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Intervention: The Case of Colombia**

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# Options and Central Banks Currency Market Intervention: The Case of Colombia \*

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## Abstract

Several central banks in emerging economies are concerned with excessive volatility in foreign exchange markets and would like to control the direction and speed with which the value of their currency changes. Historically, currency market interventions have consisted of using foreign exchange reserves to purchase and sell foreign currency directly in the spot market. However, these spot interventions are not the only type of interventions available to central banks. The Colombian central bank implemented various strategies to intervene into currency markets to smooth volatility, build reserves, and influence the direction of the exchange rate by issuing options contracts as well as using daily discretionary purchases of US dollars. In this paper we analyze these recent strategies employed by Colombia, with a special focus on the volatility option strategy. We argue that the abandonment of the options program was premature and that its success was not fully appreciated in previous literature.

*Keywords:* Exchange Rates, Intervention, Foreign Exchange Markets, Currency Options, International Reserves, International Finance.

*JEL:* F31, G15

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# 1 Introduction

In several emerging market economies, policy makers intervene into currency markets to exert control over exchange rates.<sup>1</sup> Some intervene to calm disorderly markets and relieve liquidity shortages, while others try to correct misalignment and stabilize volatile exchange rates.<sup>2</sup> 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 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.<sup>3</sup> 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 and that past literature analyzing the success of this strategy did not fully appreciate the success of options in curbing volatility.

The remaining sections of the paper are structured as follows. Section two presents a review of past literature on central bank intervention, linkages between policy goals and exchange rates, and macroeconomic fundamentals of currency markets. Section three illustrates the current macroeconomic situation in Colombia. Section four describes Colombia's central bank currency intervention strategies, and section five discusses the historical use of options as an intervention mechanism. Section six details the methodology used for analysis and section seven presents the results of the analysis for the case of Colombia. Section eight 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.

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<sup>1</sup>Emerging markets are economies where some market segments are developed, while others are still not developed or underdeveloped. These economies include countries such as Argentina, Chile, Colombia, Hungary, India, Peru, Turkey, Mexico, Hong Kong, Indonesia and Brazil, among others.

<sup>2</sup>Such volatility is argued to be a cause for banking crises, economic instability, slowing growth and, the decrease in trade.

<sup>3</sup>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.

## 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.<sup>4</sup> 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 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,<sup>5</sup> an increase in foreign interest rate,<sup>6</sup> or expectation of future depreciation<sup>7</sup> will result in a depreciation of the domestic currency. An increase in the supply of foreign bonds<sup>8</sup> or an increase in the domestic interest rate<sup>9</sup> result 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, Natalucci and Piger, 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, Goldajn and Minella (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 becomes 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, Roger, Nordstrom, Shimizu, Kisinbay and Restrepo, 2009): First, in emerging markets the presence of a high

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<sup>4</sup>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).

<sup>5</sup>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.

<sup>6</sup>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.

<sup>7</sup>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.

<sup>8</sup>An increase in the supply of foreign bonds will lead to an increase in the relative domestic interest rate and increase the demand for domestic currency relative to foreign currency, which will lead to an appreciation of the domestic currency.

<sup>9</sup>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.

exchange rate pass-through<sup>10</sup> 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, de Freitas, Goldfajn and Muinhos, 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 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<sup>11</sup> to exchange rate shocks in three inflation-targeting East Asian economies has declined after the East Asian crisis.<sup>12</sup> 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 post 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 build 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.

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<sup>10</sup>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 be also affect inflation rates.

<sup>11</sup>The monetary policy measures used by the author include money demand (M1), short-term interest rates, output gap, and inflation

<sup>12</sup>The three economies are Thailand, Korea and Philippines.

## 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.<sup>13</sup> 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 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

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<sup>13</sup>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.

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 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 Brief Macroeconomic Description of Colombia

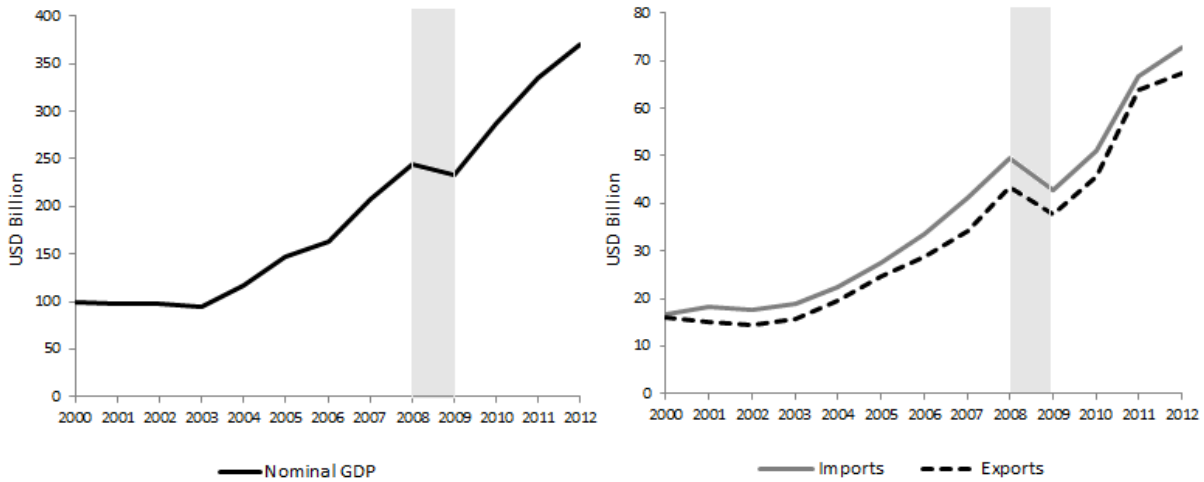
Over the last decade Colombia's economy has grown and developed despite the global recession and various domestic political and institutional concerns. Between 2000 and 2012, Colombia's economy has maintained an average annual GDP growth rate of 4.3%. From 2005 to 2010, Colombia's average annual GDP growth rate was 4.6 %. Considering that most world economies stalled following the 2008 crisis, this is high rate of growth. From 2000 to 2012, export volume grew at an average annual rate of 12.8% while imports grew at an average annual rate of 13.4%, as can be seen in Figure (1). The average annual trade deficit from 2000 to 2012 was US\$ 4.0 billion. Trade openness, measured as the sum of exports and imports as a share of GDP, increased 13.8% during the period. In 2000, the share of trade flows to GDP was 32.6%, by 2012 it had increased to 37.9%. In 2013 Standard and Poor's raised Colombia's foreign currency credit rating from BBB- to BBB due to the reduction in its vulnerability to external shocks, strengthening of the domestic capital market and a positive outlook for long-term economic growth.

The foreign direct investment (FDI) flows into the country increased from less than US\$ 2.5 billion in 2000 (2.4% of GDP) to over US\$ 15.6 billion (4.2% of GDP) in 2012, averaging US\$ 7 billion per year. Remittance inflows increased from US\$ 1.6 billion in 2000 to over US\$ 4 billion in 2012, averaging US\$ 3.5 billion per year. Foreign portfolio inflows, which are much more volatile, grew from US\$ 17 million in 2000 to US \$ 4 billion in 2012, but averaged only US\$ 614 million per year. However, since 2009, foreign portfolio investment inflows have grown from US\$ 67 million to US\$ 3.7 billion. The time series of these variables can be seen in Figure (2).

During the period of the global recession, total foreign capital and resource inflows fell by approximately 11%. Despite the global recession, remittances remained steady throughout this period, growing at an annual rate of 2% from 2007 to 2009. Unique to other types of capital inflows, remittance flows do not respond to the global and domestic economic factors that influence foreign direct investment and portfolio investment flows. Migrants may be motivated to send more funds during recessionary periods to supplement the incomes of their families and continue sending funds during adverse economic conditions.

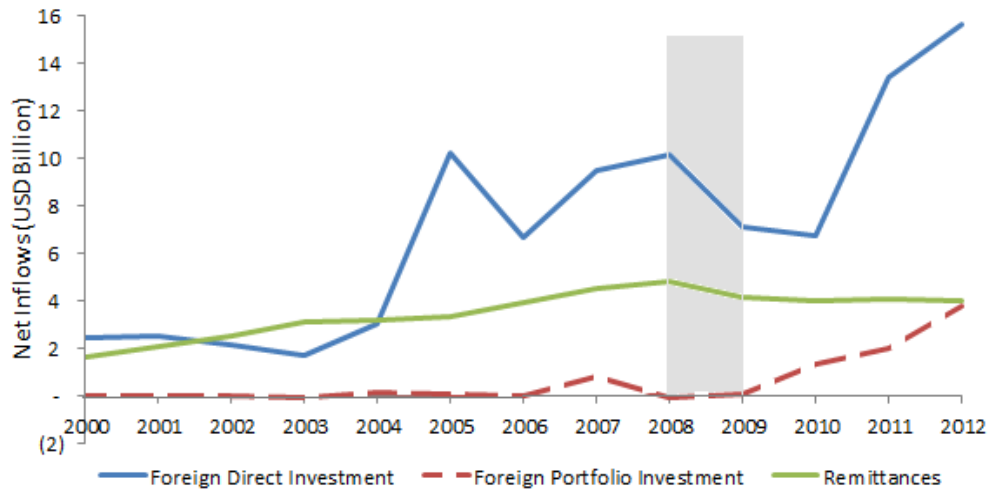
Between 2000 and 2012, manufacturing grew at an average rate of 3.3% per year whereas gross capital formation grew at an average 10.7% per year. Although the unemployment rate has hovered around 12% and the labor force participation rate has not changed significantly (an average of 69 %)

Figure 1: GDP and Trade Flows



On the left, nominal GDP in US dollars represented from 2000 to 2012. On the right, trade flows in current US dollars. The openness to trade in Colombia has increased by almost 14% since 2000. The shaded area represents the period of the global financial crisis.

Figure 2: Total Resource Inflows



Since 2000, foreign direct investment (FDI) has been on the rise in Colombia. The FDI flows into the country increased from less than US\$ 2.5 billion in 2000 (2.4% of GDP) to over US\$ 15.6 billion (4.2% of GDP) in 2012, averaging US\$ 7 billion per year. Remittances have grown, but remained stable. Remittance inflows increased from US\$1.6 billion in 2000 to over US\$4 billion in 2012, averaging US\$ 3.5 billion per year. Foreign portfolio investment (FPI) has increased in recent years with the expansion of financial development in the country. FPI inflows, which are much more volatile, grew from US\$17 million in 2000 to US \$4 billion in 2012, but averaged only US\$614 million per year. However, since 2009, FPI inflows have grown from US\$ 67 million to US\$3.7 billion. The shaded area represents the period during the global financial crisis.



during our study period, Colombia has achieved a phenomenal growth in its income levels. The GNI per capita<sup>14</sup> has increased from US\$2,340 in 2000 to over US\$7,020 in 2012, while the percentage of population earning less than US\$2 per day has decreased by almost half from 27.2% in 2000 to 15.8% in 2010. Table (1) provides additional descriptive statistics for Colombia.

Table 1: Descriptive Statistics

Macroeconomic Data for Colombia				
	GDP Growth %	GNI per capita Current USD	Labor Force Part. % Pop.	Unemployment % LFP
2000	4.42	2,340	67.50	16.20
2012	4.21	7,020	70.60	10.40
Average (2000-2012)	4.32	3,892	69.35	12.39
	Export Volume % GDP	Gross K Formation % GDP	Manufacturing % GDP	FDI % GDP
2000	15.92	14.90	15.01	2.44
2012	18.27	23.41	12.99	4.23
Average (2000-2012)	16.73	20.55	14.90	3.46

This table presents general statistics on Colombia's macroeconomic performance. As is evident, Colombia's economy has been growing steadily since 2000. It has a strong gross capital formation, strong export volume, and relatively low unemployment for the region.

Upon the adoption of inflation-targeting policies in 2000, the inflation rate in Colombia has remained fairly stable near 5.5%. Since 2010, the average annual inflation rate has been 2.9%. We can observe the inflation rate and the Colombian peso - US dollar exchange rate in Figure (3). For many emerging markets, especially those with high levels of dollarization or dependence on foreign currency inflows, there is a strong exchange rate pass through between currency market dynamics and the inflation rate. The COPUSD and inflation rate correlation is 44.5%<sup>15</sup> indicating a strong relationship between movements in the exchange rate and domestic price levels.

Following a floating regime, the Colombian peso appreciated continually during the period of our study. There were two exceptions to this: spring of 2006 which corresponds to the emerging market sell-off and the fall of 2008 which corresponds to the onset of Global Financial Crisis with the fall of Lehman Brothers in the United States. From March 2006 to June 2006, the Colombian peso depreciated at an average monthly rate of 4.05%, totaling a depreciation of 14.9%. Following the Lehman Brothers collapse, the peso depreciated at an average monthly rate of 4.49% from September 2008 to March 2009, totaling a depreciation of 17.7%.

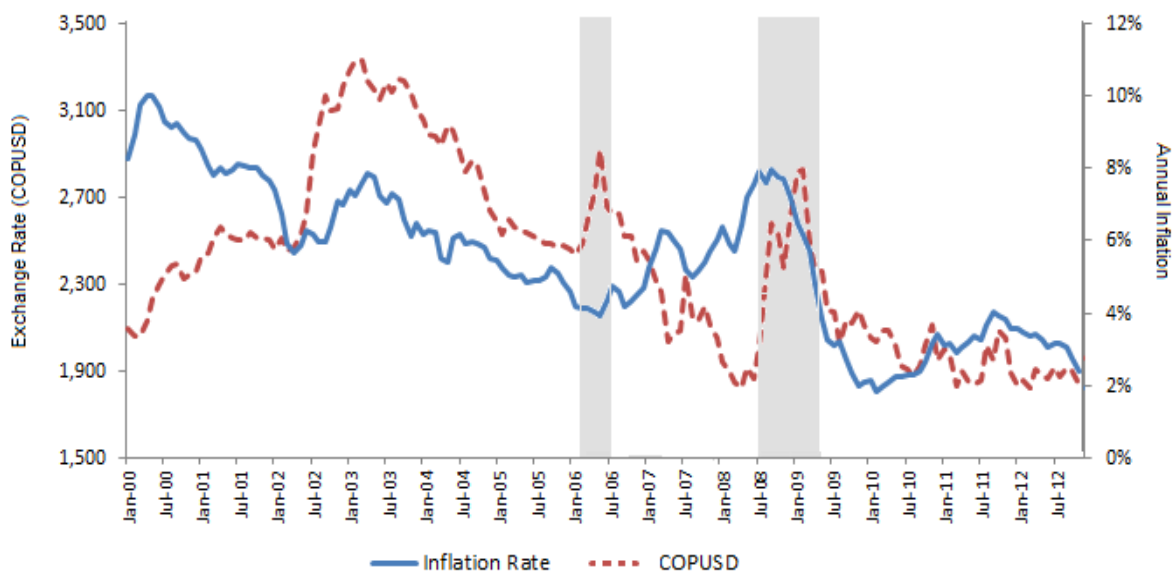
During the global financial crisis from 2008 to 2009, not only was there an absolute depreciation in the Colombian peso, but also in the 20-day volatility, as seen in the lower panel of Figure (5) where the dynamics of the Colombian peso versus the US dollar during these periods are illustrated. However, the bid-ask spread (a measure of currency risk) was much higher during the emerging market sell-off than during the global financial crisis. This can be attributed to the nature of both events. The 2006 emerging market sell-off was interpreted by investors as more dangerous in terms of currency and macroeconomic uncertainty than the financial crisis, which was linked to crisis in developed economies.

The emerging market sell-off that took place in 2006 caused an almost 15% depreciation of the Colombian peso from March to June 2006, prompting the Central Bank to intervene in the foreign

<sup>14</sup>GNI per capita in current USD

<sup>15</sup>This correlation is statistically significant at the 1% level, with a t-statistic of 6.154.

Figure 3: Inflation and Exchange Rate Dynamics



This figure illustrates the Colombian Peso - US Dollar (COPUSD) exchange rate from 2000 to 2012, as well as the annual inflation rate in Colombia. The COPUSD and inflation rate correlation is 44.5% and is statistically significant at the 1% level (t-stat: 6.154). The shaded area represents the start of the emerging market sell off in 2006 and the segment of the global financial crisis corresponding to the peso depreciation, which ended in March 2009.

exchange market repeatedly during the months of April to June 2006,<sup>16</sup> as seen in Table (4). During this period, the central bank sold US dollars through its volatility call option intervention strategy, which we will detail in the next sections. By the end of 2006, the peso recovered its losses versus other currencies and from 2007 up to fall of 2008, it appreciated to record lows versus the US dollar.

## 4 Central Bank Currency Intervention Strategies in Colombia

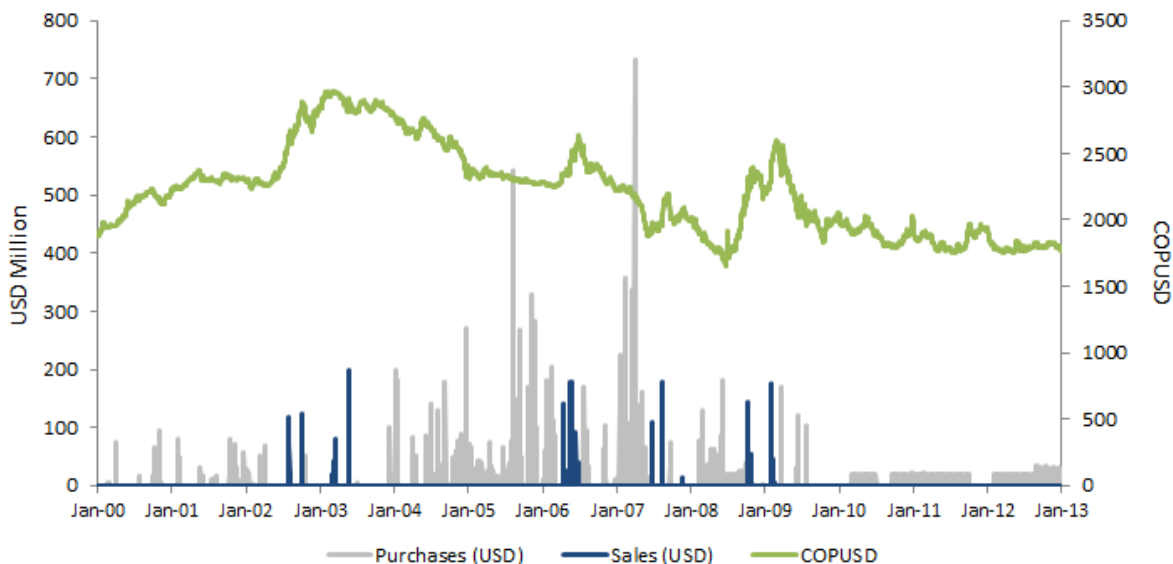
Colombia has experimented with many different intervention tools in its recent history. The Colombian central bank began systematic currency market interventions following the introduction of a floating exchange rate regime and the adoption on inflation-targeting monetary policy in 1999 (Uribe and Toro, 2005). They were the first to introduce the use of currency options for reserve accumulation and later, to control for volatility. From 2000 to 2012, the average yearly purchase of US dollars by the Colombian Central Bank was US\$ 2.2 billion,<sup>17</sup> representing an average of 1.7% of total domestic market transactions (Echavarria, Melo, Tellez and Villamizar, 2013). From 2005 to 2007 as well as from 2010 to 2012, 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 Figure (4) in the previous section.

From 2002 to 2009, the Colombian peso experienced a number of high volatility periods. The top

<sup>16</sup>In the spring of 2006 there was an emerging market sell off that included not only Colombia but also other emerging economies such as Brazil, Turkey and India. During the period of April to June 2006, the central bank of Colombia sold options to mitigate the volatility in currency markets.

<sup>17</sup>Sales were smaller at US\$ 571 million

Figure 4: 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 is 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.

panel in Figure (5) illustrates the market bid and ask prices along with the official exchange rate in Colombia from 2000 to 2014. The middle panel illustrates the spread between the bid and ask prices. Since 2012, the bid-ask spread between official rates and market rates has been much lower than in previous periods. 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. High volatility in the Colombian peso corresponds to the periods leading up to and following the global financial crisis.

From a global perspective, in 2013 Colombia's currency trading represented approximately 0.05% of all currencies traded on a net-gross basis,<sup>18</sup> representing a daily average trade of US\$ 3.34 billion. Foreign exchange markets in Chile and Peru have similar characteristics, as can be seen in Table (2). 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.

It is important to note that from 2004 to 2013, interbank foreign exchange transactions that occur domestically had grown in all three countries. However, with the exception of Peru, the share of these transactions occurring is declining with respect to the global daily average traded volume. In Chile, the share of interbank transactions with respect to all domestic spot market transactions has remained steady around 50%, declining from highs of 65% in 2004.<sup>19</sup>

Colombia is one of the few countries to date that have auctioned call and put options to mitigate

<sup>18</sup>Net-gross basis adjusts for only local inter-dealer double-counting. Data taken from the Bank of International Settlements.

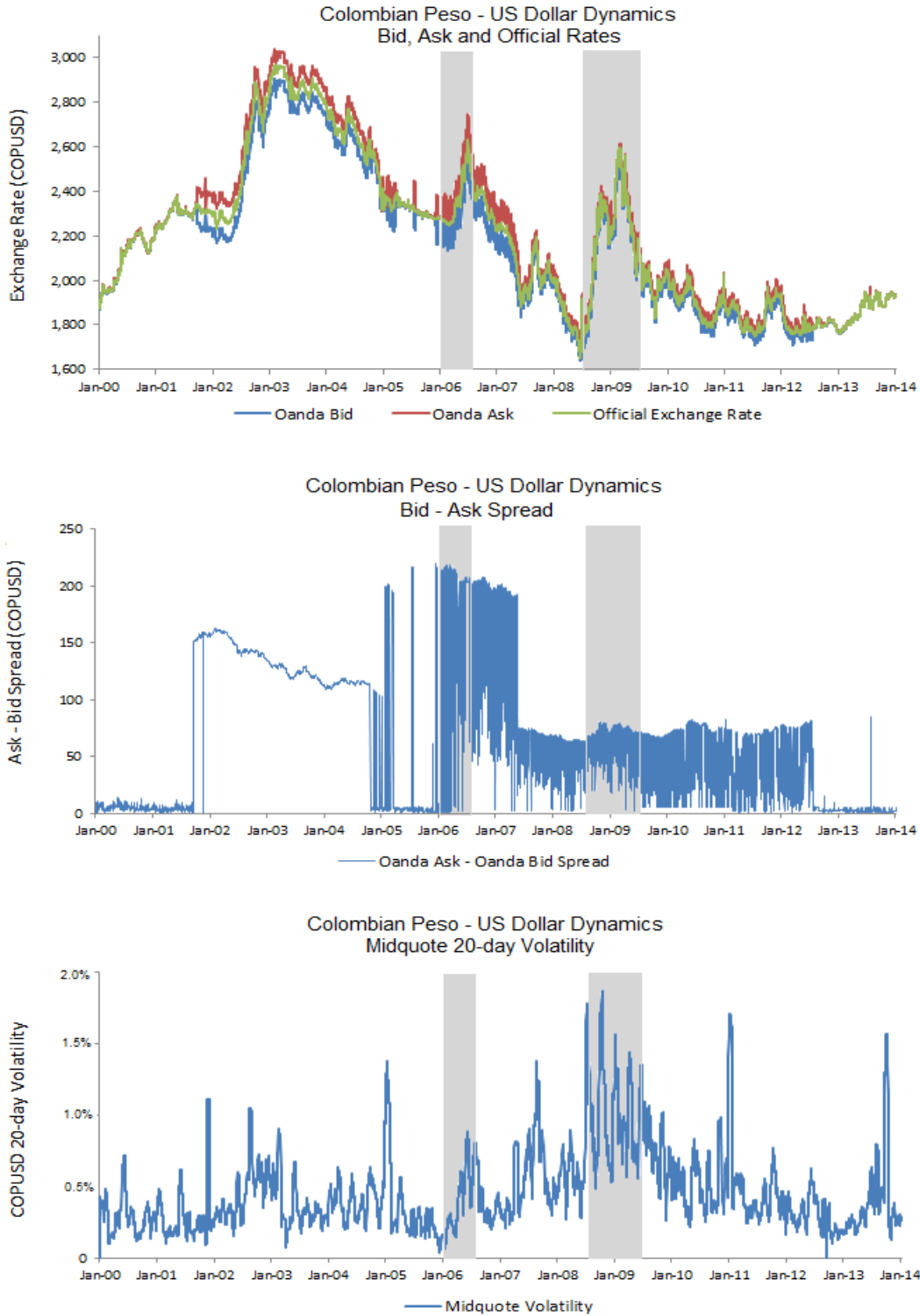
<sup>19</sup>Comparable data for Colombia and Peru on total spot market transactions is not reported by the central banks.

Table 2: Foreign Exchange Markets: Global vs. Domestic

<b>Colombia</b>					
		2004	2007	2010	2013
<b>Global Transactions</b>	Daily Average Traded Volume (USD Mil) % of Global Daily Trades	802 0.03 %	1,860 0.04 %	2,794 0.06 %	3,343 0.05 %
<b>Domestic Interbank Transactions</b>	Total Interbank Traded Volume (USD Mil) Daily Average Traded Volume (USD Mil) % of Daily Average Global Traded Volume	107,660 476 59.4 %	199,590 821 44.1 %	256,514 1056 37.8 %	219,670 904 27.0 %
<b>Chile</b>					
		2004	2007	2010	2013
<b>Global Transactions</b>	Daily Average Traded Volume (USD Mil) % of Global Daily Trades	2,462 0.09 %	4,003 0.09 %	5,544 0.11 %	11,956 0.18 %
<b>Domestic Interbank Transactions</b>	Total Interbank Traded Volume (USD Mil) Daily Average Traded Volume (USD Mil) % of Daily Average Global Traded Volume	323,975 1,295 52.6 %	419,576 1,698 42.4 %	379,433 1,518 27.4 %	617,102 2,488 20.8 %
<b>Domestic Spot Market</b>	Total Spot Market Volume (USD Mil) Interbank Trades(% Total Spot Volume)	496,175 65.3 %	712,086 58.9 %	745,207 50.9 %	1,196,890 51.6 %
<b>Peru</b>					
		2004	2007	2010	2013
<b>Global Transactions</b>	Daily Average Traded Volume (USD Mil) % of Global Daily Trades	306 0.01 %	805 0.02 %	1,425 0.03 %	2,171 0.03 %
<b>Domestic Interbank Transactions</b>	Total Interbank Traded Volume (USD Mil) Daily Average Traded Volume (USD Mil) % of Daily Average Global Traded Volume	18,602 71 23.2 %	30,294 116 14.4 %	93,378 356 25.0 %	177,431 677 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.

Figure 5: 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 OANDA. Official exchange rate data from Banco Republica de Colombia. Shaded areas represent the 2006 emerging market sell-off and 2008-2009 global financial crisis.

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 auction 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 (3) summarizes each type of option 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 were the issuers or sellers 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<sup>20</sup> 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 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 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.<sup>21</sup> In many cases, the option was auctioned and immediately exercised on the same day or the following day, as can be seen in Tables (4) and (5), 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

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<sup>20</sup>The buyer of the contract is in the long position, whereas the seller or issuer is in the short position.

<sup>21</sup>For example, in July 2006, the COPUSD appreciated more than 2% of the 20-day moving average, 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 (4).

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 Colombia 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 option 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.

Table 3: 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%* 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%* 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%* 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%* of 20-day moving average	USD \$ 2.37 billion

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. (\*) 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%.

From Tables (4) and (5), it is evident that in the majority of cases, the options were exercised almost

Table 4: 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 (US\$ per \$1000)	Trigger Value
(A)	17-Dec-04	179.9	17-Dec-04	157.9	-	4,000	-3.9 %
(B)	11-Jul-06	180.0	24-Jul-06 27-Jul-06	170.0 10.0	16	10,000	-3.3 % -2.5 %
(B)	31-Jul-06	180.0	02-Aug-06 03-Aug-06 04-Aug-06	44.5 95.0 40.5	4	11,100	-2.4 % -2.4 % -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 01-Nov-06 02-Nov-06 08-Nov-06 09-Nov-06	62.3 4.0 0.5 102.2 11.0	10	8,150	-1.9 % -2.0 % -2.1 % -1.9 % -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 04-May-07	162.0 18.0	1	3,130	-2.2 % -2.4 %
(E)	15-May-07	180.0	15-May-07 16-May-07 18-May-07 22-May-07 25-May-07	11.2 27.5 24.5 66.8 50.0	10	6,000	-4.3 % -4.3 % -3.8 % -3.4 % -3.4 %
(E)	04-Jun-07	180.0	04-Jun-07	14.5	-	7,100	-4.8 %
(F)	20-Sep-07	180.0	20-Sep-07 21-Sep-07 26-Sep-07	37.5 73.8 68.3	6	13,500	-4.5 % -4.9 % -4.1 %
	11-Dec-07	180.0	N/A	-	N/A	6,130	-2.1 %
(H)	15-Jan-08	180.0	13-Feb-08 14-Feb-08	25.7 77.0	30	8,150	-2.4 % -2.4 %
(H)	20-Feb-08	180.0	28-Feb-08 19-Mar-08	130.0 38.0	28	4,001	-2.7 % -2.3 %
(H)	25-Mar-08	179.9	24-Apr-08	62.5	30	5,000	-2.1 %
(I)	04-Jun-08	180.0	04-Jun-08 05-Jun-08	23.0 157.0	1	5,200	-2.5 % -2.4 %
(J)	18-Dec-08	180.0	18-Dec-08	2.3	-	11,050	-5.6 %
(K)	17-Mar-09	179.9	18-Mar-09 19-Mar-09	11.1 168.9	2	8,900	-5.8 % -5.7 %
	27-Apr-09	179.9	N/A	-	N/A	3,500	-4.5 %
(L)	03-Jun-09	180.0	04-Jun-09 05-Jun-09 11-Jun-09	32.0 26.5 121.6	8	11,150	-5.6 % -5.4 % -5.3 %
(M)	22-Jul-09	180.0	22-Jul-09 23-Jul-09	77.1 102.4	1	9,100	-5.0 % -5.1 %

This table captures the details of the volatility put 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 put options. The options could then be exercised on any day where the exchange rate was above the set percentage of the 20-day moving average within the contract period. The trigger value is calculated as the difference between the COPUSD and 20-day moving average or  $\frac{COPUSD_t - MA_{t,20}}{MA_{t,20}}$ . 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%. No additional put options could be auctioned until (a) the entire US\$ 180 million was exercised or (b) 30 days after the initial auction, whichever came first. Data from Banco de Central of Colombia.



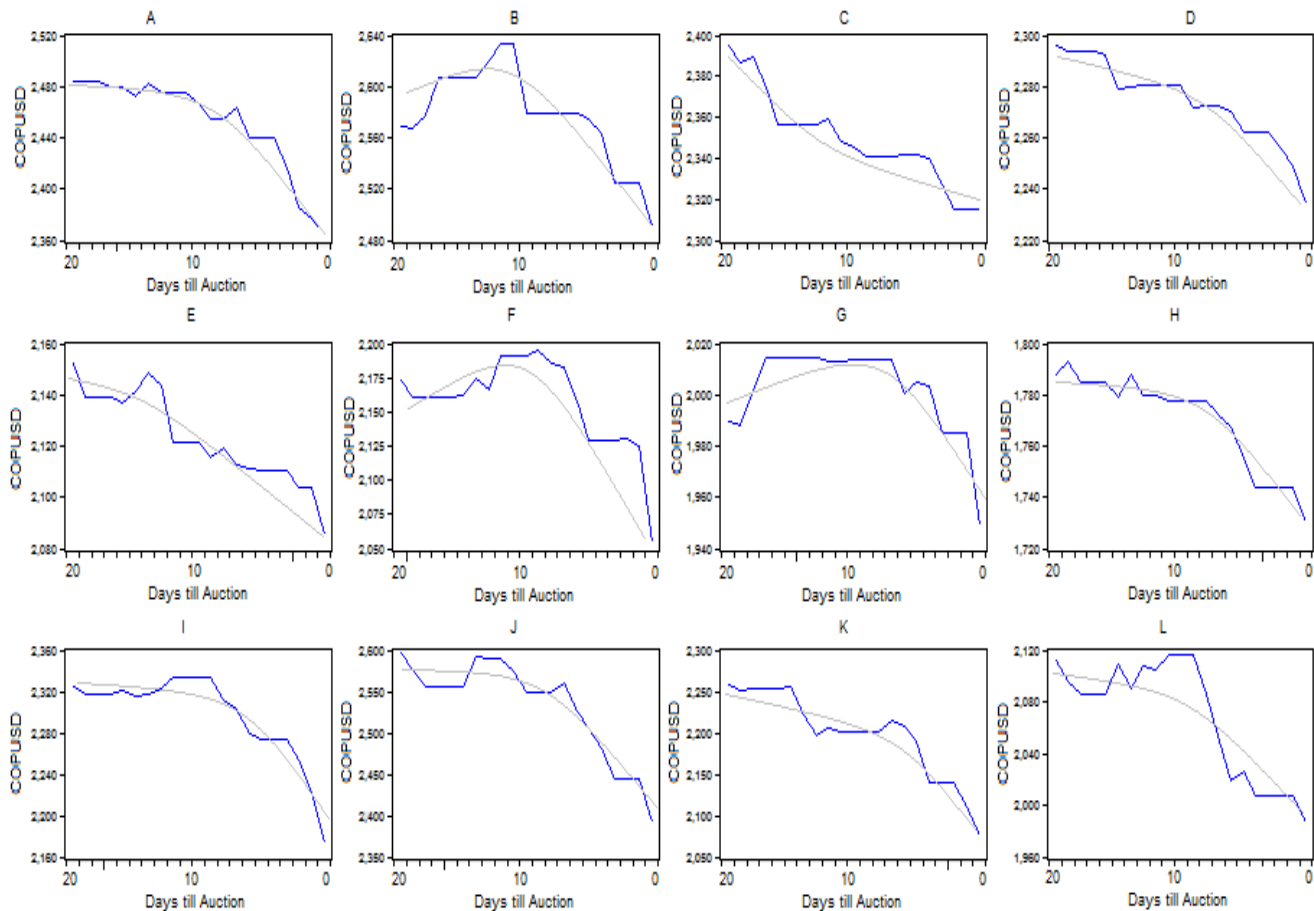
Table 5: Auction and Exercise of Volatility Call Options in Colombia

Volatility Call Options							
	Date of Auction	Auction Amount (USD Mil)	Date of Exercise	Exercise Amount (USD Mil)	Duration (Days)	Premium (US\$ per \$1000)	Trigger Value
(A)	29-Jul-02	180.0	29-Jul-02 31-Jul-02	117.0 63.0	2	3,800	4.0 % 4.3 %
(A)	01-Aug-02	180.0	01-Aug-02 02-Aug-02 06-Aug-02	69.0 17.0 23.5	5	4,220	4.3 % 4.0 % 4.1 %
(B)	02-Oct-02	180.0	02-Oct-02	124.5	-	5,157	4.1 %
(C)	10-Apr-06	180.0	10-Apr-06 12-Apr-06 27-Apr-06	140.5 2.0 26.0	17	6,000	2.8 % 2.2 % 1.9 %
(D)	16-May-06	179.8	17-May-06	179.8	1	6,000	2.0 %
(D)	18-May-06	179.8	18-May-06 19-May-06 22-May-06	103.0 1.0 75.8	4	9,000	2.8 % 3.2 % 3.0 %
(D)	23-May-06	179.9	24-May-06	179.9	1	9,100	4.0 %
(D)	25-May-06	179.9	30-May-06 31-May-06 09-Jun-06 13-Jun-06	65.5 3.0 18.5 92.9	19	12,200	2.3 % 2.4 % 1.8 % 2.3 %
(E)	27-Jun-06	180.0	27-Jun-06 28-Jun-06	39.9 16.5	1	13,501	3.0 % 3.3 %
(F)	26-Jun-07	180.0	26-Jun-07 27-Jun-07	68.7 107.8	1	3,500	2.3 % 2.4 %
(G)	13-Aug-07	180.0	14-Aug-07	179.9	1	4,000	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 08-Oct-08	143.9 31.0	1	11,000	6.0 % 6.0 %
(I)	24-Oct-08	180.0	24-Oct-08 27-Oct-08	54.4 5.3	3	17,200	4.8 % 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 04-Feb-09 10-Feb-09	125.0 46.0 14.0	8	26,400	7.0 % 7.0 % 5.0 %
(J)	12-Feb-09	180.0	16-Feb-09 18-Feb-09	3.5 5.0	6	8,700	5.0 % 5.6 %

This table captures the details of the volatility call 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 call options. The options could then be exercised on any day where the exchange rate was above the set percentage of the 20-day moving average within the contract period. The trigger value is calculated as the difference between the COPUSD and 20-day moving average or  $\frac{COPUSD_t - MA_{t,20}}{MA_{t,20}}$ . 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%. No additional call options could be auctioned until (a) the entire US\$ 180 million was exercised or (b) 30 days after the initial auction, whichever came first. Data from Banco de Central of Colombia.

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 the premium in each case. When we compare the premiums in Tables (4) and (5) to the corresponding changes in the COPUSD 20 days prior to the auction date presented in Figures (6) and (7), 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 Figure (5)) and premiums.

Figure 6: Exchange Rates 20 days Before Put Auction

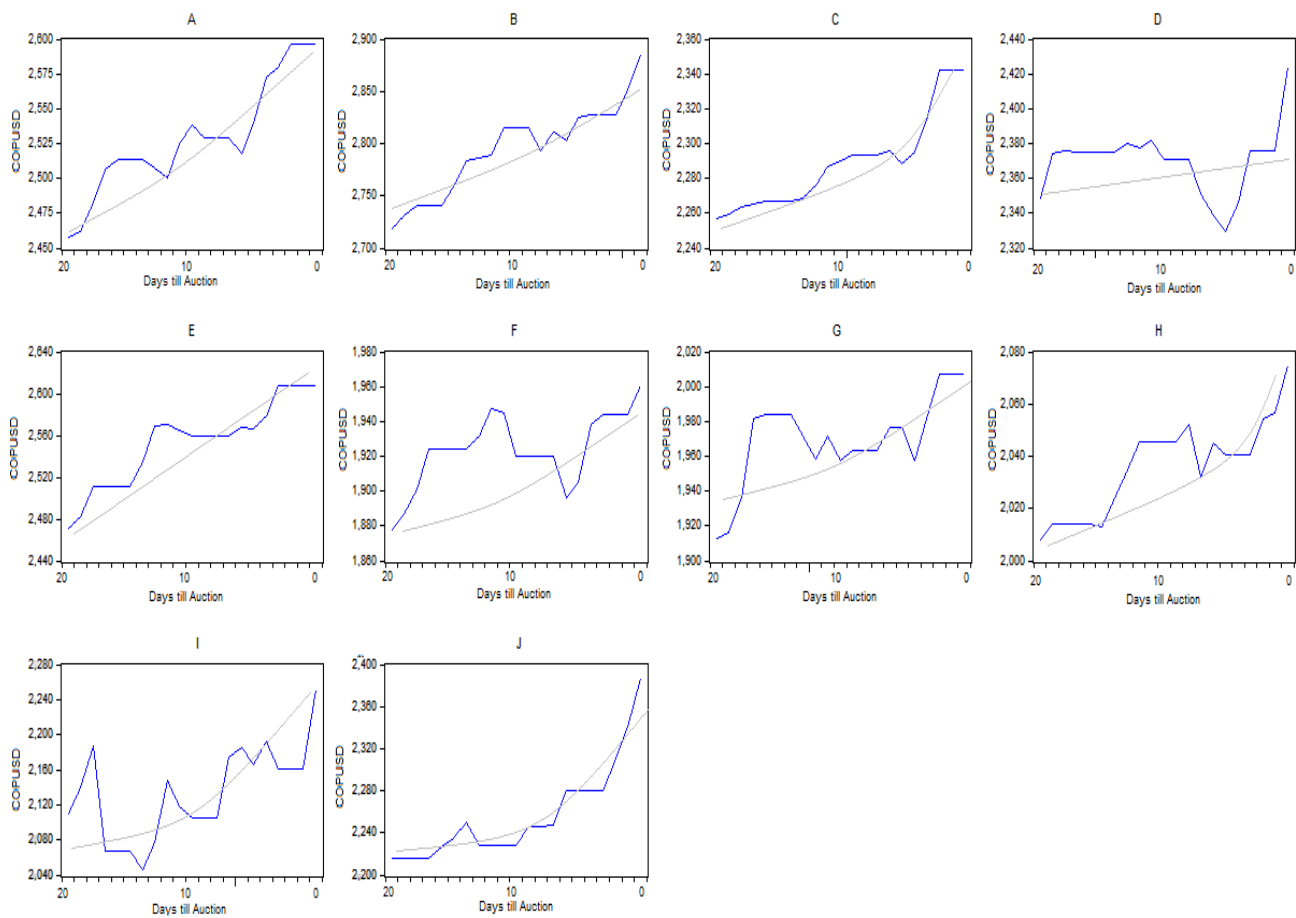


This figure illustrates the dynamics of the COPUSD official exchange rate over the 20 days before the auction of volatility put options. The letters correspond to the periods detailed in Table (6) and are designed to correct for periods where multiple option contracts were auctioned to avoid contamination of the data.

Figure (8) 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, dictated by any drastic movements of the exchange rate in the spot market.<sup>22</sup>

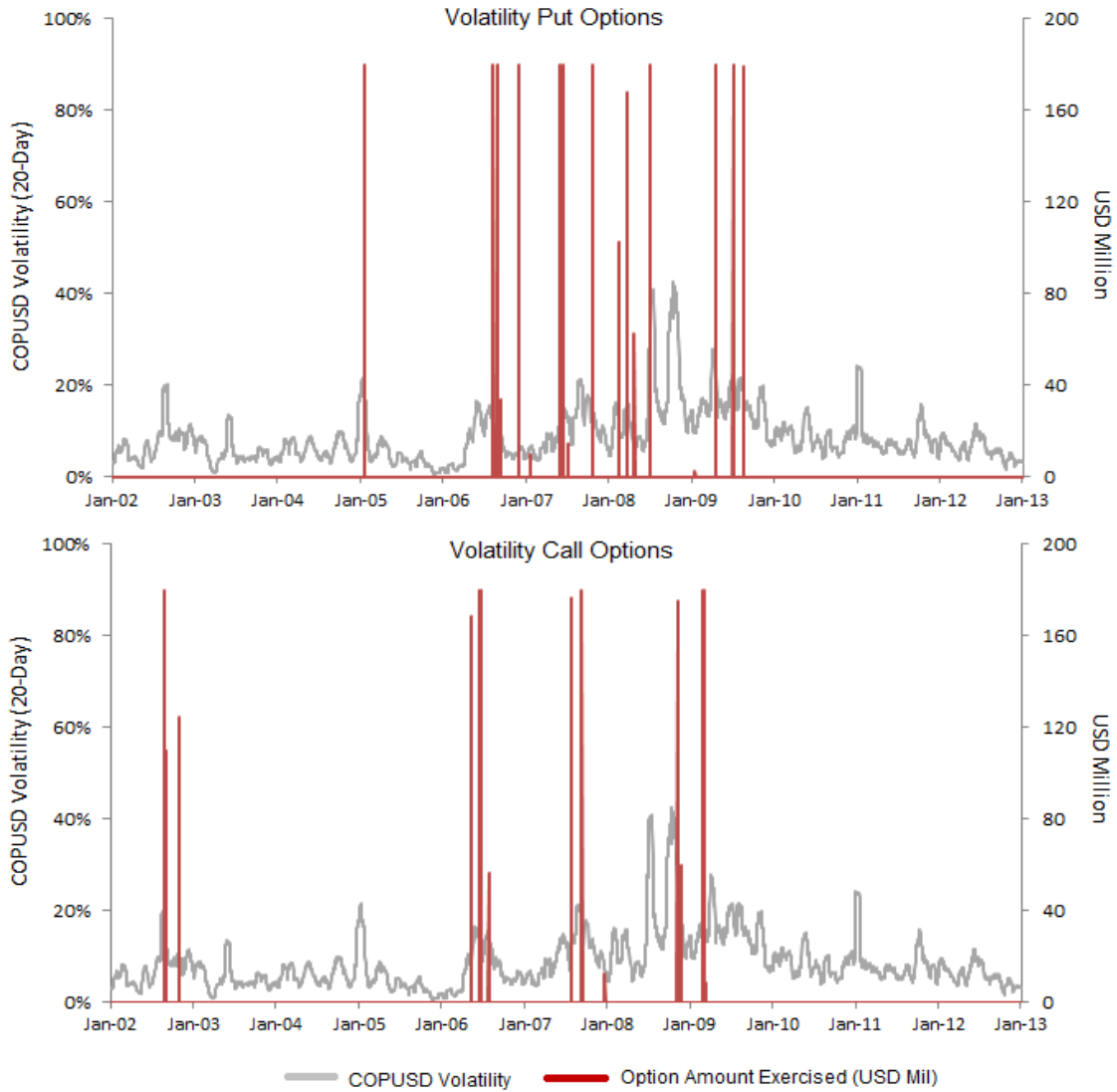
<sup>22</sup>Although the rule to trigger an auction of volatility options was established as described above, there were times when the central bank did not immediately auction options. Especially during periods with high variation when auctions already

Figure 7: 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 (6) and are designed to correct for periods where multiple option contracts were auction to avoid contamination of the data.

Figure 8: 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.

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 (Echavarría 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 option contracts by the Colombian central bank. Mandeng (2003) finds that volatility call 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 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-variance, we analyze the impact of exercising the options on variations between the official exchange rate and 20-day moving average.

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 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:

$$V = \frac{COPUSD_t - COPUSD_{t,MA}}{COPUSD_{t,MA}} \quad (1)$$

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

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occurred, the central bank chose to wait to see how the market would react to the previously auctioned options before selling more.

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.<sup>23</sup> To avoid data contamination, we 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 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, this would imply 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 Equation (1)). Upon exercise, if the value of  $V$  changes to a positive value, this implies 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  $\pm 4\%$ , the event is not successful; if it is between  $\pm 2\%$  and  $\pm 4\%$  the event is moderately successful; if it is between zero and  $\pm 2\%$  the event is highly successful.<sup>24</sup> 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.<sup>25</sup>

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

<sup>23</sup>Note that the central bank could not issue another option unless all existing options matured or were completely exercised.

<sup>24</sup>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.

<sup>25</sup>See Figures (9) and (10) for detailed description.

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 period. 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.<sup>26</sup> 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 option 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 of 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:

$$\Delta V_{pc}^* = \frac{V_{EX,i} - V_{AUC,i}}{V_{AUC,i}} \quad (2)$$

where  $V_{EX,i}$  is defined in Equation (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).

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:

$$\Delta V_d^* = V_{EX,i} - V_{AUC,i} \quad (3)$$

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 option contracts, for only call options, and for only put options.

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<sup>26</sup>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. In the 2, 5, and 10 days before and after the auction date, the standard deviation window overlaps. 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.

We include an AR(1) or AR(2) process when necessary to correct for autocorrelation.

## 6 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 (6) and Figures (9) and (10), 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 (6), 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 Equation (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.<sup>27</sup>

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.

In Table (7), we present the correlation between the before and after events. As can be seen, the correlation between the before and after puts (calls) are negative (positive).

In Figures (9) and (10), 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 counteract the drastic movement in the exchange rate, the post-exercise intraband variation should move in the opposite direction from the pre-auction period (sign effect) and should be closer to zero (magnitude effect).

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<sup>27</sup>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.



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  $\pm 2\%$  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.

Table 6: Comparison of Pre-Auction and Post-Exercise Exchange Rate Variations

Put Options								
Date of Auction	Date of Last Exercise	ID	Before Auction			After Exercise		
			2-Day	5-Day	10-Day	2-Day	5-Day	10-day
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	G	-0.76	-0.56	-0.28	0.13	0.19	0.15
15-Jan-08*	24-Apr-08*	H	-0.41	-0.36	-0.18	0.16	0.12	0.09
4-Jun-08	5-Jun-08	I	-0.16	-0.18	-0.09	-0.05	-0.03	0.00
18-Dec-08	18-Dec-08	J	-0.45	-0.48	-0.24	0.14	0.24	0.29
17-Mar-09	19-Mar-09	K	-0.48	-0.56	-0.28	0.17	0.30	0.54
3-Jun-09	11-Jun-09	L	-0.27	-0.48	-0.24	0.01	0.22	0.41
22-Jul-09	23-Jul-09	M	-0.14	-0.10	-0.05	0.31	0.59	0.39

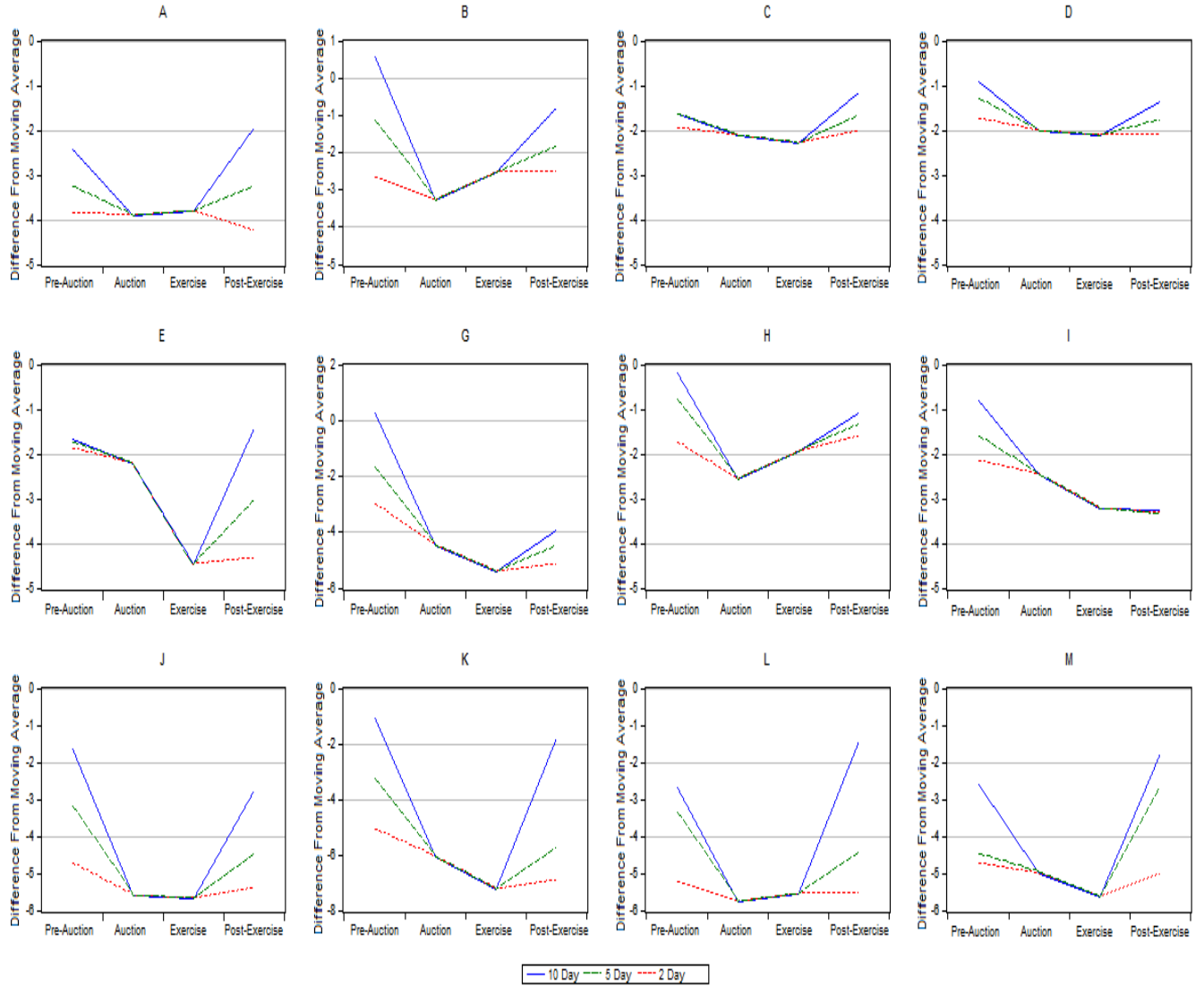
  

Call Options								
Date of Auction	Date of Last Exercise	ID	Before Auction			After Exercise		
			2-Day	5-Day	10-Day	2-Day	5-Day	10-day
29-Jul-02*	6-Aug-02*	A	0.06	0.13	0.06	-0.09	-0.42	-0.22
2-Oct-02	2-Oct-02	B	0.22	0.21	0.11	-0.14	-0.23	-0.20
10-Apr-06	27-Apr-06	C	0.28	0.26	0.13	-0.05	-0.06	-0.11
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

In this table, 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 Equation (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/post 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.

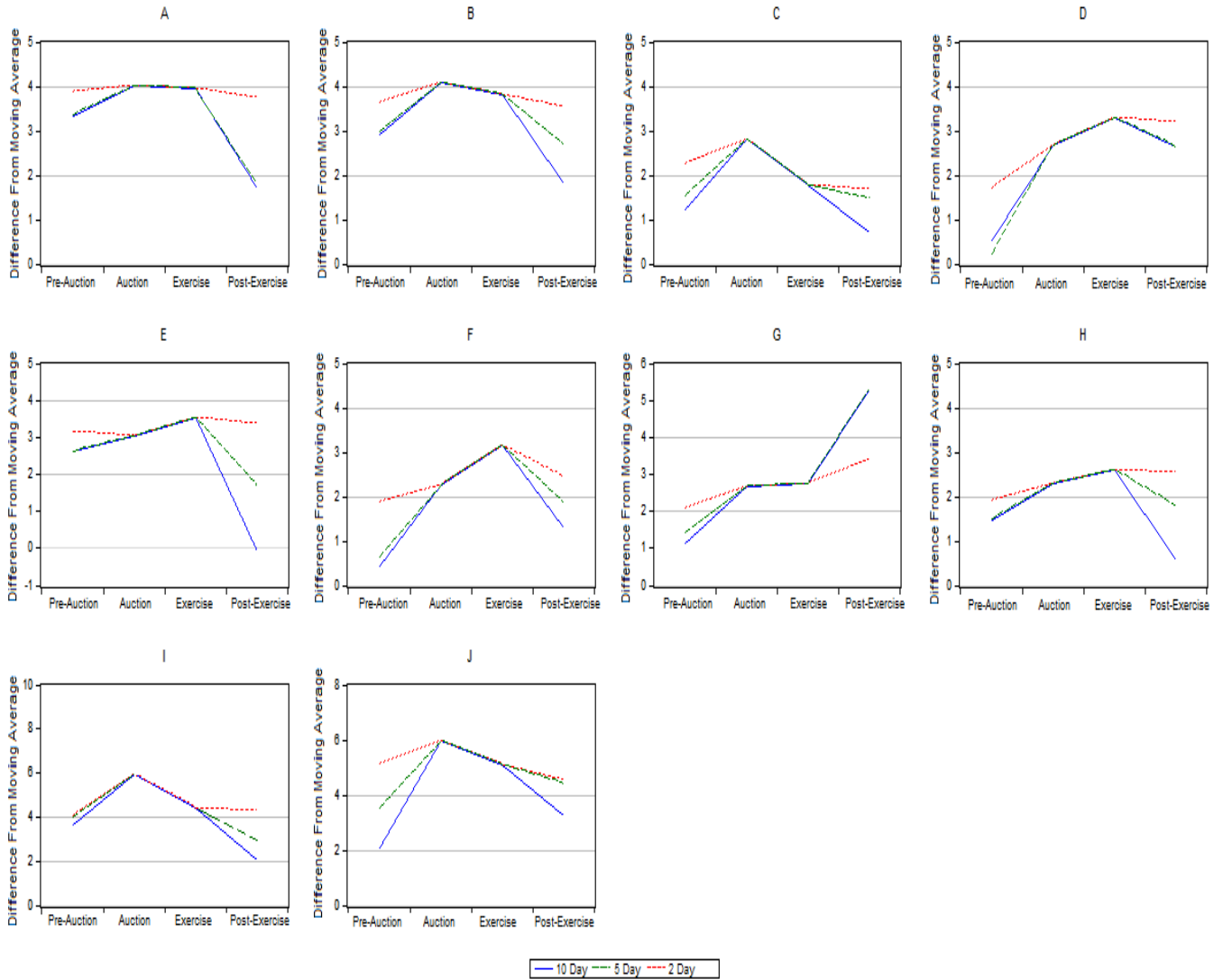
Next, we conduct a typical event study that links the volatility at auction to the volatility after the auction. In the top panel of Table (8), we compare volatility around the date of auction for volatility put options. When put options were auctioned, exchange rate volatility after auction in the short term

Figure 9: 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.

Figure 10: 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 7: Correlation in Pre-Auction and Post-Exercise Variation

	2 Day	5 Day	10 Day
Puts	-0.386	-0.008	-0.365
Calls	0.021	0.186	0.216

The values in the table present the correlation in the change in  $V$  from Equation (1) from 2, 5, and 10 days before the auction to the date of auction (“before auction” period) to the change in  $V$  from the last date of exercise to 2, 5, and 10 days after the last exercise date (“after exercise” period).

(2 days) and mid term (5 days) was lower in 48% of the cases for both.<sup>28</sup> In contrast, in the long term (10 days) in 38% of the cases. Volatility put options were therefore 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 put options increases to 76%.

In the lower panel of Table (8), 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, 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 (9) 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 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 Figure (9) and (10). In the 10 day time horizon, the event is no longer significant.

In the bottom panel of Table (9), the analysis-of-variance tests analyzes how the event of exercising an option will impact the difference in  $V$  from pre-auction to post-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 captures the success based on a change in the sign of  $V$  which reinforces the analysis presented in Table (6) and indicates 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.

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

<sup>28</sup>Or in 10 out of 21 case

Table 8: Success of Volatility Options Contracts in Colombia - at Auction

Put Options									
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
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									
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
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.

Table 9: Option 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*** (3.65)	0.204*** (3.33)	c	1.34** (2.12)	1.89*** (4.05)	c	-0.049 (-0.147)	0.459 (0.814)
$d2_t$ (Call)	-0.514*** (-3.96)		$d5_t$ (Call)	-1.49* (-1.64)		$d10_t$ (Call)	-0.435 (-0.946)	
$d2_t$ (Put)		-0.277*** (-5.33)	$d5_t$ (Put)		-2.36*** (-3.98)	$d10_t$ (Put)		-1.12 (-1.48)
AR(1)	0.362** (2.66)	0.505*** (4.34)	AR(1)	-0.206** (-2.18)	0.237*** (2.88)	AR(1)		0.175*** (2.91)
AR(2)			AR(2)	-0.267*** (-2.83)		AR(2)		
$R^2$	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

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** (2.11)	-0.004** (-2.58)	c	0.001 (0.283)	-0.008*** (-2.64)	c	-0.003 (-0.510)	-0.008* (-1.95)
$d2_t$ (Call)	-0.009*** (-3.25)		$d5_t$ (Call)	-0.007*** (-4.91)		$d10_t$ (Call)	-0.014*** (-8.05)	
$d2_t$ (Put)		0.007*** (3.69)	$d5_t$ (Put)		0.022*** (7.75)	$d10_t$ (Put)		0.022*** (11.16)
AR(1)	0.437*** (3.27)	0.699*** (5.31)	AR(1)	1.28*** (14.66)	0.838*** (9.91)	AR(1)	0.924*** (32.6)	1.12*** (18.77)
AR(2)		-0.338** (-2.53)	AR(2)	-0.456*** (-5.17)	-0.191** (-2.24)	AR(2)		-0.254*** (-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

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 Equation (2). For the bottom panel, the difference in  $V$  is calculated as  $V_d$  in Equation(3). The values in parenthesis are t-statistics, and \*, \*\*, \*\*\* represent significance of 10, 5, and 1 percent.

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).

In addition, the auctioning bundles of calls and puts at different strike prices, while holding an offsetting position in the spot market, increases the information flow between policy makers and traders, lowers the chances of speculative attacks<sup>29</sup> and mitigates some of the costs of hedging. The net hedging position is lower for a mixed portfolio of options, therefore the position of the central bank in the spot market is less disruptive.

## 7 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 option 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 option 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 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 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.

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<sup>29</sup>Speculative attacks in currency markets occur when there is a massive sell off of a particular currency, leading to a significant depreciation or devaluation of the currency, depending on whether the exchange rate regime is floating or fixed.

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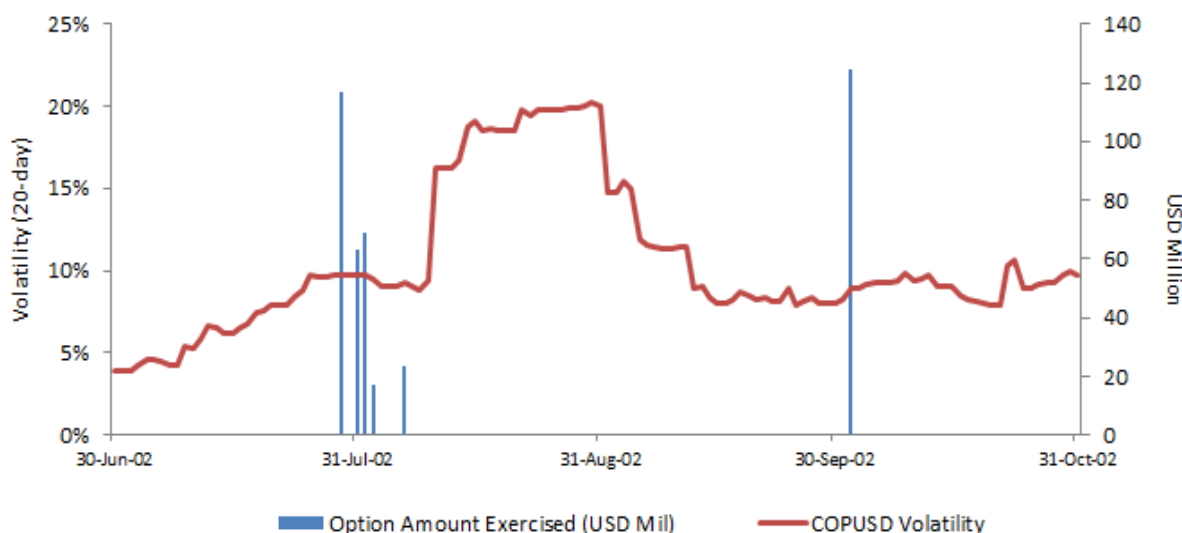
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## 8 Appendix

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.<sup>30</sup> 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.<sup>31</sup>

Using a similar approach to calculate volatility as described in Mandeng (2003), Figure (11) 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 (10), 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.

Figure 11: 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.

Table (10) analyzes volatility in COPUSD during the time of auction for all volatility call and volatility put options since the first issue date in 2002.<sup>32</sup> 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.

<sup>30</sup>At the time of his paper, Colombia had only issued three call options as means to control volatility.

<sup>31</sup>We will see that the way volatility is calculated is crucial in correctly analyzing the success of these options.

<sup>32</sup>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.

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 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 in 29% and 57% of all cases, respectively, as can be seen in Table (10).

In Table (11), 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 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.

Table 10: Volatility Options Contracts Issued in Colombia - Part 1

Put Options									
Date	Volatility Before			Volatility After			Success		
	10 Days	5 Days	2 Days	2 Days	5 Days	10 Days	Short	Mid	Long
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									
Date	Volatility Before			Volatility After			Success		
	10 Days	5 Days	2 Days	2 Days	5 Days	10 Days	Short	Mid	Long
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 calculate 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.

Table 11: Volatility Options Contracts Issued in Colombia - Part 2

Put Options									
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
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									
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
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. The data is based on a 7-day for calculations of volatility.