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Research Department

Central Bank Participation in Currency Options Markets

Prepared by Peter Breuer [1]

Authorized for distribution by Garry J. Schinasi

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Abstract

This paper analyzes whether and how central banks can use currency options to lower exchange rate volatility and maintain (implicit) target zones in foreign exchange markets. It argues that *selling* rather than *buying* options will result in market makers dynamically hedging their long option exposure in a stabilizing manner, consistent with the first objective. Selling a "strangle" allows a central bank to increase the credibility of its commitment to a target zone, and could have a lower expected cost than spot market interventions. However, this strategy also exposes the central bank to an unlimited loss potential.

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Contents Page

Appendices

I. INTRODUCTION

Traditional central bank foreign exchange intervention occurs in spot currency markets. Likewise, the attention of researchers has focused on *spot* market interventions. However, the enormous growth in derivatives products has widened the array of instruments available to central banks to achieve their monetary policy goals. Some central banks are now investigating the potential uses of derivative products. The topic first received (albeit limited) attention in the Hannoun Report (BIS, 1994), which considered the impact of recent financial innovation on the macroeconomy and monetary policy. More recently, there have been reports that several central banks have intervened in currency option markets.[2]

This paper explores the opportunities and risks involved when central banks use the currency options market to achieve exchange rate stability in the foreign exchange market.[3] The fact that monetary authorities intervene from time to time to achieve (often implicit) exchange rate target levels or to lower volatility in the foreign exchange markets has been established in the literature and is taken as given. The question considered here is whether and at what cost these objectives can also be achieved in the currency option markets.[4]

The contribution of this paper lies in analyzing possible central bank strategies in the currency option market and in showing that dynamic hedging by market makers need not always be destabilizing as commonly suggested in the literature.[5] It is demonstrated that a strategy of central banks buying currency options (as advanced by Taylor (1995)) is flawed due to the destabilizing impact on the exchange rate of dynamic hedging by market makers,

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[2] For example, a press report credits the use of Hong Kong dollar put / US dollar call options by the Bank of China in 1998 as a contributing factor for keeping the Hong Kong dollar peg intact (Risk, April 1999). Larry Summers stated in a speech on Global Integration (January 4, 1999) "[a]ny doubt I might have had about the globalization of economic thinking was shattered when I met with Chinese Premier Zhu Rhongi...I was asked a variety of searching questions about the possible use of put options in defending a currency, and how they might best be structured." Banco de México introduced a currency option program in August 1996 designed to rebuild its foreign reserves.

[3] For analyses of forward market intervention see, for example, Eaton and Turnovsky (1984) or Lall (1997).

[4] This paper does not address the use of options to manage reserves. Some central banks may consider using options to protect the value of their foreign exchange reserves. The central bank would in that case be acting similar to an end-user such as a mutual fund, trying to protect the value of its portfolio.

[5] The phrases "destabilizing" and "exacerbating volatility" are used interchangeably in this paper and imply a comparison between states with and without intervention.

as well as due to a moral hazard incentive for the central bank to influence the spot exchange rate. The paper also examines a strategy whereby the central bank sells options, either individually or packaged in a 'strangle'. Under certain conditions this strategy could lower exchange rate volatility, may boost the credibility of an exchange rate target zone and could have lower expected costs than spot market interventions. However, selling options exposes the central bank to an unlimited loss potential.

With regard to traditional central bank intervention, the main issues are whether intervention can affect exchange rates, what the objectives for intervention are, and whether intervention has been profitable.[6] Concerning the first issue, the *ability to influence* exchange rates, there is widespread agreement that unsterilized interventions in the spot market can affect nominal exchange rates. This works by virtue of changing the money supply and therefore interest rates, real demands for goods and assets, and market expectations (the monetary channel). The effect of sterilized intervention is subject to debate. Theoretically, sterilized intervention could work by changing the relative supplies of foreign and domestic bonds (the portfolio-balance channel) or by changing market expectations (signaling channel). Edison (1993) reports that the empirical literature finds the portfolio-balance channel less important than the signaling channel. The importance of the signaling channel matters for the evaluation of central bank strategies in the option market and will be considered again in that context.

Regarding the second issue, *objectives* of intervention, the literature suggests that intervention is undertaken to smooth nominal and real exchange rates and to achieve a target level of the nominal exchange rate.[7] Research in this area typically estimates some form of a reaction function, where the amount of intervention is explained by deviations of the exchange rate from a target level, volatility in the exchange rate, and other economic variables. The objective of volatility reduction is taken as given for the purposes of this paper.

Lastly, the evidence on *profitability* is fragmented as it largely depends on the time period over which profits are estimated. Central banks "lean against the wind" with their interventions, that is, they buy the domestic currency when it is depreciated and they sell it when it is appreciated relative to their target level. If an intervention is successful and the exchange rate moves in the desired direction after an intervention, the central bank will have made a profit as it bought foreign currency when it was cheap and sold it when it was expensive. However, subsequent changes in the exchange rate can easily wipe out any profits the monetary authorities may have made. This paper will address the topic of profitability of intervention in option markets by comparing it to the profitability of intervention in the spot market.

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[6] Edison (1993) surveys the central bank intervention literature rather comprehensively.

[7] For a recent study see Almekinders (1995).

The paper is organized as follows. Section II briefly considers a central bank's concern with exchange rate volatility. Section III provides a basic description of the currency option market, its size, participants and their activities. Section IV shows how one of the activities related to the currency option market, *dynamic hedging* by market makers, can affect the underlying spot currency market. This relationship between the derivatives market and the spot market is pivotal in the consideration of a central bank's participation in the currency option market. Section V considers the option buying scheme proposed by Taylor (1995) and points out some serious drawbacks of the scheme. In the following section, an alternative scheme, selling options, is analyzed that enables the monetary authority to influence exchange rates and lower volatility, but at the same time exposes it to an unlimited loss potential. The seventh section concludes the paper.

II. Volatility and Intervention

As mentioned above, the literature finds that the goals of central bank intervention are to smooth nominal exchange rates and occasionally (depending on the country) to target levels of exchange rates.[8] Why should the central bank care about volatility? Volatility is usually considered bad for the macroeconomy. In the first instance, it may adversely affect international trade. Volatility creates uncertainty about the revenues to be collected. Firms will demand a risk premium for more uncertain profits and may pass the premium on in the form of higher prices, hence reducing demand for traded goods. Similarly, the risk premium attached to foreign investments may reduce international capital flows, hence disrupting the efficient allocation of resources throughout the world. Finally, exchange rate volatility might be transmitted to domestic financial markets, which in turn may adversely affect monetary policy, and perhaps financial stability.

What are the causes of exchange rate volatility? One source is volatility of market fundamentals, which may or may not be under the control of policy makers. Volatility in the money supply, interest rates, income, relative price levels may all affect volatility of the exchange rate. A second source is that expectations about future market fundamentals can influence exchange rate volatility. When new information arrives, expectations may change to different degrees and therefore contribute to volatility. Finally, speculative bandwagons unrelated to or exaggerating market fundamentals can contribute to volatility.

What can the central bank do about volatility? If an intervention is sterilized, a central bank cannot address the first cause of volatility (volatility of market fundamentals) as the intervention leaves these variables unaffected. With traditional intervention the central bank can only affect volatility through expectations (signaling channel) and by attempting to contain speculative behavior. The intervention in the spot market may or may not reduce

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[8] See Edison (1993) or, for example, Baille and Osterberg (1997) for a more recent study.

volatility. "Leaning against the wind" may reduce volatility and contain speculative bubbles if the intervention is large enough to be successful. However, if market participants are taken by surprise, volatility may actually increase as a result of the intervention. Recent studies by Bonser-Neal (1996a, 1996b) examined the impact of spot market intervention on ex ante volatilities of $/DM and $/yen exchange rates between 1985 and 1991. She found that volatility has increased as a result of interventions by the Federal Reserve and the Bank of Japan. Hung (1997) found that during 1987-89, when the goal of US intervention was to maintain an implicit target band, volatility increased because of the presence of noise traders who amplified the central bank's moves. In this paper, it is shown that under certain conditions volatility can be reduced with options.

III. The Currency Options Market

In the interbank market, dealers often quote option prices in terms of their *implied volatilities* rather than the actual price. Given the price and other parameters of the option, the Black and Scholes option pricing model implies a volatility of the spot rate that is assumed to exist over the lifetime of the option. Implied volatility can therefore be viewed as an ex ante expectation. It differs from historical volatility in that the latter is the actually realized volatility of the spot rate. Implied volatility is a direct determinant of the option price. A higher volatility implies a higher risk for the option writer as the option is more likely to move "in the money". The option buyer, whose loss potential is limited by the premium, has to compensate the option writer, whose loss potential is unlimited, for larger risks due to higher uncertainty. Hence, a higher implied volatility means, ceteris paribus, a higher option price.

Dealers effectively trade volatilities. Quoting implied volatilities allows dealers to make comparisons across options with different specifications (strike price, maturity, etc.). The bid-ask spread is reflected in the two different implied volatilities being quoted. It should be noted that while the implied volatility is an ex ante expectation of realized volatility in the future, in empirical studies implied volatility almost always exceeds historical volatility.[9] This is due to a mark-up option writers charge over the theoretical value of the option and can be interpreted as a volatility risk premium.

A. Size and Activity

Currency options are traded in two forms of institutional settings: on organized exchanges and among banks in the over-the-counter market (OTC). The bulk of activity takes

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[9] This will be considered again in section VI. Also see Canina and Figlewski (1993), Bank of Japan (1995), and Fucile, Mastroeni and Siciliano (1995).

place in OTC markets rather than on exchanges. The notional amount[10] of total outstanding OTC currency options worldwide net of inter-dealer double counting was estimated to be $5,040 billion at the end of June 1998, which represents approximately 23 percent of all foreign exchange activity in a survey of the foreign exchange market.[11, 12] In comparison, the gross notional amount outstanding for exchange traded currency options amounted to only $30 billion in September 1998. Another measure of *market size* is the gross market value[13] of all outstanding OTC currency options. The gross market value of OTC options net of local and cross-border inter-dealer double counting was $141 billion.[14] An indicator of *market activity* is daily turnover. Net daily turnover at $87 billion in the OTC options market amounted to 15 percent of daily foreign exchange spot transactions, which averaged $600 billion per day in the month of April 1998.[15] The reported daily turnover of currency options on exchanges was only $1.85 billion. Hence, total currency options transactions represent a non-negligible and growing portion of the overall foreign exchange market. Feedback effects from the option market to the spot market are therefore not negligible.

B. Market Participants

Participants in the options market can be grouped into speculators, hedgers, and market makers. A *speculator*, e.g. hedge fund, uses options to profit from expected movements in the underlying exchange rate. A speculator is less risk-averse than a hedger and maintains open positions, hoping that at the time the contract matures, events will have moved in a favorable direction. *Hedgers* maintain a closed position by matching future

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[10] The notional amount is the amount over which the contract is written and which will be exchanged if the option is exercised and if there is no cash settlement.

[11] BIS (May 1999a). The survey covers 66 to 100 percent of all banks in 43 member countries, a total of 2787 institutions. It is estimated to encompass 95% of all worldwide foreign exchange activity.

[12] Forwards and foreign exchange swaps amounted to 66 percent and currency swaps to 10 percent of the total of $22 trillion in notional amounts outstanding.

[13] The gross market value of a portfolio of derivatives contracts is the sum of the (absolute) market values of the component contracts.

[14] The difference between notional value and gross market value is that the former refers to the amount which underlies the derivatives contract whereas the latter is the sum of positive and negative replacement costs.

[15] The relative importance of OTC currency options has increased since the last BIS survey in April 1995, when options represented only 8 percent of daily foreign exchange spot transactions.

liabilities with future assets. *Market makers*, large banks and dealers, hedge risk emanating from their line of business which is to "make the market". As the behavior of market makers is central to the paper, they are considered in detail below. A market participant, e.g. a mutual fund or oil company, can be acting as a hedger to mitigate risk emanating from the nature of their operations or as a speculator by actively taking positions.

Market makers

A market maker is in the business of providing liquidity to the market. Market-makers, mostly banks and dealers, offer a service to end-users and other financial institutions by quoting, upon demand, a bid-ask spread at which they are willing to buy or sell options, not knowing which position the client would like to take. After the client discloses whether he would like to buy or sell, the market-maker has to take the opposite position based on the quoted bid-ask spread. That means the market-maker is often exposed to open positions which need to be hedged in order to have no net exposure to price risk in the underlying currency.

As end-users tend to approach market makers to buy rather than sell options, a priori one would expect market makers to be short options by a large amount on a net basis.[16] However, the surveyed dealers had a net short position in options with a notional value of only $77 billion, representing only 1.5 percent of the total market size of $5,040 billion.[17] Hence, market makers were short options on a net basis by a surprisingly small amount.[18]

The important points of this section are that far more currency options are traded over-the-counter than on organized exchanges. The currency option market does represent a sizeable portion of total foreign exchange transactions. Dealers are generally net short options, but by much less than one might expect. The next section will show how the position held by a market maker in the options market (i.e. short or long options) affects portfolio behavior and ultimately the spot market.

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[16] A market participant is said to be 'short' an instrument if she sold it and 'long' an instrument if she bought it.

[17] The net short position in currency options stayed constant in absolute terms but decreased by 1.7 percentage points between 1995 and 1998.

[18] Furthermore, as is evident from the BIS survey, while market makers were net short options by a small amount, the flow of options actually reduced that short position even more. During the 1995 survey month dealers bought more options than they sold: on a net basis, average daily turnover of options bought exceeded that of options sold by $1.68 billion in the OTC market. In the 1998 survey, daily option purchases exceeded option sales on average by $14 million.

IV. Dynamic Hedging

Dynamic hedging, which is mostly conducted by market makers, creates a link between the spot and option markets that is crucial to the design of an appropriate intervention strategy.[19] The link between derivatives and spot markets through dynamic hedging has been studied in a number of papers (Grossman (1988), Garber and Spencer (1995), Basak (1995), Grossman and Zhou (1996)). Most of these studies establish a positive relationship between the degree of dynamic hedging and volatility in the spot market. They implicitly assume that the market maker is short options. Considering the evidence provided in the previous section, this assumption need not always be accurate. Given the small difference between overall long and short option positions, it is possible for market makers to be net long options in a particular subsegment of the options market. However, if a market maker dynamically hedges a long option exposure, volatility in the spot market may be reduced (see below). This paper explores whether a central bank can exploit this volatility-reducing relationship.

As explained in section III, market makers have to write options based on a client's demand after they have quoted a bid-ask spread. This means they will be exposed to risk emanating from movements of the exchange rate on which they wrote the option. Prudential regulations and internal risk controls within financial institutions normally limit the amount of foreign exchange risk a market-making desk can assume. Any position-taking is usually restricted to the proprietary trading desk which trades on the bank's account. The market-making desk has to hedge its risk exposure. Occasionally, options written by the market maker will offset each other so that no further action is required. In the over-the-counter market this is rare as most options are tailored to a customer's specific needs. While there are certain norms that participants adhere to, the number of variables involved in writing an option usually makes it impossible to close out an option with an equal but opposite option transaction without writing a new option.[20] If a market participant who is seeking the opposite position to the bank's current exposure cannot be found in the options market, the market maker has to *dynamically hedge* the option in the spot market. This means the market maker creates a synthetic option opposite to his current option exposure by establishing positions in the spot market. To mimic the behavior of an option these positions have to be continuously adjusted in accordance with movements in the price of the underlying instrument.

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[19] For a technical analysis of dynamic hedging see the appendix I.

[20] Variables which may vary across customers include currency pair, strike price, notional value and time to maturity.

A. Hedging Short Option Exposures

Dynamic hedging is an attempt to hedge an option exposure in the spot market by incrementally selling or buying the underlying asset in response to changes in its price. Suppose that a bank *sold* a call option. If the price of the underlying asset increases, it is more likely that the option will end up in-the-money. In that case, the bank would have to deliver the underlying asset at the expiration of the option contract to the bearer of the option for less than it actually costs in the spot market. The bank could decide to buy the asset at expiration in the spot market and deliver it to the option holder at a loss. Alternatively, the bank could have bought the asset when it entered into the option contract. However, if instead of going up, the price of the underlying decreases, the option will be out-of-the money and the bank may end up with an asset which is worth less than it was at the time of purchase.

In order to avoid either of these losses, the bank replicates a long call option with the same characteristics (parameters) as the call option it had sold. Instead of buying the entire notional value of the asset, it just holds a portion of it and changes that portion over time. The exact value of the asset to be held is given by the "delta" of the option price as determined in the Black-Scholes option pricing formula (see appendix I for details). In mathematical terms, the delta is the derivative of the option price with respect to the spot rate. It indicates the sensitivity of the option price with respect to small movements in the price of the underlying asset. It can also be interpreted as the probability that the option will end up in-the-money (and thus will be exercised). Therefore, the delta serves as the "hedge ratio", the amount of the underlying asset that needs to be held to insure against movements of the spot rate.

The delta changes with the spot rate in a non-linear fashion (see Figure 1). A market maker who wishes to be "delta neutral" — i.e., to have no net exposure to the underlying instrument — therefore needs to constantly adjust her hedge position by holding delta times the notional value of the underlying asset. For a call option, delta varies from 0 to 1, which means that the delta hedger of a *short call* option exposure holds from 0 to 100 percent of the notional amount of the underlying asset. The delta of a put option varies from -1 to 0, which means that the delta hedger of a *short put* option exposure will go short the underlying asset from 100 to 0 percent of the notional amount, depending on the spot market rate. The relationship between the spot price and delta is non-linear; its curvature is indicated by "gamma".

Gamma is the rate of change of delta, as the spot rate changes. It therefore indicates the amount by which the position in the underlying instrument has to be adjusted in order to remain delta neutral. Figure 1 plots the relationships between the value at expiration of a long call and a long put option and their corresponding deltas and gammas. The graph shows that the gamma for both the long call and the long put option is positive, representing the positive slope of the delta curve. Hence, long option positions are also referred to as being 'long gamma'. Similarly, short option positions are 'short gamma'.

Market makers hedging their short (call *or* put) option exposures by mimicking long options in the spot market buy the underlying asset in a rising market and sell it in a falling market. The market maker replicating a *long call* option holds a positive amount of the underlying asset determined by the (positive) delta times the notional value of the option contract to be simulated. If the price of the underlying asset goes up, the probability of the option ending in-the-money (and its delta) increases and the market maker needs to buy gamma times the notional value of the option contract to achieve the new required position in the underlying asset. If the price of the underlying goes down, the probability of the option ending in-the-money (and the delta) decreases, and the market maker needs to sell gamma times the notional value of the underlying asset. A market maker replicating a *long put* option holds a short position in the underlying asset as indicated by the negative delta, and—similar to the synthetic long call option—buys the underlying asset in a rising market and sells it in a falling market. If a sufficient number of market participants follow these dynamic hedging rules, exogenous price movements may be exacerbated by raising demand when the price increases and raising supply when the price falls. Dynamic hedging activity may thus contribute to increased market volatility in the spot market.

The exact impact of dynamic hedging on the price of the underlying asset cannot be estimated. It depends on the general liquidity of the spot market and on the particular activity in the market at that point in time. For example, a dynamic hedging transaction in the lira / peseta market may have a much larger impact than a similar transaction would have in the dollar / yen market. But even the latter market can move as a result of sufficiently large dynamic hedging operations.[21]

The most important concern associated with delta hedging large *short* option positions is its potentially destabilizing effect by amplifying price movements in the underlying. Given that most market makers in the options markets delta hedge their exposure, the impact on the underlying spot rate can be enormous. In fact, Garber and Spencer (1995) estimate that 20 to 30 percent of the overall selling volume of the pound during the ERM crisis in 1992 was due to dynamic hedging operations.

B. Hedging Long Option Exposure

Contrary to the emphasis in the literature, delta hedging need not be destabilizing. Delta-hedging of long positions in both put and call options is in fact stabilizing. A market making desk would hedge a long option position because the fluctuation of the option value exposes it to currency risk, an activity typically restricted to proprietary trading desks. Market making desks stand ready to buy and sell options at any time at the demand of the

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[21] Malz (1995) and International Monetary Fund (1996a) show how hedging operations for barrier options on the dollar / yen rate may have affected the spot rate in the spring of 1995.

customer, but have to hedge their exposures immediately after taking them on. Market making desks derive their profit from the bid-ask spread, rather than from speculation on open positions. If, for example, a delta hedging market-maker is long a call option, an increase in the price of the underlying instrument would mean that the option is more likely to be in-the-money and therefore more likely to be exercised. Upon exercise the market maker would assume a long position in the underlying asset on the maturity date. On the other hand, if the option expires out-of-the money, the market maker loses the option premium initially laid out. Hence, the market making desk would need to dynamically hedge a long option exposure to avoid the associated currency risk. On average, the profits from dynamically hedging the long option exposure would pay for the cost of the option.

Hedging a long position in a call option by creating a synthetic short call option involves maintaining a short position of delta times the notional value of the contract at all times. The amount by which the holdings of the underlying asset gets adjusted to maintain a level of delta is given by gamma. If, for example, the spot price of the asset increases, delta would move closer to 1, necessitating the delta hedger to increase her short position in the underlying asset. Increasing a short position means selling more of the underlying, therefore alleviating some price pressure. Similarly, if the price of the underlying asset falls, delta moves closer to 0, causing the delta hedger to reduce her short position by buying some of the underlying asset and therefore removing some of the initial price decline. This implies that the delta hedger of a long call option sells the underlying asset in a rising market and buys it in a falling market, hence lowering volatility.

Dynamic hedging of long put option exposure is also stabilizing.[22] Consider the following example, in which a peso put / dollar call option gives the bearer the right to sell 7.4650 pesos for one dollar in three months from now. The option is at-the-money, which means that the spot rate currently is 7.4650 pesos to the dollar. It would be in-the-money if the peso depreciated to a higher rate. The risk free interest rates in Mexico and the United States are 5.499 percent and 5.298 percent respectively. The delta on the put option is -.487. This would mean a market maker who purchases this option currently for a notional amount of 1 million pesos would at the same time buy 487,000 pesos to establish a hedged position, which by itself supports the peso. If the peso depreciates now to MEX$7.48/US$, the delta changes to -0.503. In order to be hedged, the dealer needs to hold 503,000 pesos. Hence, she would buy MEX$16,000 as a result of the falling peso. Similarly, if the peso had appreciated to MEX$7.45/US$, delta would have changed to -0.471. The market maker would have had to sell MEX$16,000 to establish a new long position at MEX$471,000 as a result of a more expensive peso.

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[22] As a put currency option is always a call option on the other currency in the pair, the first example in the preceding paragraph is sufficient. This paragraph merely provides a numerical illustration of stabilizing delta hedging.

In summary, short positions in European call options and long positions in European put options are hedged by establishing and dynamically adjusting long positions in the underlying asset. Long positions in call options and short positions in put options are hedged by establishing and dynamically adjusting short positions in the underlying (see Table 1). Hedging short (put and call) option positions is destabilizing and hedging long (put and call) option positions has stabilizing effects on the underlying asset.[23]

In the next section, it will be shown how the effects of dynamic hedging operations can adversely affect the effectiveness of a central bank strategy in currency option markets. Section VI considers how a central bank can take advantage of stabilizing dynamic hedging operations.

Table 1. Hedge Positions in the Underlying Asset by Position in the Option Market

	SHORT OPTION POSITION (i.e. hedge requires synthetic long options in spot market)	LONG OPTION POSITION (i.e. hedge requires synthetic short options in spot market)
call option	long underlying position negative gamma in option mkt. delta hedging destabilizing	short underlying position positive gamma in option mkt. delta hedging stabilizing
put option	short underlying position negative gamma in option mkt. delta hedging destabilizing	long underlying position positive gamma in option mkt. delta hedging stabilizing

V. Purchasing Put Options as Insurance against a Speculative Attack

Taylor (1995) suggested that a central bank might consider purchasing put options on its own currency in order to defend the domestic currency. The central bank would buy these options during regular times as a form of insurance against a speculative attack.[24] Should a speculative attack occur and the domestic currency depreciate as a result of it, the options will be in-the-money and can be exercised by the central bank. This allows the central bank to purchase foreign currency for domestic currency below the current market exchange rate

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[23] In summary, market makers who are short gamma in the options market exacerbate volatility and market makers who are positive gamma reduce volatility.

[24] A speculative attack may occur in a fixed exchange regime when market participants perceive the pegged exchange rate not to be in line with the fundamentals of the economy. See Flood and Garber (1994)

(expressed in foreign currency per domestic currency terms). The cheaply acquired foreign reserves could then be sold in the spot market to defend the domestic currency. Hence, this scheme cannot be used to prevent a speculative attack, but would be employed to arrest the deep depreciation that typically follows the abandonment of a peg.

There are several drawbacks of the Taylor proposal, which have not been previously addressed: (1) the underestimation of the option price; (2) the effect on the option market and the resulting depreciation of the peso; (3) the destabilizing effect of delta hedging; (4) the possible exacerbation of a domestic banking crisis; and (5) the signaling effect.

A. Cost of the Option

The cost of the options to be bought by the central bank may be higher than anticipated in Taylor's proposal. Consider an example based on this strategy. Suppose Banco de Mexico had bought peso put / dollar call options in 1992. At that time the peso was fixed to the dollar in a band which depreciated over time. The peso traded roughly at MEX$3.00 per dollar.[25] [26] Taylor (1995) considered an option with a strike price of MEX$4/US$ and a notional value of US$1000. Based on this assumption and without further specification of the other option pricing variables, Taylor reckons that the fair option price should not exceed 3 cents. He adjusts this estimate by allowing for fat tails in the distribution of exchange rate returns to a final estimated cost of US$1 per notional value of US$1000. In other words, the Mexican central bank would spend US$1 for the right to purchase US$1000 for MEX$4000 if the spot rate exceeds MEX$4/US$.

If a speculative attack occurs and the exchange rate is driven to MEX$5/US$, as was the case in December 1994, the options will be deep in the money. The central bank has the right to purchase each dollar for only MEX$4.00, while the same transaction in the spot market would cost an additional MEX$1 per dollar. Upon exercise of the option, the central bank can sell at the new exchange rate US$800 of the US$1000 obtained through exercising the option. It would do so in order to sterilize the effect on the monetary base of selling pesos when the option is exercised. The remaining US$200 of the US$1000 are supplemental foreign reserves which can be used to defend the exchange rate. In this scenario there is a potential gain of US$200 for US$1 expended on purchasing the option.

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[25] Refer to Figure 2 for a plot of the peso / dollar exchange rate from July 1994 to July 1996.

[26] Since the scheme would have been designed as an insurance, the option would have to be an American option which could be exercised at any time during the life time of the option. Using a European option would imply the risk that the option position could not be liquidated at the desired time.

This option price implies only a small volatility risk premium, which may not adequately reflect market conditions. To verify this estimate of the option price one needs to make some assumptions which were not spelled out in the example. Assuming a domestic interest rate of 15.62 percent and an interest rate of 3.62 percent in the United States, [27] a one-year option with a strike price of MEX$4.00 per USD and the proposed cost of three cents for every $1000 in notional value would have an implied volatility of 6.10 percent.[28] The same option with a price of US$1, the revised estimate, implies a volatility of 9.30 percent and a delta of 0.039. The implied volatility assumption reflects actual volatility before 1994, but does not reflect devaluation expectations.

It is questionable whether selling options to the central bank with these low implied volatilities would be an attractive business for commercial banks. First, the market for far out-of-the money options is typically illiquid so that commercial banks would have to charge a liquidity premium. Second, an implied volatility of 9.30 percent may be far too low. It is more likely that a commercial bank would demand a significantly higher implied volatility as it would have to price the probability of a speculative attack on the peso into the option. Volatility can, in fact, change dramatically during a speculative attack. Consider the historical volatility in 1994. The 100-day annualized volatility of the peso/dollar exchange rate jumped from 3.54 percent on December 19, 1994 to 22.51 percent the next day and peaked at 75.96 percent in May 1995 (see Figure 3). Similarly, the annualized volatility over 10 days increased from less than 10 percent to 160 percent. If commercial banks were to take into account the possibility of volatility jumps and would price the option with a slightly higher implied volatility, the cost of the option would increase significantly.[29] For example, increasing implied volatility from 9.30 to 20 percent raises the option price more than twenty-fold from US$1.00 to US$21.28 (see Figure 4), possibly making the options unaffordable to the central bank.

For the proposed scheme to have any effect it needs to be of significant size. Foreign reserves of Mexico in 1992 stood at US$18 billion. Taylor (1995) reckons that the objective of Banco de Mexico in 1992 would have been to raise at least an additional US$20 billion in reserves through such an option buying scheme. As one option generated US$200 of additional foreign reserves, he estimates that 100 million options with a total notional value of US$100 billion would have been needed to raise the necessary reserves.

With an implied volatility of 20 percent, the cost of the scheme would have surged to US$2.12 billion, or 10.6 percent of the amount to be raised. At 30 percent implied volatility,

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[27] See International Monetary Fund (1996b) for interest rate assumptions.

[28] The calculations were conducted using the Bloomberg option valuation calculator which is based on binomial tree valuation procedures for American options.

[29] Stochastic volatility models could be used for this pricing problem.

the cost of the scheme would have been US$5.31 billion. At these huge costs to resrves the option program becomes unattractive to the central bank.

B. Depreciation of the Domestic Currency

Through its impact on the option market, the proposed scheme would contribute to an instantaneous depreciation of the domestic currency. Consider the scheme in relation to market size. The notional value of the options (US$100 billion) would represent 4.2 percent of the notional value of all over-the-counter currency options *on a global basis*. While no data are available on the market size of the peso/dollar OTC currency options market per se, participating dealers estimate the daily turnover in the interbank market at approximately US$20 million in 1996, compared to US$13.2 billion in the US$/yen currency options market. Even if it were possible to purchase options on the required scale, such a transaction could have a significant impact on the options market.

Establishing a hedging position for the peso put options a market maker would sell to the central bank requires selling pesos in the amount 'delta' times the notional value of the option contracts. This may lead to immediate downward pressure on the domestic currency when the central bank purchases put options. In the example above, given a delta of 0.039 (see above), establishing a delta hedged position on options with a notional value of US$ 100 billion would require market makers to sell US$3.9 billion worth of pesos when writing the put options, putting pressure on the spot rate. Hence, from the onset the scheme would have effects adverse to the goals of stabilizing the exchange rate and dampening volatility. A significant increase in option premia resulting from large option purchases would worsen the domestic currency depreciation. Consider the following arbitrage argument. Suppose a peso put / dollar call option trades at values above its theoretical value. An arbitrageur can make a riskless profit by buying in the underpriced spot market and selling in the overpriced options market. In this example, this means selling the option and using the proceeds to buy in the dollar spot market. The arbitrageur needs to buy dollars for pesos in the spot market to establish a risk-free position by delta hedging his option position. In this process, the option price is driven down while the spot dollar exchange rate is driven up until both are synchronized again, therefore contributing to further downward pressure on the peso.

C. Destabilizing Effect of Delta Hedging

While establishing a hedge to short put option positions triggers an initial depreciation of the domestic currency, the continuous adjustment of the hedging positions increases volatility by amplifying exogenous spot price movements. As was discussed in section II, market makers will engage in dynamic hedging in order not to be exposed to price risk emanating from changes in the underlying asset. If they are net short options, they delta hedge in a destabilizing manner. Market makers would buy pesos if the peso appreciated and sell pesos if the peso depreciated, amplifying market movements. This effect would be especially

significant given the large notional value of the options. It would defeat the goal of exchange rate volatility reduction.

D. Possible Exacerbation of a Banking Crisis

If the counterparties to the option purchases are domestic banks, exercising the options may exacerbate a domestic banking crisis. During a currency crisis domestic banks can easily be thrown into a liquidity crisis.[30] The traditional defense against a speculative attack is to raise the short-term interest rate in order to squeeze speculators who attempt to take short positions in the domestic currency, hoping to repay their loans after the fall of the currency. In most countries, banks are exposed to significant interest rate risk stemming from a mismatch in maturity of their assets and liabilities. Furthermore, non-performing loans usually increase, resulting from the contractionary effect of the interest rate hike. If, in addition, banks are the counterparties to the central bank's option contracts, they would also be experiencing significant losses from the option exercise.[31,32] Such additional stress on the banking system increases the chances of bank failures. If the central banks needs to bail out failing banks, the additional reserves accumulated through exercising in-the-money options may have to be channeled back into the (illiquid) banking system. Choosing foreign banks as counterparties may prove difficult, as it is hard to segment the market accordingly.

E. The Signaling Effect

As was discussed in the introduction, among the two channels through which sterilized interventions may work, the signaling channel has been found more effective than the portfolio-balance channel. The signal sent out by the put option purchases on the part of the central bank might be counterproductive. While the monetary authority may not be in the business of making a profit from its market operations, other market participants would clearly see the gains to be made on the option strategy by the central bank if the currency depreciates. Central bank purchases of put options on the domestic currency may have an adverse impact through the signalling channel. As it is profitable for the government to devalue the currency and cash in on the options a moral hazard issue is also introduced. While it would lose credibility if it continued the scheme, it is conceivable that a myopic central bank may use it as a one-time boost of foreign reserves.

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[30] See International Monetary Fund (1995).

[31] If the banks hedge the options dynamically losses should be limited. However, in that case the hedging activities increase volatility in the spot market. Furthermore, in a crisis dynamic hedging is virtually impossible. So, there would likely be some exposure by banks if there is a discontinuous movement in the exchange rate.

[32] In fact, the losses would equal the central bank's profit.

In summary, it can be said that while it is important to consider various strategies a monetary authority could conceivably pursue by using options, buying options may not be so advantageous. Potential drawbacks include cost considerations, the impact on the foreign exchange spot market, an increase in exchange rate volatility, potential exacerbation of a domestic banking crisis, and the signaling effect together with a moral hazard problem.

VI. Selling Options

In section V it was argued that buying options on the part of the central bank may not only have negative side effects but may also fail to achieve a central bank's ultimate goal, reducing volatility in the foreign exchange rate market. This section analyzes a possible alternative option strategy —selling options. Selling options to market makers may prompt them to immediately engage in volatility reducing dynamic hedging, while exposing the central bank to an unlimited loss potential.

To take full advantage of stabilizing delta hedging the central bank would have to sell options that have a large gamma so that small changes in the spot rate are followed by large delta hedging transactions. Delta changes the most when the underlying spot rate is close to the strike price (see Figure 1). Hence, the options would have to be close to at-the-money. Furthermore, the gamma of an option at-the-money rises sharply as expiration approaches. Hence, short-term at-the-money options would be the most effective. The market for these options also happens to be the most liquid. Given the short maturity, easier to price European options could be used. The type of options to be sold would depend on the specific situation of the country. To avoid the threat of a speculative attack and to limit position taking against the domestic currency (emerging market) countries could avoid selling domestic currency put options. Selling domestic currency call options limits central bank losses to instances of domestic currency appreciation which may also be part of the central bank's objective function. Countries with currency pairs without imminent threat of a speculative attack could engage in a bilateral agreement where both central banks sell both types of options on their bilateral exchange rate. Even in those deeper markets, hedging activities could have an impact on the spot rate (see Malz, 1995) so that the benefits of stabilizing hedging would not be lost.[33]

Options could be used by central banks to boost the credibility of its commitment to a currency band. By combining short put and short call option positions a 'strangle' can be created, resembling a target zone (see Figure 5). The central bank incurs losses if the exchange rate increases beyond the strike price of the short call option or falls below the strike price of the short put option. If the exchange rate stays between these two points the

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[33] While drafting the current paper, the author became aware of a similar proposal put forward by Wiseman (1996) who primarily considers option auctions on government debt. See his paper for suggestions on how to conduct auctions.

central bank will keep the premium it collects up-front for the option sales without further losses. Hence, it creates a target band for the exchange rate. The target band is credible as the monetary authorities have a strong incentive to keep the exchange rate within its boundaries. Stabilizing delta hedging might help to keep the exchange rate inside the band without the continuous intervention which may be required for spot or forward market interventions. By participating in the options market the central bank appears to 'contract' out some of the stabilization work to dynamic hedgers who contribute to a lower volatility and to keeping the exchange rate within the target zone.

Selling options can be implemented to different degrees. The central bank could participate continuously in the market like any other market maker, except that it would not engage in delta hedging. This would assure sufficient flexibility to sell options with the optimal set of attributes (at-the-money, short maturity). Dynamic hedging by market makers could be of the volatility reducing variety if market makers are net long options, i.e. the delta position of options (in notional terms) purchased from the central bank exceed that of options sold to end-users (who are assumed not to be delta hedging). The effect dynamic hedging transactions have on the spot exchange rate depends on the degree of delta hedging in relation to spot market liquidity.

It is questionable whether central banks would in fact succeed in making market makers go net long options. As pointed out in section III, 95 percent of all market makers around the world were net short currency options with a notional value of US$77 billion in June 1998 compared to a market size of US$5,040 billion. Central banks would have to sell option with a notional amount of more than this sum, possibly more for certain currency pairs. Selling options in itself may increase demand for the options by end users, making it even harder to ensure that market makers delta hedge in a stabilizing manner. Nevertheless, if it proves impossible to make market makers go net long options, the central bank could offset the short option position of market makers partially and alleviate some of the pressure arising from destabilizing delta hedging of those positions.

A. Advantages and Disadvantages

Currency defense around the clock

Selling options provides a channel for reducing volatility in exchange rate markets without sending an adverse signal to the market. It insures the public against exchange rate changes. Stabilization has in effect been contracted out to the market. Market makers would automatically engage in stabilizing behavior. Nevertheless, market makers around the globe would hedge 24 hours a day. If the domestic currency starts to depreciate rapidly in a different time zone from the one the central bank is located in, market makers with long option positions involving the domestic currency but located in the foreign time zone would again engage in stabilizing behavior as a result of the large movement in the spot rate. If, for example, an American hedge fund would attempt to attack the euro when the European

business day is already over, the European Central Bank would normally not be able to intervene. At the start of the next business day it would face a new exchange rate which is far from its target level, making spot market interventions to restore the target level more costly. However, under the option selling scheme American market makers with long positions in the euro / dollar options market would automatically buy euros when they see its price in dollars decline. This does not a guarantee a successful defense, but may be an improvement over no defense at all, assuming that the monetary authorities have a target level in mind which warrants intervention.

Absence of moral hazard problem

Selling options is free of a moral hazard problem. If the central bank were to set up a "strangle" by selling both put and call options on the domestic currency, it would in effect establish a band, similar to the intervention bands of the European Monetary System, within which it would like to keep the exchange rate (see Figure 5). Within the band market forces are self-stabilizing. If an exogenous shock moves the exchange rate beyond either of the two strike prices (the call or the put option), the central bank can choose between allowing the rate to float and accepting a loss on the option contract or intervening in the spot market to keep the rate in the target zone. This is similar to a spot market intervention, which leans against the wind at either end of the band. If the spot market intervention is not successful, the exchange rate will begin to float with the central bank having taken a large loss on its intervention. The difference is that with the option scheme the central bank keeps the option premium. The scheme can be refined by establishing several intervention levels by selling put and call options with staggered strike prices. Nevertheless, the central bank will have to more carefully weigh the costs and benefits to a revaluation or devaluation beyond the target zone bands as it would be taking a loss on the option contracts.

Loss considerations by the central bank

By writing options the central bank exposes itself to an unlimited loss potential. It is being compensated for this loss potential by the option premia it collects up-front regardless of future exchange rate changes. This option premium typically exceeds the 'fair'(theoretical) value as implied by the Garman-Kohlhagen option pricing model. The option writer is paid a premium for taking on the risk that the volatility implied by the option price may change and exacerbate the writer's unlimited loss potential. Empirically, this risk premium, the "volatility risk premium", is reflected in the fact that the implied volatility used for calculating the option price is almost always larger than the volatility which is subsequently realized over the life time of the option.

To support this claim, daily data was obtained on four exchange rates: Spanish peseta vs. US dollar and Deutsche mark, as well as Italian lira against the same currencies. The data comprised spot rates provided by the Federal Reserve of New York as well as implied volatilities for one month and three month currency options as quoted in the interbank market

provided by an American and a British investment bank. Realized volatility was calculated from the spot rate data for each day over the next thirty and ninety days. The results are plotted in Figures 6 to 9. They show that implied volatility usually exceeds realized volatility by a large amount. The premium of implied over actually realized volatility appears to be mostly around the five percent level, but can increase up to twenty percent (see panel B of Figures 6 to 9).[34]

The volatility risk premium together with the 'fair' option premium as implied by the Garman-Kohlhagen pricing model compensate the option writer for potential losses. Hence, it is necessary to accumulate the proceeds from these premia to cover future losses. Selling options may drive the price down, but the central bank would still be able to take advantage of the premia. Statistically, losses on the options will exceed the gains from the premia if the price received is less than the 'fair value' implied by the Garman-Kohlhagen model. Therefore, the central bank would need to exit the market if it cannot obtain a price equal to or larger than the 'fair value'. If it is able to collect the volatility risk premium, on average it will be able to pay losses on the options. It would need to ensure that the premia are paid into a fund solely reserved for that purpose. A liquidity problem remains, the severity of which depends on credit lines available to the central bank. In practice, a central bank may not always have access to unlimited credit lines.

Nevertheless, the losses a central bank may face on the option contracts could be less than losses stemming from intervention in the spot market. An example will illustrate this point. Assume that a central bank decided to spend US$ 100 million in the spot market to prevent its currency from depreciating beyond MEX$4 to the dollar. After the transaction is completed the central bank will own MEX$ 400 million. If the intervention was successful, this amount is still worth the original dollar amount. If the intervention is not successful and the currency depreciates to say, MEX$5 to the dollar, the peso holding is worth only US$ 80 million, a loss of US$ 20 million. Alternatively, the monetary authority could have sold peso put options with a notional value of US$ 100 million and a strike price of MEX$4. If the intervention is successful the options will expire out-of-the money. However, the central bank will have gained the option premium. If the intervention is not successful and the peso depreciates to MEX$5 to the dollar, the central bank loses MEX$1 for each dollar of notional value, resulting in a total loss of MEX$ 100 million or US$ 20 million, which is the same as the spot market intervention. Nevertheless, the central bank will again have kept the option premium which it was paid up front regardless of whether or not the intervention was successful. Hence, selling insurance to the public against exchange rate realignments may reduce the costs of an exchange rate defense. However, spot market interventions allow the central bank to abandon its target level at any time, whereas the use of options commits it

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[34] We also note that implied volatility lags behind realized volatility and therefore is bound to perform poorly if used as the markets' forecast of future volatility. A possible explanation for that could be that it takes time for market participants to realize the switch to a new regime.

until expiration. Using short term options with a large gamma would also limit losses to the degree of currency appreciation or depreciation over the few days remaining to maturity.

Credit risk

Selling options eliminates the problem of exposing the central bank to credit risk as is the case when it buys options. The potential for a banking crisis when the central bank exercises purchased options, as discussed in section V, essentially stems from credit risk. To the extent that the central bank is concerned about its credibility, it is unlikely that the scheme exposes private banks to credit risk.

Pre-committed foreign reserves

Whether or not the option scheme is successful is an issue of relative sizes, just as in the spot market intervention case. A problem is that by implementing the scheme the monetary authorities pre-commit their foreign reserves at established levels. If this information becomes available to traders they may have an incentive to test those levels. The option transaction exposes the central bank to an unlimited loss potential to the extent that the underlying exchange rate could go to infinity within the time to maturity. The short time to maturity and the initial at-the-money requirement to ensure large stabilizing delta hedging transactions (see above) limit potential losses to the amount of domestic currency depreciation (appreciation) within that time period (a few days, say). The ex-post net impact on reserves is measured by the amount by which the option is in-the-money times the notional value minus the option premium collected in the foreign currency. If the option expires out-of-the money there is a positive impact equal to the option premium collected initially.

Readjusting a fixed exchange rate

Another drawback to the scheme is that it may make it easier for policy makers to postpone important decisions. For example, the authorities of a country may come to the conclusion that a fixed exchange rate needs to be readjusted to a new "equilibrium level" for exogenous reasons. Having an option scheme in place which may cause the central bank to lose money by doing so, may impede crucial policy decisions. However, by selling options with a short maturity the central bank may circumvent this problem. Once the decision is reached that an exchange rate needs to be realigned, the authorities may simply wait until the options expire and then proceed with their actions.

VII. Summary and Conclusion

This paper explored intervention strategies a monetary authority can pursue in the currency option market. Attention must be paid to the dynamic hedging activities by market makers who assume the opposite side of the central bank in the option market. Central bank

purchases of options would result in short option exposure on the part of market makers. The requirement that market makers cannot be exposed to price risk stemming from the underlying asset prompts them to automatically and instantaneously hedge any open positions. Establishing a hedging position for a short put option on the domestic currency involves shorting the domestic currency at the time of engaging in the option contract. This contributes to downward pressure on the domestic currency. Dynamically adjusting the hedging position of any short option exposure as prescribed by the option pricing formula involves buying and selling the domestic currency in a manner that amplifies exogenous price movements and therefore increases exchange rate volatility.

As an alternative to option purchases by the central bank, option sales were considered. Selling options involves market makers assuming long option exposures. Required by prudential regulation or by internal risk control measures to avoid open positions, market making desks need to dynamically hedge long option exposures. The dynamic hedging of long option exposures involves buying and selling the domestic currency in a manner that may reduce the impact of exogenous price movements and therefore could reduce exchange rate volatility. This automatic reduction of exchange rate volatility is achieved without central bank intervention in the spot market, which may actually increase volatility because of noise traders. However, it requires the ability of the central bank to make market makers be long (put or call) options on a net basis. The impact of hedging transactions on spot market volatility depends on the degree of hedging activity in relation to spot market liquidity. Intervention in option markets could be less costly than spot market intervention because gains are enhanced and losses reduced by the amount the central bank collects as option premium. Selling options provides an incentive structure for the central bank with which it can credibly commit itself to keeping the exchange rate within a preset target zone. The central bank needs to abandon its option strategy when the volatility risk premium is zero to avoid systematic losses. The unlimited loss potential could cause a liquidity crisis even prior to reaching this criterion.

Derivatives markets offer central banks an additional tool for the conduct of exchange rate policies. If central banks decide to participate in the currency options market, they should not buy but sell options. However, in pursuing such a strategy, central banks face the risk of unlimited potential losses associated with unhedged short option positions. The paper analyzed a few measures to manage this loss potential.

DYNAMIC HEDGING

The pricing formula for a call, C_t, and put, P_t, option on a foreign currency is given by the Garman-Kohlhagen (1983) currency option pricing model:

$$C_t(x,t) = N(d_1)S_t e^{-r^f T} - N(d_2)Ke^{-r^d T}$$

$$P_t(x,t) = (1-N(d_2))Ke^{-r^d T} - (1-N(d_1))S_t e^{-r^f T}$$

$$where\ d_1 = \frac{ln\left(\frac{S_t}{K}\right) + (r^d - r^f + 0.5v^2)T}{v\sqrt{t}}\ and\ d_2 = \frac{ln\left(\frac{S_t}{K}\right) + (r^d - r^f - 0.5v^2)T}{v\sqrt{t}}$$

$T = t^* - t$ is the time to maturity in years, S_t is the spot exchange rate indicating the number of units of the domestic currency equivalent to one unit of the foreign currency, K the exercise price, r^d the annualized domestic interest rate and r^f the annualized foreign interest rate, v is the instantaneous volatility measured in percent per annum.

For example, if you can't *buy* a *put* option to cover your short put option exposure, you can replicate it by borrowing $(1-N(d_1))$ of 1 unit of the foreign currency for the period of length T. This loan has a present value of $e^{-r^f T}$ in the foreign currency or $S_t e^{-r^f T}$ in the domestic currency. The funds borrowed abroad are converted into the home currency and used to establish a long position in the domestic currency of fraction $(1-N(d_2))$ of a loan promising to pay K units at the end of the period of length T, i.e. you lend. This loan has a present value of $Ke^{-r^d T}$ in the domestic currency. Once this position is established and any of the variables in the formula changes, the position in the two currencies is adjusted accordingly. If for example S goes down, that is the foreign currency depreciates, d_1 and d_2 go down, driving $N(d_1)$ and $N(d_2)$ down. In order to continue replicating the put option, both the short position in the foreign currency and the long position in the domestic currency must be increased. This strategy could be followed by a market maker who sold the put option and cannot find an offsetting option. Notice that if you were trying to hedge a long put option position, the currency positions would be reversed. Since this form of hedging attempts to achieve through time the correct position in the underlying currency as given by the delta of the option it is also known as **dynamic** or **delta hedging**. It insures the value of the portfolio against small movements of the underlying asset (here a foreign currency).

In the above example of hedging option exposure, all the hedging is done in the spot market. However, forwards may also be used for hedging options exposure. For foreign exchange the cost of carry relationship relating the forward and spot markets is given by:

$$F = Se^{(r^d - r^f)T}$$

When the asset price increases by ΔS, the forward price increases by $\Delta S e^{(r^d - r^f)T}$. The delta of the forward contract is $e^{(r^d - r^f)T}$. Thus $e^{(-r^d + r^f)T}$ forward contracts have the same sensitivity to asset price movements as one unit of the asset. So, if H is the required position in the asset at time t for delta hedging, we can determine the alternative required position in forward contracts, G, at time t for delta hedging:

$$G = e^{-(r_d - r_f)T} H$$

Since H is the delta of the option (for the put option: $H = -(1 - N(d_1))e^{-r_f T}$ we can rewrite the option pricing formulae using forward contracts with the same maturity as the options:

$$C_t = N(d_1)Fe^{-r^d T} - N(d_2)Ke^{-r^d T}$$

$$P_t = (1 - N(d_2))Ke^{-r^d T} - (1 - N(d_1))Fe^{-r^d T}$$

$$where\ d_1 = \frac{ln\left(\frac{F}{K}\right) + (0.5v^2)T}{v\sqrt{t}}\ and\quad d_2 = \frac{ln\left(\frac{F}{K}\right) - (0.5v^2)T}{v\sqrt{t}}$$

We can now think of the put option as the same long position in the domestic currency as before and a short position in the forward foreign currency replacing the short position in the spot market.

SELLING OPTIONS TO REBUILD RESERVES: THE MEXICAN EXPERIMENT

The scheme conducted by the Mexican central bank was designed to use the option market to acquire foreign reserves. On July 17, 1996, Banco de México announced that it would sell U.S. dollar put / peso call options which confer the right to the bearer to sell dollars to Banco de México within the month immediately following the auction of the options. The option is not a conventional one. Its strike price is not fixed at inception but is the peso fixing rate ("48 hour peso") of the previous business day and is exercisable only when the previous day's fixing rate has appreciated more than the average exchange rate over the preceding 20 working days. If the above condition is met before the final exercise date, the option is in-the-money and can be exercised. This ensures that Banco de México will be acquiring dollars through the exercise only when the peso is appreciating. Auctions are to be held at the end of every month. The notional amount underlying the options initially was US$130 million. By June 1997 this amount had risen to US$300 million a month, indicating that Banco de México has not only entered the currency options market but also expanded its operations.

The scheme is designed to raise foreign reserves without affecting the spot market. As of July 26, 1996 Mexico's international reserves were US$15.91 billion, most of which was borrowed from the International Monetary Fund. The option scheme allows the authorities to acquire a maximum of US$3.6 billion a year (US$300 million a month). Given that an estimated US$5 billion a day are traded in the peso spot market, the average daily acquisition amount of US$4.3 million is sufficiently small to be conducted on a regular basis in the spot market. The fact that the authorities utilize the option market can be interpreted as a desire to test the market and explore opportunities for selling options with a larger notional amount in the future. The scheme succeeds in acquiring foreign reserves without sending an adverse signal which may trigger a speculative attack against the peso. With this scheme Banco de México only buys dollars when the peso has appreciated.

It should be noted that the central bank can acquire the foreign reserves only at a loss. The options will be exercised only if they are in-the-money. The loss of the central bank is the gain of the counterparties, which are mainly banks resident in Mexico. It might be argued that the scheme is a way to transfer funds from the central banks to the banking sector. However, foreign and domestic banks alike are invited to bid for the options. It is not clear why Banco de México would want to transfer funds to foreign banks. Furthermore, the central bank attempts to limit the loss potential an option writer faces by having a variable strike price. Losses are limited to the appreciation the peso experiences within 24 hours because the gain of the option holder is the difference between today's peso value and yesterday's peso fixing due to the variable strike price.

The first auction was held on August 7, 1996. Market participants report that 90 percent of the banks present in México City, about 20, planned to submit bids for the options. There were 5 winning bidders with a total of 8 winning bids. The winning bids submitted

ranged from MEX$11 to MEX$20.3 in option premia per US$1000 in notional value. The average premium was MEX$11.68 per US$1000.[33] Most foreign banks submitted bids in the range of MEX$5 to MEX$9. All the winning bids were won by major Mexican banks. Banco de México collected MEX$1.51 million or about US$200,000 in premia. Two days later, on August 9, US$105 million of the options were exercised. The spot rate on that day traded around MEX$7.5100/US$, and the peso was fixed on August 8 at MEX$7.5349/US$. This means the central bank experienced a loss of about US$210,000. The remaining options were exercised on subsequent days as the peso continued to appreciate to MEX$7.4850/US$. Banco de México estimates that in total it lost MEX$3 million on the options exercise. Net of the premium the central bank lost MEX$1.5 million, or US$200,000 to acquire US$130 million in foreign reserves. Market participants did not notice any significant impact on the regular currency option market, which may have shown up in implied volatilities or the bid-ask spread.

This scheme probably had little effect on the stability of the peso, since market commentary at the time suggested that market participants had little experience with the pricing of such options.[34] It seems that the scheme is mostly used by Mexican commercial banks to off-load long dollar positions. The central bank uses it to acquire foreign reserves without moving the market. The relevance to other governments lies in designing a scheme with clear goals and meeting these goals. Furthermore, the bidding process could be of interest to other central banks. This episode represents --as far as we know-- the first official participation of a central bank in a currency option market. It should pave the way for more unconventional uses of modern financial products by central banks in the achievement of their goals.

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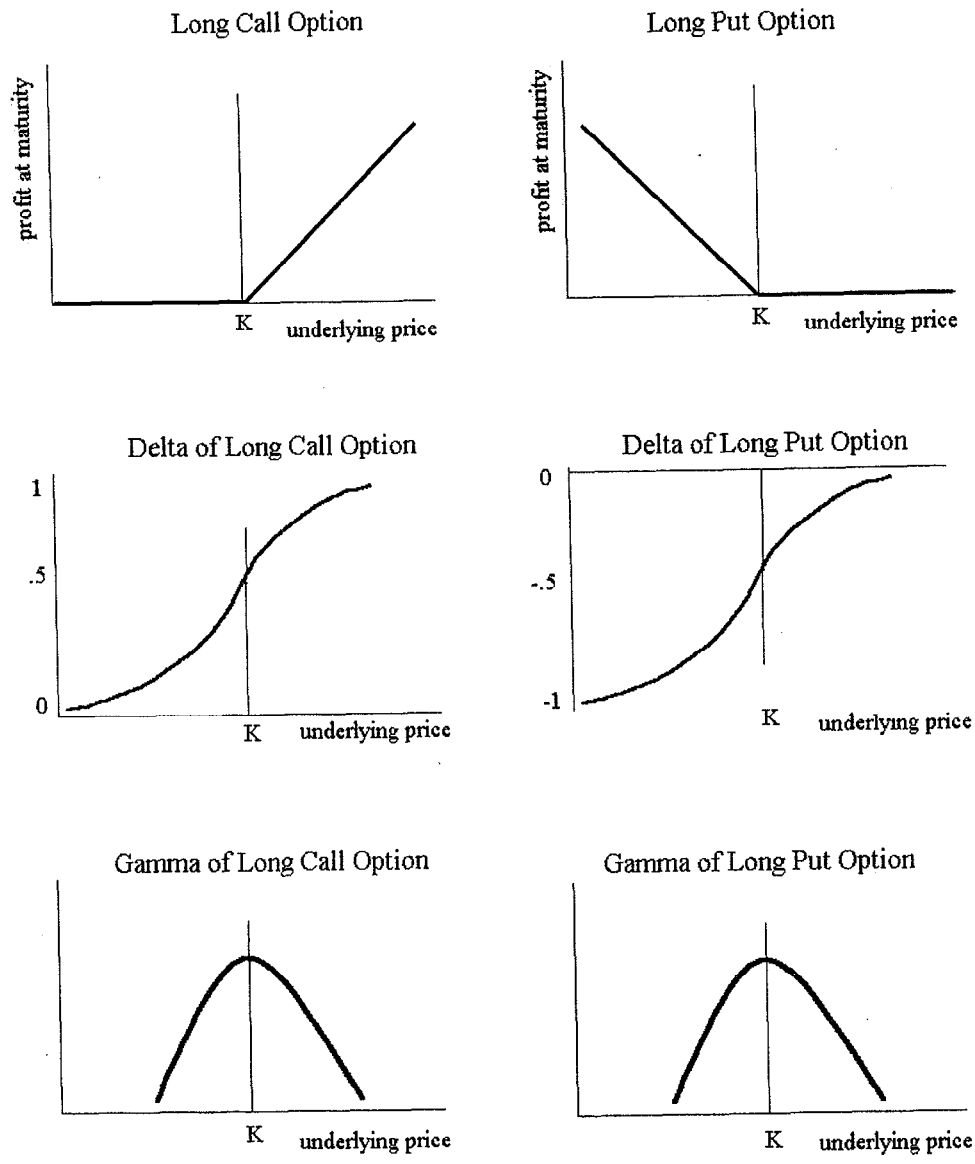
[33] In June 1997, the winning bids submitted ranged from MEX$20 to MEX$25.01, with an average of MEX20.62.

[34] Based on author's conversations with market participants.

Figure 1: Delta and Gamma of Long Option Positions



K = strike price

Figure 2: Exchange Rate Mexican Peso / U.S. Dollar, July 1994 – July 1996

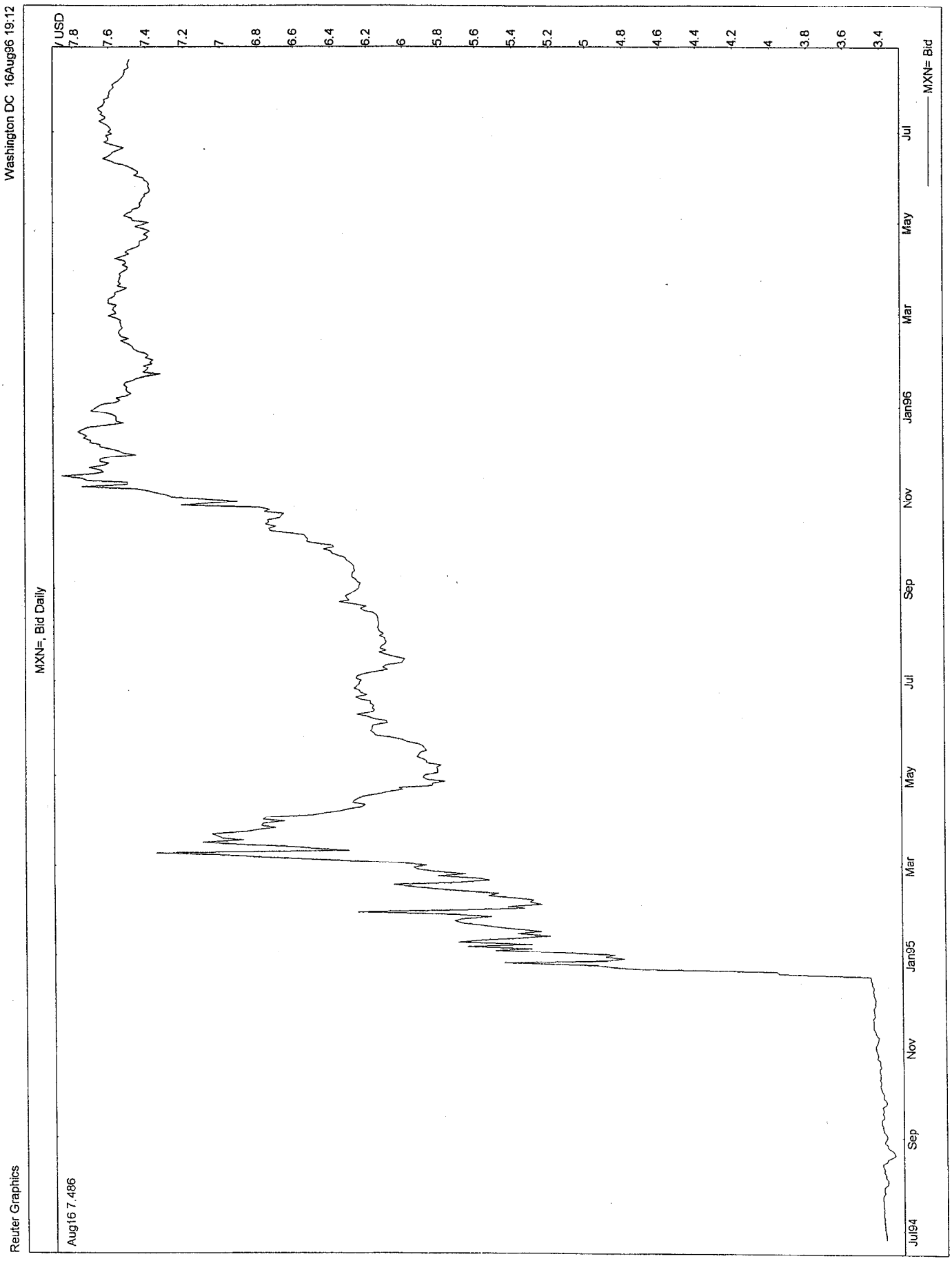
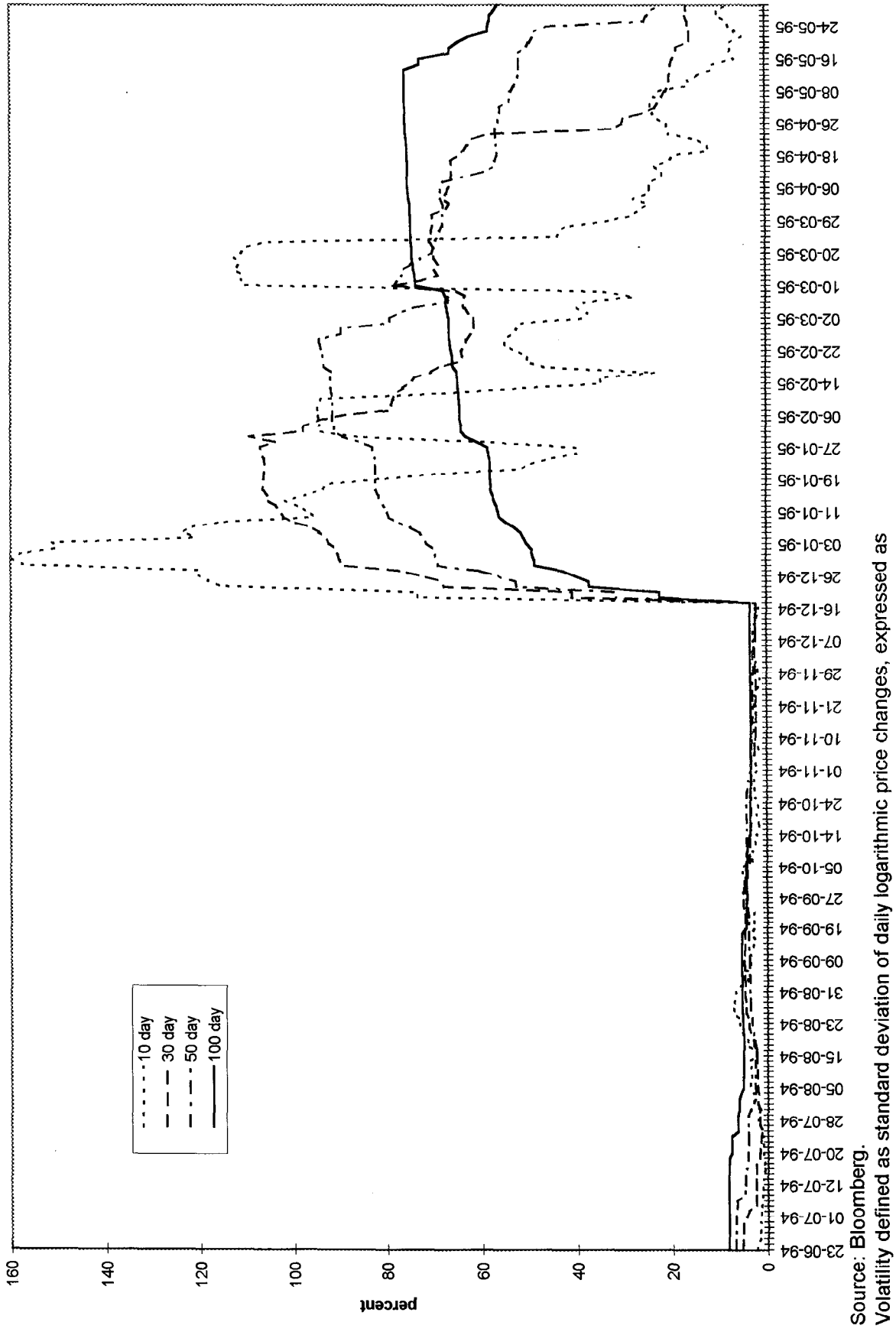
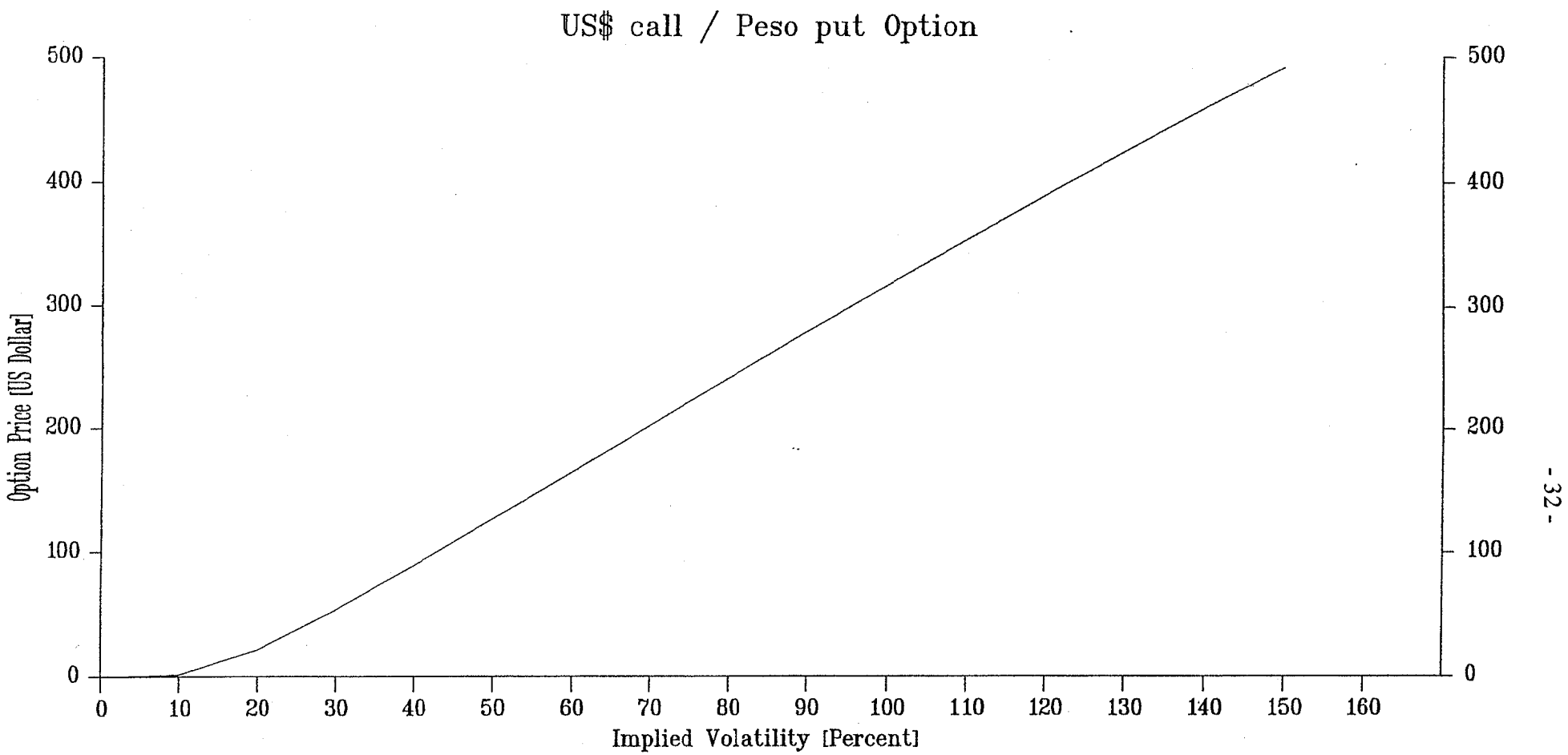


Figure 3: Historical Price Volatility Mexican Peso/ USD



Source: Bloomberg.
Volatility defined as standard deviation of daily logarithmic price changes, expressed as

Figure 4: Option Price as a Function of Implied Volatility

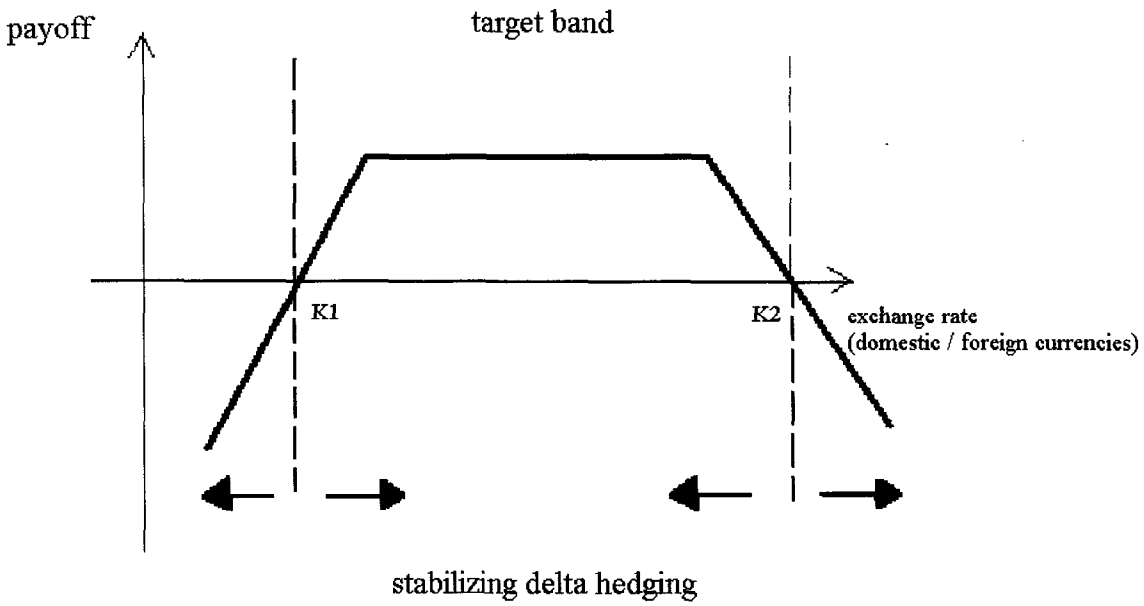


Assumptions:

Notional Value US$1000, Spot Rate 3N$/US$, Strike Price 4N$/US$, Maturity 360 days,

US interest rate 3.62 percent, Mexican interest rate 15.62 percent.

Figure 5: Strangle Sold by Central Bank



K1 = strike price of domestic currency call / foreign currency put option

K2 = strike price of domestic currency put / foreign currency call option

Figure 6a: ESP-DEM Implied vs. Realized 30 day volatility

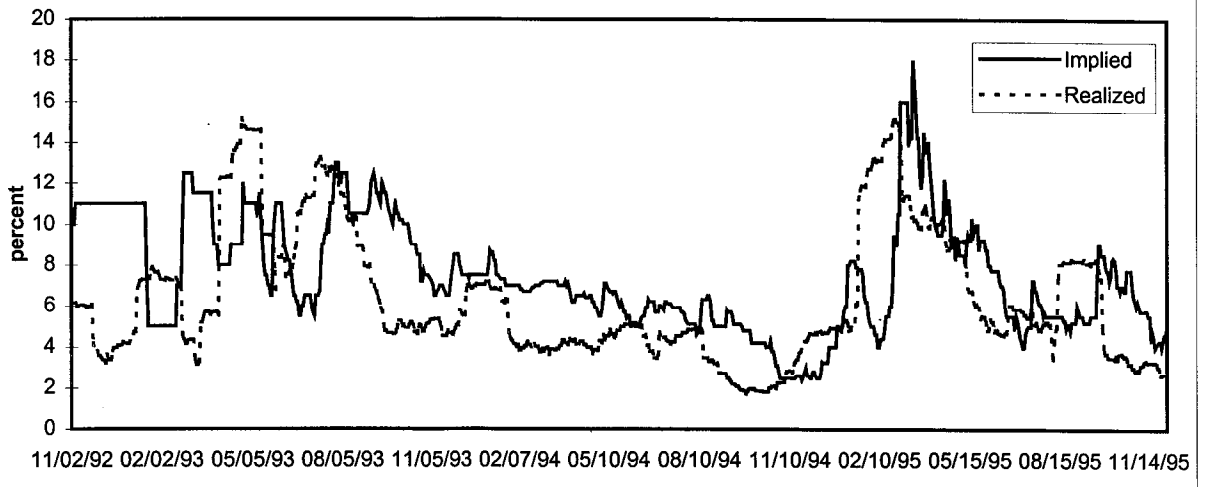


Figure 6b: ESP-DEM Implied-Realized Volatility Difference

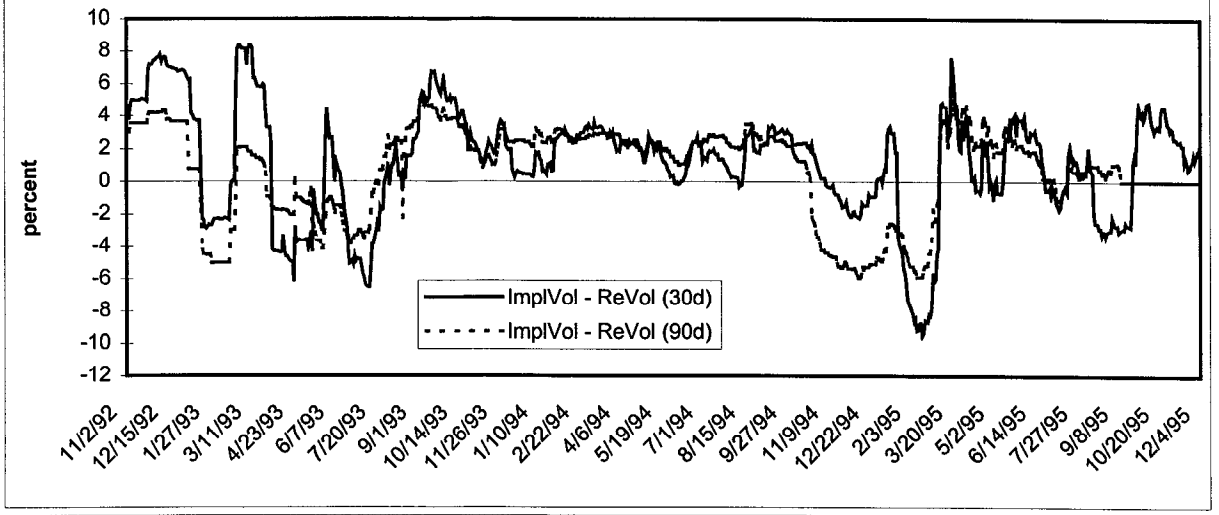


Figure 6c: ESP-DEM Implied vs. Realized 90 day volatility

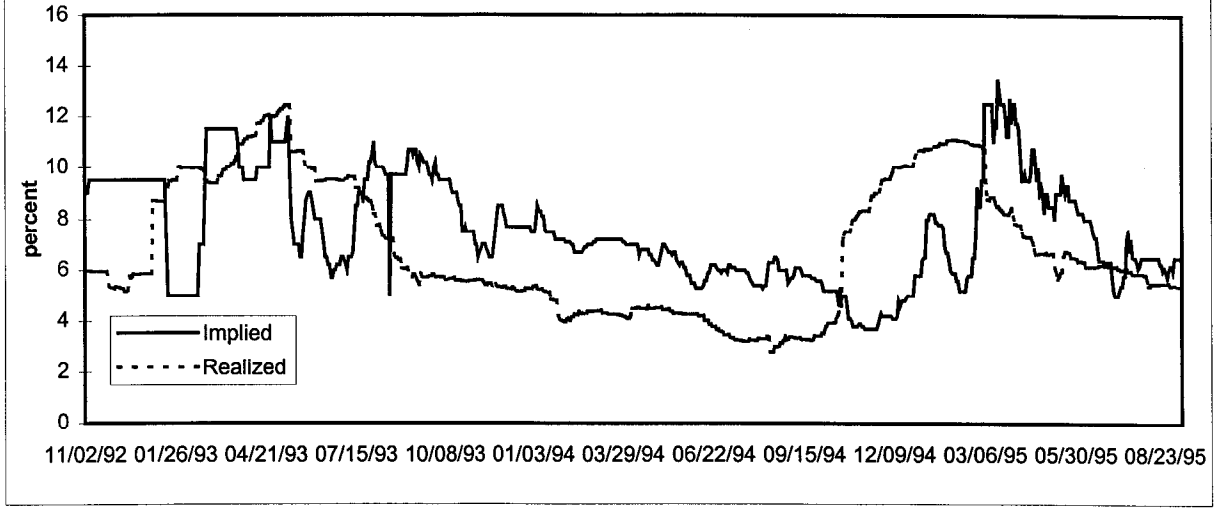


Figure 7a: ITL-DEM Implied vs. Realized 30 day volatility

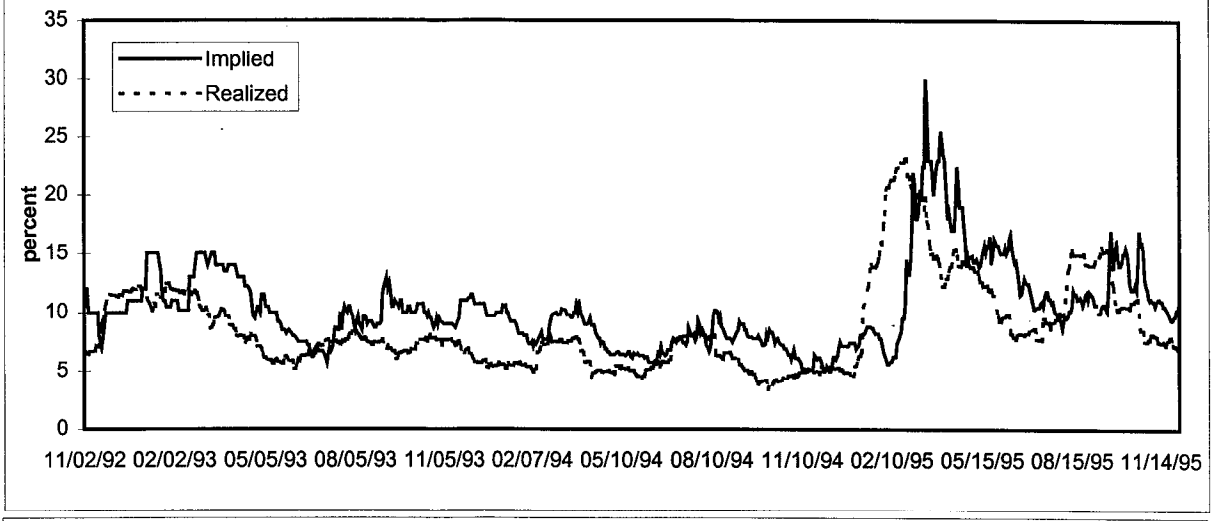


Figure 7b: ITL-DEM Implied-Realized Volatility Difference

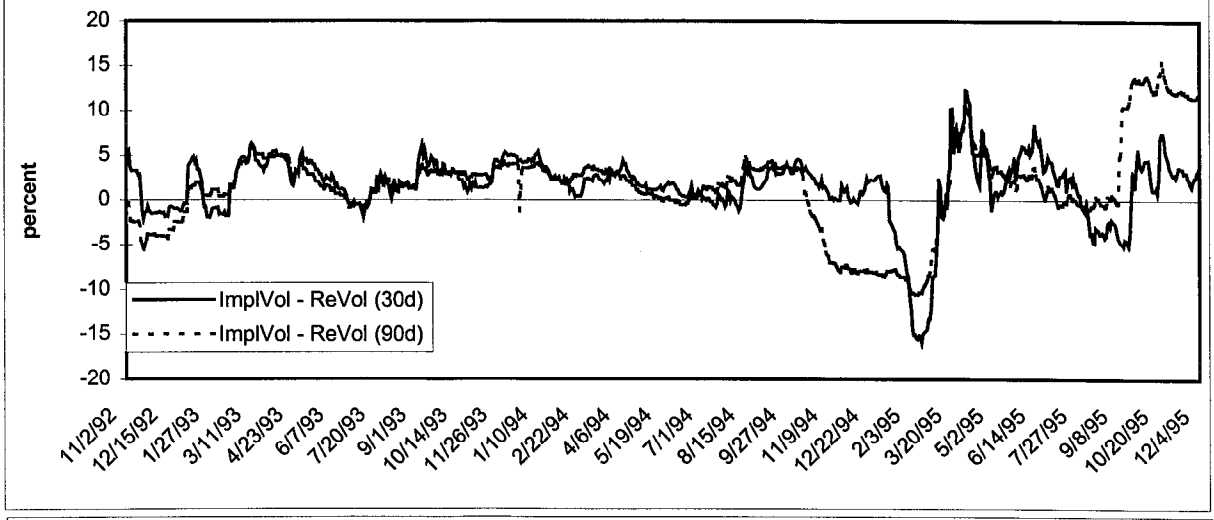


Figure 7c: ITL-DEM Implied vs. Realized 90 day volatility

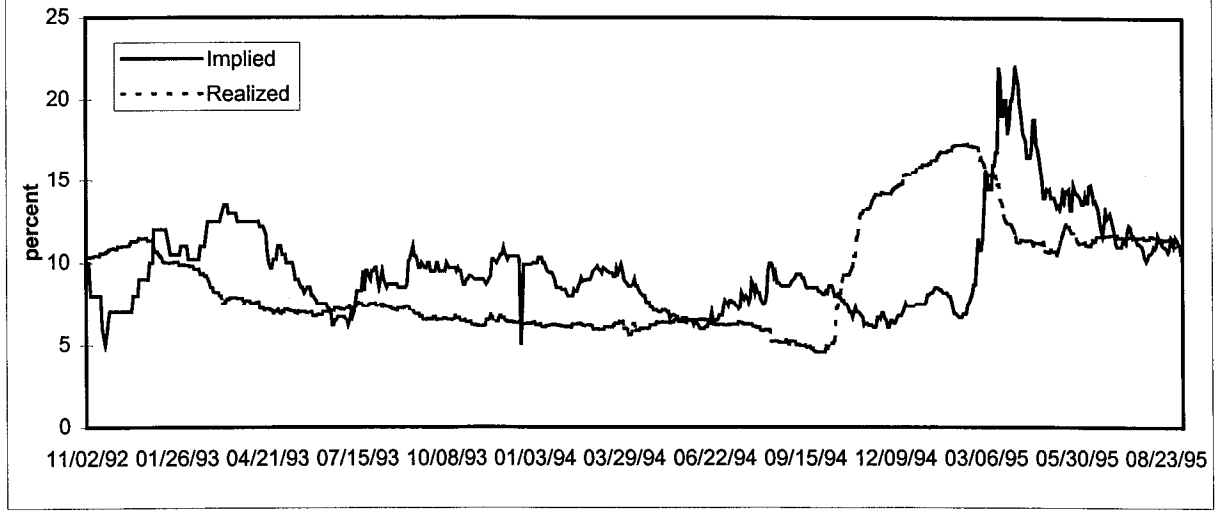


Figure 8a: ESP- USD Implied vs. Realized 30 day volatility

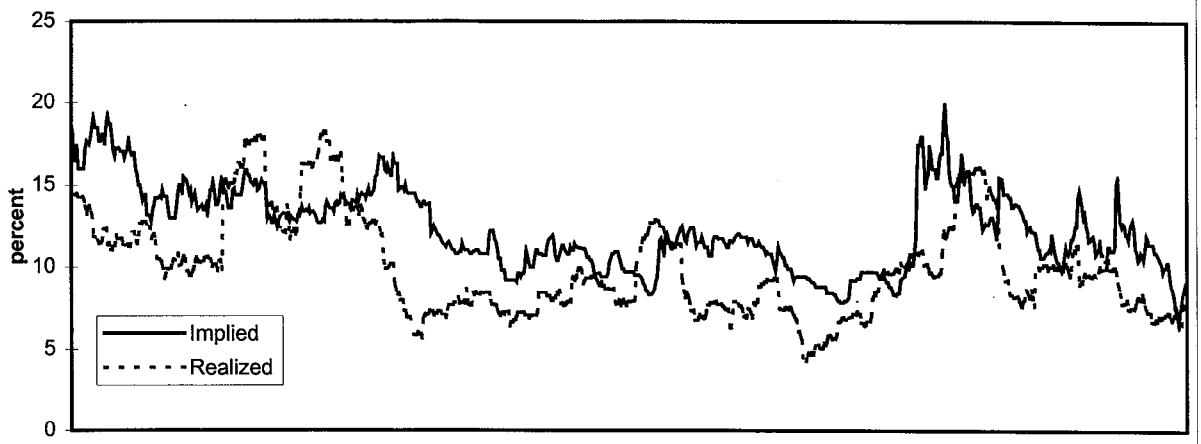


Figure 8b: ESP - USD Implied-Realized Volatility Difference

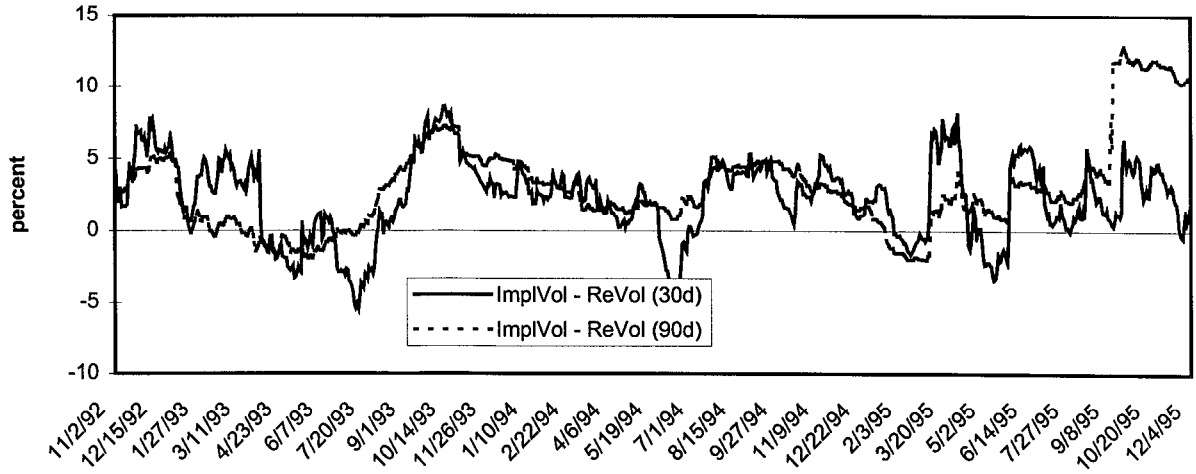


Figure 8c: ESP - USD Implied vs. Realized 90 day volatility

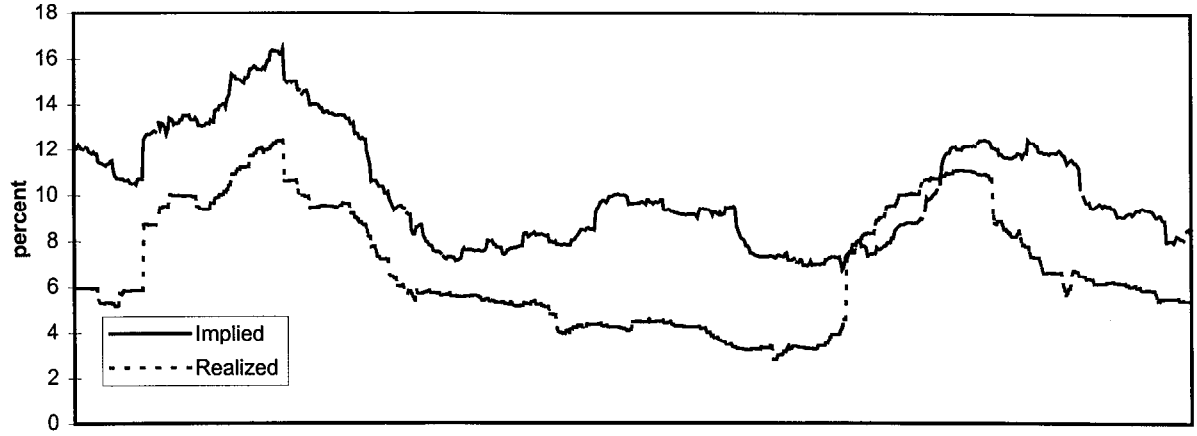


Figure 9a: ITL - USD Implied vs. Realized 30 day volatility

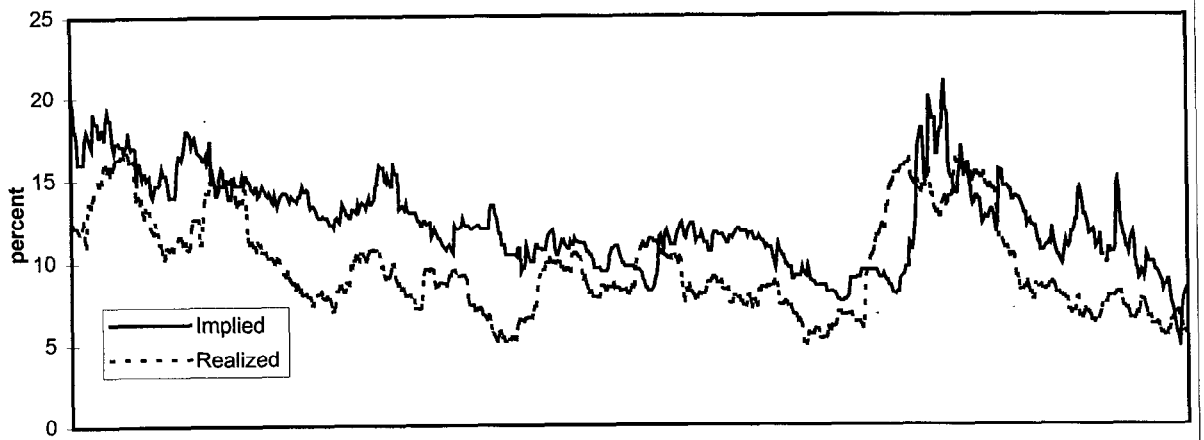


Figure 9b: ITL - USD Implied-Realized Volatility Difference

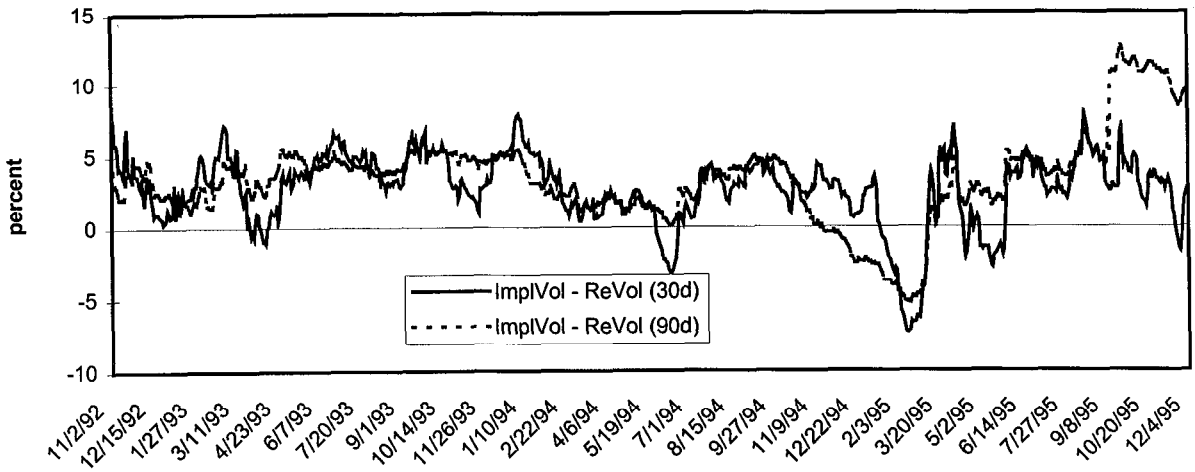
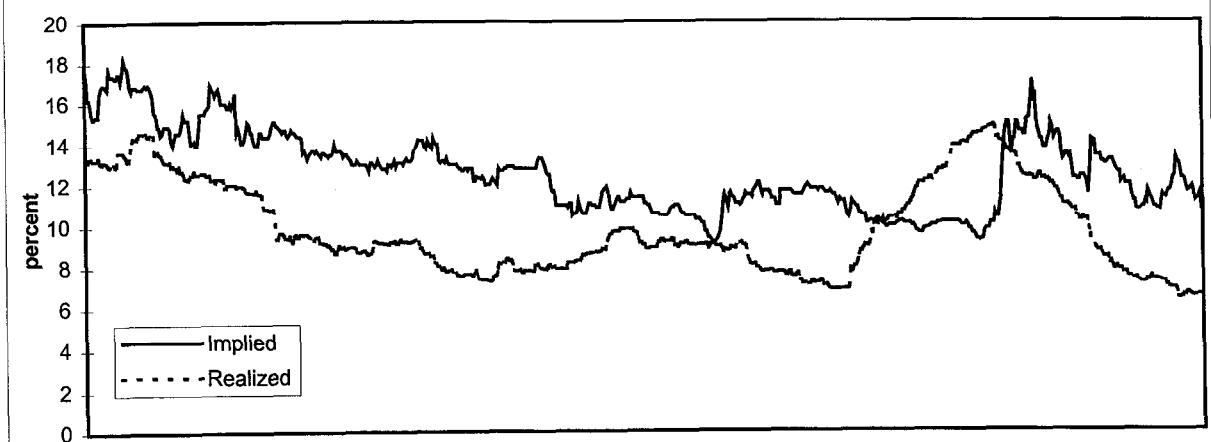


Figure 9c: ITL- USD Implied vs. Realized 90 day volatility



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