Currency Option Trading Strategies as an Alternative Tool for Central Bank Foreign Exchange Interventions

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April 3, 2018

Abstract

Many emerging markets' central banks are concerned with excessive volatility in foreign exchange rates and intervene to smooth volatility. This paper proposes a specific option trading strategy as an alternative central bank tool to aid foreign currency intervention, where dynamic delta hedging of the net portfolio position guides the central bank's intervention in the spot market. We term this trading strategy as the "W" spread, and show that the exchange rate can be stabilized and volatility lowered with this market-driven approach to foreign exchange intervention.[1]

Keywords: Exchange Rates, Foreign Exchange Intervention, Currency Options, International Finance
JEL: F31, G15

1 Introduction

Many emerging markets' central banks are concerned with excessive volatility in foreign exchange rates and wish to exert some control over the direction and speed with which the value of their currency changes. Historically, intervention methods have relied on the purchase and sale of foreign currency directly in the spot market.[2] This paper proposes a specific option trading strategy as an alternative central bank tool to aid foreign currency intervention, where dynamic delta hedging of the net portfolio position guides the central bank's intervention in the spot market.[3] The main objective of the central bank in adopting this type of an intervention strategy is to limit exchange rate volatility with an intervention position that is driven by market forces. It is important to note that no intervention strategy can overcome the effects of structural changes that cause exchange rate movements, but this strategy can dampen the effects of sudden exchange rate shocks and lower volatility. Because the strategy responds to market conditions, rather than subjective interventions determined by policymakers, it may be more effective in responding to shocks than discretionary spot market interventions.

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[1] The authors would like to thank the Global Association for Risk Professionals for their support in the funding of this research, as well as the participants of the the First Annual Meeting of the Peruvian Society of Economists and members of the Peruvian Central Bank. The usual disclaimers apply.

[2] More recently, central banks in Brazil, India, Mexico and Turkey has been intervening through the derivatives market. See Domanski, Kohlscheen, and Moreno (2016) and Nedeljkovic and Saborowski (2016).

[3] We tested a variety of traditional strategies first that did not reach the intended goal of lowering volatility through both daily interventions and at exercise. Results available upon request.

We use the Colombian Central Bank's experience with volatility options as a benchmark[4] and analyze an option trading strategy that we term the "W" spread, where the central bank holds a portfolio of two long calls, two long puts, one short call and one short put.[5] The proposed intervention happens on two fronts. First, on a daily basis, the spot market purchase/sale of USD will be determined by the responsiveness of the option price to a change in the daily exchange rate - or the option's delta. Second, at maturity, the central bank as well as the market participants can use the proceeds from the option execution to buy/sell USD on the spot market that once again complements the central bank's goal to stabilizing exchange rate movements. Our results show that since the spot market interventions are now driven by the delta of the option, the central bank lowers volatility with a clear, market-driven position.

The remaining sections of the paper are structured as follows. Section 2 provides a review of the literature. Section 3 describes the W-spread option trading strategy and argues why this strategy is an improvement on others already used in the market. Section 4 presents the analytical approach and methodology. Section 5 reports the results by testing the W-spread strategy with a simulated series of the Colombian Peso - US Dollar exchange rate (COPUSD). Here we price options contracts at various strike prices and analyze the outcome of dynamically delta hedging the net portfolio position and its effect on exchange rate movements. Section 6 concludes.

2 Literature Review

There is limited literature on the use of currency options by central banks for the purpose of exchange rate intervention. In the past, the proposition for emerging market central banks to use currency options has been more of a theoretical exercise. This may be partly due to the relatively shallow and underdeveloped derivatives markets in these economies. Despite the recent growth in demand for foreign exchange derivatives in emerging economies, they represent only a fraction to the global derivations market. Emerging markets make up only 4.4% of the daily over-the-counter (OTC) trading of foreign exchange derivatives according the data collected by the Bank of International Settlements.[6] Yet, there is demand for these financial products. Turnover in foreign exchange derivatives for emerging market economies has increased by over 300% from 2001 to 2013.

Furthermore, options made up only 6% of the total foreign exchange derivatives market traded in emerging economies as of 2010 (Mihaljek and Packer, 2010). Adoption of options-based intervention tools by central banks may aid further development of these markets. Local traders as well as export/import businesses would have a new hedging instrument readily available to them. Caballero (2003) contends that emerging markets need instruments for hedging and insurance purposes against capital flow reversals specifically, and the exchange rate volatility that they

[4]Colombia is one of the only economies known to have used currency options as a means for curbing exchange rate volatility. This strategy has been found to be successful in reaching the stated goals of smoothing the volatility (Keefe and Rengifo, 2015).

[5]In all cases, the options are in USD. E.g. in a long call position, the central bank has the right to buy USD from the issuer of the option. In a short call position, the central bank has the obligation to sell USD to the owner of the option.

[6]This excludes the top four derivatives trading centers of Hong Kong, Singapore, Korea and Brazil, which make up over 90% of the total emerging market derivatives trading (Mihaljek and Packer, 2010).

may cause. In comparing Australia and Chile, Caballero illustrates how emerging markets require insurance to assist in the response to crises and shocks that would match the effectiveness of policy responses in advanced economies.

There have been a number of arguments for the adoption of a derivatives-based intervention strategy. Wiseman (1999) argues that governments should commit themselves to frequent and regular auctions of short-dated physically-delivered currency options as a mechanism to stabilize exchange rates. Since almost all central bank authorities would like to reduce exchange rate volatility, without pushing it all the way to zero, official auctions would encourage private banks to buy options and exercise them when profitable. Dynamic delta hedging on the part of the trader can substitute for actively pursuing the same position in the market.

Zapatero and Reverter (2003) consider the intervention strategies of central banks when directly intervening in the spot market using foreign exchange reserves compared to intervention with the use of options. With the counter-party investment bank hedging its position, the options intervention method performs better than traditional spot market intervention using foreign exchange reserves. The currency stabilization occurs through the hedging activities of the investment bank in the bond market to offset its currency options position with the central bank.

Keefe and Rengifo (2015) analyze the success of volatility options used by the Colombian Central bank to mitigate deviations of the exchange rate from the 20 day moving average. In 85% to 90% of options executed, the value of the COPUSD reverted towards the trend, thereby successfully minimizing the volatility. After abandoning the strategy in 2009, the Colombian Central Bank has once again instituted the use of volatility options as of October 2015.

A fundamental assumption in our strategy is the use of dynamic delta hedging to guide the open market intervention position of central banks. According to Breuer (1999), if market makers hold net long positions, their dynamic delta hedging behavior can lower volatility. When the owners of an option contract sell USD in the spot market to hedge their positions when the domestic currency is depreciating against the dollar, and purchase USD when the domestic currency is appreciating against the dollar, this will help stabilize exchange rates. Furthermore, the transparency with which the central bank auctions option contracts to market participants may introduce stability and additional hedging instruments into the market (Archer, 2005). Garber (1994) and Malz (1995) also study the effects of hedging on currency stabilization. By influencing market liquidity and expectations, the use of currency options by central banks can be effective in stabilizing the exchange rate and controlling volatility.

Testing the effectiveness of foreign exchange interventions has been complicated, since the size, frequency, and duration of intervention may vary drastically within and between countries. The most thorough analysis of intervention effectiveness to date has been conducted by Fratzscher, Gloede, Menkhoff, Sarno, and Stoher (2015) by studying foreign exchange intervention in 33 countries. They find that foreign exchange intervention is widely used by a number of countries, and that it is an effective policy to smooth and stabilize exchange rates.

Daude, Levy Yeyati, and Nagengast (2014) review the effectiveness of traditional foreign exchange intervention in emerging market economies, specifically with the reassessment of this tool in the wake of the global financial crisis.

The authors find that the most effective interventions are those that are used as a countercyclical macroeconomic tool, smoothing out short-run volatility and currency swings. Interventions can slow appreciation, and are most effective when the currency is already overvalued. Their effectiveness decreases under conditions of greater capital account openness (Adler and Tovar, 2011).

Leon and Williams (2012) concur that foreign exchange intervention via either purchase or sale of foreign currency is effective if the goal is to keep the exchange rate within a targeted range. The interventions are an appropriate policy tool in emerging economies looking to control imported inflation while maintaining competitiveness. Egbert (2007) finds interventions in emerging European economies were successful in curbing appreciation pressure, while Guinigundo (2015) shows that by using spot market interventions as the main tool for intervention, the central bank of the Philippines was able to curb exchange rate volatility without adhering to a specific level of the exchange rate. The results in this paper support that finding. Akinci, Culha, Ozlale, and Sahinbeyoglu (2006) also found that purchase-based interventions were successful in curbing appreciation.

Our research contributes to the literature on both the potential use of currency options by central banks and the potential effectiveness of such tools in curbing exchange rate volatility. By proposing a novel trading strategy that allows the central bank to operate in both the spot and derivatives market, we explore a new approach to the question of how central banks in emerging market economies can effectively intervene in currency markets to reach their objective of smoothing exchange rate volatility.

3 W-Spread Strategy

The W-spread strategy has two key components. First, in the options market, the central bank portfolio position consists of two long calls, one short call, two long puts and one short put, where the underlying asset is the US dollar (USD). With this portfolio combination of calls and puts, the exercise of the options at maturity contributes to the intervention objectives of the central bank. Second, the dynamic delta hedging of this portfolio on a daily basis determines the central bank's daily spot market purchase/sale of USD in a way that once again complements its intervention objectives.[7] The use of options creates a stronger signaling channel between the policymakers and market participants because those following the market will have a clear understanding of the actions of the central bank. The option delta and the delta hedging inform both market participants and the central bank of intervention positions and acts as an announcement via the market.

Although the central bank will incur costs in the form of premiums paid for buying the long options and payoffs paid when the short option positions are exercised, central banks will also receive positive payoffs when the long options

[7]The combination of long and short positions as well as call and put options is the crucial element of this strategy. By holding both sides of the market the central bank limits the opportunity for market manipulation, and the intervention is driven by the responsiveness of the options' market price to changes in the exchange rate. With this strategy, the intervention position of the central bank in the spot market is now driven by the delta of the option and therefore is determined by market forces.

are exercised plus the premiums received from the sales of options. As will be presented in Section 5, the potential costs of the strategy are offset by the potential gains, making the strategy a near-zero net expected returns/losses.

3.1 Details of W-Spread Strategy

To understand the W-spread strategy, consider first the call side and the put side separately.[8] Figure (1) depicts the W-call spread which consists of two long call positions with a strike price of K_1 and K_3, and one short position with a strike price of K_2. The middle strike price for the short position is determined as $\frac{K_1+K_3}{2}$. For the W-call spread strategy, as the spot exchange rate value depreciates beyond K_3, the central bank gains $S - K_2$ at maturity, as seen in Table (1). The gains continue to increase as the spot exchange rate, S, increases (local currency depreciates). On the other hand, if S appreciates beyond K_1, all call options will expire without exercise and the losses will be limited to the premiums paid on the long call options.

The net cost to the central bank will be the premium paid on the long call options plus the payoff on the short call option if it is exercised. As can be seen, the losses are limited to the premium paid on the long options, but the gains are unlimited if the currency depreciates beyond K_3. It would be counterintuitive for the central bank to attempt to move the market into a deep depreciation as soon as we assume that the goals of the central bank to maintain stability prevail over any objective to maximize gains.

The W-put spread presented in Figure (2) consists of two long put positions with strike prices at K_1 and K_3, and one short put with a strike price of K_2. The middle strike price for the short position is determined as $\frac{K_1+K_3}{2}$. Once again, the strategy offers unlimited gains and limited losses in payoffs. As the currency value appreciates beyond K_1, the central bank obtains a payoff of $K_2 - S$, as seen in Table (2), which increases as the spot exchange rate, S, continues decreasing (local currency appreciates). On the other hand, if the exchange rate depreciates beyond K_3, all put options expire without exercise and the only losses the central bank faces are those of the long put option premiums.

As can be seen in both W-call spread and W-put spread strategies, the risks are limited and the gains unlimited if the exchange rate moves beyond the strike price K_3 for the W-call spread and K_1 for the W-put spread. Combining both spreads creates the W-spread strategy, depicted in Figure (4). In a neutral W-spread strategy, there is an equal distribution of funds into the W-call spread and W-put spread strategy, depicted by the graph on the left in Figure (4).[9] The neutral strategy is used as the characteristic example to explain how the strategy functions. In reality, if the central bank is observing persistent movement of the exchange rate or strong expectations of appreciation or depreciation of the currency, it can and should enact a biased strategy.

[8]The underlying asset for all options is the US dollar and all option contracts are European, and therefore cannot be exercised until maturity.

[9]We refer to the even split in W-puts/W-calls in the W-spread strategy as "neutral" because the weight of the delta hedging (purchase or sale of USD) based on appreciation or depreciation will be equal between the W-put spreads and W-call spreads.

In a biased strategy, the portfolio is weighted heavier with either W-calls or W-puts, as is illustrated in Figure (3) and Figure (4). In an appreciationary scenario, the central bank adjusts its strategy to reflect the actual or expected appreciation of the domestic currency. More traders would be seeking put options, which for the long position provide protection against further appreciation and on the short side, allow them to bet the appreciation will be curbed (working in favor for the central bank's goals). In a put-biased strategy, the central bank holds a relatively larger concentration of W-puts to W-calls in the portfolio. If 10,000 contracts are traded as part of the intervention strategy, 80% of the contracts would be allocated towards W-put spreads, and the remaining 20% towards W-calls. The W-put/W-call ratio would be 4. The net dynamic delta hedging activity of the central bank leading up to maturity will force the central bank to buy USD on the spot market, thereby countering the appreciation pressure more strongly than in a neutral position (the explanation for how the hedging works will be provided in detail below).

Conversely, under conditions of depreciation of the local currency, a portfolio weighted heavier with W-calls than W-puts would be appropriate. In this scenario, more market participants are seeking out call options in general. For the long position, the call options would protect against losses associated with further depreciation of the currency, whereas market participants holding short positions are betting that the depreciation will be curbed before maturity (again, an action that would compliment the goals of the central bank in this scenario). The net dynamic delta hedging activity of the central bank leading up to maturity will force the central bank to sell USD on the spot market, thereby countering the depreciation pressure more strongly than in a neutral position. The biased strategies can be employed in conditions when there are expectations of strong or persistent depreciation (ratio smaller than 1) or appreciation (ratio larger than 1), so that the central bank is essentially "doubling up" on its effort to combat the deviations of the exchange rate.

It is important to note that the weights associated with the central bank's portfolio may be adjusted continuously to reflect market conditions. There is nothing precluding the central bank for waiting until maturity to issue a new set of options. Nor must the date be fixed to 30 days, which is a relatively short time span that allows adjustment as is deemed necessary. If the central bank begins in a neutral strategy, but more calls are transacted than puts, by default it is now holding a W-call biased strategy. Therefore, the adjustment can be either overt, based on the weights assigned by the central bank, or dictated by demand from market participants. In either case, the weights, and thereby the intervention, adjusts to reflect market realities.

Table (3) details the payoffs associated with the W-strategy. In the top panel of Table (3), the payoffs at maturity for the neutral W-spread strategy are presented, showing the position of the central bank when all contracts have expired or have been exercised. The lower two panels of Table (3) shows the payoffs for a call-biased and put-biased W-spread strategy. As can be seen, the W-spread strategy yields the potential for unlimited gains with limited risk. When the exchange rate at maturity, S, moves beyond strike prices K_1 or K_3, this results in payoffs greater than zero which increase as S is farther from the strike prices. When the exchange rate at maturity is between strike prices K_1

or K_3, the payoffs for the central bank are still positive even though limited in size. The same holds true for the biased strategies as can be seen in the lower panels of Table (3).

The costs the central bank faces include the premium it must pay to hold the long option positions and the payoffs it must pay for the short positions when the contracts are exercised. Table (3) takes into account the net payoffs, and therefore already accounts for the cost of paying the short position payoffs. Theoretically, the accumulated delta hedging transactions until maturity, measured by the cumulative financial costs incurred, equal the options' premiums.[10] Moreover, the net payoffs obtained in any of the W-spread strategies cover the costs associated with premiums paid by the central banks. This is particularly true for deep in- or out-of-the-money final exchange rates. On average, by pairing the W-spread strategy with dynamic delta hedging, the central bank is able to cover its hedging costs with the net payoffs, creating a position where in fact the central bank does not face compounding gains or losses, presenting another positive advantage for central banks to incorporate dynamic delta hedging as part of the options-based intervention strategy. We show this in several simulations presented in Section 5.

3.2 Details of Dynamic Delta Hedging

The W-spread strategy's dynamic delta hedging informs the central bank of the correct size of USD to purchase or sell on the spot market in order to cover its option positions. With dynamic delta hedging, the central bank can reduce volatility by providing (reducing) liquidity and, by clearly signaling its intentions to all market participants. Since the delta of the option captures the responsiveness of the option value to changes in the spot exchange rates and because these changes can be estimated on a daily basis, hedging based on the delta of the option harnesses the central bank with a market-driven strategy to guide its spot market interventions.

The delta of the option is the derivative of the option price with respect to the spot exchange rate and can be presented as follows (DeRosa, 2011, Chen, 1998):

$$\delta_{call} = e^{-r^*\tau}\Phi(x + \sigma\sqrt{2}) \tag{1}$$

$$\delta_{put} = e^{-r^*\tau}\Big(\Phi(x + \sigma\sqrt{2}) - 1\Big) \tag{2}$$

where

$$x = \frac{ln\frac{S_t}{K} + \left(r - r^* + \frac{\sigma^2}{2}\right)\tau}{\sigma\sqrt{2}}$$

and $0 \leq \delta_{call} \leq 1$ for call deltas and $-1 \leq \delta_{put} \leq 0$ for put deltas.

[10] For example, see Chapter 7 of Hull (2012) "Risk Management and Financial Institutions", third edition.

The delta of the option is influenced by the daily spot exchange rate (S), the foreign interest rate (r^*), domestic interest rate (r), the strike price (K) and volatility (σ). Therefore, as the central bank responds to changes in the deltas of the options in its portfolio, it is responding in essence to changes in each of these variables.

To understand how the hedging of the W-spread strategy contributes to the intervention goals of central banks, we must first consider what occurs during the hedge. Dynamically delta hedging of a long call on USD when the local currency depreciates, implies that the owner of the option sells USD in the domestic spot market.[11] By doing so, the supply of USD in the spot market rises, thereby introducing appreciation pressures that counter the depreciation of the local currency. Similarly, by dynamically delta hedging a long put position as the local currency depreciates, the owner of the long put sells USD in the domestic spot market to offset his position at maturity of the option contract. The offsetting spot market positions contribute to appreciation pressure that counters the depreciation of the local currency (COP for example). These scenarios are summarized in Table (4).

In the W-spread strategy, the central bank hedges the net portfolio position (recall that the W-spread strategy is made of two long calls, one short call, two long puts and one short put). Therefore, whether it is buying or selling USD depends on the aggregated deltas of each of the six options in the portfolio. As we demonstrate in the following section, the W-spread strategy is designed specifically so that the buying/selling of the foreign currency through the hedge contributes to countering the deviations of the exchange rate.

3.3 Dynamics of the W-Spread Strategy

As presented previously in Figure (4), the mix of W-call and W-put spreads in the central bank's portfolio may be altered to reflect the expectations of the persistent exchange rate movements. First, if the central bank wants to hold a position that does not signal expectations of depreciation or appreciation, they can evenly distribute their portfolio between the W-call spread and W-put spread (W-put/W-call spread ratio equal to one). By doing so, their daily interventions via the delta hedging position are equally large for an appreciation or depreciation of their currency.

On the other hand, if there are expectations of persistent appreciation or depreciation (not driven by fundamentals), accompanied by high volatility in the market, the central bank can choose to hold a biased W-spread portfolio to signal a stronger intervention in response to the persistent and not fundamentals-driven appreciation or depreciation, as discussed above. For example, with persistent depreciation, the central bank can hold a call-biased W-spread. Under this strategy and on a daily basis, the central bank's delta hedging in the spot market implies a net sale of USD that is greater than under the neutral W-spread strategy (W-put/W-call spreads ratio equal to one). Through the sales of USD on the spot market, central bank counteracts the persistent depreciation and contribute to decreasing volatility

[11] The long call gives the owner the option to buy USD at the strike price in a given future time. For these owners, depreciation benefits them since their payoff is given by max(S-K,0). Thus, at any time during the life of the option, they should (short) sell whenever $S_t > K$ and buy whenever $S_t < K$. Of course, this implies first, that the owner is comfortable performing periodic delta hedges and that the financial costs associate with it are adequately considered.

by providing greater liquidity into the market. With persistent appreciation, the central bank can hold a put-biased W-spread. Under this strategy and on a daily basis, the central bank's delta hedging interventions in the spot market implies a net purchase of USD which are greater than under the neutral W-spread strategy. Through the purchase of USD on the spot market, the central bank counteracts the persistent appreciation by absorbing excess liquidity of USD into the market.

For every option the central bank holds or issues, there is an offsetting position by a market participant that has purchased or sold the option. The risk associated with the offsetting positions of market participants is derived from the delta hedging of short positions, which may exacerbate the movements in the exchange rate. Delta hedging of the long position complements the goals of the central bank.[12] Since options act as a risk management tool for many corporations and traders, market participants can choose to hedge all, part or none of their net portfolio positions. In many cases, the option itself acts as a hedge against other positions the market participants' are holding. Since hedging can be costly, not all market participants hedge their entire portfolio position. Additionally, in derivative markets not all the participants are willing, interested or capable of delta hedging their positions on a daily basis. The desire to hedge depends on the nature of the business under consideration (trading, international trade - exporters and importers, among others) and their knowledge of the derivatives markets. In the Appendix, three potential scenarios are presented: where the offsetting market positions are hedged 100%, 50% and 10%, while the central bank hedges 100% of both long and short positions. If the cumulative offsetting market positions are hedged by less than 100%, then the central bank's dynamic delta hedging position provides an intervention strategy that is conducive to its goals of stabilizing exchange rate movements.

We focus on the W-spread in this paper after testing various other traditional strategies. We develop the W-spread because the central element which drives the day-to-day intervention is the delta hedging conducted by the central bank. This element, along with the option value, acts to influence the exchange rate both through the volume transacted as well as through the signaling channel, where the anticipation of central bank intervention in reaction to exchange rate movements influences the position of traders. The hedging of other strategies traditionally considered for central bank usage, such as short calls or short puts, along with other trading strategies, such as the short straddle or short strangle, exacerbate the exchange rate movements the central bank is attempting to curb.[13]

Dynamic delta hedging is a critical element of any option trading strategy adopted by policymakers to mitigate losses and avoid the excessive build up or draw down of foreign exchange reserves. By the nature of the hedge, the equivalent volume of foreign or domestic currency that will be transacted at maturity will already by accumulated through the delta hedge. Therefore, the intervention does not create a need to alter the level of foreign exchange reserves in medium term. Through the delta hedging, the reserves will return to the original pre-intervention level at

[12] Examples shown in Appendix.
[13] More detailed explanation and intervention impact analysis using these strategies is available upon request.

exercise.

The W-spread strategy also has a number of important by-products associated with it. By using options to guide its interventions, the central bank is creating or deepening the options market while strengthening the institutional framework that previously either did not exist or that was very shallow, as is the case in many emerging market economies.[14] By operating in the options market, the central bank is assisting in creating a deeper risk trading platform for the private sector. Additionally, the greater information flow between market participants and policymakers that occurs when the central bank participates in options contracts will strengthen the responsiveness of the central bank to market conditions and thereby allow policymakers to act more effectively in ensuring that optimal market conditions are in place. Central banks in emerging markets can also get valuable information from traders' behavior and expectations that can be implied from these markets. In this way, intervention via the options market provides a two-way information platform that can convey useful information for all participants.

4 Methodology

In testing the W-spread strategy, the goal is to understand whether at maturity and with daily dynamic delta hedging the central bank is able to mitigate exchange rate volatility. We focus on the following conditions: persistent depreciation, depreciation with a shock, persistent appreciation, appreciation with a shock, volatility in the exchange rate with no specific trend.

First, we simulate the W-spread strategy with no impact on exchange rates to illustrate how the dynamic delta hedging element reacts to exchange rate movements. Then, we incorporate the impact of the daily interventions on the exchange rate to analyze how the intervention lowers volatility. We use a random generation of exchange rates within set bounds such as deviations between (-0.10%, +0.10%); (-0.25%, + 0.25%); (-0.50%, +0.50%) (-0.50%, +0.10%); (-0.50%, +0.25%); (-0.10%, +0.25%), (-0.10%, +0.50%); (-0.25%, +0.50%) of the COPUSD with starting values between 1995 and 2010 and an average daily change of +/- 0.12%. We also include a "shock" in the second series of simulations with intervention impact analysis. The shock size was a deviation in the exchange rate by between +/- 1.25% to +/- 5.0%. This shock reflects a drastic increase/decrease in the COPUSD value to mirror a time of distress in the markets.

Using a simulated series of the COPUSD, we calculate the option deltas, from which we establish daily USD purchases/sales. The volume of purchase/sales through the delta hedge determine the intervention position of the central bank on the spot market.

To start, we use the following strike prices in the results presented below:

[14] Note that the creation and support of these markets has sizable economic value, since the beneficiaries of these derivatives markets are not only the FX traders but also exporters and importers and any other economic agents that want to hedge their foreign exchange rate risk. In this sense central banks are contributing with the creation of risk markets that contribute with the development of credit markets in particular and, with economic growth in general.

$$K_{1,0} = 0.9975 * S_0$$

$$K_{3,0} = 1.0025 * S_0$$

$$K_{2,0} = \frac{K_{1,0}+K_{3,0}}{2}$$

where S_0 represents the spot market exchange rate one day before issuance of the W-spread strategy and the strike prices are very close to at-the-money position. After the volatility and strike prices are determined, we estimate the call and put deltas using the Garman-Kohlhagen model as per Equations (1) and (2) including Colombia's risk free interest rate, the US risk free interest rate, and the simulated exchange rate series. The time to maturity for all contracts is 30 days.

For our analysis, the portfolio consists of 10,000 contracts, with each contract worth USD 10,000. The total value of these contracts is then USD 100 million. It is simple to alter the contract size and total number of contracts transacted, and we have tested the impact of such changes on the W-spread strategy.[15] In accordance with the descriptions presented in Section 3, we simulate the use of a neutral W-spread strategy (W-put/W-call spread equal to one), a call-biased W-spread (W-put/W-call spread less than one) and a put-biased W-spread (W-put/W-call spread greater than one). With a neutral strategy, there is an even distribution between W-puts and W-calls with 5,000 contracts in each (W-put/W-call spread equal to one). In the call-biased W-spread, there are 8,000 contracts allocated to the W-call spread and 2,000 contracts allocated to the W-put spread (W-put/W-call spread equal to 0.25). In the put-biased W-spread, there are 2,000 contracts allocated to the W-call spread and 8,000 contracts allocated to the W-put spread (W-put/W-call spread equal to four).

4.1 Daily Transactions

In the dynamic delta hedge, the central bank purchases/sells USD daily based on the delta of the option. Therefore, we calculate total USD purchased or sold on a daily basis, the daily interest cost, and daily cumulative value transacted.

The USD transacted on the spot market on day t for option i is calculated as the difference between the option delta on day t and $t-1$ multiplied by the option contract size. For one contract, the USD transacted ($SpotDelta_{t,i}$) based on the dynamic delta hedge will be:

$$SpotDelta_{t,i} = (\delta_{t,i} - \delta_{t-1,i}) * X \tag{3}$$

where X represents USD per contract or the contract size, which is USD 10,000 in this analysis, and $\delta_{t,i}$ represents the delta of option i on day t. Recall that in the W-spread strategy, we have two long calls and one short call (W-call spread) as well as two long puts and one short put (W-Put spread), thus $i = 1...6$. For example, $\delta_{15,sp}$ represents the delta of the short put on day 15.

[15] Results available upon request.

The total net USD transacted via the dynamic delta hedge is calculated as:

$$DailySpotDelta_t = \sum_{i=1}^{6}(SpotDelta_{t,i} * Q_i) \tag{4}$$

again $SpotDelta_{t,i}$ represents the delta hedge for one contract and Q_i represents the number of contracts issued per type of options i with $\sum_{i=1}^{6} Q_i = 10,000$. Each type of option has its contract size that can vary. For our analysis, we assume equal contract size across options unless otherwise stated. Moving forward, we will refer to the total W-spread strategy option value of USD 100 million as Y where $Y = Q * X$ (the number of contracts multiplied by the contract size).

The cumulative value of the daily transactions ($DailyCV_t$) at $t = 1$ equals the total USD transacted on the spot market. For $t > 1$, the cumulative daily transactions are calculated as:

$$DailyCV_t = DailyCV_{t-1} + IntC_{t-1} + DailySpotDelta_t \tag{5}$$

The daily cumulative USD transacted includes the potential cost for the central bank to conduct the hedge in the form of the interest costs ($IntC_t$). The interest costs paid to obtain (or borrow) USD[16] at time t and are determined as:

$$IntC_t = \left(e^{\frac{r}{365}} - 1\right) DailyCV_{t-1} \tag{6}$$

where r represents the domestic interest rate, which for our simulations is the Colombian interbank lending rate.

4.2 End-of-Period Transactions

To present the total accumulated USD transacted at maturity (T), we calculate the end-of-period USD transacted ($EOPVT_T$) as:

$$EOPVT_T = DailyCV_T + NetPayoffs_T \tag{7}$$

where $DailyCV_T$ is the cumulative USD transacted at maturity, i.e. $T = 30$. As seen in the previous equation, $EOPVT_T$ depends on the accumulated value of the USD from the dynamic delta hedge and the net payoffs.

Net payoffs can be divided into long payoffs, which are revenues for the central bank, and short payoffs, which are costs for the central bank. The net payoffs at maturity are presented in Table (5), showing the resulting payoffs for the W-spread strategy at all possible outcomes for the exchange rate at maturity, S_{30}.

Table (6) presents a summary of calculations of costs and gains associated with the W-spread strategy and dynamic delta hedging at maturity. It includes the accumulated USD transacted through delta hedging, the interest costs, the

[16] In this paper we consider this cost even though central banks normally do not have this cost since they can borrow from their international reserves. We are taking a more conservative stance here.

net payoffs for both the long and short positions, and the long and short premiums. The premiums of each contract will be paid by the central bank in the long positions and received by the central bank in the short positions. The net gains of the W-spread strategy are represented as:

$$NetGains_T = (LongPayoff_T + ShortPremium_T) - (IntC_T + ShortPayoff_T + LongPremium_T) \quad (8)$$

we refer to $NetGains_T$ as the profit/cost of the W-spread strategy, since it is possible that the central bank can profit from the strategy. Specifically, the gains of the W-spread strategy in the form of long payoffs and short premiums could outweigh the costs, as they do under conditions of persistent depreciation or appreciation that we present in Section 5.

The analysis of the daily position of the central bank along with the position at maturity with respect to the amount of USD transacted, the payoffs, and the costs of the strategy will provide insight into the ability of the central bank to employ the W-spread strategy to smooth drastic exchange rate movements and reach its intervention goals. It is important to consider both the daily and at-maturity positions with respect to the four possible scenarios: $S_{30} < K_1$; $K_1 \leq S_{30} < K_2$; $K_2 \leq S_{30} < K_3$; and $S_{30} \geq K_3$. The simulations in the following section provide clear insight into all four possible outcomes.

4.3 Intervention Impact Analysis

To determine how the W-strategy may impact exchange rate volatility, we simulate the COPUSD movements under the following conditions: persistent depreciation, depreciation with shock, persistent appreciation, appreciation with shock, and volatility with no set trend. For the simulations we use a linear price impact function,[17] where the change in the exchange rate is a function of the volume transacted. It is important to note that data on volume (amount of dollars bought per intervention) of central banks intervention is not available and thus, we rely on a statistical method to derive possible linear impact functions.

To estimated the linear approximation of the price impact function, the moving average over 30 days of the COPUSD from 2010 to 2013 is used, yielding 1370 observations. The changes in the 30-days moving average are then calculated and classified into appreciation (-1) or depreciation (1) of the COPUSD. The confidence intervals are then computed, per side, using a 95% confidence level. In this way, we determine the upper and lower limits for the exchange rate movements when Colombia peso appreciates or depreciates. We use the lower and upper limits as the limits of the price impact functions, thereby assuming that the interventions have a lower (upper) impact on the exchange rate equal to the lower (upper) limit of the confidence intervals. For this simulation we assume that the lowest purchased (sold) amount of USD corresponds to one million up to USD one hundred million. This yields a linear price change based on

[17] We thank the referee for suggesting to include this analysis in the paper.

the volume transacted, from one million to one hundred million USD, giving an approximation of how the COPUSD reacts to a given quantity (volume) purchase/sale of USD. Finally, we use a simple OLS estimation to determine the coefficients which will allow us to estimate the price impact that will be used to determine the approximate impact of the quantity bought or sold as mandated by the delta hedging strategy. The impact of volume on the currency exchange is then modeled as:

$$P = \alpha + \beta V + \mu \tag{9}$$

where P represents the exchange rate change, α represents the coefficient for the price impact, β represents the coefficient corresponding to the impact of volume on the exchange rate, and V represents volume transacted. μ represents the i.i.d. error term. The OLS regression is run separately for appreciation and depreciation values, since the impact of intervention may differ under each.

With this information we start the simulation to determine the impact of acting according to the delta hedge based on the W-strategy presented in the paper. We do this by simulating random values of the COPUSD to reflect the conditions mentioned before. To compare our results, we keep the original random exchange rates, i.e. values of the exchange rate without intervention (FX). We calculate the delta based on the changes of FX from day 0 to day 1. The delta will determine the volume of USD purchased/sold (V) as explained above. Once we have calculated the volume transacted, we determine the impact on this such that:

$$FX_{new} = (\hat{\alpha} + \hat{\beta} V) + FX \tag{10}$$

where FX_{new} represents the new COPUSD value based on the price impact, V is the volume transacted in the spot market based on delta hedging, and FX represents the COPUSD generated without intervention impact. We continue to calculate the deltas now based on FX_{new} for the next day and continue estimating the value of COPUSD with the intervention impact based on the delta hedging. This simple linear approximation allows us to test how the delta hedging based on the W-strategy can affect the exchange rate. Once we have these numbers (FX without intervention and FXNEW with volume impact on the exchange rates), we calculate the standard deviations and compare the effect of the intervention on volatility. We use the same approach to calculate the effect of a neutral W-strategy compared to a biased W-strategy to determine whether the biased strategy described in Section 3.1 is more effective in lowering volatility.

5 Results

In presenting the results of the W-spread strategy analysis, we begin with a general perspective on the outcomes at maturity considering the key components of the strategy - the option exercise and the daily hedging. Then, we present the results of the simulations under scenarios of persistent depreciation and persistent appreciation with no impact, and finally the simulations accounting for the impact of the daily dynamic delta hedging.

The possible outcomes at maturity are presented in Table (7) in terms of option exercise, share of W-spread strategy exercised, and the net amount of USD transacted based on where the spot exchange rate at maturity lands in relation to each strike price. The four scenarios depicted align with the scenarios discussed in Table (5) in Section 4.

Consider the first scenario where S_{30} is less than strike price K_1 (or an appreciation of the local currency). In this scenario, the central bank sells USD at a higher price than S_{30} through the long put positions that are exercised at K_1 and K_3. Under a neutral W-spread strategy, the central bank sells USD 16.6 million, meaning that it has an equivalent of USD 16.6 million in local currency (16.6 x S_{30}) that can be used to buy USD to counter appreciation pressure. Also, by buying USD from the owners of the put positions at K_2, the central bank helps to decrease the selling pressure in the spot market. This is true because the owners of the short puts of the W-put spread at K_2 are sell USD to the central bank instead of to the market, which in turn relieves some of the selling pressure and again, helping to counteract the appreciation pressure on the local currency. Moreover, if the owner of the W-put spread at K_2 wants to make a profit on their purchase[18] they need to buy USD at S_{30} from the market in such a way that achieves a positive payoff ($K_2 - S_{30} > 0$), contributing with a buying pressure that counters appreciation. Finally, by exercising the central bank's two long-put positions, the offsetting short-put positions will have no incentive to sell USD in the spot market since they bought USD from the central bank at a price higher than S_{30} based on the option contract. It would be unwise for the traders holding the offsetting short-put positions to turn around and sell the USD purchased from the central bank through the option contract because this would lead to a scenario where they are buying high and selling low. Therefore, the likelihood that their activity would increase selling pressure of USD in the local market is low. Note that this impact increases with higher appreciation expectations where the W-put/W-call spread ratio moves from 1 to 4.

If we analyze the last case ($S_{30} \geq K_3$) where there is depreciation of the local currency, the reverse action is be observed. Specifically, under the neutral W-spread strategy, the central bank buys USD 16.6 million that can be sold to counter the depreciation pressure. Also, by selling USD to the owner of the call (long call) at K_2, the central bank can help decrease the buying pressure in the spot market, again helping to counteract the depreciation of the local currency. This is true because the long-call positions at K_2 are buying USD from the central bank rather than from the market, which in turn relieves some of the buying pressure. Moreover, traders with the long-call position that want

[18]Note, the long put position at K_2 is exercised when $K_2 > S_{30}$.

to cash their positive payoffs need to buy USD in the spot market ($S_{30} - K_2 > 0$). Finally, by exercising the central bank's two long-call positions, the offsetting short-call positions will have no incentive to buy USD in the spot market since they sold USD to the central bank at a price lower than S_{30} based on the option contract. It would be unwise for the traders holding the offsetting short-call positions to turn around and buy USD on the spot market because this would lead to a scenario where they are buying high and selling low. Therefore, the likelihood that their activity would increase buying pressure of USD in the local market is low. Note that this impact increases with higher depreciation expectations where the W-put/W-call spread ratio moves from 1 to 0.25. For the intermediate cases ($K_1 \leq S_{30} < K_2$ and $K_2 \leq S_{30} < K_3$) more discretion is necessary since there is no clear appreciation or depreciation pressure.

5.1 Simulation with Persistent Depreciation

We begin with the simulated exchange rates series that presents persistent depreciation in the COPUSD. In these simulations, the intervention impact function has not been included and the goal is to test whether the W-strategy aligns with the goals of the central bank. Figure (5) illustrates the simulation. Figures (6) and (7) present the calculated dynamic delta hedging position and daily cumulative USD transacted during a period of depreciation. In Figure (6) we present a neutral W-spread strategy where the ratio of W-puts to W-call spreads equals one. In Figure (7) we present a call-biased W-strategy where the ratio of W-puts to W-call spreads is less than one. The daily USD transacted represents the actual amount of USD the central bank is buying or selling in the spot market based on the net portfolio position and is determined by the deltas of each option contract in the portfolio. Positive values indicate net purchases, whereas negative values indicate net sales. The daily cumulative value transacted include the interest costs and shares purchased/sold of the foreign currency in the spot market denominated in local currency (COP).

There are three scenarios depicted in each figure. The first is a W-call spread strategy, where the central bank is holding (long) and issuing (short) call options. The second is a W-put spread strategy, where the central bank is holding (long) and issuing (short) put options. The last is a W-spread strategy that combines the W-call and W-put spreads. According to the W-call spread position delta, the first day initial spot market position is substantial, requiring the central bank to sell approximately USD 30 million of foreign currency (USD) in the spot market. Throughout the period to maturity the net call portfolio position will require the central bank to continue selling USD in the spot market to dynamically delta hedge its options portfolio. By doing so, it in turn introduces a counteracting pressure to the persistent depreciation of the simulated series because, all else equal, the consistent sale of USD by the central bank should contribute to driving down the value of the foreign currency relative to the local currency leading to an appreciation of the Colombian peso. Under a W-put spread position, the central bank initially conducts a large purchase of USD in the spot market and subsequently sells off its initial spot market position throughout the period to maturity. In the first day, the central bank buys approximately USD 18 million. Note that, if the W-put spread is considered independently, the initial buying may exert an undesired impact on the exchange rate. Specifically, it would contribute to the depreciation pressure observed in Figure (5) by increasing the value of the foreign currency to local currency leading to further depreciation of the Colombian peso. However, the net position of the W-spread strategy (third column of Figures (6) and (7)) show that the spot market interventions have the potential to counteract the depreciation pressure. Specifically, the net spot market transactions suggest a large sale of USD followed by small sales that in reality should help to relieve some of the depreciation pressure as the the relative supply of USD to COP on the spot market increases, all else equal.

The cumulative value transacted is known and limited, as can be seen in the bottom three graphs of Figures (6) and (7). The cumulative value transacted takes into account the accumulation of sales/purchases of USD to hedge the net portfolio position throughout the time to maturity as well as the interest costs associated with the transactions. In the call-biased W-spread strategy, presented in Figure (7), the central bank sells more USD on the initial day that in the neutral strategy presented in Figure (6), but does not notably change the spot market position in the remaining days leading to maturity. By changing the ratio of W-call spreads and W-puts in the W-spread strategy, the central bank can alter its initial position in the spot market in such a way that makes the initial intervention larger, which may counter the persistent movement of the exchange rate more significantly upfront. The ratio can also signal to the market that the central bank is trying to more strongly counteract the depreciation.

The total value transacted represents the accumulated daily dynamic delta hedging transactions and interest costs throughout the contract period. Presented in Table (8) is the outstanding position of the central bank from its hedging operations and its options contracts, which includes the hedging costs, payoffs and premiums as described in Table (6). Table (8) illustrates the average across all 100 series, and depicts the value of transactions for series when the portfolio position is neutral (W-put/W-call spread ratio is one) as well as for a call biased portfolio (W-put/W-call spread ratio less than one) during a period of depreciation.

As can be seen in Table (8), the total cumulative interest costs are low considering that the total outstanding USD in option contracts is USD 100 million. The net value transacted throughout the option contract is determined by the W-put/W-call spread ratio.[19] Since only the W-call spreads are exercised when the spot market price depreciates above the strike price K_3, the outstanding volume of USD the central bank is obligated to transact is covered by the net value collected from their long positions. The W-puts expire out of the money and not be exercised as the currency depreciates above K_3.[20] The initial purchase position on the first day for the W-puts is offset by the subsequent smaller sales throughout the contract period. Therefore, the central bank is only transacting on the spot market the amount needed to cover its option obligations. By doing so, they limit excessive reserve accumulation and purchase/sell USD

[19] As a percentage of the total option value (USD 100 million), the net value transacted is only 0.52% and 1.14% for the neutral and call biased strategies, respectively.

[20] It is important to note that the exercise of each of the puts or calls will be determined by whether the spot exchange rate at maturity is greater than or less than the corresponding strike price. In the scenario presented here, the spot exchange rate as depreciated above K_3, which is 1884.

according to the relationship between the exchange rate and option price, or the delta of the option.

5.2 Simulation with Persistent Appreciation

The next analysis tests the use of the W-spread strategy under scenarios with persistent appreciation. Figure (8) illustrates the simulation. Figures (9) and (10) present the calculated dynamic delta hedging position and the daily cumulative value transacted during a period of persistent appreciation. Once again, three scenarios are presented in each figure. If we consider only the W-call spread strategy, the initial spot market position requires the central bank to sell approximately USD 30 million in day one. This move contributes to local currency appreciation, and, as such, can be potentially destabilizing to the market. However, after this initial selling and throughout the period to maturity, the net portfolio position requires the central bank to buy USD in the spot market to dynamically delta hedge its position. The daily purchases of USD may in turn introduce a counteracting pressure to the persistent appreciation by driving up the value of USD relative to the domestic currency.

Considering the W-put spread alone, the central bank initially conducts a large purchase of USD in the spot market (approximately USD 18 million) and continues purchasing USD throughout the period to maturity. By continually purchasing USD on the spot market, the hedging activity of the central bank alters the relative supply of USD to COP in the spot market in a way that may introduce depreciation pressure to counter the persistent appreciation, all else equal. Note that in the neutral W-spread strategy (third column in Figure (9)), the central bank initially sells USD, but then continually purchases USD over the period to maturity. However, since the initial position is a sale of USD 12 million, it may be sizable enough to contribute to the appreciation, and therefore counter the goals of the central bank. In this case, by altering the W-put/W-call spread ratio more heavily towards the W-put spread, as seen in Figure (10), the central bank can avoid this situation and now purchase USD 17 million in the spot market on the initial day of the contract and continue to purchase USD throughout the period to maturity (third column in Figure (10)). Altering the ratio not only signals to the market that the central bank is acting to curb the appreciation, but also the spot market hedging position of the central bank may drive up the relative price of USD to COP and act to counter the appreciation.

Table (9) depicts the value of transactions for series when the portfolio position is neutral (W-put/W-call spread ratio equal to 1) as well as for a put biased portfolio (W-put/W-call spread ratio equal to 4) during a period of appreciation. The calculations reflect those described in the summary Table (6). Once again, the total cumulative interest costs are low considering that the total outstanding USD in option contracts is USD 100 million (0.09% and 0.17% for W-put/W-call spread ratios of 1 and 4, respectively). The net value transacted throughout the option contract is determined by the W-put/W-call spread ratio. Since only the W-puts will be exercised when the spot market price appreciates below strike price K_1, the outstanding amount of USD the central bank is obligated to transact is covered by the USD proceeding from its long position. The W-call spreads expire out of the money and are not exercised when the spot exchange rate at maturity falls below K_1.[21] The initial purchase position on the first day for the W-call spreads is offset by the subsequent smaller purchases throughout the contract period. Therefore, the central bank is only transacting on the spot market the amount needed to cover its option obligations in the W-spread strategy.

5.3 Simulation with Intervention Impact on Exchange Rate Movements

After establishing the operations of the W-strategy above, we now present the impact of the W-strategy on exchange rate movements. We consider the following scenarios: persistent depreciation, depreciation with shock, persistent appreciation, appreciation with shock, and volatility with no trend. Specifically, we are simulating how dynamic delta hedging of the W-strategy affects the exchange rate. This represents the day-to-day purchases/sales in the spot market conducted by the central bank until the time to maturity of the options bundle.

Figure (11) illustrates the impact of the W-strategy on exchange rate movements under depreciation pressure when there is no intervention impact, when a neutral W-strategy is enacted, and when a bias W-strategy is enacted. As can be seen, the trend remains consistent even with the use of the W-strategy, but the volatility of the exchange rate is smoothed. Furthermore, the trend is stabilized when dynamic delta hedging dictates the size of the daily intervention. The depreciation is not as severe when the central bank is buying/selling USD in the spot market to uphold its delta hedging position. As can be seen in Table (10), exchange rate volatility during the time to maturity is lower when the strategy is enacted, and is lowest when the strategy is biased with a stronger position in calls. This holds true even with the presence of a sizable shock in the exchange rate (steep and sudden depreciation).

Figure (12) similarly illustrates the impact of the W-strategy on exchange rate movements under appreciation pressure. The daily position requires the central bank to sell USD under persistent appreciation, as presented in previous graphs. When the impact on the exchange rate is accounted for, the W-strategy once again does not alter the trend of the exchange rate but lowers the volatility and size of the change. In Table (11), exchange rate volatility during time to maturity is lowered when the central bank intervenes daily based on the delta hedging position dictated by the W-strategy. Volatility is lowest when a biased, put-heavy strategy is enacted. Furthermore, as can be seen from Figure (12), the trend is stabilized with the daily interventions via dynamic delta hedging.[22]

In Figure (13), the exchange rate is moving with no specific trend. Even under this scenario, enacting the W-strategy lowers volatility of the exchange rate. When there is no specific trend and no shock present, the neutral

[21] It is important to note that the exercise of each of the puts or calls will be determined by whether the spot exchange rate at maturity is greater than or less than the corresponding strike price. In the scenarios presented here, the spot exchange rate as appreciated below K_1, which is 1875.

[22] It is important to note once again that if changes in the trend are driven by changes in fundamentals, this cannot be changed by W-strategies or any intervention method, but central banks can observe the final composition of the W-spread to obtain important insights from the market participants.

W-strategy provides an intervention position via the dynamic delta hedge that lowers volatility more than a biased strategy. This can be seen in both the figure as well as Table (12). When a shock occurs during the time to maturity, the biased W-strategy gives the central bank a stronger position in the spot market via dynamic delta hedging and therefore is more effective in lowering volatility. Both the neutral and biased strategies lead to lower volatility in the exchange rate.

Once more, it is important to note that intervention following the delta hedging position does not permanently alter the foreign exchange reserve balance. As discussed previous, at maturity, the central bank will have accumulated a foreign currency balance to satisfy its obligations as the options are executed. The net effect on reserve balances will therefore be very close to zero. Therefore, dynamic delta hedging of this strategy allows the central bank to effectively intervene in the spot market daily where the intervention position is based on market forces without depleting or over-accumulating foreign exchange reserves.

6 Conclusion

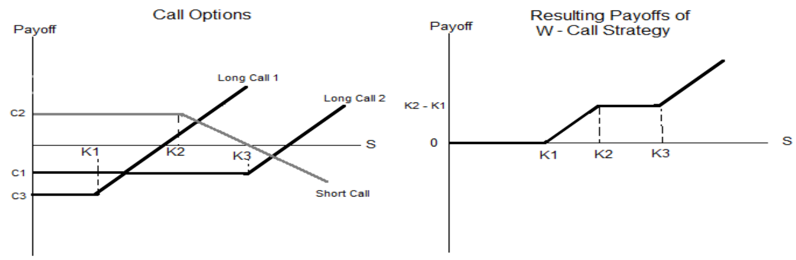
Foreign exchange intervention as a means to smooth volatility and protect the economy from external shocks is an underlying concern for many emerging market policymakers. Many now struggle with finding strategies that would limit volatility while allowing them to maintain flexible exchange rates. Currently, spot market purchase/sale of USD to limit volatility is an imperfect solution to this issue because the the intervention may overshoot/undershoot its intended goal and set off speculative activity. This paper has argued that the use of currency options may be a stronger and more market driven approach to foreign exchange interventions.

In past literature, currency options have been considered as a potential tool for central bank currency market intervention, but those strategies have fallen short because they considered only one side of the market (call or put) or only one position (short or long). With the W-spread strategy, the central bank is operating in both sides of market with more than one position. The intervention still occurs in the spot market, but it is now driven by market forces that dictate the size of the purchase/sale of USD on a daily basis through dynamic delta hedging, as well as at contract maturity. The portfolio mix of calls and puts can be altered by the central bank or change based on market expectations, making the central bank's position more responsive to the market. A major secondary benefit to this strategy, and the use of options by central banks in general, is the establishment or deepening of risk markets. In many emerging market economies, local import/export businesses would benefit from access to options in the local currency, yet these tools make up only a small share of the total foreign exchange tools currently available (BIS, 2016).

The goal of the analysis presented in this paper has been to lay the foundation for a serious discussion on the implementation of currency options as a central bank policy tool. We find that with an alternative option trading strategy, such as the W-spread strategy, the central bank can reach its goal of limiting exchange rate volatility and smoothing the exchange rate trend with a market-driven intervention approach.

7 Tables and Figures

Figure 1: W-Call Spreads



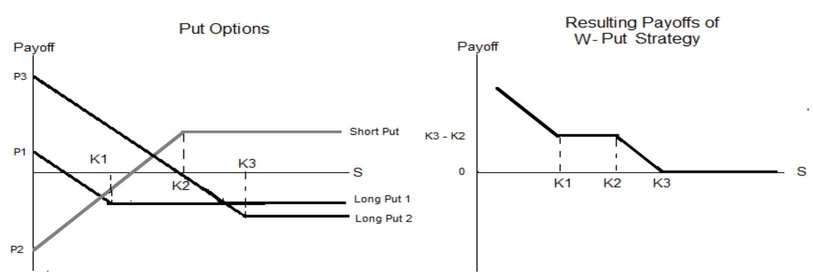
The W-call spread presents a position with limited risks but unlimited gains in case of depreciation beyond K_3. It consists of one short call with strike price K_2, one long call with strike price K_1 and one long call with strike price K_3. The middle strike price (K_2) for the short position is determined as $\frac{K_1+K_3}{2}$.

Table 1: W-Call Spread Payoffs

	Calls			
	Long Call (K_1)	Short Call (K_2)	Long Call (K_3)	TOTAL
S $\leq K_1$	0	0	0	0
$K_1 \leq$ S $< K_2$	S - K_1	0	0	S - K_1
$K_2 \leq$ S $< K_3$	S - K_1	-(S - K_2)	0	K_2 - K_1
S $\geq K_3$	S - K_1	-(S - K_2)	S - K_3	S - K_2

This table presents the payoffs that would be paid by the issuer of the short call and received by the owner of the long calls.

Figure 2: W-Put Spread



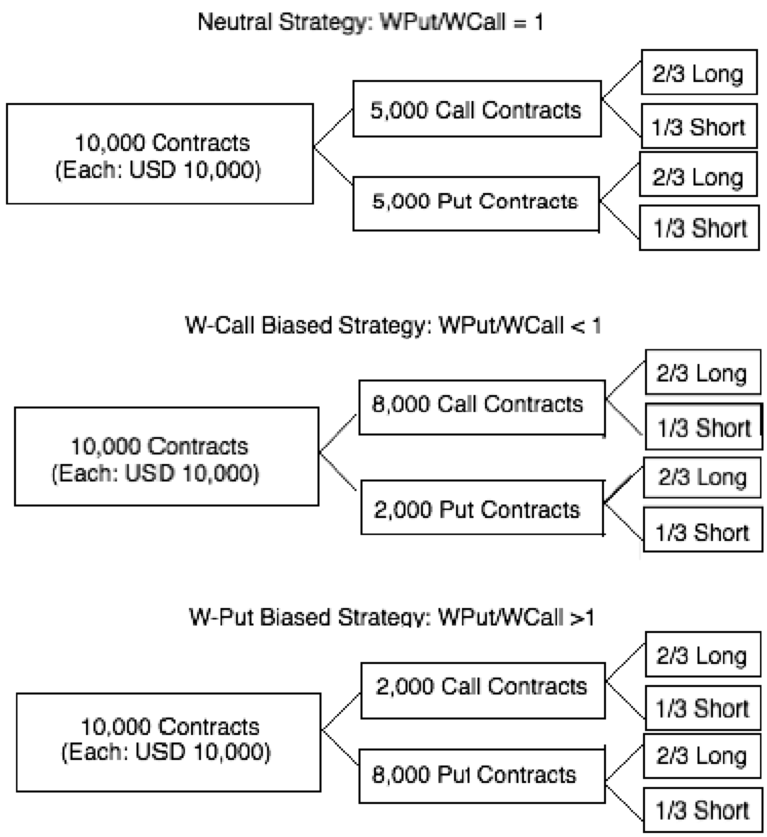
The W-put spread presents a position with limited risks and limited gains. It consists of one short put with the strike price (K_2), one long put with strike price (K_1) and one long put with strike price (K_3). The middle strike price (K_2) for the short position is determined as $\frac{K_1+K_3}{2}$.

Table 2: W-Put Spread Payoffs

	Puts			
	Long Put (K_1)	Short Put (K_2)	Long Put (K_3)	TOTAL
S < K_1	K_1 - S	-(K_2 - S)	K_3 - S	K_2-S
$K_1 \leq$ S < K_2	0	-(K_2 - S)	K_3 - S	K_3 - K_2
$K_2 \leq$ S < K_3	0	0	K_3 - S	K_3 - S
S $\geq K_3$	0	0	0	0

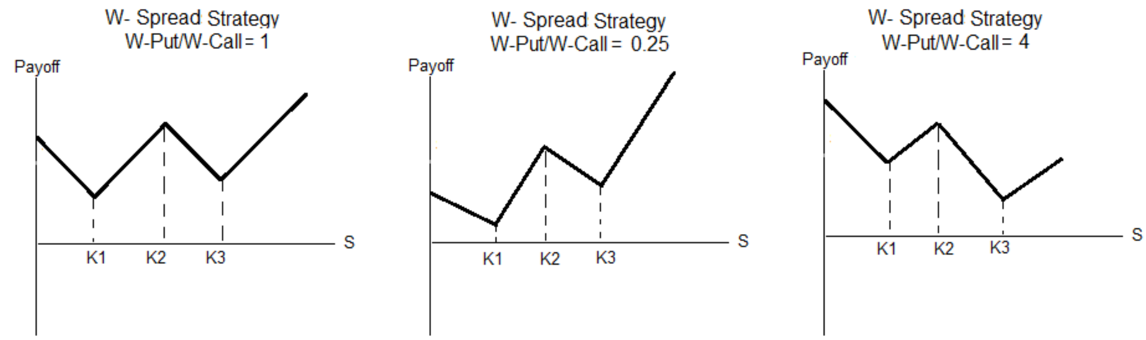
The table represents the payoffs that would be paid by the issuer of the short put and received by the owner of a long put.

Figure 3: Distribution of W-Spread



In a neutral position, the W-put/W-call spread ratio is 1. In a call-biased W-strategy, the W-put/W-call spread ratio is 0.25, and would be enacted under conditions of strong depreciation. In a put-biased W-strategy, the W-put/W-call spread ratio is 4, and would be enacted under conditions of strong appreciation.

Figure 4: W-Spread Strategy



The W-spreads with calls and puts presents a position with limited risks and unlimited gains. It consists of combining the W-call spread with the W-put spread. In a neutral position, the W-put/W-call spread ratio is 1, depicted in the left graph. In a call-biased W-strategy, the W-put/W-call spread ratio is 0.25, depicted in the middle graph. In a put-biased W-strategy, the W-put/W-call spread ratio is 4, depicted in the right graph.

Table 3: W-Spread Strategy Payoffs

W-put/W-call spread = 1

	Calls				Puts				
	Long Call (K_1)	Short Call (K_2)	Long Call (K_3)	TOTAL	Long Put (K_1)	Short Put (K_2)	Long Put K(3)	TOTAL	NET
S < K_1	0	0	0	0	K_1-S	-(K_2-S)	K_3-S	K_2-S	K_2-S > 0
K_1 ≤ S < K_2	S-K_1	0	0	S-K_1	0	-(K_2-S)	K_3-S	K_3-K_2	S-2K_1+K_2
K_2 ≤ S < K_3	S-K_1	-(S-K_2)	0	K_2 - K_1	0	0	K_3-S	K_3-S	3K_2 - 2K_1-S
S ≥ K_3	S-K_1	-(S-K_2)	S-K_3	S-K_2	0	0	0	0	S-K_2 > 0

W-put/W-call spread = 0.25

	Calls				Puts				
	Long Call (K_1)	Short Call (K_2)	Long Call (K_3)	TOTAL	Long Put (K_1)	Short Put (K_2)	Long Put K(3)	TOTAL	NET
S < K_1	0	0	0	0	K_1-S	-(K_2-S)	K_3-S	K_2-S	K_2-S > 0
K_1 ≤ S < K_2	4(S-K_1)	0	0	4(S-K_1)	0	-(K_2-S)	K_3-S	K_3-K_2	4S-5K_1+K_2
K_2 ≤ S < K_3	4(S-K_1)	-4(S-K_2)	0	4(K_2-K_1)	0	0	K_3-S	K_3-S	6K_2-5K_1-S
S ≥ K_3	4(S-K_1)	-4(S-K_2)	4(S-K_3)	4(S-K_2)	0	0	0	0	4(S-K_2) > 0

W-put/W-call spread = 4

	Calls				Puts				
	Long Call (K_1)	Short Call (K_2)	Long Call (K_3)	TOTAL	Long Put (K_1)	Short Put (K_2)	Long Put K(3)	TOTAL	NET
S < K_1	0	0	0	0	4(K_1-S)	-4(K_2-S)	4(K_3-S)	4(K_2-S)	4(K_2-S) > 0
K_1 ≤ S < K_2	S-K_1	0	0	S-K_1	0	-4(K_2-S)	4(K_3-S)	4(K_3-K_2)	S - 5K_1 + 4K_2
K_2 ≤ S < K_3	S-K_1	-(S-K_2)	0	K_2-K_1	0	0	4(K_3-S)	4(K_3-S)	9K_2-5K_1-4S
S ≥ K_3	S-K_1	-(S-K_2)	S-K_3	S-K_2	0	0	0	0	S-K_2 > 0

This table presents the payoffs that would be paid by the issuer of the short put and call and received by the owner of a long put and call. This table presents W-put/W-call spread ratios of 1, 0.25, and 4.

Table 4: Impact of Dynamic Delta Hedging on Exchange Rate Movements

Dynamic Delta Hedging Position				
	Calls		Puts	
	Long	Short	Long	Short
Depreciation	Short Sell USD	Buy USD	Short Sell USD	Buy USD
	Counters	*Exacerbates*	*Counters*	*Exacerbates*
Appreciation	Buy USD	Short Sell USD	Buy USD	Short Sell USD
	Counters	*Exacerbates*	*Counters*	*Exacerbates*

This table presents the overall daily dynamic delta hedging outcomes under conditions of depreciation or appreciation for short and long positions for calls and puts.

Table 5: Payoffs with W-Spread Segmentation

End-of-Period (T = 30)			**Definition of F**	
$S < K_1$	$F_2(K_1 + K_3 - K_2 - S)$		W-Put/W-call spread = 1	$F_1 = \frac{0.5*Y}{3}$; $F_2 = \frac{0.5*Y}{3}$
$K_1 < S \leq K_2$	$F_1(S - K_1) + F_2(K_3 - K_2)$		W-Put/W-call spread = 4	$F_1 = \frac{0.2*Y}{3}$; $F_2 = \frac{0.8*Y}{3}$
$K_2 < S \leq K_3$	$F_1(K_2 - K_1) + F_2(K_3 - S)$		W-Put/W-call spread = 0.25	$F_1 = \frac{0.8*Y}{3}$; $F_2 = \frac{0.2*Y}{3}$
$S \geq K_3$	$F_1(S + K_2 - K_1 - K_3)$			

This table presents the payoff structure based on the W-spread strategy segmentation. Y represents the total USD transacted which is the contract size (USD 10,000) multiplied by the total number of contracts (10,000).

Table 6: Summary of Cost Calculations at Maturity

End-of-Period (T = 30)	
	W-spread strategy
End-of-Period USD Transacted	$DailyCV_T + NetPayoffs_T$
Interest Cost	$IntC_T = \left(e^{\frac{r}{365}} - 1\right) DailyCV_{T-1}$
Long Payoff	$\sum_{j=1}^{4}[max(S_T - K_1, 0) * Y_j + max(K_1 - S_T, 0) * Y_j] + \sum_{j=1}^{4}[max(S_T - K_3, 0) * Y_j + max(K_3 - S_T, 0) * Y_j]$
Short Payoff	$-\sum_{j=1}^{2}[(max(S_T - K_2, 0) + max(K_2 - S_T, 0)] * Y_j)$
Long Premium	$-\sum_{j=1}^{4}(LongOptionPrice_i) * Y_j$
Short Premium	$\sum_{j=1}^{2}(ShortOptionPrice_i) * Y_j$
Profit/Cost of Option Strategy	$(LongPayoff + ShortPremium) - (IntC_T + ShortPayoff + LongPremium)$
Share of Total	$Profit/Y$ or $Cost/Y$

Y represents the contract size which is USD 10,000 multiplied by the total number of contracts, or 10,000. The payoff structure will depend on the segmentation of the W-spread strategy and the distribution of W-Puts to W-call spreads, as seen in Table (5).

Table 7: W-Spread Strategy Results at Maturity

$S_{30} < K_1$	W-put/W-call = 1	W-put/W-call = 4	W-put/W-call = 0.25
Sell USD at K_1 (Long Put)	$-0.5\frac{Y}{3}$	$-0.8\frac{Y}{3}$	$-0.2\frac{Y}{3}$
Sell USD at K_3 (Long Put)	$-0.5\frac{Y}{3}$	$-0.8\frac{Y}{3}$	$-0.2\frac{Y}{3}$
Buy USD at K_2 (Short Put)	$0.5\frac{Y}{3}$	$0.8\frac{Y}{3}$	$0.2\frac{Y}{3}$
Net Transacted	$-0.5\frac{Y}{3}$	$-0.8\frac{Y}{3}$	$-0.2\frac{Y}{3}$
Net Transacted in USD	-16.6 million	-26.6 million	-6.6 million

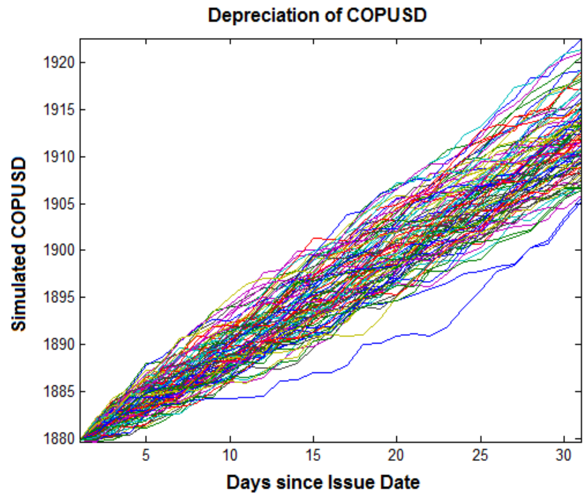
$K_1 \leq S_{30} < K_2$	W-put/W-call = 1	W-put/W-call = 4	W-put/W-call = 0.25
Buy USD at K_1 (Long Call)	$0.5\frac{Y}{3}$	$0.2\frac{Y}{3}$	$0.8\frac{Y}{3}$
Sell USD at K_3 (Long Put)	$-0.5\frac{Y}{3}$	$-0.8\frac{Y}{3}$	$-0.2\frac{Y}{3}$
Buy USD at K_2 (Short Put)	$0.5\frac{Y}{3}$	$0.8\frac{Y}{3}$	$0.2\frac{Y}{3}$
Net Transacted	$0.5\frac{Y}{3}$	$0.2\frac{Y}{3}$	$0.8\frac{Y}{3}$
Net Transacted in USD	16.6 million	6.6 million	26.6 million

$K_2 \leq S_{30} < K_3$	W-put/W-call = 1	W-put/W-call = 4	W-put/W-call = 0.25
Buy USD at K_1 (Long Call)	$0.5\frac{Y}{3}$	$0.2\frac{Y}{3}$	$0.8\frac{Y}{3}$
Sell USD at K_3 (Long Put)	$-0.5\frac{Y}{3}$	$-0.8\frac{Y}{3}$	$-0.2\frac{Y}{3}$
Sell USD at K_2 (Short Call)	$-0.5\frac{Y}{3}$	$-0.2\frac{Y}{3}$	$-0.8\frac{Y}{3}$
Net Transacted	$-0.5\frac{Y}{3}$	$-0.8\frac{Y}{3}$	$-0.2\frac{Y}{3}$
Net Transacted in USD	-16.6 million	-26.6 million	-6.6 million

$S_{30} \geq K_3$	W-put/W-call = 1	W-put/W-call = 4	W-put/W-call = 0.25
Buy USD at K_1 (Long Call)	$0.5\frac{Y}{3}$	$0.2\frac{Y}{3}$	$0.8\frac{Y}{3}$
Buy USD at K_3 (Long Call)	$0.5\frac{Y}{3}$	$0.2\frac{Y}{3}$	$0.8\frac{Y}{3}$
Sell USD at K_2 (Short Call)	$-0.5\frac{Y}{3}$	$-0.2\frac{Y}{3}$	$-0.8\frac{Y}{3}$
Net Transacted	$0.5\frac{Y}{3}$	$0.2\frac{Y}{3}$	$0.8\frac{Y}{3}$
Net Transacted in USD	16.6 million	6.6 million	26.6 million

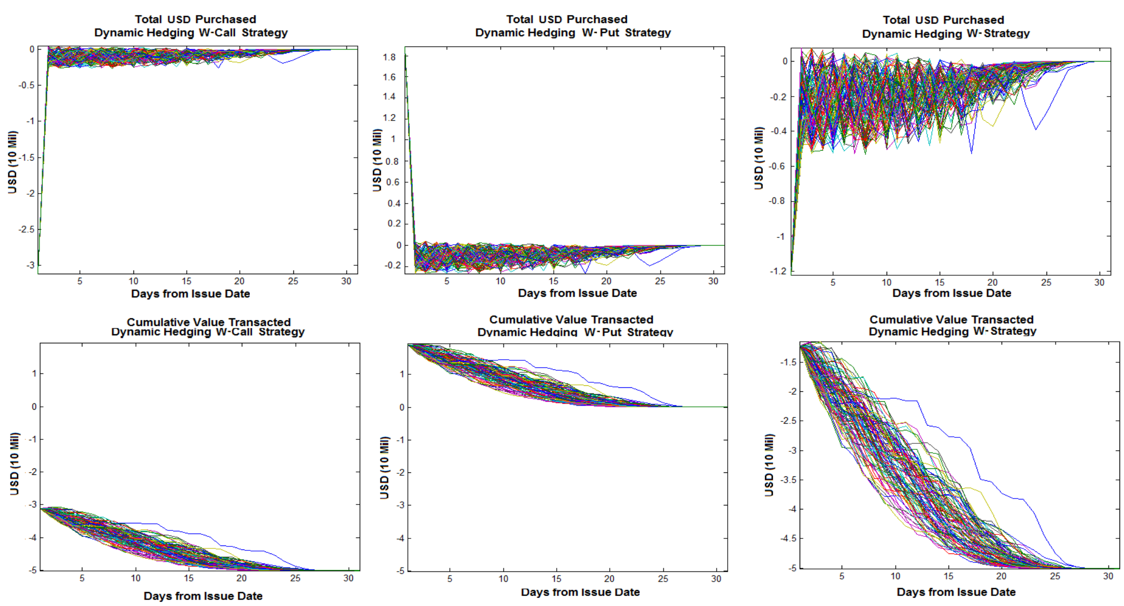
This table presents the action at maturity with the W-spread strategy segmentation based on the relationship between the spot exchange rate at day 30 (S_{30}) and the three strike prices (K_1, K_2, K_3). Y is the contract size (USD 10,000) multiplied by the total number of contracts (10,000), therefore Y equals USD 100 million. Positive values represent purchases and negative values represent sells.

Figure 5: Series of Simulated Exchange Rates for Periods with Persistent Depreciation



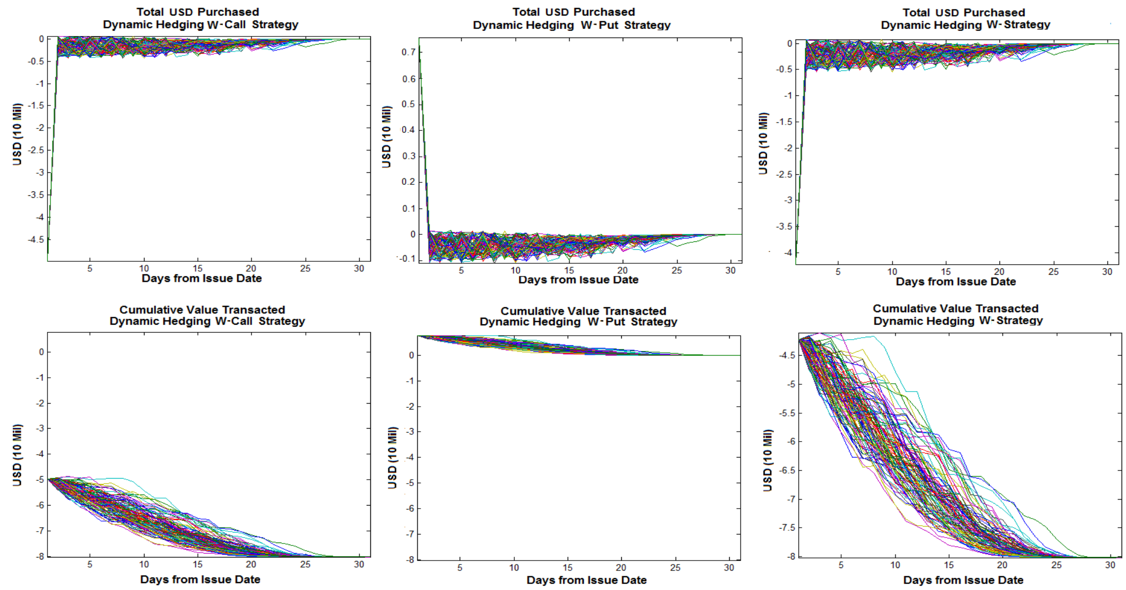
Exchange rates are simulated using a uniform pseudo random distribution to represent periods of persistent and significant depreciation. The starting value of simulation is based on the 10-day average COPUSD exchange rates ending on October 20, 2012. Maximum depreciation in this simulation equals 1922 Colombian pesos per US dollar, which is a 2.23% depreciation over 30 days.

Figure 6: Depreciation Dynamic Delta Hedging Outcomes (W-put/W-call spread: 1)



The dynamic delta hedging position is calculated for 100 series for a 30 day contract period. By construction, the simulated exchange rates are steadily depreciating over the 30-day period. The W-spread strategy presented here is a neutral one since the W-put/W-call spread ratio is 1. As can be seen, holding a position in both a W-call spread and W-put spread strategy is the least disruptive to the spot market.

Figure 7: Depreciation Dynamic Delta Hedging Outcomes (W-put/W-call spread: 0.25)



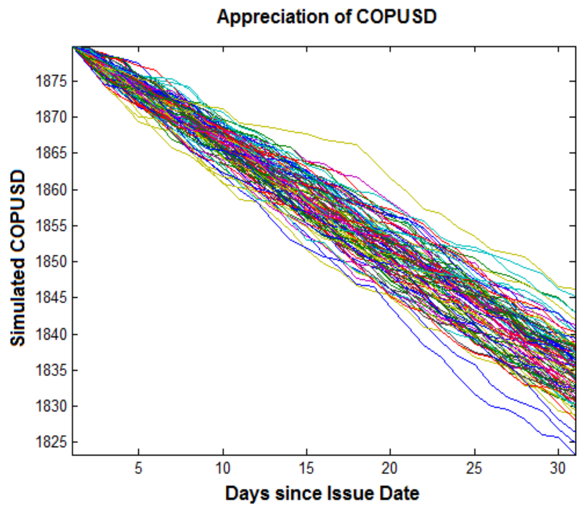
The dynamic delta hedging position is calculated for 100 series for a 30 day contract period. By construction, the simulated exchange rates are steadily depreciating over the 30-day period. The W-spread strategy presented here is a call-biased one since W-put/W-call spread ratio is 0.25. As can be seen, holding a position in both a call and put strategy is the least disruptive to the spot market.

Table 8: End-of-Period Dynamic Delta Costs, Payoffs and Premiums

Average Across Series (USD)				
	W-put/W-call = 1	St. Dev.	W-put/W-call = 0.25	St. Dev.
End-of-Period USD Transacted	-50,108,000	3,613	-80,188,000	3,884
Interest Cost	-112,220	3,613	-195,360	3,884
Long Payoff	2,474,600	5,271	3,908,700	8,524
Short Payoff	-1,237,300	2,636	-1,954,400	4,262
Long Premium	-659,160	1,404	-812,580	1,772
Short Premium	314,630	670	391,340	853
Profit/Cost of Option Strategy	780,550	4,938	1,337,700	6,423
Share of Total	0.78 %	0.005 %	1.34 %	0.006 %

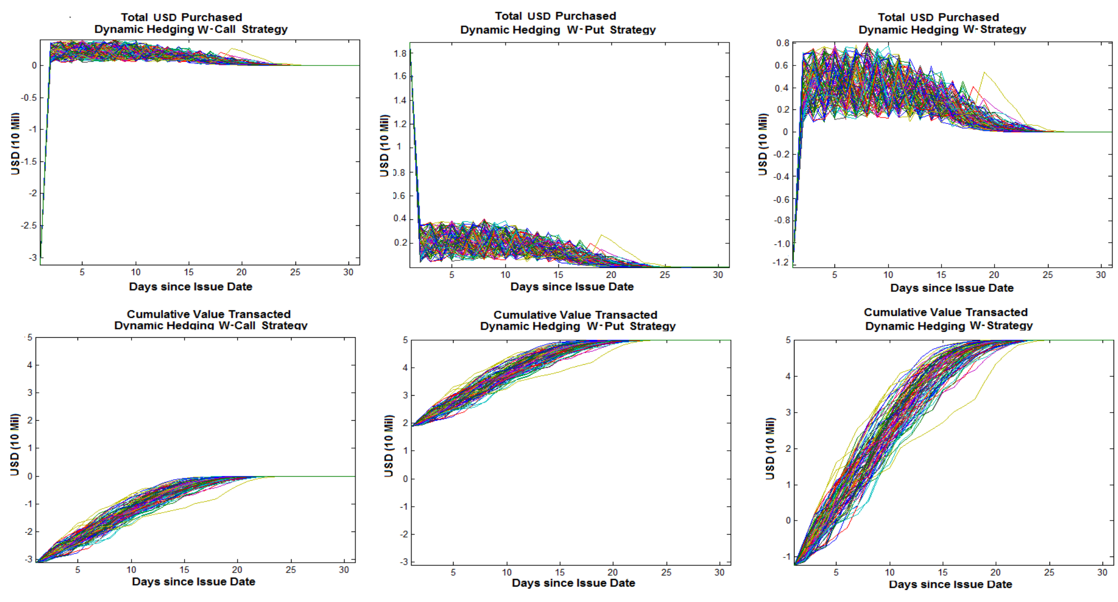
End-of-Period total USD transacted represents the cumulative value of daily dynamic delta hedging and interest costs. Each contract size in USD 10,000 and there are 10,000 contracts issued. The table depicts the costs for series when the portfolio position is neutral (W-put/W-call spread ratio of 1) as well as for a call biased portfolio (W-put/W-call spread ratio of 0.25) during a period of depreciation. The calculations reflect those described in the summary table of Table (6). The negative values reflect a cost or outlay of funds for the central bank, whereas the positive values reflect funds acquired by the central bank. Profit/Cost of Option Strategy is the sum of the long payoff and short premium minus the sum of the net value transacted, interest cost, short payoff and long premium.

Figure 8: Series of Simulated Exchange Rates for Periods of with Persistent Appreciation



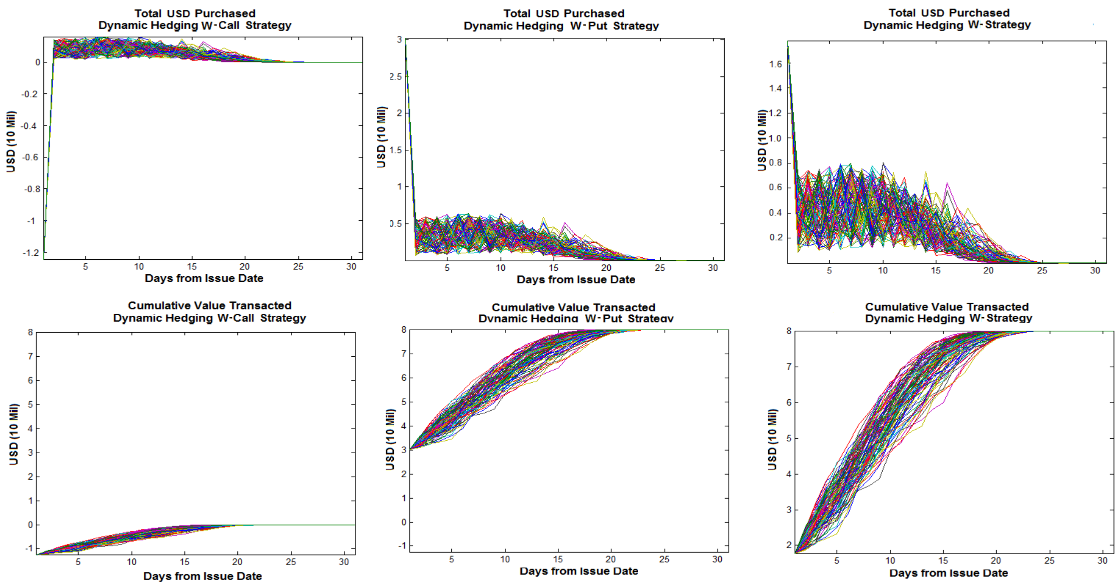
Exchange rates are simulated using a pseudo random uniform distribution to represent periods of appreciation. The starting value of the simulation is based on 10 day average COPUSD exchange rates ending on October 20, 2012. Maximum appreciation in this simulation is to 1824, which is a 2.97% appreciation over 30 days.

Figure 9: Appreciation Dynamic Delta Hedging Outcomes (W-put/W-call spread: 1)



The dynamic delta hedging position is calculated for 100 series for a 30 day contract. The exchange rate is steadily appreciating over the period to maturity. The W-put/W-call spread ratio is 1. As can be seen, holding a position in both a W-call spread and W-put spread strategy is the least disruptive to the spot market.

Figure 10: Appreciation Dynamic Delta Hedging Outcomes (W-put/W-call spread: 4)



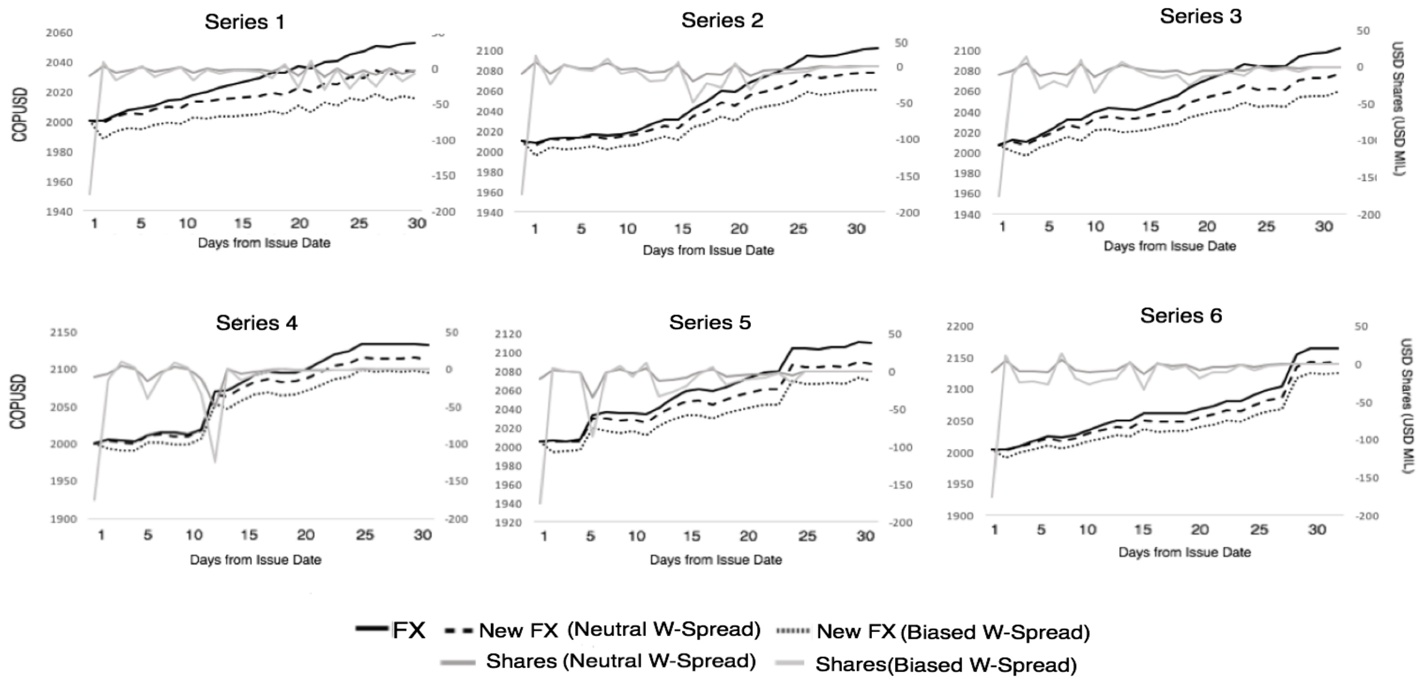
The dynamic delta hedging position is calculated for 100 series for a 30 day contract. The exchange rate is steadily appreciating over the period to maturity. The W-put/W-call spread ratio is 4. As can be seen, holding a position in both a W-call spread and W-put spread strategy is the least disruptive to the spot market and contributes to countering the persistent appreciation simulated in the market.

Table 9: End-of-Period Dynamic Delta Costs, Payoffs and Premiums

Average Across Series (USD)				
	W-put/W-call = 1	St. Dev.	W-put/W-call = 4	St. Dev.
End-of-Period USD Transacted	50,082,000	5,910	80,164,000	5,379
Interest Cost	-92,052	4,942	-170,830	5,379
Long Payoff	1,791,700	3,968	3,480,700	6,951
Short Payoff	-895,850	1,984	-1,740,300	3,475
Long Premium	-687,050	1,522	-527,320	1,053
Short Premium	327,940	726	248,070	495
Profit/Cost of Option Strategy	444,688	4,236	1,290,320	4,076
Share of Total	0.44 %	0.004 %	1.29 %	0.004 %

End-of-Period total value transacted represents the cumulative value of daily dynamic delta hedging and interest costs. Each contract size in USD 10,000 and there were 10,000 contracts issued. The table depicts the values for series when the portfolio position is neutral and the W-put/W-call spread ratio is one, as well as for a biased portfolio, with a W-put/W-call spread greater than one during a period of appreciation. The calculations reflect those described in the summary table of Table (6). The negative values reflect a cost or outlay of funds for the central bank, whereas the positive values reflect funds acquired by the central bank.

Figure 11: Intervention Impact on COPUSD under Trending Depreciation



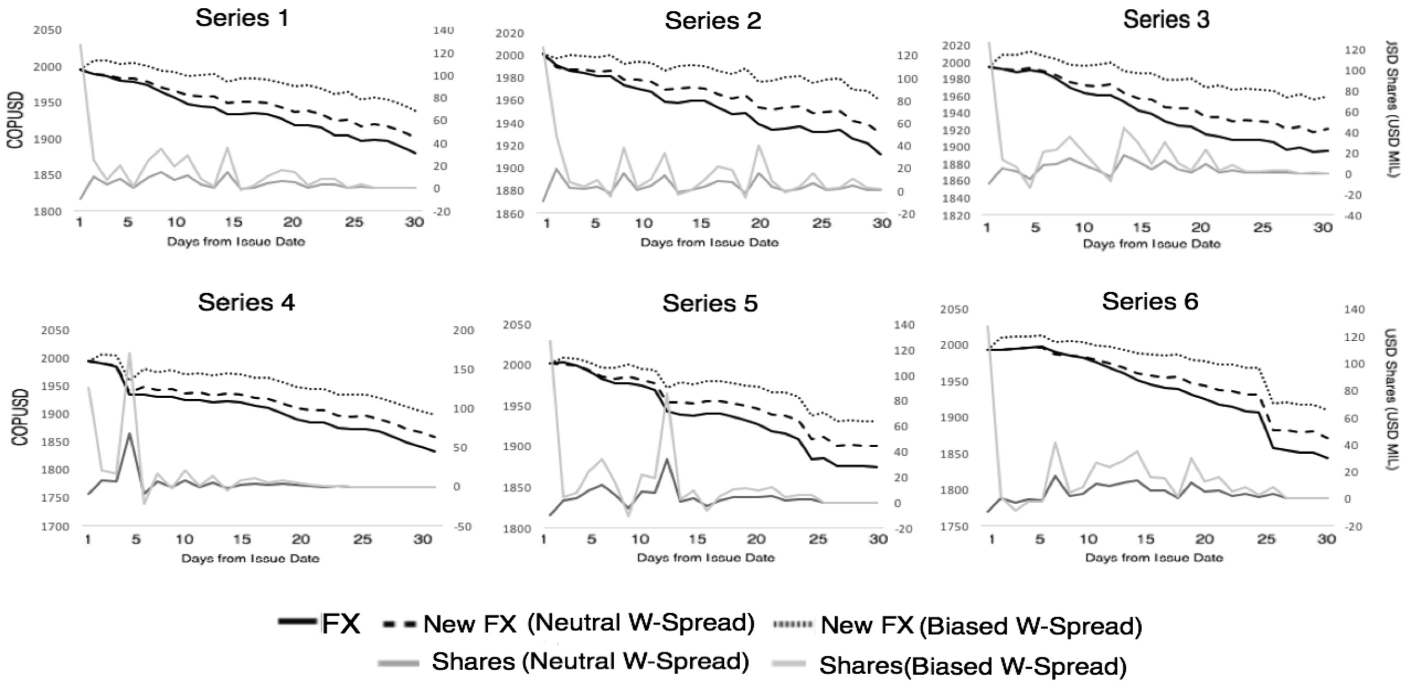
This figure presents a sample of the simulation results for the W-spread strategy where the dynamic delta hedging in the spot market impacts the value of the exchange rate under depreciations. The top three graphs illustrate persistent depreciation without any shocks. The bottom three graphs illustrate depreciation with a "shock" to the exchange rate. Included are both the neutral strategy (W-put/W-call spread ratio equal to 1) as well as a biased strategy (W-put/W-call spread ratio equal to 0.25). Adopting the W-strategy allows the central bank to lower volatility while stabilizing the trend.

Table 10: Volatility for Intervention Impact of W-strategy under Trending Depreciation

	Series (1)	Series (2)	Series (3)	Simulation
Volatility (no intervention)	16.76	34.39	29.89	29.85
Volatility (neutral W-strategy)	10.61	26.56	21.72	23.14
Volatility Reduction	37%	23%	27%	22%
Volatility (biased W-strategy)	8.05	23.15	18.53	20.32
Volatility Reduction	52%	33%	38%	32%
	Series (4)	Series (5)	Series (6)	Simulation
Volatility (no intervention)	51.69	35.24	49.90	31.18
Volatility (neutral W-strategy)	45.31	28.33	42.86	24.87
Volatility Reduction	12%	20%	13%	20%
Volatility (biased W-strategy)	41.59	25.17	40.00	21.76
Volatility Reduction	20%	29%	19%	30%

This table presents the volatility measures of the COPUSD related to the intervention impacts illustrated in Figure (11). Simulation column represents the average values across 100 simulations in each scenario. The volatility reduction percentages represent $1 - \frac{Vol_{Intervention}}{Vol_{NoIntervention}}$. In all cases, the W-strategy is effective in lowering volatility of the COPUSD, which is calculated as the standard deviation of the exchange rate during the time to maturity of the option.

Figure 12: Intervention Impact on COPUSD under Trending Appreciation



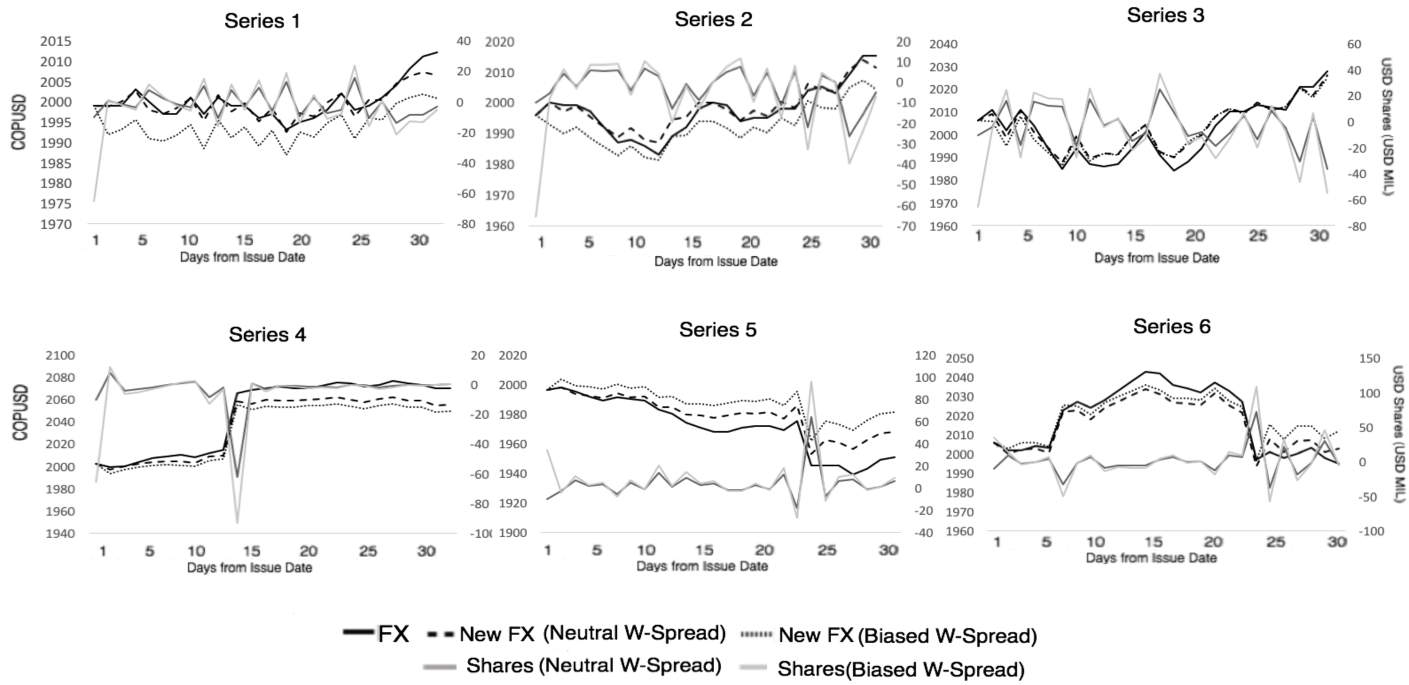
This figure presents a sample of the simulation results for the W-spread strategy where the dynamic delta hedging in the spot market impacts the value of the exchange rate under appreciations. The top three graphs illustrate persistent appreciation without any shocks. The bottom three graphs illustrate appreciation with a "shock" to the exchange rate. Included are both the neutral strategy (W-put/W-call spread ratio equal to 1) as well as a biased strategy (W-put/W-call spread ratio equal to 4). Adopting the W-strategy allows the central bank to lower volatility while stabilizing the trend.

Table 11: Volatility for Intervention Impact of W-strategy under Trending Appreciation

	Series (1)	Series (2)	Series (3)	Simulation
Volatility (no intervention)	33.95	23.84	35.21	22.91
Volatility (neutral W-strategy)	26.93	17.88	26.25	16.35
Volatility Reduction	21%	25%	25%	29%
Volatility (biased W-strategy)	19.77	11.01	17.63	11.98
Volatility Reduction	43%	54%	50%	48%
	Series (4)	Series (5)	Series (6)	Simulation
Volatility (no intervention)	42.90	42.75	51.64	29.45
Volatility (neutral W-strategy)	35.80	33.55	41.03	22.91
Volatility Reduction	17%	22%	21%	22%
Volatility (biased W-strategy)	29.00	25.94	33.00	18.92
Volatility Reduction	32%	39%	36%	36%

This table presents the volatility measures of the COPUSD related to the intervention impacts illustrated in Figure (12). Simulation column represents the average values across 100 simulations in each scenario. The volatility reduction percentages represent $1 - \frac{Vol_{Intervention}}{Vol_{NoIntervention}}$. In all cases, the W-strategy is effective in lowering volatility of the COPUSD, which is calculated as the standard deviation of the exchange rate during the time to maturity of the option.

Figure 13: Intervention Impact on COPUSD under no trend



This figure presents a sample of the simulation results for the W-spread strategy where the dynamic delta hedging in the spot market impacts the value of the exchange rate with no clear trend and only volatility. The top three graphs illustrate the COPUSD without any shocks. The bottom three graphs illustrate the exchange rate reaction with a "shock". Included are both the neutral strategy (W-put/W-call spread ratio equal to 1) as well as a biased strategy (W-put/W-call spread ratio equal to 4 or 0.25 depending on shock). Adopting the W-strategy allows the central bank to lower volatility while stabilizing the trend.

Table 12: Volatility for Intervention Impact of W-strategy under no trend

	Series (1)	Series (2)	Series (3)	Simulation
Volatility (no intervention)	4.55	7.99	12.50	5.56
Volatility (neutral W-strategy)	3.62	6.85	10.37	4.15
Volatility Reduction	20%	14%	17%	25%
Volatility (biased W-strategy)	4.00	6.80	10.48	4.89
Volatility Reduction	12%	15%	16%	12%
	Series (4)	Series (5)	Series (6)	Simulation
Volatility (no intervention)	32.36	18.73	16.97	13.47
Volatility (neutral W-strategy)	27.42	12.88	12.67	11.06
Volatility Reduction	15%	31%	18%	22%
Volatility (biased W-strategy)	26.10	10.45	11.68	9.70
Volatility Reduction	19%	44%	31%	28%

This table presents the volatility measures of the COPUSD related to the intervention impacts illustrated in Figure (12). Simulation column represents the average values across 100 simulations in each scenario. The volatility reduction percentages represent $1 - \frac{Vol_{Intervention}}{Vol_{NoIntervention}}$. In all cases, the W-strategy is effective in lowering volatility of the COPUSD, which is calculated as the standard deviation of the exchange rate during the time to maturity of the option.

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8 Appendix

Offsetting Position of Market Participants

For every transaction in the options market the central bank engages in, there is an offsetting position by a market participant that must purchase or sell the option. It is important to understand what happens, in terms of delta hedging, on the other side of the market when the central bank is engaging in the W-spread proposed in this paper. Traders can choose to hedge part or all of their net portfolio position. Since hedging can be costly and not all market participants have the same motives to use the options markets[23], not all traders will hedge their entire portfolio position, which has important implications for our analysis.

The hedging of the short position is what may exacerbate the adverse movements in the exchange rates. If we start by assuming that when the central bank is holding a net long position through the W-spread, there is only one trader that is holding all of the offsetting options, which implies that this trader would be in a net short portfolio position, making it feasible that this trader may engage in delta hedging. His delta hedging increases volatility and can potentially modify the exchange rate trend, which is problematic for the central bank. However, the likelihood of one trader holding all of the central banks offsetting position is very small, and not advisable for the central bank to allow such a situation to materialize. On the other hand, for individual hedgers and speculators, it is costly to hedge their entire position in the options market. Moreover, some may be using the option itself as the risk management tool of choice. Therefore, the hedging activity of traders may not match one for one the hedging activity of the central bank.

Tables (13) to (15) present the total USD that is purchased and sold by central banks and market participants when the central bank is hedging 100 percent of its net portfolio position in the W-spread, and the traders are hedging 100, 50 and 10 percent respectively of their offsetting W-spread positions. In the examples presented below, we assume that the COPUSD is depreciating, and that the hedging position (or spot market intervention driven by the hedging position) does not directly impact the movement of the exchange rate in this simulation. This assumption is used simply to convey the positions the delta hedge would create in the spot market. Under the depreciationary pressure, all calls are exercised, while the puts expire without exercise. The delta hedging therefore nets to $10,000foreachofthecallpositionsand0$ for each of the put positions.

As can be seen in Table (13), if both parties engage in 100 percent delta hedging of their portfolios, then the hedging activity in the spot market between the central bank and traders cancel each other out. If traders hedge anything less than 100% of their portfolio, the central bank's hedging activity creates stabilizing transactions on the spot market to compliment their intended intervention goals. If traders hedge only 50 percent of their portfolio, as seen in Table (14), then there is a net sale of USD on the spot market between the traders and central bank. Finally, if traders hedge only 10 percent of their portfolio, the net position in the spot market is a sale of $ 8,999, as seen in Table (15). Therefore, if the net offsetting position by market participants is hedged by anything less than 100%, the delta hedging activity of the central bank provides a spot market intervention strategy that complements the goals of curbing drastic movements of the exchange rate.

It is possible to assume that in fact the offsetting position would not be hedged 100% since the only agents interested in dynamic delta hedging would be market markets and large currency traders. Local import/export business and multinationals use the option itself as a hedge. As a proxy, we can turn to the growth in forward contracts. According to the Triennial Foreign Exchange Market Survey conducted by the Bank of International Settlements, the share of options to total foreign exchange transactions in emerging market economies has remained steady at 2.5% since 1998, which may be partially due to the shallowness of this market in these economies. On the other hand, the use of forwards has increased from 7% to 10% of total foreign exchange transactions, representing growth of 48%. By design, forward contracts are not hedged and are used by non-market makers as a hedge in-and-of themselves, as the option would be in our proposed strategy. Therefore, if the central bank makes options more readily available to these players by operating in and building up this market, it is possible to assume that the share of options that would be dynamically delta hedged would be less than 100%.

[23] For example, exporters and importers in general are not interested in delta hedging their positions. They use options to eliminate exchange rates uncertainty at maturity.

Table 13: Central Bank and Traders Hedging Positions with 100% Hedge

	Net USD Purchased By Central Bank						**Net USD Purchased By Traders**						**Net USD Transacted By Both**
	Calls			**Puts**			**Calls**			**Puts**			
Ex. Rate	Long (K_1)	Long (K_3)	Short (K_2)	Long (K_1)	Long (K_3)	Short (K_2)	Short (K_1)	Short (K_3)	Long (K_2)	Short (K_1)	Short (K_3)	Long (K_2)	Net USD
COPUSD	USD	USD	USD	USD	USD	USD	100%	100%	100%	100%	100%	100%	
2044.00	-5,856	-5,042	5,451	4,144	4,958	-4,549	5,856	5,042	-5,451	-4,144	-4,958	4,549	0
2050.00	-494	-498	499	-494	-498	499	494	498	-499	494	498	-499	0
2053.00	-231	-230	232	-231	-230	232	231	230	-232	231	230	-232	0
2054.00	-66	-55	61	-66	-55	61	66	55	-61	66	55	-61	0
2054.00	-45	-32	39	-45	-32	39	45	32	-39	45	32	-39	0
2060.00	-489	-518	507	-489	-518	507	489	518	-507	489	518	-507	0
2066.00	-444	-484	466	-444	-484	466	444	484	-466	444	484	-466	0
2076.00	-627	-723	678	-627	-723	678	627	723	-678	627	723	-678	0
2076.00	-77	-78	79	-77	-78	79	77	78	-79	77	78	-79	0
2085.00	-524	-646	586	-524	-646	586	524	646	-586	524	646	-586	0
2093.00	-359	-467	413	-359	-467	413	359	467	-413	359	467	-413	0
2099.00	-214	-292	252	-214	-292	252	214	292	-252	214	292	-252	0
2106.00	-217	-316	264	-217	-316	264	217	316	-264	217	316	-264	0
2111.00	-122	-187	152	-122	-187	152	122	187	-152	122	187	-152	0
2114.00	-61	-97	78	-61	-97	78	61	97	-78	61	97	-78	0
2119.00	-69	-118	91	-69	-118	91	69	118	-91	69	118	-91	0
2126.00	-56	-106	78	-56	-106	78	56	106	-78	56	106	-78	0
2135.00	-32	-68	47	-32	-68	47	32	68	-47	32	68	-47	0
2141.00	-10	-25	16	-10	-25	16	10	25	-16	10	25	-16	0
2144.00	-3	-9	6	-4	-9	6	3	9	-6	4	9	-6	0
2149.00	-2	-6	3	-2	-6	3	2	6	-3	2	6	-3	0
2156.00	-1	-2	1	-1	-2	1	1	2	-1	1	2	-1	0
2162.00	0	0	0	0	0	0	0	0	0	0	0	0	0
2166.00	0	0	0	0	0	0	0	0	0	0	0	0	0
2175.00	0	0	0	0	0	0	0	0	0	0	0	0	0
2182.00	0	0	0	0	0	0	0	0	0	0	0	0	0
2188.00	0	0	0	0	0	0	0	0	0	0	0	0	0
2189.00	0	0	0	0	0	0	0	0	0	0	0	0	0
2195.00	0	0	0	0	0	0	0	0	0	0	0	0	0
2196.00	0	0	0	0	0	0	0	0	0	0	0	0	0
2196.00	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	-9,999	-9,999	9,999	0	1	-1	9,999	9,999	-9,999	0	-1	1	0

This table illustrates the spot market position of the central bank and traders during daily dynamic delta hedging of a W-spread when there is persistent depreciation. It represents the net hedging strategy where each contract in the strategy is for 10,000 USD. Here, the traders are hedging 100 percent of their position.

Table 14: Central Bank and Traders Hedging Positions with 50% Hedge

	Net USD Purchased By Central Bank						**Net USD Purchased By Traders**						**Net USD Transacted By Both**
	Calls			**Puts**			**Calls**			**Puts**			
Ex. Rate	Long (K_1)	Long (K_3)	Short (K_2)	Long (K_1)	Long (K_3)	Short (K_2)	Short (K_1)	Short (K_3)	Long (K_2)	Short (K_1)	Short (K_3)	Long (K_2)	Net USD
COPUSD	USD	USD	USD	USD	USD	USD	50%	50%	50%	50%	50%	50%	
2044.00	-5,856	-5,042	5,451	4,144	4,958	-4,549	2,928	2,521	-2,726	-2,072	-2,479	2,275	-447
2050.00	-494	-498	499	-494	-498	499	247	249	-250	247	249	-250	-493
2053.00	-231	-230	232	-231	-230	232	116	115	-116	116	115	-116	-229
2054.00	-66	-55	61	-66	-55	61	33	28	-31	33	28	-31	-60
2054.00	-45	-32	39	-45	-32	39	23	16	-20	23	16	-20	-38
2060.00	-489	-518	507	-489	-518	507	245	259	-254	245	259	-254	-500
2066.00	-444	-484	466	-444	-484	466	222	242	-233	222	242	-233	-462
2076.00	-627	-723	678	-627	-723	678	314	362	-339	314	362	-339	-672
2076.00	-77	-78	79	-77	-78	79	39	39	-40	39	39	-40	-76
2085.00	-524	-646	586	-524	-646	586	262	323	-293	262	323	-293	-584
2093.00	-359	-467	413	-359	-467	413	180	234	-207	180	234	-207	-413
2099.00	-214	-292	252	-214	-292	252	107	146	-126	107	146	-126	-254
2106.00	-217	-316	264	-217	-316	264	109	158	-132	109	158	-132	-269
2111.00	-122	-187	152	-122	-187	152	61	94	-76	61	94	-76	-157
2114.00	-61	-97	78	-61	-97	78	31	49	-39	31	49	-39	-80
2119.00	-69	-118	91	-69	-118	91	35	59	-46	35	59	-46	-96
2126.00	-56	-106	78	-56	-106	78	28	53	-39	28	53	-39	-84
2135.00	-32	-68	47	-32	-68	47	16	34	-24	16	34	-24	-53
2141.00	-10	-25	16	-10	-25	16	5	13	-8	5	13	-8	-19
2144.00	-3	-9	6	-4	-9	6	2	5	-3	2	5	-3	-7
2149.00	-2	-6	3	-2	-6	3	1	3	-2	1	3	-2	-5
2156.00	-1	-2	1	-1	-2	1	1	1	-1	1	1	-1	-2
2162.00	0	0	0	0	0	0	0	0	0	0	0	0	0
2166.00	0	0	0	0	0	0	0	0	0	0	0	0	0
2175.00	0	0	0	0	0	0	0	0	0	0	0	0	0
2182.00	0	0	0	0	0	0	0	0	0	0	0	0	0
2188.00	0	0	0	0	0	0	0	0	0	0	0	0	0
2189.00	0	0	0	0	0	0	0	0	0	0	0	0	0
2195.00	0	0	0	0	0	0	0	0	0	0	0	0	0
2196.00	0	0	0	0	0	0	0	0	0	0	0	0	0
2196.00	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	-9,999	-9,999	9,999	0	1	-1	5,000	5,000	-5,000	0	-1	1	-5,000

This table illustrates the spot market position of the central bank and traders during daily dynamic delta hedging of a W-spread when there is persistent depreciation. It represents the net hedging strategy where each contract in the strategy is for 10,000 USD. Here, the traders are hedging 50 percent of their position.

Table 15: Central Bank and Traders Hedging Positions with 10% Hedge

	Net USD Purchased By Central Bank						**Net USD Purchased By Traders**						**Net USD Transacted By Both**
	Calls			**Puts**			**Calls**			**Puts**			
Ex. Rate	Long (K_1)	Long (K_3)	Short (K_2)	Long (K_1)	Long (K_3)	Short (K_2)	Short (K_1)	Short (K_3)	Long (K_2)	Short (K_1)	Short (K_3)	Long (K_2)	Net USD
COPUSD	USD	USD	USD	USD	USD	USD	10%	10%	10%	10%	10%	10%	
2044.00	-5,856	-5,042	5,451	4,144	4,958	-4,549	586	504	-545	-414	-496	455	-805
2050.00	-494	-498	499	-494	-498	499	49	50	-50	49	50	-50	-887
2053.00	-231	-230	232	-231	-230	232	23	23	-23	23	23	-23	-412
2054.00	-66	-55	61	-66	-55	61	7	6	-6	7	6	-6	-108
2054.00	-45	-32	39	-45	-32	39	5	3	-4	5	3	-4	-68
2060.00	-489	-518	507	-489	-518	507	49	52	-51	49	52	-51	-900
2066.00	-444	-484	466	-444	-484	466	44	48	-47	44	48	-47	-832
2076.00	-627	-723	678	-627	-723	678	63	72	-68	63	72	-68	-1,210
2076.00	-77	-78	79	-77	-78	79	8	8	-8	8	8	-8	-137
2085.00	-524	-646	586	-524	-646	586	52	65	-59	52	65	-59	-1,051
2093.00	-359	-467	413	-359	-467	413	36	47	-41	36	47	-41	-743
2099.00	-214	-292	252	-214	-292	252	21	29	-25	21	29	-25	-457
2106.00	-217	-316	264	-217	-316	264	22	32	-26	22	32	-26	-484
2111.00	-122	-187	152	-122	-187	152	12	19	-15	12	19	-15	-283
2114.00	-61	-97	78	-61	-97	78	6	10	-8	6	10	-8	-144
2119.00	-69	-118	91	-69	-118	91	7	12	-9	7	12	-9	-173
2126.00	-56	-106	78	-56	-106	78	6	11	-8	6	11	-8	-151
2135.00	-32	-68	47	-32	-68	47	3	7	-5	3	7	-5	-95
2141.00	-10	-25	16	-10	-25	16	1	3	-2	1	3	-2	-34
2144.00	-3	-9	6	-4	-9	6	0	1	-1	0	1	-1	-12
2149.00	-2	-6	3	-2	-6	3	0	1	0	0	1	0	-9
2156.00	-1	-2	1	-1	-2	1	0	0	0	0	0	0	-4
2162.00	0	0	0	0	0	0	0	0	0	0	0	0	0
2166.00	0	0	0	0	0	0	0	0	0	0	0	0	0
2175.00	0	0	0	0	0	0	0	0	0	0	0	0	0
2182.00	0	0	0	0	0	0	0	0	0	0	0	0	0
2188.00	0	0	0	0	0	0	0	0	0	0	0	0	0
2189.00	0	0	0	0	0	0	0	0	0	0	0	0	0
2195.00	0	0	0	0	0	0	0	0	0	0	0	0	0
2196.00	0	0	0	0	0	0	0	0	0	0	0	0	0
2196.00	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	-9,999	-9,999	9,999	0	1	-1	1,000	1,000	-1,000	0	0	0	-8,999

This table illustrates the spot market position of the central bank and traders during daily dynamic delta hedging of a W-spread when there is persistent depreciation. It represents the net hedging strategy where each contract in the strategy is for 10,000 USD. Here, the traders are hedging 10 percent of their position.