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Foreign Exchange Hedging with Synthetic Options and  
the Interest Rate Defense of a Fixed Exchange Rate Regime

Prepared by Peter M. Garber and Michael G. Spencer 1/

Authorized for distribution by David Folkerts-Landau

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Abstract

In the end-game of a fixed exchange rate regime, increases in interest rates to defend the currency may lead to an apparently perverse market response: further downward pressure on the exchange rate. This may result if a large proportion of investors' foreign exchange exposure is dynamically hedged. This paper describes the trading operations involved in implementing dynamic hedges and the impact of these operations on central bank policy. The success of an interest rate defense hinges on the size and timing of the funding operations of those who are being squeezed relative to those engaged in dynamic hedging.

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Summary

The usual prescription for the defense of a fixed exchange rate during a speculative attack is aggressive sales of foreign currency on the spot and forward markets, combined with increases in short-term interest rates of a sufficient magnitude to squeeze speculators who are short in the currency. Two developments in international financial markets in recent years may have reduced the effectiveness of this advice. First, institutional and other large investors have diversified their portfolios internationally. Consequently, the potential exposures to currency risk are growing, and also the potential selling pressure if the ability of the authorities to maintain a fixed exchange rate comes into question. Second, the growth in the markets for foreign exchange derivatives has both improved the ability of investors to hedge their exposures and provided instruments through which speculators can take highly leveraged positions against weak currencies.

This paper discusses the possibility that the operations of banks and nonbanks to hedge their currency exposures may weaken the effectiveness of the classic interest rate defense. The focus is on market and central bank behavior in the last moments of a fixed exchange rate regime. In addition to providing powerful tools for speculation, options-pricing models can be used by banks and investors to construct synthetic currency put options by trading regularly in the cash markets. These synthetic options provide a hedge against exchange rate changes if the positions can be adjusted continually. In the presence of this dynamic hedging, an increase in interest rates to defend against a speculative attack may automatically trigger even more selling of the currency that is under attack. The paper finds that interaction between the timing of different trading strategies--dynamic hedging programs and the reaction of speculators who are caught by the interest rate increase--is crucial to the outcome of the central bank's policy. If the volume of selling motivated by dynamic hedging overwhelms that of the purchases by speculators seeking to close out their positions, the central bank may reach its credit limits with commercial banks or its own position limits, forcing it to abandon the fixed exchange rate. However, raising rates gradually in an interest rate defense may immunize the central bank against being pushed beyond its position limits.



## I. Introduction

Coincident with the internationalization of portfolios and the interlinking of money markets across currencies has been the expanded use of methods to hedge currency risk. While basic hedging instruments such as forward exchange contracts have a long history, the use of newer instruments such as exchange-traded options and futures contracts and over-the-counter (OTC) options and currency swaps has grown dramatically in the past decade. In addition, option pricing methods have been used in dynamic hedging strategies to construct tailor-made synthetic derivative products--a transplanted to currency markets of the portfolio insurance methods used to hedge equity market exposure.

The crash of 1987 led to justifiable skepticism about the ability of mechanistic trading strategies like dynamic hedging actually to deliver the intended hedge protection when markets are illiquid. <sup>1/</sup> In addition, these strategies have been criticized for their tendency to exacerbate price trends. Such criticisms carry over to the use of dynamic hedging in currency markets, although currency markets are usually among the most liquid of financial markets.

In this paper, we examine the impact of dynamic hedging strategies on foreign exchange markets during those crisis periods when even the exchange markets can become illiquid. Though we place some emphasis on the well-known inability of these strategies to perform well for the hedger when a discontinuity in the exchange rate or an upsurge of volatility occurs, we are concerned primarily with the impact of hedging strategies on the efficacy of the classic central bank interest rate defense of a fixed exchange rate. It is generally believed that a central bank can defend an exchange rate if it is willing to raise short-term interest rates sufficiently high to squeeze speculators who are short in its currency. In the presence of dynamic hedging, however, mechanistic selling of the domestic currency may arise in the end game of the interest rate defense, and this may overwhelm the credit lines available to the central bank for intervention in the exchange market before those squeezed by the interest rate increase start to buy. Thus, our ultimate focus is on market and central bank behavior in the crucial last moments of a fixed exchange rate, the boundary point toward which the collapsing system converges.

The essay is organized as follows. In Section II, we outline the growth of the foreign exchange markets in general, and the markets for currency derivatives in particular. In Section III, we consider the hedging operations of nonbanks and the techniques in general use. In Section IV, we

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<sup>1/</sup> See for example the Brady Commission (1988) and Securities and Exchange Commission (1988) reports. Grossman (1988) forecast this problem. Gennotte and Leland (1990) model the relationship between hedging operations and market liquidity and show how a relatively small volume of transactions initiated by hedgers can lead to a large price change.

examine the theory and practice of dynamic hedging, and the hedging operations of banks in particular. In Section V, we examine the mechanics of central bank currency intervention and the effect of interest rate defenses on market liquidity, focussing particularly on the response of dynamic hedging programs to interest rate increases. We also consider how the interaction between the timing of different trading programs--dynamic hedging *versus* closing positions to avoid a squeeze--and the credit lines of the central bank may force the central bank to abandon a fixed exchange rate if it is driven either to the limit of its credit lines with commercial banks or to its self-imposed position limit before buyers of the currency arrive. Section VI contains some concluding remarks.

## II. Markets for Foreign Exchange Products

The foreign exchange market is the largest financial market in the world, with average daily turnover in April 1992 estimated at \$880 billion, compared with \$620 billion in April 1989. <sup>1/</sup> The largest market segment is that for spot delivery--generally two days later--which accounted for just under half of the turnover in 1992, followed by the market for foreign exchange swaps which accounted for 40 percent of turnover. The proportions of turnover due to outright forward deals, options and futures were 7 percent, 5 percent and 1 percent respectively.

The market is largely an inter-dealer market: 84 percent of transactions were made among financial institutions and other foreign exchange brokers and dealers in 1992. This characteristic is reflected in the average deal size, which for the U.S. dollar was approximately \$6 million overall. Deals were relatively smaller in the spot market, in which the proportion of transactions with end-users was higher, while in the derivatives markets deals tended to be higher. For example, the average size of an over-the-counter (OTC) deutschemark-pound sterling option was \$32 million.

The bulk of foreign exchange market activity still involves the U.S. dollar on one side of the transaction. The dollar was involved in 83 percent of all deals in 1992--including 72 percent of spot trades and 95 percent of swaps contracts--although this proportion had fallen since the previous survey conducted by the Bank for International Settlements (BIS) in 1989. Transactions between currencies in the European Exchange Rate Mechanism (ERM) accounted for only 7 percent of aggregate turnover.

The 1992 survey results indicate how rapidly the use of financial derivatives has grown in recent years. While spot turnover increased only 14 percent between 1989 and 1992, forward transactions increased 60 percent, as did turnover in currency futures. Swaps trading increased 50 percent, and options trading increased by 124 percent.

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<sup>1/</sup> Bank for International Settlements (1993).

The notional value of outstanding exchange-traded and OTC financial derivative contracts--including futures, forwards, forward rate agreements, swaps, options, caps, floors and collars--grew from approximately \$7.2 trillion at end-1989 to \$17.6 trillion at end-1992. 1/ The 1992 notional amounts are comprised of \$4.8 trillion in exchange-traded contracts, \$4.7 trillion in swaps and \$8.1 trillion in OTC options and forward contracts. By expanding the opportunities for borrowers and lenders to change the risk characteristics--such as maturity or currency denomination--of their portfolios, the growth in these markets has dramatically altered the nature of international finance and the behavior of market participants.

Exchange-traded derivative products--futures and options--are standardized, retail-sized products. Though they are retail in nature they are frequently used by the dealers in OTC markets to balance positions when credit lines with other financial institutions are filled or when wholesale counterparties are hard to find. Because the exchange's clearinghouse is the counterparty to each contract and because positions are usually well-collateralized through margin requirements, the evaluation of creditworthiness is less of an issue on organized exchanges than in the OTC market. 2/ The most actively traded financial derivatives on organized exchanges are futures on interest rates, primarily U.S. Treasury bond rates, Eurodollars, French Government bonds (OAT), German Bunds, and Japanese Government Bonds.

The OTC markets in derivative products are concentrated in a small number of large banks and securities firms in the major financial centers. For example, bank holding companies with more than \$10 billion in assets hold between 98 percent and 100 percent of all OTC derivative positions

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1/ These estimates are derived in General Accounting Office (1994). The notional value of a contract is the nominal amount used as a base to calculate a transfer of payments according to a contractual formula. For example, an interest rate swap may have a notional value of \$10 million. This notional value is not delivered as principal. Rather, counterparties deliver or receive the net between fixed interest on \$10 million and floating interest on \$10 million, so the claims that counterparties might have on each other are far smaller than the notional value.

2/ OTC derivatives dominate exchange traded products with limited liquidity such as longer dated contracts or options that are not at or near the money.

taken by U.S. banks. 1/ OTC contracts are often designed specifically for the needs of particular end-users and therefore have tailor-made features such as maturity, currency denomination, and notional principal, and are frequently combined with other derivatives and sold as a package. Many OTC trades are inter-dealer trades in which dealers seek to balance their positions.

Foreign exchange derivatives are important components of these markets, particularly the OTC markets. While the notional principal of outstanding exchange-traded foreign exchange derivatives at the end of 1992 was only \$105 billion, there were \$860 billion in currency swaps and \$5.5 trillion in foreign exchange forwards and OTC options outstanding. In contrast, the notional principal of outstanding interest rate products were: \$4.4 trillion in exchange-traded contracts, \$3.9 trillion in swaps, \$634 billion in OTC options, and \$2 trillion in forward rate agreements. Stock index derivatives totalled \$245 billion.

1. The markets for currency options

The market segment of particular interest in this paper is the market for options. The options market is divided into two parts: the market for exchange-traded options, and the OTC market. Currency options are listed on six exchanges in Europe and North America, but most trading takes place on the Philadelphia Stock Exchange (PHLX) and the Chicago Mercantile Exchange's International Monetary Market (IMM). PHLX lists options on spot currency, while most of the contracts on the IMM are options on currency futures. Most listed options are available with a limited choice of maturities up to one year and have American exercise characteristics. 2/ In the OTC market, contract specifications are in principle negotiable, although there is considerable standardization. Furthermore, OTC options are options on currency rather than options on futures, and the European exercise convention is the norm. OTC options are also contracted in much higher amounts. While an individual deutsche mark contract on PHLX provides an option to buy or sell DM 62,500, options in the OTC market are written for amounts of at least \$1 million.

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1/ Estimates reported in Board of Governors of the Federal Reserve System, Federal Deposit Insurance Corporation and Office of the Comptroller of the Currency (1993). See also Bank of England (1993), Bank for International Settlements (1992), Bundesbank (1993), Commodity Futures Trading Commission (1993), General Accounting Office (1994), Group of Thirty (1993), Goldstein and others (1993b), and Office of the Comptroller of the Currency (1993) for discussions of the activities of banks in OTC derivatives markets.

2/ That is, the option can be exercised at any time prior to maturity. Under the European exercise convention, the option may only be exercised at maturity.

The BIS data show that activity in the OTC market segment dominates total trading in currency options, accounting for 85 percent of turnover in April 1992. As with the bulk of foreign exchange trading, the U.S. dollar dominates the options markets: 98 percent of exchange trading and 74 percent of the OTC market's turnover involved the dollar on one side of the transaction. Assuming that the currency composition of deutsche mark OTC options trading is representative of that for the other ERM currencies, only an estimated 10 percent of the OTC options market involves intra-ERM transactions. Moreover, two-thirds of the banks' options transactions, measured by notional principal, had other banks or dealers as counterparties.

While the BIS (1993) does not provide data on the maturity structure of the options market, it does provide it for forward contracts. These show that maturities are heavily concentrated in the near term: 64 percent of contracts mature within 7 days, and only 1 percent have a maturity of longer than 1 year.

### III. The Demand for Hedging in Foreign Exchange Markets

Open positions denominated in foreign currencies expose market participants to losses from exchange rate changes. Accounting for such risk is vital for portfolio managers with foreign currency exposure, corporates with foreign-currency-denominated assets or liabilities such as receivables or payables, or banks with currency exposure. These risks can be reduced by taking an offsetting position in the foreign currency. For example, a long position is hedged by shorting the currency in some fashion. This may consist of a spot sale with borrowing in the foreign currency to cover settlement, the purchase of a forward or future contract that locks in the level of the exchange rate for future payment, or the acquisition of a put option or the sale of a call option on the currency. Access to these instruments differs across types of hedgers: exchange-traded futures or options are retail products with little credit risk but with relatively high margin requirements; OTC products provided by banks and nonbank dealers are typically offered in much larger notional values and require a credit line from the bank to the customer along with a bank's assessment of its exposure to a given client. Options generally provide a partial hedge. For example, a portfolio manager may buy a put option to ensure a floor to the domestic currency value of the foreign currency component of its portfolio, but the portfolio remains subject to risk of currency fluctuations while the portfolio value is above the floor. 1/

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1/ In addition, portfolios will be subject to basis risk when the security underlying the hedge instrument is not identical to the security whose return is being hedged so that the returns on the two securities are not perfectly correlated. A hedge constructed with a related, but not identical, instrument to the one whose value is being hedged is called a cross hedge.

At the end of 1991, institutional investors--mutual funds, pension funds and insurance companies--in OECD countries had total assets of approximately \$11.7 trillion, compared to the assets of commercial banks, which totalled \$19.6 trillion. 1/ The sizes of their foreign currency exposures in absolute terms and even in relation to their total assets can be quite large. For example, U.S. mutual funds and pension funds held \$214 billion in foreign assets, or 5 percent of their combined end-1991 assets of \$4.1 trillion. In contrast, U.K. mutual funds and pension funds invested \$151 billion abroad--23 percent of their total assets. Institutional investors in Germany, Japan and the Netherlands also invest sizable proportions of their assets abroad. More significant perhaps, there are few restrictions on the foreign investments of institutional investors in industrial countries, and the trend appears to be toward relaxing those constraints that do exist. Banks, in contrast, often have well-defined position limits--either statutory or self-imposed--on their foreign exchange exposures.

Managers of pension funds, mutual funds, and bank trust accounts generally hedge their currency risk, often using dynamic hedging operations to create synthetic securities. For fixed-interest holdings of pension funds with obligations denominated in a given currency, the hedge reflects the desire by fund management to place a floor on the long-term value of foreign-currency-denominated holdings. For funds investing in foreign equities, the long-term reasons for establishing currency hedges is not as obvious because of the long-run tendency for exchange rates to conform with purchasing power parity. Nevertheless, in the short term--on a quarterly or annual basis--fund managers' performance, and therefore their compensation, often is compared to a benchmark. Moreover, fund managers seek to protect short term performance from significant declines to prevent an increase in redemptions. Similarly, for pension funds, underfunding of liabilities may force an injection of securities into the fund that tests the liquidity of the parent entity. For these reasons, fund managers are sensitive in the short term to exchange rate movements and will wish to hedge positions. In the simplest hedging operation, fund directors may establish currency risk targets or limits to which management must adhere by following agreed hedging strategies. To place an absolute ceiling on losses from currency fluctuations, fund directors may mandate the acquisition of a put option to cover the entire foreign exchange position of the fund.

If they are willing to bear more risk from volatility changes, fund directors may instruct management to replicate a put dynamically. 2/ This method has become typical for fund management. As indicated below, this

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1/ See Goldstein and others (1993a) for a discussion of the foreign holdings of institutional investors in industrial countries.

2/ Using real put contracts to hedge long positions is not entirely free of volatility risk, of course, since changes in volatility can result in losses when put contracts are rolled over if the maturity of the contracts is shorter than horizon of the hedging operation.

buy-high, sell-low strategy will, ex-post, have been less costly than an actual put if volatility declines and more costly if volatility increases. Finally, many portfolio managers follow a constant-percentage portfolio insurance strategy: this is a buy-high, sell-low dynamic strategy that does not replicate a put option. 1/ Rather, it is driven entirely by price movements. For example, one realization of this strategy may aim at outperforming a fifty-percent hedged position and would begin with a fifty-percent hedge. A one-percent move in the exchange rate would trigger an x-percent change in the hedge ratio. If the foreign currency appreciated by 10 percent, the hedge ratio would fall to 50-10x percent. Currency depreciations would be met with opposite adjustments in the hedge ratio. The strategy tends to work well when exchange rate changes come in trends but fails with a jump in volatility. 2/

Dynamic strategies are often implemented through cross-hedges--that is, a hedge may be implemented through shorting a currency whose exchange rate is highly correlated with the currency in which the fund holds securities. The purpose is to take advantage of greater liquidity in the exchange market or an interest rate premium in the currency used for the cross-hedge.

Individual firms and portfolio managers ultimately must turn to banks to engage in foreign exchange hedging since banks are the principal dealers in the foreign exchange spot and derivatives markets. By taking the opposite side of a transaction undertaken by a customer, a bank will acquire foreign exchange exposure that it will then attempt to eliminate. For those exposures that do not net out in the course of a day's trading with other customers--for example, currency or value-date mismatches in forward contract long and short positions or different features of options contracts--the bank must actively seek coverage by initiating its own transactions in the same OTC and exchange-traded derivatives markets or in the underlying markets.

Because of internal risk-control operations and regulations on foreign exchange risk, banks are active in using dynamic hedging techniques. Typically, they will hedge the net exposure to exchange rate changes acquired through transactions with clients, but they may leverage exchange risk when trading for proprietary accounts.

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1/ This strategy is referred to by Leland, O'Brien and Rubinstein and Associates as a Perpetual Protection policy.

2/ A constant percentage portfolio insurance strategy has an advantage over an option replication strategy in that at the end of the period a renewal of the hedge does not require a large trading operation. For an option replication strategy, at expiration the portfolio is either 100-percent hedged or completely unhedged. Renewal of the strategy for another period then requires a large jump in the hedge ratio.

Regulation on banks' net foreign exchange positions varies widely across industrial countries. <sup>1/</sup> In some countries, such as the United States, banks' exposures and internal controls are monitored on a regular basis, although there are no specified limits. Elsewhere, as in, for example, Germany, Japan and the United Kingdom, guidelines or stronger constraints limit open positions to a specified ratio to total capital. Banks' internal risk management controls include the separation of dealing operations--in which buy/sell orders are taken--and back-office activities where contracts are confirmed and settled, the imposition of open position limits on the dealing book and limits on the extension of credit to individual counterparties.

A bank that writes an option becomes exposed to the possibility that the option will be exercised and it will have to buy or sell foreign currency (depending upon whether it has written a put or a call). The simplest hedge in this case would be to acquire a perfectly offsetting contract. For a bank that maintains a large options book, many of its options contracts will indeed offset each other. However, to hedge the remaining options exposure, banks will generally turn to the more liquid underlying markets and hedge their exposures by creating synthetic options. Dynamic hedging strategies provide a simple means by which complicated options books can be hedged by constructing synthetic options.

As the discussion in Section II indicates, trading in options is only a small part of the foreign exchange market. Most of banks' foreign exchange exposure comes from dealing in the spot and forward (including swaps) markets. As with their options-based exposures, banks will actively hedge their net exposure arising from these other transactions. Moreover, not all options (or other) transactions entered into by banks are derived from hedging operations. Unlike transactions in the underlying markets, options provide tools for taking positions in the volatility of spot exchange rates or exchange rate futures, instead of or in addition to speculating on the future direction of these underlying assets. Banks both sell packages of options to their customers that allow them to choose their own degree of exposure to the level, direction of change, and volatility of the underlying asset, and enter into transactions with other dealers to do the same for their own account.

#### IV. Mechanics of Option Pricing and Dynamic Hedging

##### 1. Pricing put options on foreign currency

Because option pricing theory is at the heart of dynamic hedging, it is helpful at this point to review the basic option pricing formula for foreign exchange--the Garman/Kohlhagen formula--before describing how

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<sup>1/</sup> See Goldstein and others (1993a) for a discussion on the regulatory and internal constraints on banks' foreign exchange trading.

dynamic hedging works. 1/ Although banks and other wholesale traders may use more sophisticated pricing methods that account for varying interest rates and exchange rate volatility, the Garman/Kohlhagen formula is in general operational use by pension fund and other portfolio managers and it is pedagogically useful for illustrating the management of risk in a bank's foreign exchange book. 2/

Suppose that a customer buys a European put option to deliver deutsche mark for dollars after T periods for an exercise price of \$X per deutsche mark. The value of the put option,  $P_t$ , is:

$$P_t = -[1-N(d_1)]\exp[-r_{DM}T]S + [1-N(d_2)]\exp[-r_sT]X \quad (1)$$

where  $r_{DM}$  and  $r_s$  are the (constant) risk-free instantaneous deutsche mark and dollar interest rates, S is the current dollar/deutsche mark spot exchange rate, and X is the exercise or strike exchange rate of the option. 3/  $N(d_1)$  is the value of the normal distribution function evaluated at the argument

$$d_1 = \{\ln(S/X) + [r_s - r_{DM} + \sigma^2/2]T\}/\sigma\sqrt{T}, \quad (2)$$

where  $\sigma$  is the (constant) instantaneous standard deviation or volatility of the exchange rate S. Finally,  $d_2 = d_1 - \sigma\sqrt{T}$ . The put price, or premium, is

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1/ See Garman and Kohlhagen (1983) for the development of this formula. For pricing formulas taking account of stochastic volatility, see Chiang and Okunev (1993), Kroner and Sultan (1993), Melino and Turnbull (1990), Naik (1993), and Perraudin and Sorenson (1992). Dumas, Jennergren and Näslund (1993) derive options pricing formulas for currencies restricted by target zones as in the European Exchange Rate Mechanism. However, as the data in Section II above indicate, the majority of OTC and exchange-traded options contracts are written for dollar exchange rates.

2/ Most exchange-traded currency options, except those traded on the Philadelphia Stock Exchange are options on futures, for which the Garman/Kohlhagen formula for spot exchange options is inapplicable. In the standard formula for pricing options on futures, the foreign interest rate does not appear. The effect of foreign interest rate changes are felt through their impact on the futures price. Moreover, in the OTC market it is more common to price options with respect to the forward exchange rate rather than the spot rate (see DeRosa (1992), p. 109).

3/ This equation is identical in form to the Merton adaptation of the Black-Scholes put formula for a stock that pays a continuous, constant dividend. This formula is constructed on the assumption that the percentage change in the price of the underlying security, in this case the dollar-deutsche mark exchange rate, follows a Wiener process, that the instantaneous interest rates in both countries and the standard deviation of the percentage exchange rate change are fixed parameters for the life of the option. Such a simple formula does not exist for American put options; these must be evaluated by numerical methods (see DeRosa (1992)).

graphed against the spot exchange rate in Figure 1. The premium is a downward-sloping, convex, function of the exchange rate and lies closer to the option's intrinsic value,  $\max [0, X-S]$  (depicted as the dashed 45° line, which coincides with the horizontal axis to the right of X) the shorter the time to maturity. Note that it is possible for the price of the option to be less than its intrinsic value for deep-in-the-money puts.

## 2. Implementing the dynamic hedge

The put pricing formula is determined by finding the short position in deutsche mark loans and the long position in dollar loans such that a portfolio with these positions and also short a put is riskless with respect to small exchange rate movements.

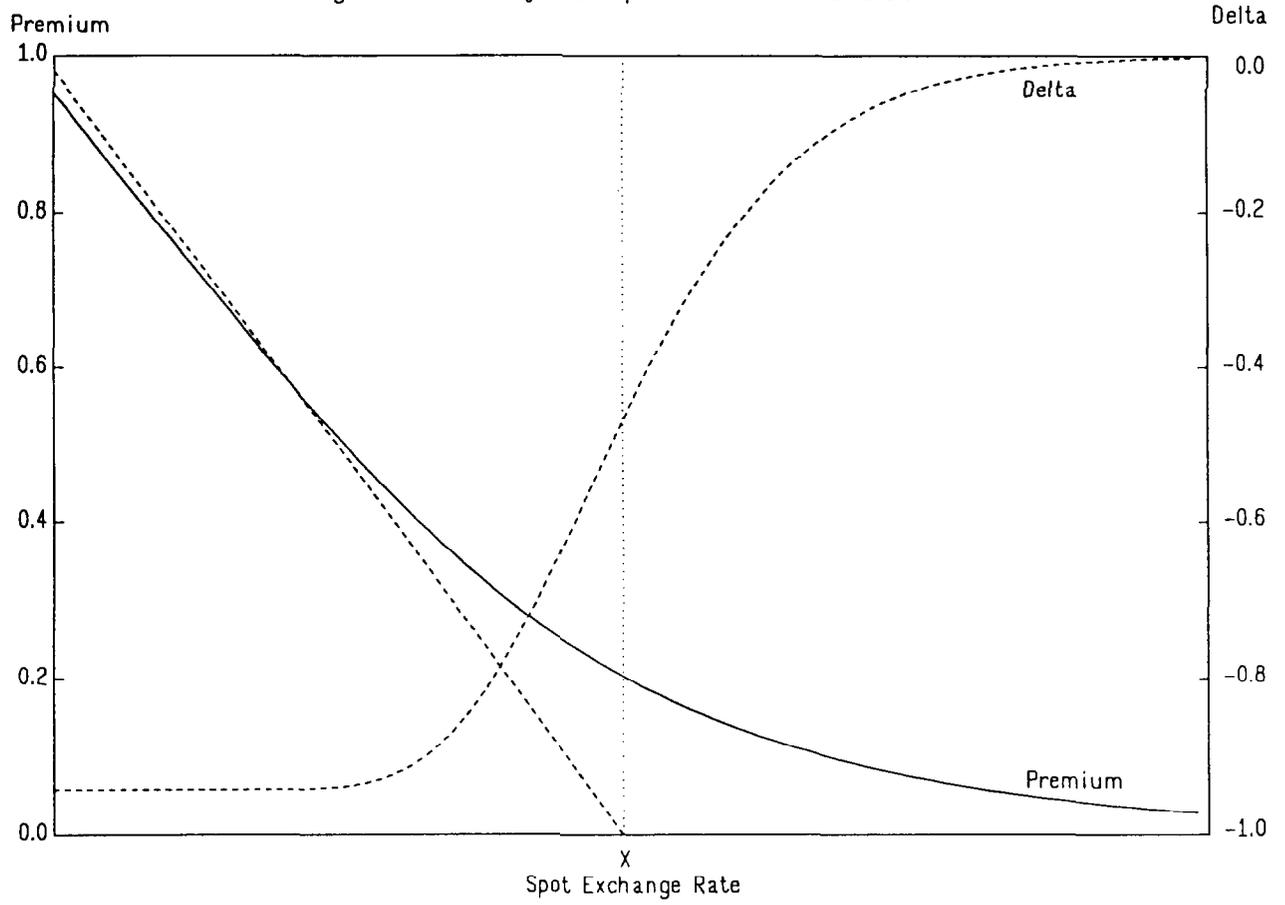
Thus, an investor that wants to hedge its exposure to fluctuations in the dollar/deutsche mark exchange rate can either hedge a long deutsche mark position by buying a put option, or use equation (1) to determine positions in deutsche mark and dollar loans that mimic the value of a put--that is, to create a synthetic put. The basic security in the first half of the formula is a loan promising to deliver 1 deutsche mark in T periods--this has a deutsche mark present value of  $\exp[-r_{DM}T]$  and a dollar value of  $\exp[-r_{DM}T]S$ . The coefficient  $-[1-N(d_1)]$  indicates that the mimicking portfolio should consist of a short position of a fraction of such a deutsche mark loan--that is, a short deutsche mark position. Similarly, the dollar position is long a fraction  $[1-N(d_2)]$  of a loan promising to pay X dollars in T periods with a present dollar value of  $\exp[-r_3T]X$ . However, since  $d_1$  and  $d_2$  constantly move with the exchange rate, the interest rate differential, and the standard deviation projected for exchange rate movements, the positions must be adjusted constantly--hence the term dynamic hedging--to maintain the equivalence of the position to a put option. 1/

The foreign exchange exposure of the bank that sells the put is to the possibility of having to buy deutsche mark at the exercise price at date T. Under the assumptions behind the pricing formula, it is not necessary to hedge the total face value of the contract prior to the exercise date. How much of the face value to hedge, which in turn determines the hedge ratio, is provided by the option's delta, the change in the value of the option with respect to a movement in the exchange rate. From the pricing formula developed above, the delta of a currency put option is  $-[1-N(d_1)]\exp(-r_{DM}T)$ . Thus, a rise in the dollar value of the deutsche mark makes it less likely that the option will be exercised and reduces the value of the put. The put delta takes values between -1, for a deep in-the-money option that would

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1/ Note that the ability to maintain a dynamic hedge depends critically on the existence of a liquid spot foreign exchange market in which the rebalancing trades can be executed. If, as happens during a crisis, markets become illiquid, investors that rely on dynamic hedging may not be able to adjust their portfolios and will be exposed to further exchange rate changes.

Figure 1. Currency Put Option Premium and Delta





almost certainly be exercised, to 0, for a deep out-of-the-money option that would never be exercised (see Figure 1). The negative of delta, therefore, provides a proxy for the probability of exercise. Delta multiplied by the number of units of foreign currency provides an estimate of the expected foreign exchange that is sold short at any point in time to hedge against possible exercise of the option.

A writer of a put option may, therefore, hedge the option dynamically according to the prescriptions of the put pricing formula. First, it must establish the portfolio that mimics the value of the option: for example by shorting  $[1-N(d_1)]$  deutsche mark forward for dollars and buying  $[1-N(d_2)] \exp[-r_3 T]X$  in U.S. Treasury bills. As the exchange rate fluctuates, the now-hedged writer of the option must adjust the short deutsche mark and long dollar positions according to the formula to continue to mimic the option. Typically, the adjustments will not be continuous; instead, to avoid transactions costs, adjustments to the mimicking portfolio will be made as part of a regular rebalancing exercise. 1/

Among other assumptions, the put pricing formula is based on assuming that exchange rate volatility will remain constant during the life of the contract. Because volatility typically is not constant, the mimicking portfolio will never perfectly track the actual option's value--gains or losses relative to the initial option premium will always occur--and so the portfolio must constantly be adjusted to changes in volatilities as measured, frequently, by implied volatilities in options prices. If volatility jumps above the value implicit in the price of the actual put option, the writer of the put who engages in dynamic hedging will take a loss and the buyer of the put will gain. It is well known that strategies to create synthetic options to hedge actual options through the use of dynamic trading, designed to be delta neutral, can be used to take positions on volatility in underlying prices and in interest rates. 2/

The loss to the writer is immediately apparent if the portfolio is marked to market. A volatility increase will, ceteris paribus, increase the value of the actual option (a liability) and leave unchanged the value of the hedging portfolio (the supposedly balancing asset). Alternatively, if the option value is not marked to market, the loss will be booked through the dynamic adjustment of deutsche mark and dollar positions until the exercise date. According to the hedging strategy, a rise in the exchange rate will cause the writer of the put to reduce the short deutsche mark position: the writer of the option will buy deutsche mark when the deutsche mark appreciates and sell when it depreciates. This "buy dear-sell cheap" strategy generates a foreseeable loss to the writer of the put, or indeed of

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1/ Since the hedge is not adjusted continuously, the bank will incur losses between rebalancing exercises. Leong (1991) argues that the option premium charged by a bank will, in equilibrium, equal the expected value of this "hedge slippage."

2/ See for example Cookson (1993) or DeRosa (1992).

any other option, for which it is compensated by the put premium. If volatility jumps, however, the premium will be insufficient to cover the now greater-than-expected realized loss on these hedging trades.

To hedge the risks acquired from their OTC options transactions with other dealers, banks generally construct a dynamic hedge by purchasing or selling currency in the spot market to close the currency exposure, and entering into a swap contract to shift the exposure to coincide with the maturity date of the option. Indeed, such transactions have become part of banks' normal operating procedures (Walmsley (1992)).

In order to monitor its overall exposure, a bank must have a method to break down each option in its book into its implied foreign exchange position. It can then determine its global net position in each currency by adding its net position from trading in other foreign exchange products to its net position implied in its options book, and then hedge the combined exposure. The foreign exchange equivalent into which a bank will decompose its options will depend on the currency options pricing formula used by the bank, but it will usually be based on delta hedging methods. The bank calculates the delta for all the contracts it has written or bought and multiplies these by the face values of the contracts. These are then added up for each currency to estimate the expected net foreign currency delivery requirement. For European-style options, in which exercise is only possible at maturity, the hedge portfolio will include futures or forward contracts that offset these amounts, while for American-style options, the hedge will include cash positions because the exercise date is uncertain. Because the management of the foreign exchange book is global, the amounts required to hedge the options will be netted against spot and forward net positions.

For example, suppose that the global position in the currency option book of a bank making a market in derivatives is short one OTC European deutsche mark put option that allows the holder to sell DM 1 for \$X at time T, and long one European put option to sell DM 1 for French francs at T\*. If the bank uses the Garman/Kohlhagen formula, its deutsche mark position from its options book is:

<u>Option</u>	<u>DM Position</u>
1. Short 1 Put DM/\$	$[1 - N(d_1)] \exp[-r_{DM}T]$
2. Long 1 Put DM/FF	$-[1 - N(d_1^*)] \exp[-r_{DM}T^*]$

In these formulas  $d_1$  and  $d_1^*$  are defined as above with the appropriate volatilities and exercise prices substituted for each option. If the bank is also long deutsche mark in its forward and spot trading, it can determine its global foreign exchange exposure in deutsche mark by adding these three quantities. The bank can then hedge the foreign exchange risk by taking the opposite position in the forward market. Because the implied delivery dates across its deutsche mark contracts may differ, this still leaves the bank with an interest rate risk that can be hedged through appropriate deutsche mark forwards or swaps.

### 3. Properties of the put option delta

Given the centrality of delta to the construction of the hedge portfolio, it is worth considering its properties. In particular, we are interested in identifying the response of delta to changes in the parameters of the model. Unfortunately, these relationships are often not monotonic.

The partial derivative of delta with respect to the exchange rate is the option's gamma, or convexity. For a put option, this is always positive, as portrayed in Figure 2. Thus, an increase in the exchange rate makes the option less likely to be exercised and lowers the absolute value of delta. Note that the put delta is most sensitive to changes in the exchange rate when the option is close to being at-the-money. Conversely, an increase in the exercise price,  $X$ , increases the value of the option, raising the probability of exercise and the short position needed to hedge it. Thus, delta is a decreasing function of  $X$  as shown in Figure 3. The only other partial derivative of delta that is unambiguous is that with respect to  $r_s$ , which is positive. An increase in this rate lowers the present value of the dollars that will be received if the option is exercised. This lowers the likelihood that the option will be exercised, and so delta is an increasing function of  $r_s$  as in Figure 4.

The remaining derivatives, with respect to the volatility, time to maturity and  $r_{DM}$ , are all of ambiguous sign. Figure 5 shows the effect of changes in volatility on the put option delta. For at-the-money options, there is little change in the delta. For out-of-the-money options, delta is a decreasing function of exchange rate volatility: an increase in volatility increases the probability that the exchange rate will fall far enough that the option will move in-the-money and so the probability of exercise increases. For in-the-money options, delta increases with volatility since an increase in the latter only increases the probability that the exchange rate will rise above  $X$  by the time the option expires. Clearly, for very deep in- or out-of-the-money options, a very large increase in volatility is necessary for there to be an appreciable change in delta.

An increase in the time to maturity has a similar effect on the option delta as does an increase in volatility. <sup>1/</sup> Figure 6 shows that for in-the-money options, a longer time to maturity increases the probability that the option will move out-of-the-money before expiration, and so the delta decreases, and conversely for out-of-the-money options. For at-the-money options, the effect on delta is sensitive to the sign of the interest rate differential. Some intuition about the effect of changing time to maturity is obtained from Figure 1. As the time to maturity falls, the options price function,  $P$ , collapses onto the intrinsic value function. Thus, reversing

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<sup>1/</sup> This is the negative of the change in delta with respect to the remaining time to maturity of the option, which is sometimes called "charm" (see Garman (1992)).

the process, as the time to maturity increases, the price function moves upwards and to the right, away from the intrinsic value function. Hence, for out-of-the-money options, delta, which is the slope of the price function, falls from zero to some negative value, while for in-the-money options the slope rises from -1. For at-the-money options (and possibly for options for which the spot price and the exercise price are very close), the change in slope depends on the convexity of the price function, which in turn depends upon, *inter alia*, the interest rate differential.

The most important partial derivative for the purposes of the discussion in the next section is the effect of changes in  $r_{DM}$  on the put option delta. Under most circumstances, the relationship is as it is depicted in Figure 4: downward-sloping. However, since the derivative is of ambiguous sign, and given the importance of this relationship, Figures 7-9 show how this derivative varies with values of the other parameters. Figure 7 shows that for most common values of the volatility parameter the relationship is always negative. However, if the exchange rate's annualized volatility falls below 5 percent, the curve slopes upwards after  $r_{DM}$  rises above approximately 45 percent. Figure 8 shows that as the intrinsic value of the option,  $X-S$ , rises, a similar reversal in slope is possible. Indeed, for deep-in-the-money options, delta is everywhere increasing in  $r_{DM}$ . Finally, Figure 9 shows that as the time to maturity of the option increases, further increases in  $r_{DM}$  can lead to an increase in delta (a fall in the short foreign exchange position).

The inference that can be drawn from these last three Figures is that, for the most commonly observed parameter values, delta declines with increases in the foreign interest rate. However, for options that have long terms to maturity or that are in-the-money or written on very low volatility options--or, more likely, a combination of these characteristics--it is possible that for a sufficiently large increase in  $r_{DM}$ , the relationship between delta and  $r_{DM}$  could actually become positive. Subsequent increases in  $r_{DM}$  would then lower the short deutsche mark position held to hedge the short put position. Note however, that except for multi-year options--which are extremely rare--it is highly unlikely that any increase in  $r_{DM}$  would actually lead to a decline in the initial short deutsche mark position.

## V. Hedging in a Crisis

Dynamic hedging strategies are not an entirely new activity--stop-loss trading has always been triggered by price movements beyond a certain threshold. Dynamic hedging simply mechanizes this response. To the extent, however, that the technique has been adopted by large segments of the financial intermediation industry and can be implemented more rapidly than previous techniques, dynamic hedging strategies have added to trading volume and have accentuated price movements by contributing to momentary illiquidity. In this section, we consider how the widespread use of dynamic hedging techniques may interact with central bank exchange rate and liquidity policies to undermine a defense of a fixed exchange rate system.

Figure 2. Currency Put Option Gamma

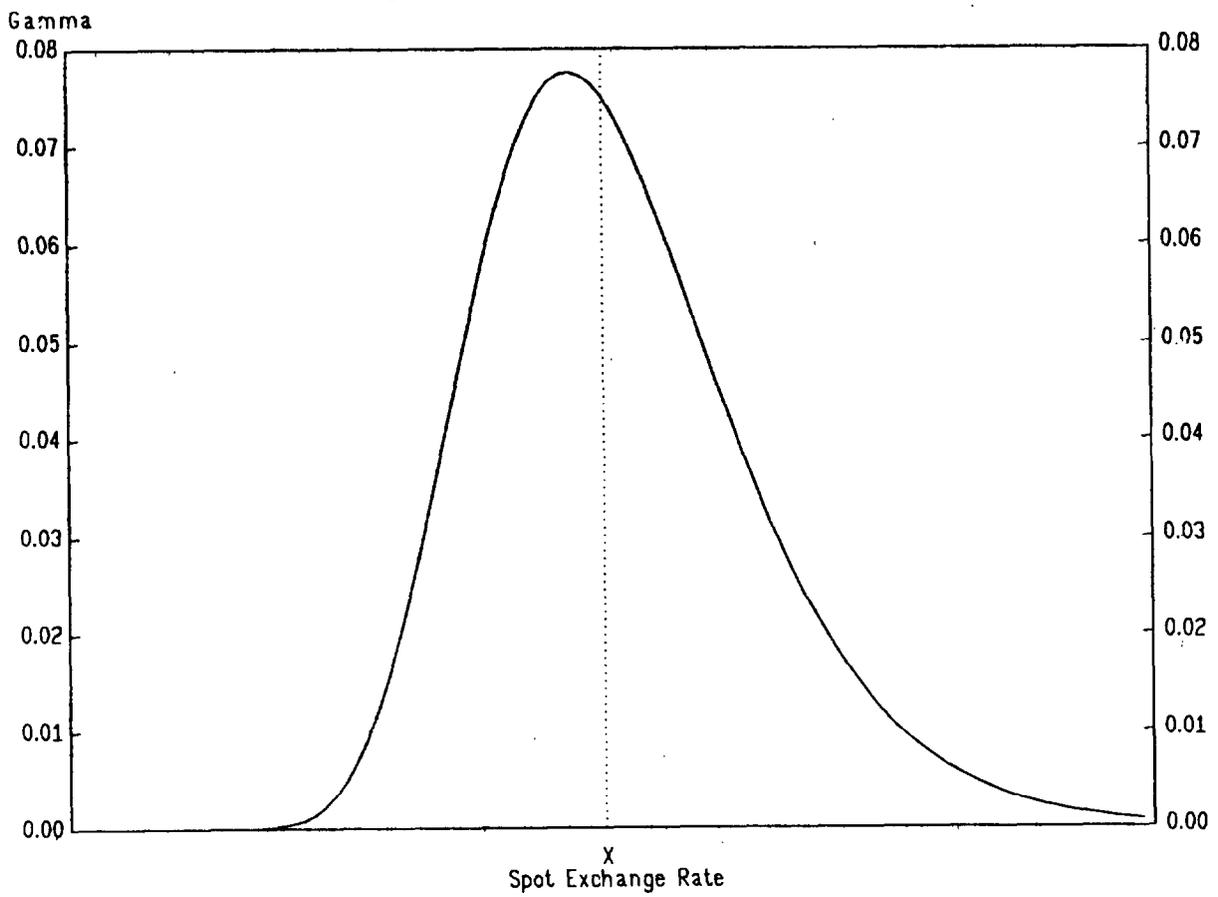


Figure 3. Sensitivity of Put Delta to the Exercise Price

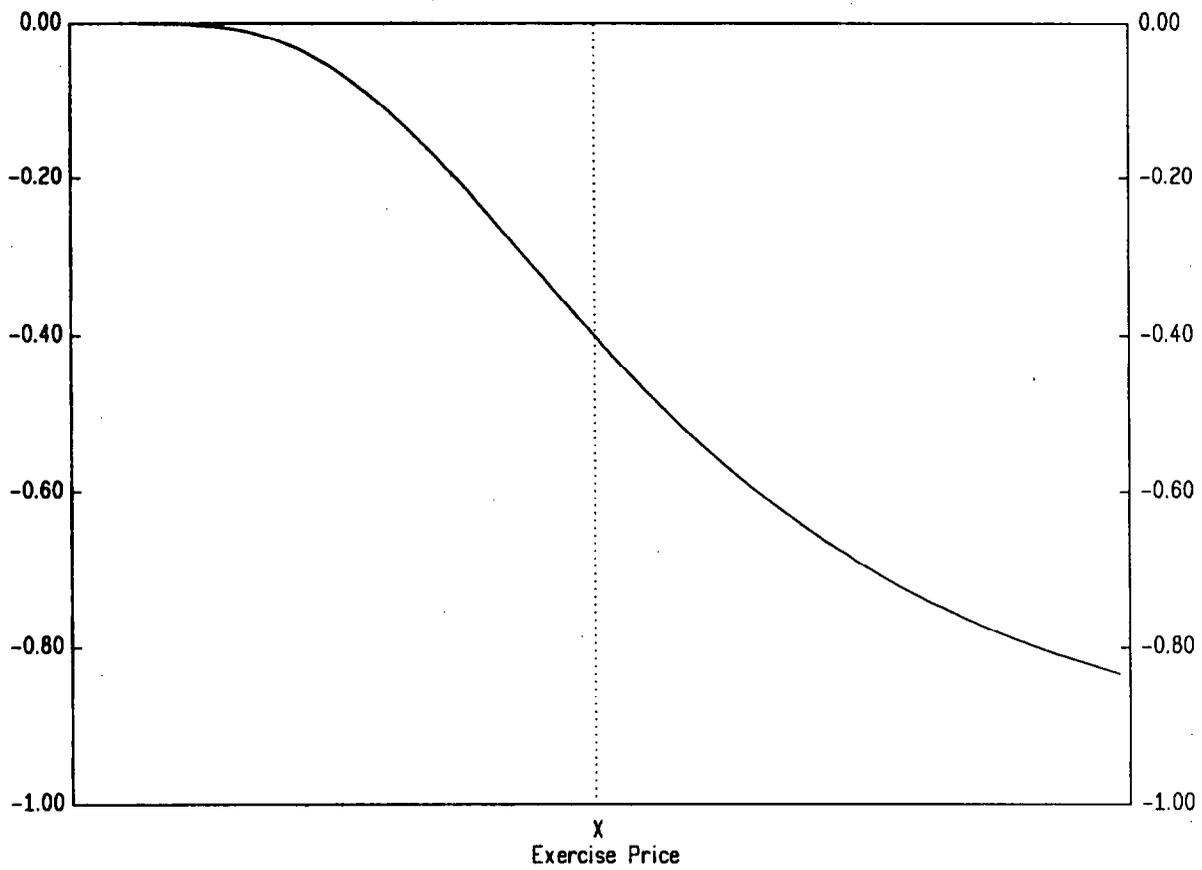


Figure 4. Sensitivity of Put Delta to Domestic and Foreign Interest Rates

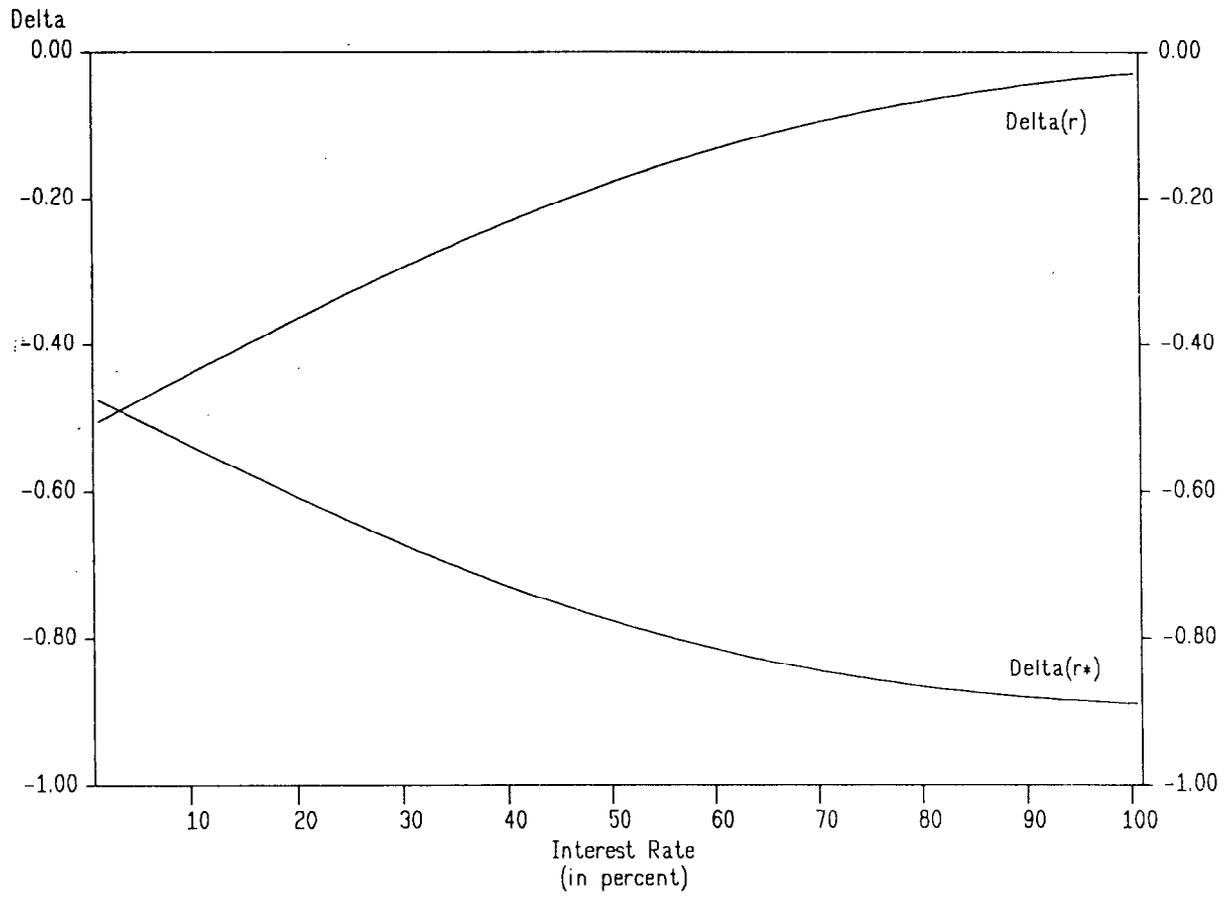


Figure 5. Sensitivity of Put Delta to Volatility

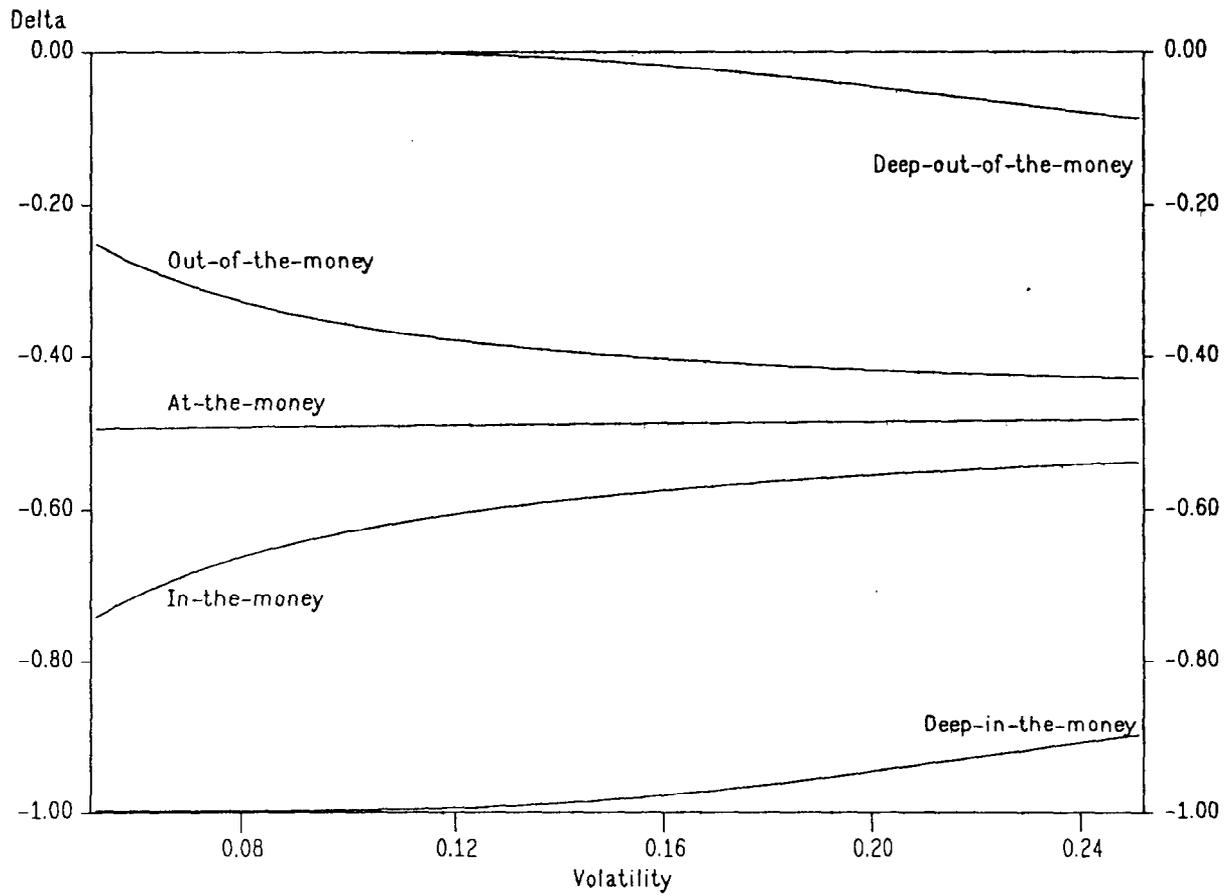
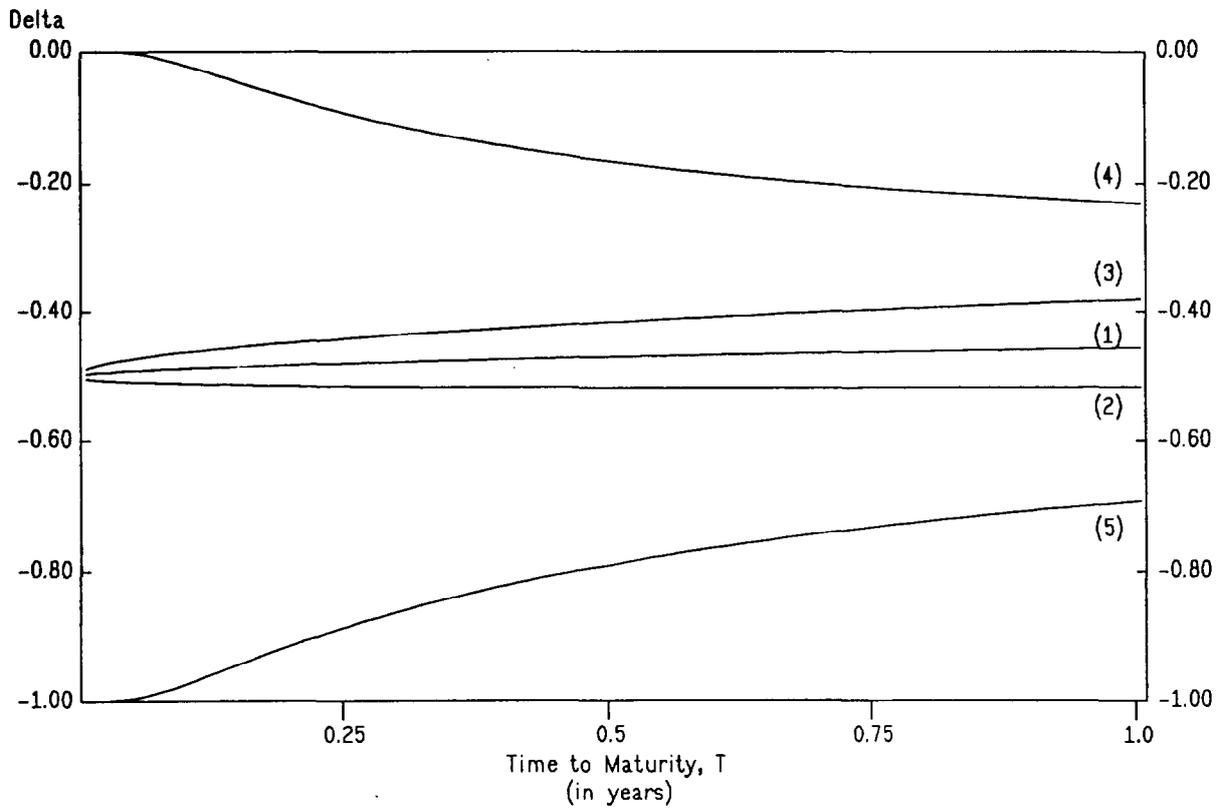
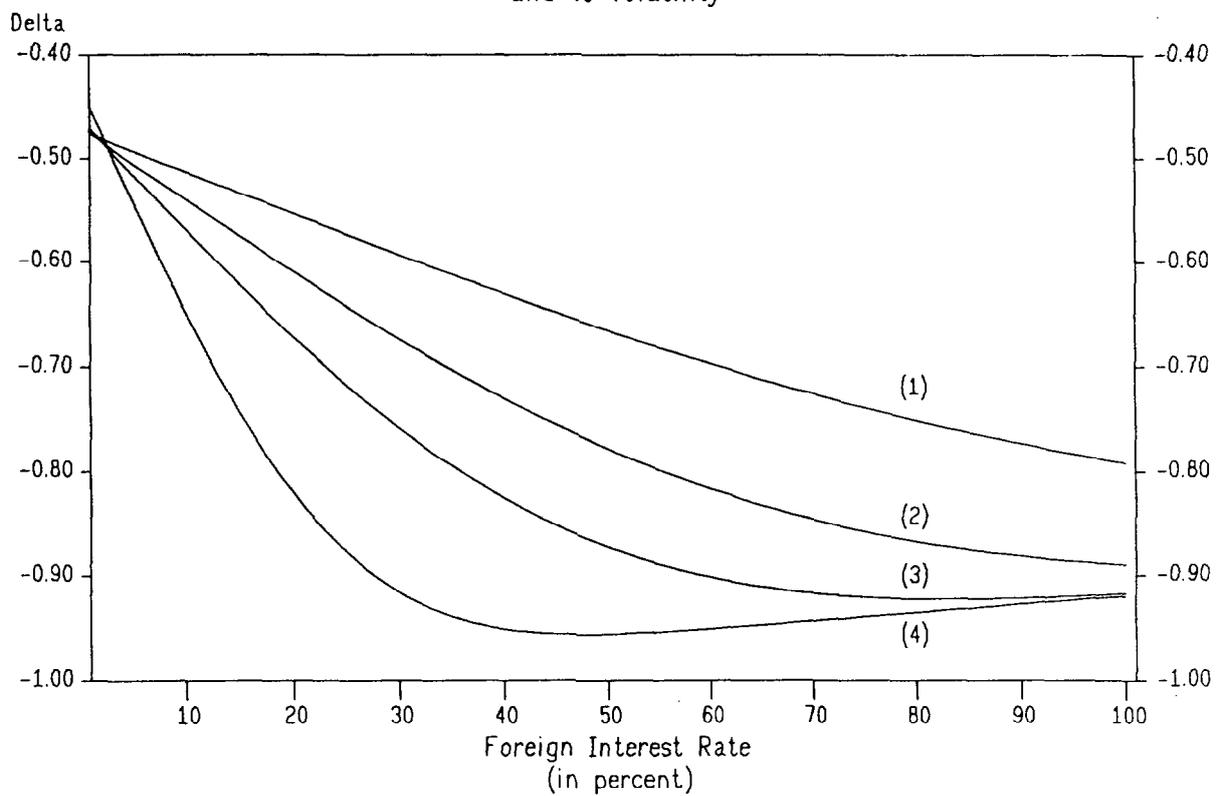


Figure 6. Sensitivity of Put Delta to the Expiration Date



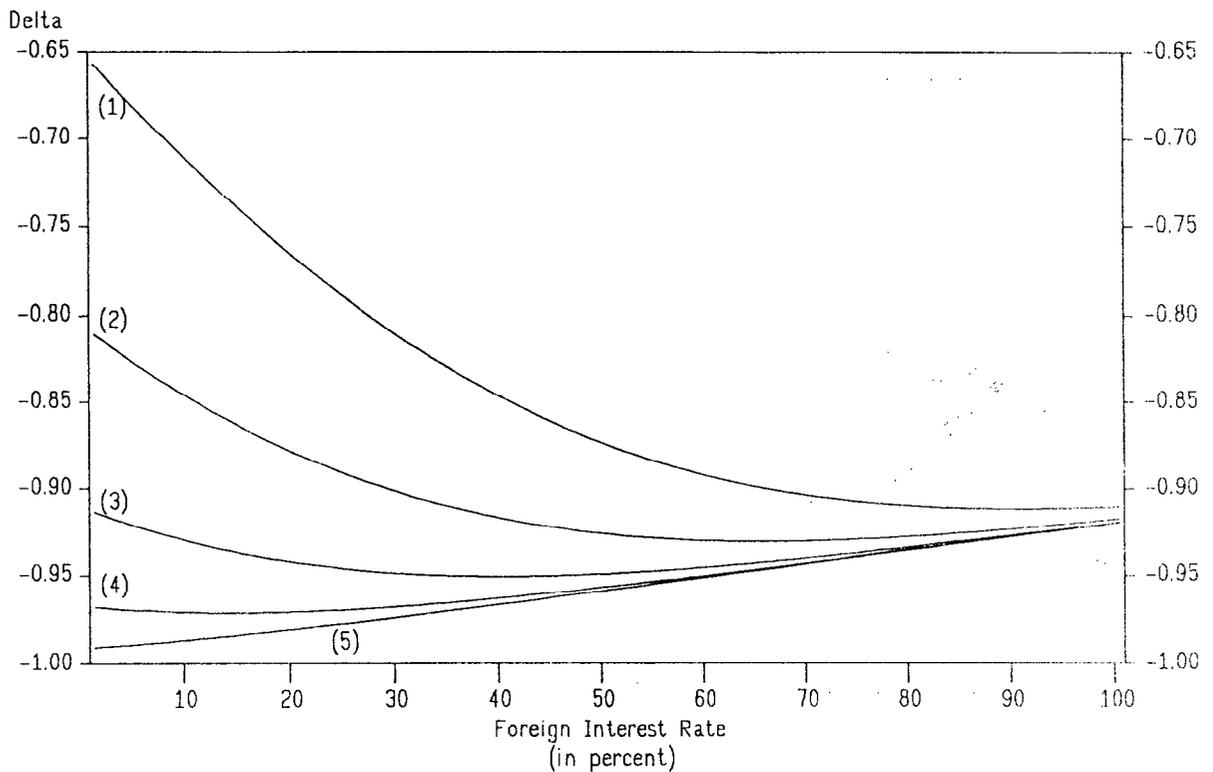
- (1) at-the-money,  $r=r^*$ ; (2) at-the-money,  $r<r^*$ ; (3) at-the-money,  $r>r^*$ ;  
(4) out-of-the-money,  $r=r^*$ ; (5) in-the-money,  $r=r^*$

Figure 7. Sensitivity of Put Delta to the Foreign Interest Rate and to Volatility



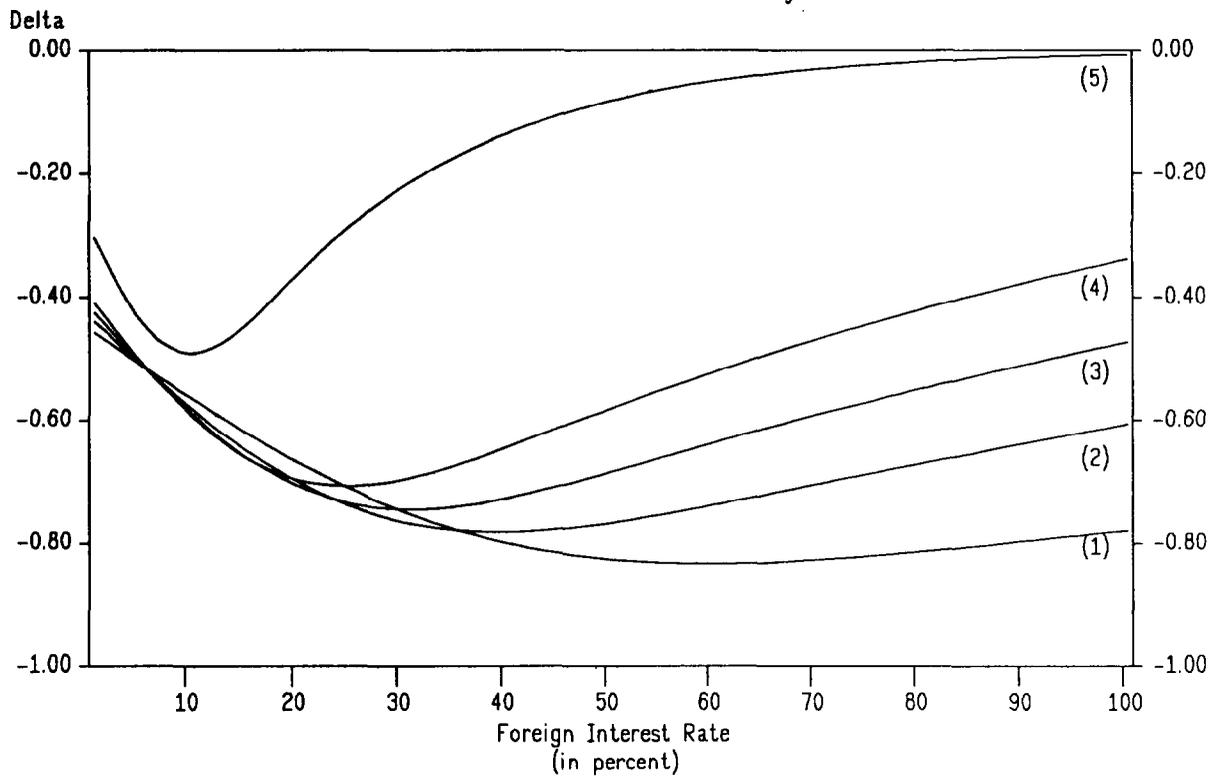
(1) 20% volatility; (2) 15% volatility; (3) 10% volatility; (4) 5% volatility.

Figure 8. Sensitivity of Put Delta to the Foreign Interest Rate and to the Intrinsic Value



(1)  $S/X = 0.98$ ; (2)  $S/X = 0.96$ ; (3)  $S/X = 0.94$ ;  
(4)  $S/X = 0.92$ ; (5)  $S/X = 0.90$ .

Figure 9. Sensitivity of Put Delta to the Foreign Interest Rate and to the Contract Maturity



(1) T = 3 months (2) T = 6 months (3) T = 9 months  
(4) T = 1 year (5) T = 4 years

When a fixed exchange rate regime moves toward a crisis, speculation against the currency is generally channelled through forward sales of the currency to the banking system. Some margin is required by counterparty banks, but this can be leveraged up by a factor of ten or more by the speculator. In a crisis, these sales will generally not be matched by other customers' forward purchases of the currency. The central bank defending the currency may intervene with forward purchases, but the extent of such an operation is limited by the unwillingness of a central bank to risk large capital losses on negative net foreign exchange positions and by limits on credit lines to the central bank made available by the major dealing banks. 1/ Once the central bank ceases to buy its currency in the forward market, banks must balance their forward purchases with spot sales of the currency (to balance the net currency position) and by currency swaps (to balance maturities).

Once again, during a crisis, the central bank will be the most important buyer on the spot market through its intervention to maintain the fixed exchange rate. At the same time, it provides its currency through the discount window to the banks who need to sell currency in order to match their forward and spot foreign exchange positions as discussed in the previous paragraph. By providing liquidity to banks through this kind of facility, the central bank is effectively financing the attack on its own reserves. To settle its spot transactions, the central bank must deliver its own foreign exchange reserves or draw down lines of credit from other central banks or multilateral entities. As its short foreign exchange position mounts during the intervention, the central bank must act by raising the discount rate. This increases the cost to speculators who speculate against the currency by borrowing from the central bank. The central bank may also impose a squeeze on short sellers by channeling available credit away from identified speculators.

This final operation is the classic interest rate defense of a fixed exchange rate. It works though a liquidity effect in the money market--domestic credit grows less rapidly than central bank net reserves decline, thereby producing a decline in the supply of the domestic settlement medium. If large short positions in the currency are due for settlement, holders of short positions may sell foreign exchange to the central bank rather than face the high interest costs of rolling over overnight loans in the weak currency. The costs to holders of short positions are further accentuated if in addition they are caught in a squeeze so that they have to pay more than the discount rate to obtain funds.

The market's acquisition of foreign exchange from the central bank does not arise exclusively from forward sales by nonbank speculators.

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1/ The ability of the central bank to enter forward contracts with its own nationally chartered banks is circumscribed by credit line limits imposed by banks elsewhere on these banks.

Speculators and hedgers may also buy put options on the weak currency from the banks. Again, in a crisis, the banking system will likely be unable to find nonbank sellers of puts to balance these positions. 1/ To hedge, the bank that writes the put may create a long position in a synthetic put by selling the weak currency forward, by selling on the futures market, or by selling spot and entering a swap contract. Any of these operations will trigger a spot sale of the weak currency to the central bank as described above.

A common hedging strategy employed by customers is the implementation of a range forward, depicted in Figure 10. 2/ An investor holding Italian government BTPs (Buoni del Tesoro Poliennali--medium- and long-term bonds), for example, who invested in these bonds because of their relatively high interest rate, might buy a put option and sell a call with a higher exercise price chosen so that the revenue from the sale of the call equals the price of the put. In addition, the investor would purchase lire in a forward contract (which has zero cost at inception). In such a strategy, the investor bears the risk of exchange rate depreciation in the range,  $\bar{X} - \underline{X}$ , but is protected from very large depreciations, as demonstrated by the payoff function RF. The bank that sells the range forward is short a put option and long a call option with similar strike prices. The bank may choose to hedge these exposures by creating synthetic options. The hedge portfolio for both of these option positions requires a short lira position. 3/

1. The effect of interest rate changes on dynamic hedging

Once a central bank raises interest rates in defense of the fixed exchange rate, hedging operations may trigger further sales of the currency rather than the purchases anticipated from the squeeze. This result follows from the relation between interest rate movements and the hedging portfolio in equation (1).

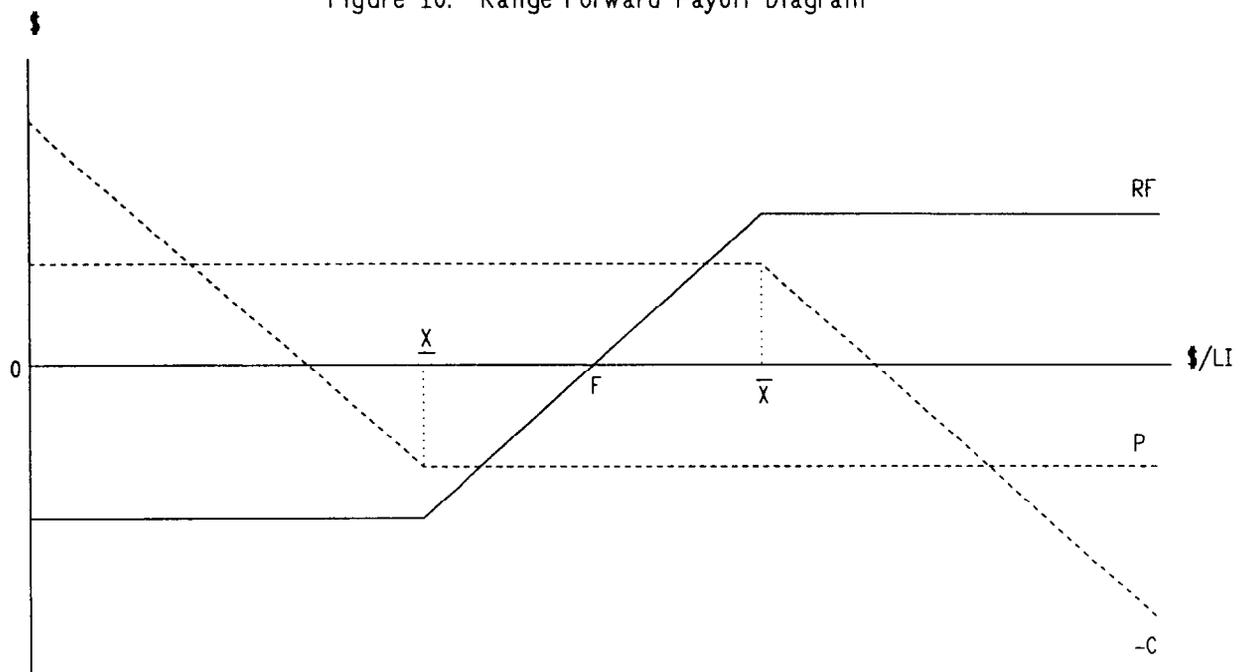
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1/ Even if nonbank sellers of puts exist somewhere in the financial system, the selling bank seeking cover may not find them through the banking system. In a crisis, gross trading volumes surge, thereby causing many banks to reach their credit ceilings with other banks. As the banking system becomes illiquid in this way, transactions that passed through the banking system on a credit basis now must seek a cash market. To hedge, the selling bank will place an order to buy a put onto the organized currency options market, where credit risk is not an issue, and will find the potential seller in this market. As the crisis progresses and more interbank credit lines fill, volume will tend to move to the more secure organized exchanges.

2/ We are grateful to Paolo Kind for suggesting this example.

3/ Intuitively, a short put position is a contingent long position in the foreign currency (here lira), as is a long call position. Hence, both are hedged by going short in lire.

Figure 10. Range Forward Payoff Diagram



- P: Payoff to long put with exercise price  $\bar{X}$
- C: Payoff to short call with exercise price  $\underline{X}$
- F: Contracted forward exchange rate
- RF: Payoff to range forward strategy



Intuitively, the interest rate differential between the two currencies reflects the expected rate of depreciation of the exchange rate plus a risk premium. Unless volatility increases or attitudes toward risk change, a rise in the differential between deutsche mark and dollar interest rates means that the deutsche mark is expected to depreciate more rapidly against the dollar--that is, the hedge ratio increases. <sup>1/</sup>

With an unchanged current exchange rate, exercise price, and exchange rate volatility, the put option is much more likely to finish in the money when the foreign interest rate jumps upwards. That the option is more likely to be exercised means that it provides a higher effective hedge to a portfolio manager covering a deutsche mark exposure. The manager of the bank's portfolio who uses a synthetic put in a dynamic hedging operation must likewise provide an increased hedge ratio in response to the greater probability that the option will be exercised. This means that he must short sell more deutsche mark so that his synthetic put continues to mimic an actual put. Taken to an extreme, if deutsche mark interest rates rise so high that, according to the underlying theory, it is almost certain that a put option will be exercised, the put then provides the equivalent of a 100 percent hedge ratio. The bank's portfolio manager using a synthetic put must similarly sell sufficient deutsche mark to cover his entire deutsche mark position to provide the same coverage as an actual put.

How important will the dynamic hedging response be? Figure 8 provides some indication of the response of dynamic hedging programs during the final days of a managed or fixed exchange rate regime. In the days leading up to the collapse of an exchange rate band regime the gradual depreciation in the spot exchange rate will have a significant effect on the hedge ratio, necessitating a gradual increase in the short foreign currency position. However, in the final hours or minutes of such a regime or of an absolutely fixed exchange rate, the use of large interest rate increases to defend the fixed exchange rate can result in increases in the hedge ratio of a similar magnitude. What makes this effect important is that in a fixed exchange rate regime, or a quasi-fixed system such as the ERM, the boundary values for the nominal exchange rate become focal points for speculation about the direction of change of the exchange rate. Not only will more investors begin to hedge their exposures as the risk of realignment or a change in the parity increase, but the options that are written for customers will all tend to have similar exercise prices, so that they will tend to react similarly to changes in foreign interest rate. Moreover, as the spot foreign exchange rate falls toward the lower boundary value--a natural value for the put option's exercise price--the option's delta will become more sensitive to changes in the foreign interest rate (Figure 8).

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<sup>1/</sup> A central bank squeeze generally operates through overnight interest rates, which are not the interest rates used to value longer-dated options. Nevertheless, in a squeeze, a jump in overnight rates will usually have a strong impact on short- and medium-term interest rates, which are relevant to option pricing.

For example, in the United Kingdom on September 16, 1992, the Bank of England increased the base lending rate twice, from 10 percent to 12 percent and then again to 15 percent (effective the next day). 1/ The one-month London interbank offer rate increased from 10.4 percent at the end of the previous day to 28.9 percent at the end of the 16th. According to equation (1), such an interest rate increase would have resulted in a 22 percent decrease in the delta (or increase in the hedge ratio) of an at-the-money put, from -0.54 to -0.66--a larger change than would have been obtained from a 1.5 percent depreciation at the initial interest rate. 2/ In the Swedish market, the increase in the marginal lending rate from 75 percent to 500 percent on September 16 led to an increase in the one-month STIBOR rate from 25 percent to 70 percent. An increase of this magnitude implies a 14 percent decrease in delta. 3/ On November 19, the eve of the Swedish devaluation, the one-month STIBOR rate rose from 13.9 percent to 28 percent, implying an 18 percent increase in the hedge ratio. 4/

Industry sources indicate that indeed when there is an increase in the interest rate spread with no movement in the exchange rate, the forward rate discount will trigger a sell-off in the currency through dynamic hedging. During the ERM crisis of September 1992, for example, industry sources estimate that dynamic hedging sales to adjust positions because of increases in interest rate spreads, exchange rate movements, and increases in volatility accounted for 20-30 percent of the selling in the crisis. 5/ It apparently was a major factor in the lira market one week after the first devaluation and also in the Swedish krona market later in 1992. Up to ten percent of the sales were due to increases in interest rate spreads. In the case of the United Kingdom, on September 16, 1992 the dramatic increase in forward discounts triggered sales of pounds. When interest rates rose and nothing happened to the exchange rates, the selling programs were turned on. The lack of movement (appreciation) in the exchange rate meant that the forward rate fell farther below the floor. Thus, the full force of programmed sales triggered by interest rate movements was not offset by exchange rate improvement. Another source of the sales volumes at this moment was the rising perceived volatility resulting from the suddenly larger movement of the forward rate below the floor. The effect of dynamic

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1/ See Goldstein and others (1993) and Group of Ten (1993) for descriptions of the European currency crisis of 1992-93.

2/ On September 15, the one-month LIBOR rate for dollars closed at 3.0625 percent and the historical volatility of the \$/£ exchange rate, estimated over the previous month, was 15.8 percent per annum. As Figure 7 shows, if the banks sold options with volatilities higher than their historical levels, which during a speculative attack is very likely, the change in the hedge ratio may have been smaller.

3/ Based on a historical volatility, calculated over the previous month, of 6.08 percent.

4/ With an estimated volatility of 12.9 percent.

5/ These estimates were obtained during confidential interviews with market participants in October 1992 (see Goldstein and others (1993)).

hedging sales may also have been a source of some of the selling pressure observed on August 12, 1994 when the Italian lira depreciated sharply after the Banca D'Italia raised the discount rate by 50 basis points, though the consensus view is that markets reacted mostly in the belief that the interest rate increases were fiscally unsustainable.

In an exchange crisis therefore, a large defensive rise in the interest rate aimed at imposing a squeeze on speculators will instantaneously trigger hedging programs to order sales of the weak currency. 1/ The experiments conducted using the actual data on interest rates and historical volatility suggest that the selling triggered by dynamic hedging programs during an interest rate defense can be significant. The existence of a large amount of such programs in the market would undermine the use of an interest rate defense of a weak currency--the moment that a central bank raises interest rates, it might face an avalanche of sales of its currency rather than the purchases of the squeezed shorts that it had anticipated. In effect, the hedging programs make the hedgers insensitive to the added costs of funding their weak currency sales.

If the central bank has a credit line limit in foreign exchange or a self-imposed negative net reserve position, the upsurge of selling brought about by the interest rate increase might cause a sudden jump to its limit and force it to cease intervention in defense of the exchange rate. Whether this counterintuitive result occurs depends on the weight of these mechanistic 1/ traders relative to those caught in the short squeeze.

In one scenario, the hedging operation may in any case far exceed the amount of the weak currency demanded by those caught in the squeeze. In this case, the timing of the hedging sales--the prearranged rule for awakening the selling programs--relative to the time at which those caught in the short squeeze appear on the market is immaterial to the survival of

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1/ Who is actually squeezed in such a defense? All borrowers in the weak currency whose debts are due for settlement or rollover soon (after two days) will find that their costs and risks have suddenly jumped as they now have to pay high and volatile yields to the money market scalpers that are unleashed by the squeeze. This group could conceivably include even those who have constructed synthetic puts if they have established their short currency position by borrowing on overnight rollover credit, as Richard Lyons has pointed out to us. Typically, however, a synthetic option is constructed by establishing a short forward position whose expiration date coincides with the expiration date of the option. If many of the existing hedges were constructed within a one or three month period before the speculative attack and with a relatively long maturity, they would have locked in longer-term finance and the position would be immune from a short squeeze.

the fixed exchange rate. Dominance by the mechanistic hedgers will defeat the interest rate defense.

In the scenario in which the amounts of these opposite transactions are roughly balanced or even where those caught in the short squeeze dominate, the timing of transactions is key. If the selling programs switch on instantly, but the buying operations to cover short positions occur with some lag, the central banks' net short foreign exchange limit may be exceeded prior to the appearance of the buyers of its currency, causing the abandonment of the fixed exchange rate. Buyers might have appeared by the end of the day to offset the sellers, but the initial selling may unnerve the central bank and force devaluation. The devaluation will ratify both the actions of the sellers and of those caught in the squeeze who hesitated. Sellers will have sold prior to the devaluation of the exchange rate, and those caught in the squeeze can buy back into the weak currency at a lower price. If the central bank simultaneously relaxes the high interest rates, overnight borrowing will cease to be a problem for those caught short, and the squeeze will be suspended.

## VI. Conclusion

In their impact on the viability of the interest rate defense of a fixed exchange rate, dynamic hedging programs can be interpreted as a new wrinkle on an old phenomenon. Skeptical participants in the foreign exchange market have sometimes interpreted a defensive increase in the interest rate as the last rear-guard action preparatory to the abandonment of a fixed rate. In this light, the suddenly higher interest rate differential signals only the extent of the impending depreciation of the exchange rate and certainly not a drastic and extended tightening of liquidity in the weak currency's money markets. Interpreting the interest rate increase in this way dictates that a speculative selling program should be begun. Dynamic hedging programs automatically place this interpretation on an interest rate increase; thus, they are a mechanization of the previously informal skepticism that occasionally arose about exchange rate defenses. To the extent that such programs are present in generating large selling volumes, they signal a major shift toward skepticism about the strength of the central bank's adherence to the policy of defending the exchange rate, thereby undermining the efficacy of a previously useful defensive tool.

The scenario that we depict here is a technical story about the character of minute-by-minute trading in the death-throes of a fixed exchange rate. A dramatic interest rate increase in a last ditch defense triggers dramatic selling pressure. If this technical feature of the market is important in the last moments of a fixed exchange rate, it is necessary to implement a defense operation that takes it into account. For example, it is often argued that a resolute defense of a fixed exchange rate regime requires that at an early date interest rates be raised gradually, though

ultimately to high levels. 1/ Such a policy would trigger daily selling of the currency by dynamic hedgers, but not in quantities that would overwhelm the central bank's net reserve limits before the appearance as buyers by the end of the day of those caught short in the currency. Thus, raising rates gradually in an interest rate defense may immunize the central bank against being pushed beyond its position limits.

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1/ "Early" is relative to the time of outbreak of the next speculative attack. How to recognize when an attack will come in order to implement this early defense is problematic.

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