exchange rate volatility and use all available data from 2002 to 2009. In this way, we compare and complement their results using a more complete dataset with some additional technical aspects that we fully describe in the next section and develop in Section 5.

## 4. Methodology

To determine the success of the volatility options issued in Colombia from 2002 to 2009, we employ an exhaustive statistical analysis and event study methodologies to analyze the effectiveness of options in smoothing volatility and influencing the dynamics of the Colombian peso–US dollar exchange rate. First, we focus on determining the success of the volatility options in terms of deviations of the COPUSD from the 20-day moving average. Next, we compare exchange rate volatility before and after the auction date using 2 day, 5 day and 10 day volatilities to test the duration of effectiveness. Lastly, using an analysis-of-

**Fig. 2.** Colombian peso dynamics.The top graph represents the value of the official COPUSD exchange rate, the bid price and the ask price in the market. The middle graph illustrates the spread between the bid and ask prices. The bottom graph depicts the midquote 20-day volatility, which is calculated as the standard deviation of the percent change in the midquote value of the COPUSD over a 20-day rolling window. Market rates from Bloomberg. Official exchange rate data from Banco Republica de Colombia. Shaded areas represent the 2006 emerging market sell-off and 2008–2009 global financial crisis.

**Table 2**
Details of currency option strategies used by Colombia.

| | Action by buyer | Purpose | Conditions for auction | Amount for auction | Maturity | Conditions for exercise | Total amount exercised |
|---|---|---|---|---|---|---|---|
| Reserve adjustment call options | Right to buy USD from Central Bank | Decumulation of reserves | Based on policy directive: occasional | Determined at the end of the previous month (Max: USD $ 200 million) | 30 days, auctioned each month | COPUSD at maturity is greater than strike price | USD $ 344 million |
| Reserve adjustment put options | Right to sell USD to Central Bank | Accumulation of reserves | Regular auction per month | Determined at the end of the previous month (Max: USD $ 200 million) | 30 days, auctioned each month | COPUSD at maturity is less than strike price | USD $ 3.35 billion |
| Volatility call option | Right to buy USD from Central Bank | Counter depreciation pressure | Depreciation of COPUSD by more than 4%[a] of 20-day moving average | USD $ 180 million | 30 days, auctioned as deemed necessary | Any time within contract period when COPUSD has depreciated more than 4%[a] of 20-day moving average | USD $ 2.33 billion |
| Volatility put option | Right to sell USD to Central Bank | Counter appreciation pressure | Appreciation of COPUSD by more than 4%[a] of 20-day moving average | USD $ 180 million | 30 days, auctioned as deemed necessary | Any time within contract period when COPUSD has appreciated more than 4%[a] of 20-day moving average | USD $ 2.37 billions |

Strike prices for all options: Official exchange rate at close of the day before auction as reported by Tasa Representativa de Mercado. Details from Banco de Central of Colombia and Mandeng (2003). The total amount exercised presents the total volume of options that were exercised at maturity in each category from 1999 to 2009, at which time the use of options as an intervention tool was abandoned.

[a] Until December 2001, the set percentage was 5%; from December 2001 to February 6, 2006 it was 4%; from February 6, 2006 to June 24, 2008 it was 2%; from June 24, 2008 to October 13, 2011 it was 5%.

**Table 3**
Auction and exercise of volatility put options in Colombia.

| Volatility put options | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Date of auction | Auction amount (USD Mil) | Date of exercise | Exercise amount (USD Mil) | Duration (days) | Premium | Trigger value |
| (A) | 17-Dec-04 | 179.9 | 17-Dec-04 | 157.9 | – | 4000 | −3.9% |
| (B) | 11-Jul-06 | 180.0 | 24-Jul-06 | 170.0 | 16 | 10,000 | −3.3% |
| | | | 27-Jul-06 | 10.0 | | | −2.5% |
| (B) | 31-Jul-06 | 180.0 | 02-Aug-06 | 44.5 | 4 | 11,100 | −2.4% |
| | | | 03-Aug-06 | 95.0 | | | −2.4% |
| | | | 04-Aug-06 | 40.5 | | | −2.7% |
| (B) | 10-Aug-06 | 179.9 | 15-Aug-06 | 33.8 | 5 | 12,000 | −2.4% |
| (C) | 30-Oct-06 | 180.0 | 31-Oct-06 | 62.3 | 10 | 8150 | −1.9% |
| | | | 01-Nov-06 | 4.0 | | | −2.0% |
| | | | 02-Nov-06 | 0.5 | | | −2.1% |
| | | | 08-Nov-06 | 102.2 | | | −1.9% |
| | | | 09-Nov-06 | 11.0 | | | −1.9% |
| (D) | 21-Dec-06 | 179.9 | 21-Dec-06 | 10.0 | – | 12,000 | −2.0% |
| | 30-Mar-07 | 161.0 | N/A | – | N/A | 100 | −1.9% |
| (E) | 03-May-07 | 180.0 | 03-May-07 | 162.0 | 1 | 3130 | −2.2% |
| | | | 04-May-07 | 18.0 | | | −2.4% |
| (E) | 15-May-07 | 180.0 | 15-May-07 | 11.2 | 10 | 6000 | −4.3% |
| | | | 16-May-07 | 27.5 | | | −4.3% |
| | | | 18-May-07 | 24.5 | | | −3.8% |
| | | | 22-May-07 | 66.8 | | | −3.4% |
| | | | 25-May-07 | 50.0 | | | −3.4% |
| (E) | 04-Jun-07 | 180.0 | 04-Jun-07 | 14.5 | - | 7100 | −4.8% |
| (F) | 20-Sep-07 | 180.0 | 20-Sep-07 | 37.5 | 6 | 13,500 | −4.5% |
| | | | 21-Sep-07 | 73.8 | | | −4.9% |
| | | | 26-Sep-07 | 68.3 | | | −4.1% |
| | 11-Dec-07 | 180.0 | N/A | – | N/A | 6130 | −2.1% |
| (G) | 15-Jan-08 | 180.0 | 13-Feb-08 | 25.7 | 30 | 8150 | −2.4% |
| | | | 14-Feb-08 | 77.0 | | | −2.4% |
| (G) | 20-Feb-08 | 180.0 | 28-Feb-08 | 130.0 | 28 | 4001 | −2.7% |
| | | | 19-Mar-08 | 38.0 | | | −2.3% |
| (G) | 25-Mar-08 | 179.9 | 24-Apr-08 | 62.5 | 30 | 5000 | −2.1% |
| (H) | 04-Jun-08 | 180.0 | 04-Jun-08 | 23.0 | 1 | 5200 | −2.5% |
| | | | 05-Jun-08 | 157.0 | | | −2.4% |
| (I) | 18-Dec-08 | 180.0 | 18-Dec-08 | 2.3 | – | 11,050 | −5.6% |
| (J) | 17-Mar-09 | 179.9 | 18-Mar-09 | 11.1 | 2 | 8900 | −5.8% |
| | | | 19-Mar-09 | 168.9 | | | −5.7% |
| | 27-Apr-09 | 179.9 | N/A | – | N/A | 3500 | −4.5% |
| (K) | 03-Jun-09 | 180.0 | 04-Jun-09 | 32.0 | 8 | 11,150 | −5.6% |
| | | | 05-Jun-09 | 26.5 | | | −5.4% |
| | | | 11-Jun-09 | 121.6 | | | −5.3% |
| (L) | 22-Jul-09 | 180.0 | 22-Jul-09 | 77.1 | 1 | 9100 | −5.0% |
| | | | 23-Jul-09 | 102.4 | | | −5.1% |

This table depicts the volatility put options issued by the central bank of Colombia from 2002 to 2009. When the COPUSD appreciated more than the set percentage of the 20-day moving average, the Central Bank auctioned US$ 180 million in put options. The options could then be exercised on any day when the exchange rate surpassed the set percentage within the contract period. Until December 2001, the set percentage was 5%; from December 2001 to February 6, 2006 it was 4%; from February 6, 2006 to June 24, 2008 it was 2%; and from June 24, 2008 to October 13, 2011 it was 5%.

variance, we analyze the impact of exercising the options on variations between the official exchange rate and 20-day moving average.[21]

By analyzing the dynamics between the COPUSD and 20-day moving average, we are focusing on what we call intraband variation. Central banks can target volatility ranges or bands to ensure that exchange rate

[21] The use of high frequency data for analyzing volatilities would be very interesting and provide a strong robustness check for our analysis. Due to limitations on data availability, we are unable to conduct such an analysis at this time, but we hope to find a way to do so in the future. We thank the anonymous reviewer for this suggestion.

**Table 4**
Auction and exercise of volatility call options in Colombia.

| Volatility call options | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Date of auction | Auction amount (USD Mil) | Date of exercise | Exercise amount (USD Mil) | Duration (days) | Premium | Trigger value |
| (A) | 29-Jul-02 | 180.0 | 29-Jul-02 | 117.0 | 2 | 3800 | 4.0% |
| | | | 31-Jul-02 | 63.0 | | | 4.3% |
| (A) | 01-Aug-02 | 180.0 | 01-Aug-02 | 69.0 | 5 | 4220 | 4.3% |
| | | | 02-Aug-02 | 17.0 | | | 4.0% |
| | | | 06-Aug-02 | 23.5 | | | 4.1% |
| (B) | 02-Oct-02 | 180.0 | 02-Oct-02 | 124.5 | – | 5157 | 4.1% |
| (C) | 10-Apr-06 | 180.0 | 10-Apr-06 | 140.5 | 17 | 6000 | 2.8% |
| | | | 12-Apr-06 | 2.0 | | | 2.2% |
| | | | 27-Apr-06 | 26.0 | | | 1.9% |
| (D) | 16-May-06 | 179.8 | 17-May-06 | 179.8 | 1 | 6000 | 2.0% |
| (D) | 18-May-06 | 179.8 | 18-May-06 | 103.0 | 4 | 9000 | 2.8% |
| | | | 19-May-06 | 1.0 | | | 3.2% |
| | | | 22-May-06 | 75.8 | | | 3.0% |
| (D) | 23-May-06 | 179.9 | 24-May-06 | 179.9 | 1 | 9100 | 4.0% |
| (D) | 25-May-06 | 179.9 | 30-May-06 | 65.5 | 19 | 12,200 | 2.3% |
| | | | 31-May-06 | 3.0 | | | 2.4% |
| | | | 09-Jun-06 | 18.5 | | | 1.8% |
| | | | 13-Jun-06 | 92.9 | | | 2.3% |
| (E) | 27-Jun-06 | 180.0 | 27-Jun-06 | 39.9 | 1 | 13,501 | 3.0% |
| | | | 28-Jun-06 | 16.5 | | | 3.3% |
| (F) | 26-Jun-07 | 180.0 | 26-Jun-07 | 68.7 | 1 | 3500 | 2.3% |
| | | | 27-Jun-07 | 107.8 | | | 2.4% |
| (G) | 13-Aug-07 | 180.0 | 14-Aug-07 | 179.9 | 1 | 4000 | 2.0% |
| (H) | 22-Nov-07 | 180.0 | 23-Nov-07 | 12.5 | 1 | 14,600 | 2.2% |
| (I) | 07-Oct-08 | 179.9 | 07-Oct-08 | 143.9 | 1 | 11,000 | 6.0% |
| | | | 08-Oct-08 | 31.0 | | | 6.0% |
| (I) | 24-Oct-08 | 180.0 | 24-Oct-08 | 54.4 | 3 | 17,200 | 4.8% |
| | | | 27-Oct-08 | 5.3 | | | 5.2% |
| (J) | 30-Jan-09 | 180.0 | 30-Jan-09 | 175.0 | – | 21,800 | 6.0% |
| (J) | 02-Feb-09 | 180.0 | 02-Feb-09 | 125.0 | 8 | 26,400 | 7.0% |
| | | | 04-Feb-09 | 46.0 | | | 7.0% |
| | | | 10-Feb-09 | 14.0 | | | 5.0% |
| (J) | 12-Feb-09 | 180.0 | 16-Feb-09 | 3.5 | 6 | 8700 | 5.0% |
| | | | 18-Feb-09 | 5.0 | | | 5.6% |

This table depicts the volatility call options issued by the central bank of Colombia from 2002 to 2009. When the COPUSD depreciated more than the set percentage of the 20-day moving average, the Central Bank auctioned US$ 180 million in call options. The options could then be exercised on any day where the exchange rate surpassed the set percentage within the contract period. Until December 2001, the set percentage was 5%; from December 2001 to February 6, 2006 it was 4%; from February 6, 2006 to June 24, 2008 it was 2%; and from June 24, 2008 to October 13, 2011 it was 5%.

volatility is under control. The intraband variation is determined by the difference between the COPUSD and the 20-day moving average, which we calculated as:

$$V = \frac{COPUSD_t - COPUSD_{t,MA}}{COPUSD_{t,MA}} \tag{1}$$

where $COPUSD_t$ is the official exchange rate at the given date and $COPUSD_{t,MA}$ is the 20-day moving average value of the official exchange rate. This calculation is used by the central bank in determining whether the COPUSD had appreciated or depreciated more than its benchmark rate (20-day average) which could trigger the auction of volatility options. During times of persistent appreciation or depreciation, there were occasions where the central bank auctioned multiple options within a short period.[22] To avoid data contamination, we

[22] Note that the central bank could not issue another option unless all existing options matured or were completely exercised.

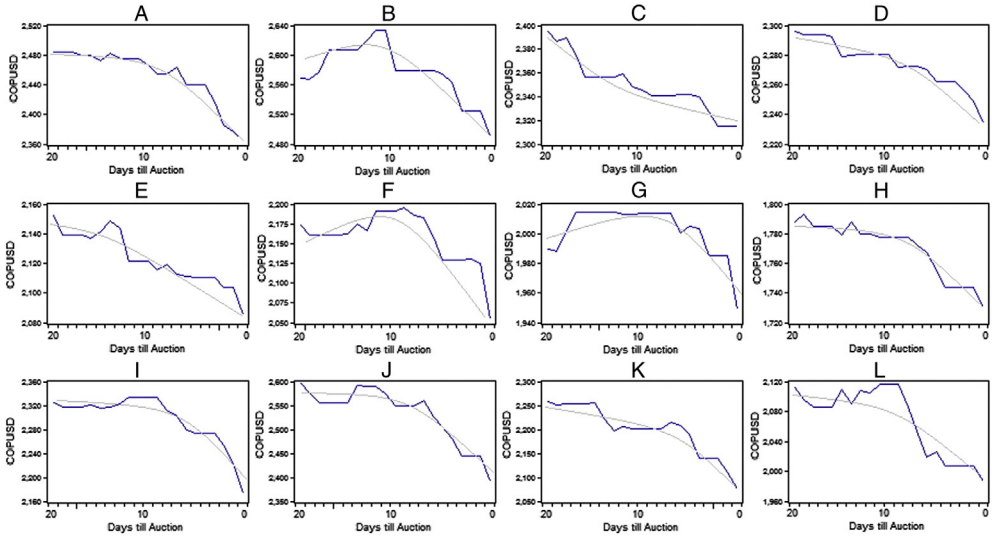



**Fig. 3.** Exchange rates 20 days before put auction. This figure illustrates the dynamics of the COPUSD official exchange rate over the 20 days before the auction of volatility put options. The letters correspond to the periods detailed in Table 5 and are designed to correct for periods where multiple options contracts were auctioned to avoid contamination of the data.

conduct this analysis using the first option at auction date, which has no overlapping days with any previous options, and the last date of exercise of the final option in the period, which has no overlapping days with any subsequent options. By segmenting the options in such a manner, the impact of the auction and exercise on changes in *V* will not be overstated.

Following this methodology for calculating exchange rate movements, we analyze the change in *V* from 2, 5, and 10 days before the auction to the date of auction ("before auction" period) and the change in *V* from the

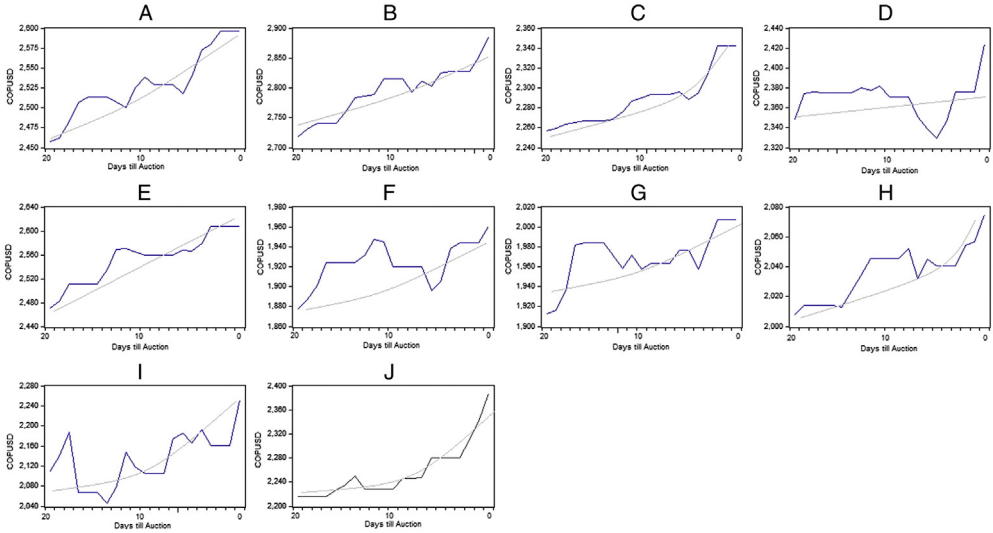



**Fig. 4.** Exchange rates 20 days before call auction. This figure illustrates the dynamics of the COPUSD official exchange rate over the 20 days before the auction of volatility call options. The letter indices correspond to the periods detailed in Table 5 and are designed to correct for periods where multiple options contracts were auctioned to avoid contamination of the data.

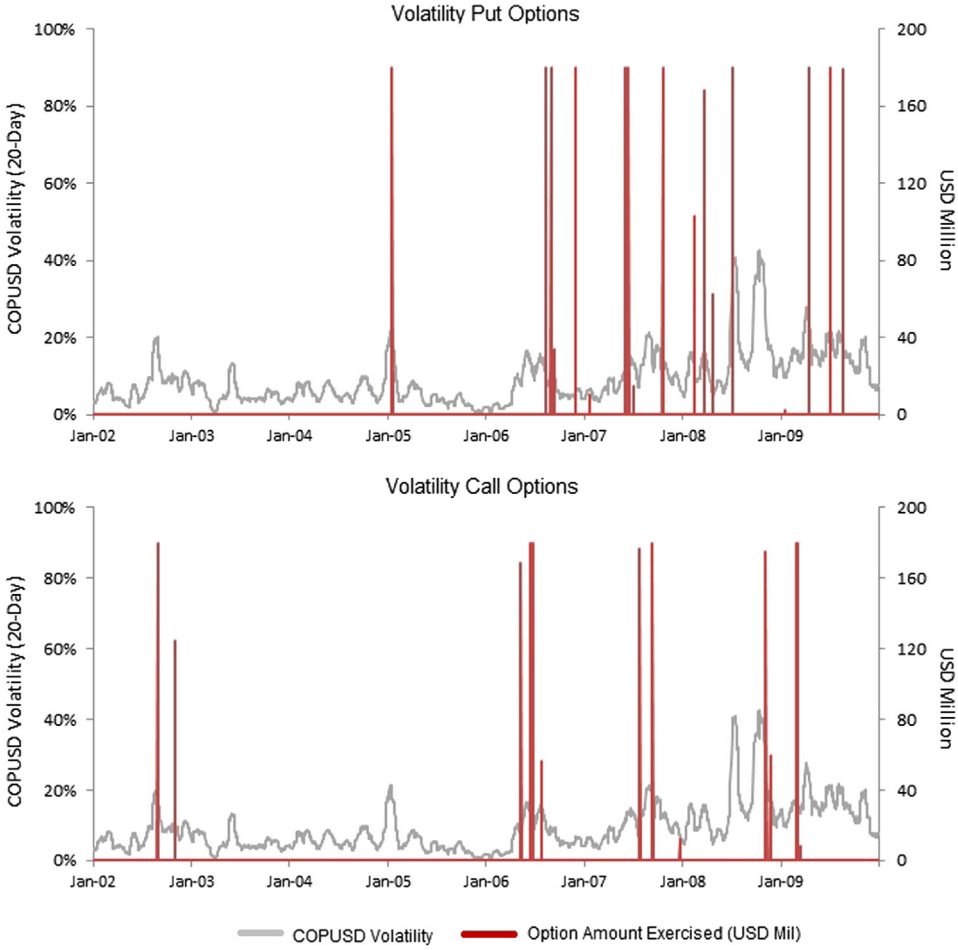



**Fig. 5.** COPUSD volatility and options interventions. This figure illustrates the volatility of the COPUSD based on the standard deviation of the log difference over a 20-day rolling window, and the amount exercised of volatility options. The top figure illustrates the exchange rate volatility of COPUSD and corresponding amount exercised at maturity of volatility put options. The bottom figure illustrates the exchange rate volatility of COPUSD and corresponding maturity of call options. The central bank of Colombia issued 21 put options from 2003 to 2009, and 17 call options from 2002 to 2009, with the maximum amount exercised reaching $ 180 million USD. Put options were issued when the exchange rate appreciated more than 4% over the 20-day moving average. Call options were issued when the exchange rate depreciated more than 4% over the 20-day moving average. Data from Banco Republica de Colombia.

last date of exercise to 2, 5, and 10 days after the last exercise date ("after exercise" period). The success of the options in lowering volatility is determined by both the sign and magnitude of the change. When there is a change in sign from the "before auction" to the "after exercise" period, the use of options is deemed successful in reverting the trend. For example, if a put option is auctioned, which occurs during a period of appreciation of the official exchange rate, the difference between COPUSD and the moving average would be growing, and the "before auction" period value of $V$ would be negative (see Eq. (1)). Upon exercise, if the value of $V$ changes to a positive value, this implies that the COPUSD is depreciating relative to the moving average, the difference between the two is diminishing, and the option was successful in reverting the trend from appreciation to depreciation for puts and depreciation to appreciation for calls.

To determine success in terms of magnitude, we compare the size of $V$ for a different number of days leading up to auction, at the auction date, at the last exercise date, and the days following the last exercise date. As established by the Colombian central bank, for $V$ to trigger an auction, it must surpass the

predetermined set percentages discussed in the previous section. The success of the volatility option to mitigate the drastic difference between the official exchange rate and the 20-day moving average will be captured by the size of *V*. The closer *V* is to zero after the last date of exercise, the more successful the event has been in bringing the exchange rate closer to the moving average and smoothing out any drastic movements. The thresholds we set for determining success are based on the set percentages of the central bank's trigger bands. For example, for a given trigger value of 4%, if the value of *V* after the last date of exercise is greater than ±4%, the event is not successful; if it is between ±2% and ±4% the event is moderately successful; and if it is between zero and ±2% the event is highly successful.[23] By conducting this analysis in terms of both sign and magnitude of the change in *V*, we determine the success of volatility options from the perspective of maintaining its movements within the desired boundaries of volatility, which align with the goals of the central bank.[24]

We also perform other tests to verify the significance of the impact of volatility options. In this sense, the purpose of the event study is to determine the behavior of volatility in the Colombian Peso–US dollar exchange rate at the time when the volatility options were auctioned and to determine the presence of any signaling effects derived from the auctions. In this case, we measure volatility as the annualized standard deviation of the log difference in daily exchange rates with a rolling window of 2, 5, and 10 days. Comparing volatility at the time of auction to 2, 5, and 10 days after the auction with the varying calculation for volatility yields results without overlapping days and with clear before and after comparisons. The short period compares volatility at auction and volatility 2 days after the auction date, using a 2 day rolling window for volatility. The mid period compares volatility at auction and volatility 5 days after the auction date, using a 5 day rolling window for volatility. The long period compares volatility at auction and volatility 10 days after the auction date, using a 10 day rolling window for volatility. Here, the calculation of volatility varies depending on the period in question.

As mentioned previously, by allowing the volatility to differ depending on the time frame in question, we avoid overlapping days in the "before" and "after" time periods. Only the days after contract maturity are included in the volatility calculation for the "after" period, which yields clear and concise results on how volatility options impacted exchange rate volatility in Colombia.[25] We also exclude weekends from the dataset.

Finally, we perform an analysis-of-variance, or ANOVA to determine the impact of the exercise of volatility options contracts on variations in the exchange rate. Here, the significance of the signaling and expectations channel will be tested. In the event of exercise, the relative supply of currency changes, which will impact the value of the exchange rate. In the first test, the dependent variable is the percent change in *V* from the period before auction to the period after the last exercise date. The percent change is calculated as:

$$\Delta V^{*}_{pc} = \frac{V_{EX,i} - V_{AUC,i}}{V_{AUC,i}} \tag{2}$$

where $V_{EX,i}$ is defined in Eq. (1) and captures the period after the last date of exercise, $V_{AUC,i}$ is the period prior the first auction, and *i* represents the number of days in the period (2, 5, and 10 days).

[34] For put options, the boundaries will be negative values due to the appreciation of the COPUSD. For call options, the boundaries will be positive values due to the depreciation of the COPUSD.

[24] See Figs. (6) and (7) for detailed description.

[25] Previous analyses based on the event study methodology have used a single exchange rate volatility, such as in Mandeng (2003). Using a similar short, mid, and long term periods for comparison, the calculation for volatility remains the same across all three periods and is estimated as the annualized standard deviation of the log difference in daily exchange rates over a 20-day rolling window. There are a number of drawbacks to keeping the 20-day rolling window for the computation of volatility in all three periods. Most notably, this approach will provide misleading results in each period because in the 2, 5, or 10 days around the auction date, the standard deviation window overlaps with this calculation. Therefore, the exchange rates used for calculation are not mutually exclusive in these time periods. For example, when we compare the 2 day event study, the volatility two days before and volatility two days after auction have 16 overlapping days when calculating volatility with the 20-day rolling window. In addition, the volatility 2 days after the auction date includes values for the COPUSD 18 days before the option contract is auctioned. These overlaps yield misleading results when attempting to determine whether volatility was lower before or after the auction dates. In the appendix, we provide an additional analysis using this approach to demonstrate why past analysis has erroneously deemed volatility options as unsuccessful in lowering volatility.

In the second test, the dependent variable is the difference in $V$ from the period before auction to the period after the last exercise date. The difference is calculated as:

$$\Delta V_d^* = V_{EX,i} - V_{AUC,i}. \tag{3}$$

Similarly with the previous methods, we use the analysis-of-variance to test the impact of the event on the 2, 5, and 10 day variations to determine whether there is only a short term impact or if the event has prolonged effects. In the short period, $d2_t$ represents a dummy variable that takes on the value 1 for the day of exercise and the subsequent two days after the exercise, zero otherwise. In the mid period, $d5_t$ represents a dummy variable that takes on the value 1 for the day of exercise and the subsequent five days after the exercise, zero otherwise. In the long period, $d10_t$ represents a dummy variable that takes on the value 1 for the day of exercise and the subsequent ten days after the auction, zero otherwise. The analysis-of-variance is conducted for all options contracts, for only call options, and for only put options. We include an AR(1) or AR(2) process when necessary to correct for autocorrelation.

## 5. Results

As we have discussed throughout this paper, one of the main concerns of many central banks is to keep exchange rate volatility low and smooth any drastic movements in currency markets. One clear and concise way to achieve this goal is to rely on bands or boundaries of volatility that will trigger a certain response by the central bank to act in a way that will provide liquidity into the market (with either local or foreign currency) and smooth any drastic movements in the exchange rate. In Colombia, the central bank has used bands from 2 to 5% to determine the appropriate time for intervention.

In Table 5 and Figs. 6 and 7, we analyze how the use of volatility options has impacted exchange rate dynamics by considering the sign and magnitude change from pre-auction to post-exercise periods. In these examples, we consider intraband variation or the difference between the COPUSD and the 20-day moving average. This intraband variation aligns with the central bank's boundaries for intervention using options.

In Table 5, we measure the success of volatility put and call options in terms of changes in the COPUSD relative to the 20-day moving average. The values presented in the table capture the change in $V$ from Eq. (1) from 2, 5, and 10 days before the auction to the date of auction ("before auction" period) and the change in $V$ from the last date of exercise to 2, 5, and 10 days after the last exercise date ("after exercise" period). For volatility put options in the top panel, the "before auction period" consists of intraband variation that is negative, signaling the appreciation of the COPUSD relative to the 20-day moving average. In 10 out of 12 periods, the intraband variation changed signs after the last date of exercise, signaling that the COPUSD was now depreciating relative to the 20-day moving average. This indicates that the put option was successful in curbing the drastic movement in the exchange rate in 80 to 90% of all cases by counteracting the appreciation prior to auction with depreciation after exercise.[26]

For volatility call options in the bottom panel, the "before auction period" consists of intraband variation that is positive, signaling the depreciation of the COPUSD relative to the 20-day moving average. In 10 out of 11 periods, the intraband variation changed signs after the last date of exercise, signaling that the COPUSD was now appreciating relative to the 20-day moving average. The call option had over 90% success in curbing the drastic movement in the exchange rate by counteracting the depreciation prior to auction with appreciation after exercise. Additionally, as seen in Table 5, the correlation between the before and after periods for puts (calls) are negative (positive).

In Figs. 6 and 7, we capture the magnitude of the change in intraband variation. Here, we present the $V$ 2, 5, and 10 days before auction, at auction, one day after the last exercise date, and 2, 5, and 10 days after the last exercise date. Note that as $V$ moves closer to zero, the difference between the exchange rate and 20-day moving average diminishes. During the at auction and at exercise periods, $V$ surpasses the established percentage variation trigger value, which in turn triggers the event (of either auction or exercise). If the event was successful in counteracting the drastic movement in the exchange rate, the post-exercise intraband

[26] We have checked for any abnormal events during the period analyzed, and we did not find anything extraordinary or at least significantly different from the trend observed around those days.

**Table 5**
Comparison of pre-auction and post-exercise exchange rate variations.

| Date of auction | Date of last exercise | ID | Before auction | | | After exercise | | |
|---|---|---|---|---|---|---|---|---|
| | | | 2-day | 5-day | 10-day | 2-day | 5-day | 10-day |
| *Put options* | | | | | | | | |
| 17-Dec-04 | 17-Dec-04 | A | −0.03 | −0.14 | −0.07 | −0.23 | 0.11 | 0.19 |
| 11-Jul-06* | 15-Aug-06* | B | −0.31 | −0.43 | −0.22 | 0.02 | 0.14 | 0.17 |
| 30-Oct-06 | 9-Nov-06 | C | −0.09 | −0.09 | −0.05 | 0.14 | 0.12 | 0.11 |
| 21-Dec-06 | 21-Dec-06 | D | −0.14 | −0.14 | −0.07 | 0.03 | 0.07 | 0.08 |
| 3-May-07* | 4-Jun-07* | E | −0.18 | −0.10 | −0.05 | 0.07 | 0.29 | 0.30 |
| 20-Sep-07 | 26-Sep-07 | F | −0.76 | −0.56 | −0.28 | 0.13 | 0.19 | 0.15 |
| 15-Jan-08* | 24-Apr-08* | G | −0.41 | −0.36 | −0.18 | 0.16 | 0.12 | 0.09 |
| 4-Jun-08 | 5-Jun-08 | H | −0.16 | −0.18 | −0.09 | −0.05 | −0.03 | 0.00 |
| 18-Dec-08 | 18-Dec-08 | I | −0.45 | −0.48 | −0.24 | 0.14 | 0.24 | 0.29 |
| 17-Mar-09 | 19-Mar-09 | J | −0.48 | −0.56 | −0.28 | 0.17 | 0.30 | 0.54 |
| 3-Jun-09 | 11-Jun-09 | K | −0.27 | −0.48 | −0.24 | 0.01 | 0.22 | 0.41 |
| 22-Jul-09 | 23-Jul-09 | L | −0.14 | −0.10 | −0.05 | 0.31 | 0.59 | 0.39 |
| Correlations | 2 day | −0.386 | | | | | | |
| | 5 day | −0.008 | | | | | | |
| | 10 day | −0.365 | | | | | | |
| *Call options* | | | | | | | | |
| 29-Jul-02* | 6-Aug-02* | A | 0.06 | 0.13 | 0.06 | −0.09 | −0.42 | −0.22 |
| 2-Oct-02 | 2-Oct-02 | B | 0.22 | 0.21 | 0.11 | −0.14 | −0.23 | −0.20 |
| 10-Apr-06 | 27-Apr-06 | C | 0.28 | 0.26 | 0.13 | −0.05 | −0.06 | −0.11 |
| 16-May-06* | 13-Jun-06* | D | 0.48 | 0.49 | 0.24 | −0.06 | −0.13 | −0.07 |
| 27-Jun-06 | 28-Jun-06 | E | −0.07 | 0.08 | 0.04 | −0.08 | −0.37 | −0.36 |
| 26-Jun-07 | 27-Jun-07 | F | 0.20 | 0.33 | 0.16 | −0.35 | −0.26 | −0.18 |
| 13-Aug-07 | 14-Aug-07 | G | 0.29 | 0.24 | 0.12 | 0.33 | 0.50 | 0.25 |
| 22-Nov-07 | 23-Nov-07 | H | 0.20 | 0.16 | 0.08 | −0.05 | −0.17 | −0.20 |
| 7-Oct-08* | 27-Oct-08* | I | 0.93 | 0.39 | 0.20 | −0.08 | −0.19 | −0.24 |
| 30-Jan-09* | 18-Feb-09* | J | 0.42 | 0.50 | 0.25 | −0.27 | −0.14 | −0.18 |
| Correlations | 2 day | 0.021 | | | | | | |
| | 5 day | 0.186 | | | | | | |
| | 10 day | 0.216 | | | | | | |

In this table, we measure the success of volatility put and call options in terms of the sign change in the COPUSD relative to the 20-day moving average. The values presented in the table capture the change in $V$ from Eq. (1) from 2, 5, and 10 days before the auction to the date of auction ("before auction" period) and the change in $V$ from the last date of exercise to 2, 5, and 10 days after the last exercise date ("after exercise" period). Specifically the "before auction" period calculates the change in $V$ as $\Delta V = \frac{V_{auc} - V_{auc-t}}{t}$ and the "after exercise" period calculates the change in $V$ as $\Delta V = \frac{V_{ex+t} - V_{ex+1}}{t}$ where $t$ is the number of days prior/after the event, $V_{auc}$ is the deviation of the exchange rate from the 20-day moving average at auction, and $V_{ex+1}$ is the deviation of the exchange rate from the 20-day moving average one day after exercise. The success of the options in lowering volatility is determined by both the sign and magnitude of the change. When there is a change in sign from the "before auction" to the "after exercise" period, the use of options is deemed successful in reverting to the before-auction trend. The asterisk represents periods where more than one option was auctioned and exercised from the first auction date to the last exercise date. The correlations are for the change in $V$ from the "before auction" period to the 'after exercise' period.

variation should move in the opposite direction from the pre-auction period (sign effect) and should be closer to zero (magnitude effect).

In general, the lowest success occurs in the 2-day window, indicating that the time it takes for the exchange rate to correct itself and smooth out is not instantaneous. The 10-day window is the most successful in terms of change in sign and magnitude. In 9 out of 12 (6 out of 10) cases for put (call) options, intraband variation 10 days after the last exercise event ended up within the ±2% threshold to be deemed highly successful in diminishing the difference between the COPUSD and 20-day moving average. Therefore, in terms of both sign and magnitude, the majority of periods where volatility options were auctioned and exercised were successful in smoothing out the drastic movements in the exchange rate.

Next, we conduct a typical event study that links the volatility at auction to the volatility after the auction. In the top panel of Table 6, we compare volatility around the date of auction for volatility put options. When put options were auctioned, exchange rate volatility after auction in the short term (2 days) and mid term (5 days) was lower in 48% of the cases for both.[27] In contrast, in the long term (10 days) in 38% of the

[27] Or in 10 out of 21 cases.

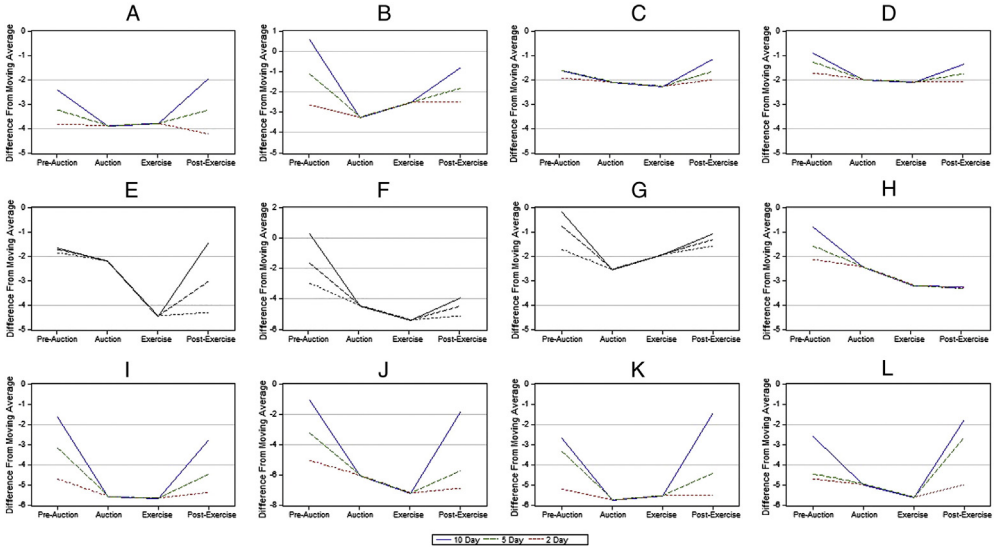



**Fig. 6.** Volatility put options event study. This figure illustrates the dynamics of the COPUSD official exchange rate from the period before auction to 2, 5, and 10 days after the last option was exercised for volatility put options, avoiding overlapping dates. When an option was auctioned within a 10-day period of the last exercise date of the previous option, it was considered an overlapping period.

cases. Therefore, the volatility put options were most successful in lowering volatility in the short and medium term, represented by the 2 and 5 day periods. When considering a successful event as lower volatility in any one of the three scenarios, the success rate of volatility put options increases to 76%.

In the lower panel of Table 6, we compare volatility around the date of auction for volatility call options. When call options were auctioned, exchange rate volatility after auction in the short term (2 days) was lower in 53% of the cases, volatility after auction in the mid term (5 days) was lower in 59% of the cases,

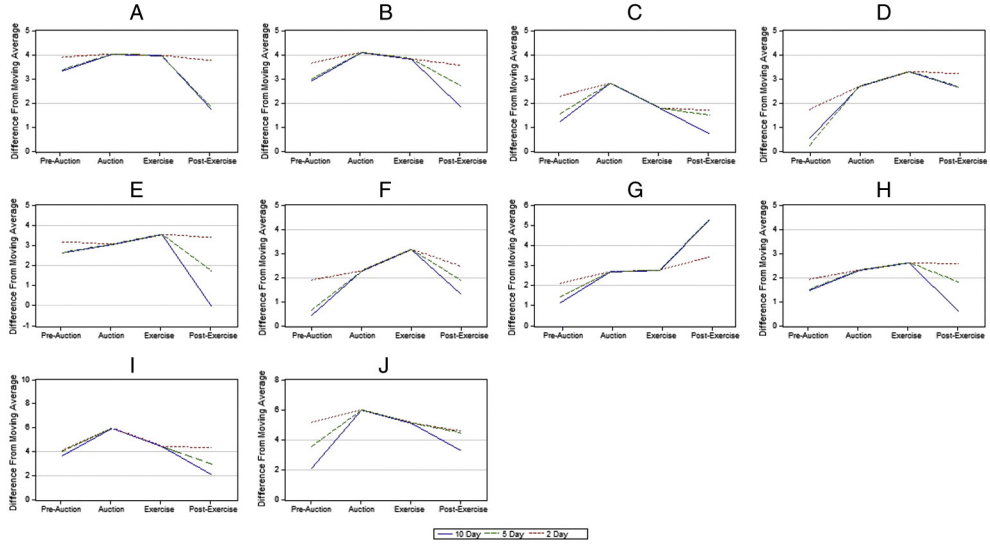



**Fig. 7.** Volatility call options event study. This figure illustrates the dynamics of the COPUSD official exchange rate from the period before auction to 2, 5 and 10 days after the last option was exercised for volatility call options, avoiding overlapping dates. When an option was auctioned within a 10-day period of the last exercise date of the previous option, it was considered an overlapping period.

**Table 6**
Success of volatility options contracts in Colombia — at auction.

| Date | Volatility at auction | | | Volatility after | | | Success | | |
|---|---|---|---|---|---|---|---|---|---|
| | $\sigma(2)$ | $\sigma(5)$ | $\sigma(10)$ | $\sigma(2)$ | $\sigma(5)$ | $\sigma(10)$ | 2 days | 5 days | 10 days |
| *Put options* | | | | | | | | | |
| 17-Dec-04 | 1.1% | 7.6% | 9.5% | 15.8% | 30.6% | 24.4% | – | – | – |
| 11-Jul-06 | 1.5% | 13.0% | 16.9% | 14.7% | 8.5% | 17.8% | – | Lower | – |
| 31-Jul-06 | 3.4% | 12.2% | 14.5% | 5.2% | 10.7% | 9.8% | – | Lower | Lower |
| 10-Aug-06 | 12.8% | 9.6% | 9.8% | 4.8% | 5.7% | 6.1% | Lower | Lower | Lower |
| 30-Oct-06 | 0.1% | 5.5% | 4.7% | 4.4% | 4.1% | 6.1% | – | Lower | – |
| 21-Dec-06 | 5.3% | 3.9% | 4.4% | 2.8% | 4.3% | 5.2% | Lower | – | – |
| 30-Mar-07 | 7.6% | 6.6% | 7.3% | 22.6% | 17.3% | 11.9% | – | – | – |
| 3-May-07 | 12.2% | 7.3% | 7.4% | 0.1% | 13.3% | 10.8% | Lower | – | – |
| 15-May-07 | 10.1% | 10.6% | 11.5% | 0.2% | 4.1% | 11.6% | Lower | Lower | – |
| 4-Jun-07 | 11.3% | 17.9% | 16.0% | 0.3% | 12.0% | 13.6% | Lower | Lower | Lower |
| 20-Sep-07 | 40.7% | 25.2% | 22.6% | 2.5% | 18.7% | 14.2% | Lower | Lower | Lower |
| 11-Dec-07 | 0.4% | 9.0% | 11.3% | 1.4% | 7.8% | 5.8% | – | Lower | Lower |
| 15-Jan-08 | 12.2% | 15.2% | 12.0% | 8.4% | 12.5% | 19.2% | Lower | Lower | – |
| 20-Feb-08 | 10.4% | 9.0% | 8.4% | 24.9% | 13.4% | 12.2% | – | – | – |
| 25-Mar-08 | 0% | 15.5% | 13.4% | 24.5% | 15.7% | 11.7% | – | – | Lower |
| 4-Jun-08 | 10.4% | 6.2% | 5.8% | 13.3% | 12.7% | 15.1% | – | – | – |
| 18-Dec-08 | 11.6% | 14.3% | 15.7% | 9.3% | 9.2% | 9.4% | Lower | Lower | Lower |
| 17-Mar-09 | 10.6% | 10.9% | 15.1% | 4.4% | 17.6% | 28.2% | Lower | – | – |
| 27-Apr-09 | 0.2% | 21.6% | 16.9% | 20.2% | 24.9% | 19.2% | – | – | – |
| 3-Jun-09 | 1.1% | 15.0% | 18.0% | 1.2% | 19.4% | 14.3% | – | – | Lower |
| 22-Jul-09 | 13.9% | 15.9% | 18.0% | 7.4% | 20.9% | 27.9% | Lower | – | – |
| Success (%) | | | | | | | 48% | 48% | 38% |
| *Call options* | | | | | | | | | |
| 29-Jul-02 | 4.4% | 12.8% | 12.2% | 11.5% | 7.1% | 22.0% | – | Lower | – |
| 1-Aug-02 | 7.4% | 6.2% | 10.7% | 0.7% | 5.9% | 27.2% | Lower | Lower | – |
| 2-Oct-02 | 5.7% | 11.6% | 11.8% | 4.3% | 5.1% | 6.3% | Lower | Lower | Lower |
| 10-Apr-06 | 6.4% | 11.7% | 8.3% | 15.3% | 7.7% | 11.2% | – | Lower | – |
| 16-May-06 | 10.2% | 20.8% | 17.0% | 21.1% | 16.3% | 18.2% | – | Lower | – |
| 18-May-06 | 21.1% | 17.9% | 18.3% | 7.3% | 14.4% | 16.8% | Lower | Lower | Lower |
| 23-May-06 | 21.6% | 16.3% | 17.6% | 17.4% | 19.1% | 15.3% | Lower | – | Lower |
| 25-May-06 | 17.4% | 14.4% | 15.5% | 22.1% | 15.3% | 15.7% | – | – | – |
| 27-Jun-06 | 15.2% | 9.0% | 10.4% | 0.8% | 20.5% | 16.9% | Lower | – | – |
| 26-Jun-07 | 7.2% | 20.8% | 17.7% | 8.2% | 14.6% | 11.8% | – | Lower | Lower |
| 13-Jul-07 | 10.2% | 12.1% | 9.0% | 10.5% | 6.2% | 17.5% | – | Lower | – |
| 22-Nov-07 | 10.7% | 8.7% | 10.4% | 8.9% | 14.4% | 12.8% | Lower | – | – |
| 7-Oct-08 | 75.8% | 41.9% | 39.5% | 31.2% | 47.0% | 50.9% | Lower | – | – |
| 24-Oct-08 | 20.8% | 34.4% | 46.9% | 18.6% | 12.7% | 18.0% | Lower | Lower | Lower |
| 30-Jan-09 | 8.4% | 13.8% | 17.3% | 2.0% | 14.2% | 19.4% | Lower | – | – |
| 2-Feb-09 | 7.1% | 13.7% | 14.2% | 20.9% | 17.5% | 19.2% | – | – | – |
| 12-Feb-09 | 0.3% | 22.4% | 19.0% | 3.8% | 18.4% | 18.3% | – | Lower | Lower |
| Success (%) | | | | | | | 53% | 59% | 35% |

Volatility is measured as the annualized standard deviation of the log difference in daily exchange rates with a rolling window of 2, 5, and 10 days, and does not include weekends. Comparing volatility at the time of auction to 2, 5, and 10 days after contract auction yields successful results. After the option is auctioned, volatility decreases in 76 and 88% of all cases for puts and calls, respectively, when considering a lowering of volatility in any one of the three periods as a successful event. The short period compares volatility at auction and 2 days after the auction date. The mid period compares volatility 5 days at auction and 5 days after the auction date, using a 5 day rolling window for volatility. The long period compares volatility at auction and 10 days after the auction date, using a 10 day rolling window for volatility. The calculation of volatility varies depending on the period in question.

and in the long term (10 days) in 35% of the cases. Like their put counterparts, volatility call options were most successful in lowering volatility in the short to mid term. When considering a successful event as lower volatility in any one of the three scenarios, the success rate of volatility call options increased to 88%.

Finally, using an analysis-of-variance, the top panel of Table 7 analyzes how the event of exercising an option will impact the percent change in $V$. The results are significant and negative for both call and put volatility options in the 2 and 5 day time horizons. This result implies that through the exercise of volatility

**Table 7**
Options contract auctions and exchange rate volatility.

| Dependent: Percent change in $V$ after exercise | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 2-day period ($V_{pc,2}$) | | | 5-day volatility ($V_{pc,5}$) | | | 10-day volatility ($V_{pc,10}$) | | |
| | Calls only | Puts only | | Calls only | Puts only | | Calls only | Puts only |
| c | 0.466*** | 0.204*** | c | 1.34** | 1.89*** | c | −0.049 | 0.459 |
| | (3.65) | (3.33) | | (2.12) | (4.05) | | (−0.147) | (0.814) |
| $d2_t$ (call) | −0.514*** | | $d5_t$ (call) | −1.49* | | $d10_t$ (call) | −0.435 | |
| | (−3.96) | | | (−1.64) | | | (−0.946) | |
| $d2_t$ (put) | | −0.277*** | $d5_t$ (put) | | −2.36*** | $d10_t$ (put) | | −1.12 |
| | | (−5.33) | | | (−3.98) | | | (−1.48) |
| AR(1) | 0.362** | 0.505*** | AR(1) | −0.206** | 0.237*** | AR(1) | | 0.175*** |
| | (2.66) | (4.34) | | (−2.18) | (2.88) | | | (2.91) |
| AR(2) | | | AR(2) | −0.267*** | | AR(2) | | |
| | | | | (−2.83) | | | | |
| $R^2$ | 0.328 | 0.450 | $R^2$ | 0.115 | 0.155 | $R^2$ | 0.004 | 0.042 |
| F-stat | 11.26 | 24.99 | F-stat | 4.54 | 12.77 | F-stat | 0.895 | 5.85 |
| N.obs | 49 | 64 | | 108 | 142 | | 210 | 272 |
| Dependent: Difference in $V$ after exercise | | | | | | | | |
| 2-day ($V_{d,2}$) | | | 5-day ($V_{d,5}$) | | | 10-day ($V_{d,10}$) | | |
| | Calls only | Puts only | | Calls only | Puts only | | Calls only | Puts only |
| c | 0.006** | −0.004** | c | 0.001 | −0.008*** | c | −0.003 | −0.008* |
| | (2.11) | (−2.58) | | (0.283) | (−2.64) | | (−0.510) | (−1.95) |
| $d2_t$ (call) | −0.009*** | | $d5_t$ (call) | −0.007*** | | $d10_t$ (call) | −0.014*** | |
| | (−3.25) | | | (−4.91) | | | (−8.05) | |
| $d2_t$ (put) | | 0.007*** | $d5_t$ (put) | | 0.022*** | $d10_t$ (put) | | 0.022*** |
| | | (3.69) | | | (7.75) | | | (11.16) |
| AR(1) | 0.437*** | 0.699*** | AR(1) | 1.28*** | 0.838*** | AR(1) | 0.924*** | 1.12*** |
| | (3.27) | (5.31) | | (14.66) | (9.91) | | (32.6) | (18.77) |
| AR(2) | | −0.338** | AR(2) | −0.456*** | −0.191** | AR(2) | | −0.254*** |
| | | (−2.53) | | (−5.17) | (−2.24) | | | (−4.27) |
| $R^2$ | 0.319 | 0.467 | $R^2$ | 0.850 | 0.692 | $R^2$ | 0.873 | 0.883 |
| F-stat | 10.78 | 17.21 | F-stat | 197.1 | 102.3 | F-stat | 708.9 | 669.5 |
| N.obs | 49 | 63 | | 108 | 141 | | 209 | 271 |

This table presents an analysis-of-variance testing the impact of volatility option contracts on 2, 5, and 10 day volatility after the auction date and after the contract maturity date. The dummy variable takes on the value of 1 from the day of auction to 2, 5, and 10 days after the last exercise date, and zero otherwise. For the top panel, the percent change in $V$ after the last exercise date is calculated as $V_{pc}$ in Eq. (2). For the bottom panel, the difference in $V$ is calculated as $V_d$ in Eq. (3). The values in parenthesis are t-statistics, and *, **, and *** represent significance of 10, 5, and 1%.

options, the differences between the official exchange rate and the moving average diminish and this difference is smaller in the after-exercise period than in the before-auction period. These results align with the observations presented in Figs. 6 and 7. In the 10 day time horizon, the event is no longer significant.

In the bottom panel of Table 7, the analysis-of-variance tests analyze how the event of exercising an option will impact the difference in $V$ from pre-auction to pot-exercise. For volatility call options, the event of exercise is significant in the 2, 5 and 10 day periods. The negative coefficient indicates that difference between the exchange rate and moving average is closer to zero after the exercise event than prior to the auction. Once again, these results capture the success based on a change in the sign of $V$ which reinforces the analysis presented in Table 5 and indicate the success of the call options in introducing appreciationary pressure. Volatility put options are also significant in all periods but the coefficients are positive. Given the dynamics of the exchange rate movements during these periods, a positive coefficient indicates that $V$ is moving closer to zero after the exercise event and that the put option was successful in introducing depreciationary pressure to counter drastic deviations of the exchange rate from 20 day moving average.

We should stress that there are no cross dependencies across the types of options analyzed in the paper since there were no overlapping periods among the issuing dates of the calls and puts used by the

Colombian Central Bank. In this sense, we do not have this type of contamination that could have made the analysis harder and less clear.

As an additional test of autocorrelation of the errors, we have used the Breusch–Godfrey Serial Correlation LM Test and we were not able to reject the null hypothesis of no autocorrelation for all errors that correspond to the ANOVA analyses presented in Table 7, except for one ($V_{d,10}$) where we reject the null. The results of this test are presented in Table 8. We obtain similar results performing the Box–Pierce/Ljung–Box Q-stat autocorrelation test of the residual, with two exceptions. In $V_{d,5}$ and $V_{pc,5}$ for the put options, there is no serial correlation up to lag 10 based on the Box–Pierce/Ljung–Box Q-stat test. All other results remain consistent with the Breusch–Godfrey Serial Correlation LM Test.

It is important to note that the Colombian central bank only issued either calls or puts and the success observed in the volatility option intervention strategy has been attained without any dynamic delta hedging to offset the risks associated with issuing these options. However, we believe that the positive impact of these interventions could be improved. Specifically, the benefits of greater liquidity, building markets and increasing the flow of information between policy makers and traders occur with consistent auctioning of the contracts, as discussed in Breuer (1999) and Keefe and Rengifo (2014).

## 6. Conclusions and future research

Central banks in emerging markets are concerned with the movement of their country's exchange rates, and have attempted to influence expectations, smooth volatility, and control the direction of the exchange rate through spot market interventions using foreign exchange reserves. Such interventions tend to be costly in terms of reserve accumulation and sterilization, with an unclear strategic approach to the purchase and sale of foreign currency in the domestic spot market.

Colombia has tried various strategies of intervention, including issuing options to accumulate foreign exchange reserves and to smooth volatility, as well as relying on daily spot market interventions. The use of volatility options in the past had been deemed unsuccessful due mainly to the lack of data to accurately and effectively assess these strategies. This paper has demonstrated that the use of options contracts had a significant impact on exchange rate volatility. Using a rigorous statistical analysis and event study methodologies, we have tested the influence of the volatility options contracts auctioned by the Colombian central bank on curbing volatility at both the auction date and the date of exercise. At the time of auction, volatility put and call options were successful in lowering exchange rate volatility in 76 and 88% of the cases, respectively. After the options were exercised, the impact on reverting the appreciation/depreciation trend, mitigating the drastic exchange rate movements that triggered an auction, and bringing the official exchange rate value closer to the 20 day moving average was successful in 90% of the cases.

From our analysis, the abandonment of options contracts as a tool for central bank intervention into currency markets was premature. Revisiting the use of currency options contracts as a central bank intervention mechanism is an important next step in developing methods for successful currency risk management by central banks.

An area of future research includes testing whether the auctioning of bundles of both call and put options while simultaneously dynamically hedging the net position of the portfolio would provide the central bank

**Table 8**
Breusch–Godfrey LM Test for serial correlation.

| | Calls | | Puts | |
|---|---|---|---|---|
| | B–G LM Test stat | P-value | B–G LM Test stat | P-value |
| $V_{pc,2}$ | 2.73 | 0.256 | 3.94 | 0.139 |
| $V_{pc,5}$ | 0.78 | 0.678 | 0.25 | 0.882 |
| $V_{pc,10}$ | 0.17 | 0.918 | 3.37 | 0.186 |
| $V_{d,2}$ | 3.65 | 0.161 | 4.28 | 0.118 |
| $V_{d,5}$ | 3.23 | 0.199 | 0.99 | 0.610 |
| $V_{d,10}$ | 5.01 | 0.082 | 18.16 | 0.000 |

This table presents the results of the Breusch–Godfrey Serial Correlation LM Test. Based on the results, we are not able to reject the null hypothesis of no autocorrelation for all errors that correspond to the ANOVA analyses presented in Table 7, except for one ($V_{d,10}$) where we reject the null.

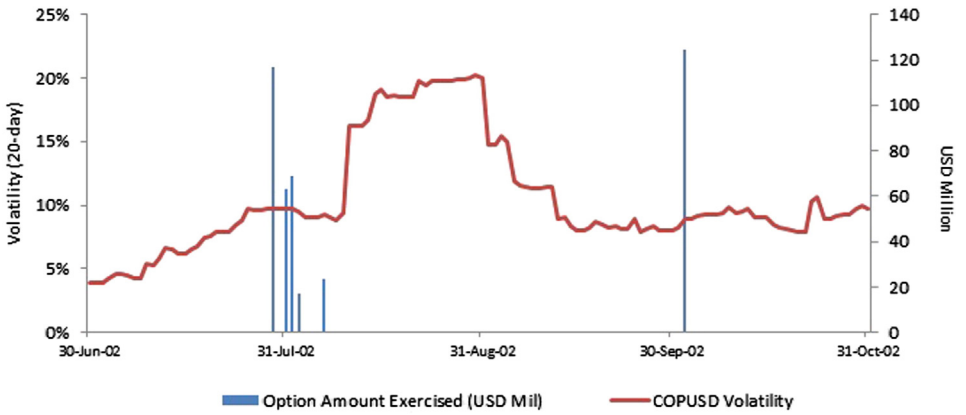



**Fig. 8.** Volatility call options in 2002. The figure represents the first three volatility call options that were issued by the Colombian central bank in 2002, as well as the 20-day rolling window volatility of the COPUSD. Both reflect the dataset available during the study compiled by Mandeng (2003) in analyzing the success of using volatility options as an intervention mechanism by central banks. Though our numerical values of volatility differ slightly from Mandeng's, the volatility follows a very similar trend.

with a stronger and more strategic approach to issuing options as a policy tool. When currency options are auctioned on a consistent basis using a mix of call and put options at various strike prices, the strategy can increase liquidity, build markets and financial development, and increase the flow of information between market participants and policy makers. By pursuing such a strategy, the central bank will ensure liquidity in the market, it will have a strategic approach to its spot market position that is driven by market forces, and it will limit the opportunity for speculative attacks on the currency. We believe that this strategy will aid the central bank's ability to influence expectations and future movement of the exchange rate at a lower cost than daily interventions.

## Appendix A

As previously mentioned, Mandeng (2003) uses an event study to analyze the impact of only three call options on exchange rate volatility auctioned until 2003.[28] In his paper, Mandeng finds them to be only slightly successful in lowering volatility. As we have discussed previously, the apparent lack of success of these options can be due to the methodology used to calculate volatility.[29]

Using a similar approach to calculate volatility as described in Mandeng (2003), Fig. 8 presents the three volatility call options that were used for analysis in Mandeng's paper, the only ones exercised at the time of the study. Though there are slight differences in the volatility numbers between our calculations, presented in Table 9, and Mandeng's, they follow a very similar pattern. As can also be seen, there is a period of high volatility in the weeks following the auction of the first series of volatility call options. This shows the fact that the success of most interventions is limited to the very short run. To analyze the impact of these options, we turn to the event study methodology to compare volatilities prior to the auction date and after the date of auction.

Table 9 analyzes volatility in COPUSD during the time of auction for all volatility call and volatility put options since the first issue date in 2002.[30] In this table, volatility is measured as the annualized standard deviation of the log difference in daily exchange rates over a 20-day rolling window. The event study windows presented correspond to 2, 5 and 10 days before and after the contract maturity. Note that with this way of measuring volatility, there are overlaps between the “before” and “after” periods. For example, the 20-day volatility for the 5 day window before will use part of the same information to estimate the 20-day volatility

[28] At the time of his paper, Colombia had only issued three call options as means to control volatility.

[29] We will see that the way volatility is calculated is crucial in correctly analyzing the success of these options.

[30] As mentioned previously, from 1999 to 2002, only options used for reserve accumulation or decumulation were auctioned by the central bank. Here, we are interested in analyzing the success of the volatility options, and hence analyze these options which began in 2002.

**Table 9**
Volatility Options Contracts Issued in Colombia — Part 1.

| Date | Volatility before | | | Volatility after | | | Success | | |
|---|---|---|---|---|---|---|---|---|---|
| | 10 days | 5 days | 2 days | 2 days | 5 days | 10 days | Short | Mid | Long |
| *Put options* | | | | | | | | | |
| 17-Dec-04 | 4.88% | 6.24% | 8.33% | 8.10% | 9.30% | 17.00% | Lower | – | – |
| 11-Jul-06 | 12.73% | 10.92% | 12.62% | 14.33% | 14.10% | 14.11% | – | – | – |
| 31-Jul-06 | 14.11% | 14.36% | 14.02% | 13.26% | 11.59% | 11.48% | Lower | Lower | Lower |
| 10-Aug-06 | 14.02% | 11.59% | 11.39% | 8.94% | 8.59% | 7.52% | Lower | Lower | Lower |
| 30-Oct-06 | 5.17% | 5.00% | 5.04% | 5.04% | 3.96% | 4.01% | Lower | Lower | Lower |
| 21-Dec-06 | 6.52% | 6.10% | 4.15% | 4.06% | 4.08% | 4.23% | Lower | Lower | Lower |
| 30-Mar-07 | 6.89% | 6.59% | 5.21% | 9.26% | 9.77% | 9.39% | – | – | – |
| 3-May-07 | 6.12% | 5.60% | 5.65% | 6.32% | 7.04% | 7.74% | – | – | – |
| 15-May-07 | 6.32% | 8.31% | 7.74% | 8.87% | 8.92% | 10.14% | – | – | – |
| 4-Jun-07 | 10.14% | 10.99% | 12.50% | 11.72% | 14.11% | 13.55% | Lower | – | – |
| 20-Sep-07 | 13.58% | 12.81% | 12.48% | 16.64% | 16.70% | 17.35% | – | – | – |
| 11-Dec-07 | 10.33% | 10.55% | 10.59% | 9.10% | 9.14% | 7.40% | Lower | Lower | Lower |
| 15-Jan-08 | 4.70% | 5.45% | 6.42% | 10.31% | 10.71% | 15.54% | – | – | – |
| 20-Feb-08 | 13.74% | 8.16% | 8.61% | 9.40% | 8.71% | 9.46% | – | – | Lower |
| 25-Mar-08 | 13.98% | 15.43% | 15.26% | 15.70% | 13.88% | 11.77% | – | Lower | Lower |
| 4-Jun-08 | 7.44% | 5.81% | 5.81% | 6.79% | 7.35% | 7.96% | – | – | – |
| 18-Dec-08 | 10.20% | 10.22% | 8.10% | 12.36% | 12.37% | 13.28% | – | – | – |
| 17-Mar-09 | 14.48% | 14.02% | 13.43% | 14.68% | 16.29% | 19.78% | – | – | – |
| 27-Apr-09 | 23.42% | 18.31% | 13.03% | 15.58% | 16.58% | 16.92% | – | Lower | Lower |
| 3-Jun-09 | 13.04% | 11.93% | 15.18% | 14.51% | 14.38% | 15.48% | Lower | – | – |
| 22-Jul-09 | 17.90% | 15.60% | 15.19% | 14.80% | 15.61% | 21.35% | Lower | – | – |
| Success (%) | | | | | | | 43% | 33% | 39% |
| *Call options* | | | | | | | | | |
| 29-Jul-02 | 7.71% | 8.92% | 9.89% | 9.95% | 9.25% | 8.46% | – | – | – |
| 1-Aug-02 | 8.08% | 9.89% | 9.51% | 9.25% | 9.24% | 16.58% | Lower | Lower | – |
| 1-Oct-02 | 8.23% | 8.11% | 8.11% | 9.09% | 9.46% | 9.77% | – | – | – |
| 10-Apr-06 | 2.89% | 3.07% | 6.30% | 7.35% | 7.44% | 9.66% | – | – | – |
| 16-May-06 | 8.82% | 7.61% | 9.59% | 12.54% | 12.69% | 14.71% | – | – | – |
| 18-May-06 | 8.82% | 9.59% | 12.45% | 12.69% | 14.16% | 16.56% | – | – | – |
| 23-May-06 | 9.59% | 12.54% | 12.69% | 14.66% | 16.56% | 15.29% | – | – | – |
| 25-May-06 | 12.45% | 12.69% | 14.16% | 16.56% | 15.96% | 16.10% | – | – | – |
| 27-Jun-06 | 11.42% | 11.47% | 9.97% | 9.16% | 12.73% | 11.05% | Lower | – | Lower |
| 26-Jun-07 | 13.28% | 13.33% | 13.04% | 13.36% | 13.65% | 13.36% | – | – | – |
| 13-Aug-07 | 13.16% | 12.76% | 14.89% | 15.24% | 19.83% | 20.94% | – | – | – |
| 22-Nov-07 | 9.72% | 8.47% | 8.46% | 7.89% | 7.87% | 10.33% | Lower | Lower | – |
| 7-Oct-08 | 34.56% | 36.29% | 36.54% | 40.51% | 35.32% | 40.36% | – | Lower | – |
| 24-Oct-08 | 34.72% | 40.88% | 40.42% | 40.01% | 36.78% | 30.68% | Lower | Lower | Lower |
| 30-Jan-09 | 9.25% | 11.21% | 10.24% | 13.46% | 14.13% | 14.29% | – | – | – |
| 2-Feb-09 | 9.68% | 10.24% | 13.46% | 14.13% | 14.29% | 15.91% | – | – | – |
| 12-Feb-09 | 13.46% | 14.29% | 14.27% | 16.64% | 16.64% | 16.07% | – | – | – |
| Success (%) | | | | | | | 24% | 24% | 12% |

Volatility is measured as the annualized standard deviation of the log difference in daily exchange rates over a 20-day rolling window, which is similar to the calculation used in Mandeng (2003). Using this calculation to test whether volatility is lowered after the option is exercised yields only moderately successful results partly because it accounts of movements in the exchange rate before, during and after the contract maturity. The short period compares volatility 2 days before and 2 days after the date of option maturity. The mid period compares volatility 5 days before and 5 days after the date of option maturity. The long period compares volatility 10 days before and 10 days after option maturity. Here, the calculation of volatility remains constant across all three periods using the 20-day rolling window.

after. This yields misleading results. Due to the overlap in days between periods and inclusion of days prior to auction in the volatility calculations in 2 and 5 day "after" periods, the comparison of volatility before and after the auction date is not clear. Based on this calculation, the volatility call and put options were successful in lowering COPUSD volatility in only 29% and 57% of all cases, respectively, as can be seen in Table 9.

In Table 10, volatility is measured as the annualized standard deviation of the log difference in daily exchange rates with a rolling window of 2, 5, and 10 days. Here, the calculation of volatility varies depending

**Table 10**
Volatility options contracts issued in Colombia — Part 2.

| Date | Volatility at auction | | | Volatility after | | | Success | | |
|---|---|---|---|---|---|---|---|---|---|
| | $\sigma(2)$ | $\sigma(5)$ | $\sigma(10)$ | $\sigma(2)$ | $\sigma(5)$ | $\sigma(10)$ | 2 days | 5 days | 10 days |
| *Put options* | | | | | | | | | |
| 17-Dec-04 | 1.10% | 9.97% | 10.19% | 2.45% | 10.91% | 22.23% | – | – | – |
| 11-Jul-06 | 18.34% | 13.68% | 11.11% | 14.70% | 9.51% | 11.27% | Lower | Lower | – |
| 31-Jul-06 | 0.00% | 10.43% | 14.17% | 5.22% | 4.09% | 9.21% | – | Lower | Lower |
| 10-Aug-06 | 12.84% | 8.61% | 9.21% | 4.83% | 2.91% | 4.86% | Lower | Lower | Lower |
| 30-Oct-06 | 0.00% | 5.47% | 4.29% | 4.39% | 4.09% | 4.17% | – | Lower | Lower |
| 21-Dec-06 | 5.33% | 5.24% | 4.34% | 2.76% | 1.90% | 3.22% | Lower | Lower | Lower |
| 30-Mar-07 | 7.62% | 5.39% | 6.76% | 21.91% | 17.03% | 11.58% | – | – | – |
| 03-May-07 | 12.24% | 7.53% | 5.82% | 0.05% | 7.66% | 9.76% | Lower | – | – |
| 15-May-07 | 18.20% | 10.86% | 11.94% | 0.21% | 4.14% | 9.04% | Lower | Lower | Lower |
| 04-Jun-07 | 0.00% | 17.37% | 14.65% | 0.32% | 11.99% | 9.40% | – | Lower | Lower |
| 20-Sep-07 | 40.66% | 27.97% | 20.43% | 2.48% | 8.03% | 14.09% | Lower | Lower | Lower |
| 11-Dec-07 | 4.66% | 5.29% | 8.25% | 1.40% | 7.62% | 5.44% | Lower | – | Lower |
| 15-Jan-08 | 24.67% | 15.47% | 12.06% | 8.36% | 12.47% | 18.77% | Lower | Lower | – |
| 20-Feb-08 | 10.41% | 9.01% | 7.31% | 24.88% | 12.72% | 11.94% | – | – | – |
| 25-Mar-08 | 0.00% | 0.00% | 12.69% | 24.45% | 14.70% | 11.15% | – | – | Lower |
| 04-Jun-08 | 10.42% | 7.63% | 6.15% | 13.33% | 8.88% | 10.10% | – | – | – |
| 18-Dec-08 | 11.55% | 18.34% | 14.09% | 12.20% | 5.13% | 6.61% | – | Lower | Lower |
| 17-Mar-09 | 30.36% | 18.51% | 16.46% | 4.44% | 17.57% | 21.00% | Lower | Lower | – |
| 27-Apr-09 | 0.00% | 8.38% | 15.26% | 20.20% | 24.92% | 18.46% | – | – | – |
| 03-Jun-09 | 1.05% | 19.55% | 17.48% | 1.25% | 3.42% | 14.27% | – | Lower | Lower |
| 22-Jul-09 | 13.85% | 10.28% | 14.96% | 7.38% | 14.13% | 24.92% | Lower | – | – |
| Success (%) | | | | | | | 48% | 57% | 52% |
| *Call options* | | | | | | | | | |
| 29-Jul-02 | 0.00% | 10.43% | 10.59% | 11.46% | 7.07% | 6.57% | – | Lower | Lower |
| 01-Aug-02 | 7.41% | 7.89% | 10.25% | 2.60% | 6.28% | 6.25% | Lower | Lower | Lower |
| 02-Oct-02 | 5.67% | 10.59% | 11.44% | 4.31% | 11.33% | 9.76% | Lower | – | Lower |
| 10-Apr-06 | 0.00% | 10.46% | 8.80% | 15.29% | 7.75% | 10.98% | – | Lower | – |
| 16-May-06 | 27.25% | 16.50% | 16.60% | 21.13% | 11.51% | 13.37% | Lower | Lower | Lower |
| 18-May-06 | 21.13% | 19.50% | 17.90% | 15.17% | 8.71% | 17.57% | Lower | Lower | Lower |
| 23-May-06 | 22.66% | 13.76% | 15.92% | 17.38% | 24.77% | 16.62% | Lower | – | – |
| 25-May-06 | 17.38% | 15.72% | 16.25% | 22.08% | 19.10% | 15.32% | – | – | Lower |
| 27-Jun-06 | 0.00% | 9.39% | 7.07% | 0.84% | 20.48% | 13.92% | – | – | – |
| 26-Jun-07 | 11.29% | 13.89% | 14.45% | 8.19% | 14.58% | 10.26% | Lower | – | Lower |
| 13-Aug-07 | 0.00% | 18.11% | 12.70% | 19.09% | 32.76% | 27.18% | – | – | – |
| 22-Nov-07 | 10.68% | 8.03% | 10.13% | 8.85% | 5.52% | 10.81% | Lower | Lower | – |
| 07-Oct-08 | 55.54% | 40.19% | 33.43% | 31.23% | 47.03% | 49.22% | Lower | – | – |
| 24-Oct-08 | 20.84% | 28.82% | 44.15% | 14.50% | 10.01% | 14.69% | Lower | Lower | Lower |
| 30-Jan-09 | 8.42% | 16.65% | 14.44% | 18.93% | 15.11% | 14.12% | – | Lower | Lower |
| 02-Feb-09 | 0.00% | 16.76% | 15.29% | 20.85% | 17.45% | 17.43% | – | – | – |
| 12-Feb-09 | 0.26% | 18.14% | 17.43% | 3.81% | 6.17% | 15.81% | – | Lower | Lower |
| Success (%) | | | | | | | 53% | 53% | 59% |

Volatility is measured as the annualized standard deviation of the log difference in daily exchange rates with a rolling window of 2, 5, and 10 days. Comparing volatility at the time of maturity to 2, 5, and 10 days after contract maturity yields more successful results. After the option is exercised, volatility decreases in 76 to 82% of all cases. The short period compares volatility 2 days before and 2 days after the date of option maturity, using a 2 day rolling window for volatility. The mid period compares volatility 5 days before and 5 days after the date of option maturity, using a 5 day rolling window for volatility. The long period compares volatility 10 days before and 10 days after option maturity, using a 10 day rolling window for volatility. Here, the calculation of volatility varies depending on the period in question.

on the period in question. The short period compares volatility 2 days before and 2 days after the date of option maturity, using a 2 day rolling window for volatility. The mid period compares volatility 5 days before and 5 days after the date of option maturity, using a 5 day rolling window for volatility. The long period compares volatility 10 days before and 10 days after option maturity, using a 10 day rolling window for volatility. Comparing volatility at the time of auction to 2, 5, and 10 days after auction yields more successful results. After the auctioning of volatility call and put options, exchange rate volatility decreased in 76 to 82% of all cases, respectively.

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