Volume Title: The Microstructure of Foreign Exchange Markets

Volume Author/Editor: Jeffrey A. Frankel, Giampaolo Galli, Alberto Giovannini, editors

Volume Publisher: University of Chicago Press

Volume ISBN: 0-226-26000-3

Volume URL: http://www.nber.org/books/fran96-1

Conference Date: July 1-2, 1994

Publication Date: January 1996

Chapter Title: Dynamic Hedging and the Interest Rate Defense

Chapter Author: Peter M. Garber, Michael G. Spencer

Chapter URL: http://www.nber.org/chapters/c11366

Chapter pages in book: (p. 209 - 228)

6 Dynamic Hedging and the Interest Rate Defense

Peter M. Garber and Michael G. Spencer

Hand in glove with the internationalization of portfolios and the interlinking of money markets across currencies has been the expanded use of methods to hedge currency risk. The rapid proliferation of hedging techniques and the reduction in communication and transactions costs have proceeded simultaneously with these trends. 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 transplantation 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.[1] 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 effect of dynamic hedging strategies on for-

Peter M. Garber is professor of economics at Brown University. Michael G. Spencer is an economist in the Research Department of the International Monetary Fund.

The authors thank Philippe Jorion, Paolo Kind, Richard Lyons, John Montgomery, Victor Ng, David Ordoobadi, the editors, and other conference participants for helpful comments and for discussions on the use of dynamic hedging by portfolio managers. The conclusions of this paper are those of the authors and are not necessarily those of the International Monetary Fund.

1. See, e.g., the Brady Commission (1988) and SEC (1988) reports. Grossman (1988) forecast this problem. Gennotte and Leland (1990) model the relation 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.

eign exchange markets during those crisis periods when even the exchange markets can become illiquid. Although 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 effect of hedging strategies on the efficacy of the classic central bank interest rate defense of a fixed exchange rate. It is typically believed that a central bank can defend an exchange rate if it is willing to raise short-term interest rates sufficiently high to squeeze holders of short positions 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 6.1, we outline the growth of the derivative markets in currency products and analyze the instruments available for balancing a currency position. We then describe the role of dynamic hedging in the currency markets. In section 6.2, we consider the hedging operations of nonbanks and the techniques in general use. We then analyze schematically the methods used by banks to hedge the currency exposures in their foreign exchange books. In section 6.3, we examine the mechanics of central bank currency intervention and the effect of interest rate defenses on market liquidity, 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 line or to its self-imposed position limit before buyers of the currency arrive.

6.1 The Role of Dynamic Hedging in Foreign Exchange Markets

6.1.1 Markets for Foreign Exchange Products

The use of financial derivatives has grown rapidly in recent years. The notional value of outstanding exchange-traded and over-the-counter (OTC) financial derivative contracts—including futures, forwards, forward rate agreements, swaps, options, caps, floors, and collars—has grown from approximately \$7.2 trillion at the end of 1989 to \$17.6 trillion at the end of 1992.[2]

2. 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, a simple interest rate swap may have a notional principal of \$10

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 derivatives markets has dramatically altered the nature of international finance and the behavior of market participants.

The 1992 notional amounts are composed of $4.8 trillion in exchange-traded contracts, $4.7 trillion in swaps, and $8.1 trillion in OTC options and forward contracts. 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 was $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 totaled $245 billion.

The OTC markets in derivative products are concentrated in the hands of 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 and 100 percent of all OTC derivative positions taken by U.S. banks.[3] 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 interdealer trades in which dealers seek to balance their positions.

Exchange-traded derivative products—futures and options—are standardized, retail-sized products. Although they are retail in nature, they are generally 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, evaluation of creditworthiness is less of an issue on organized exchanges than in the OTC market.[4] The most actively traded financial derivatives on organized exchanges are futures on interest rates, primarily U.S.

million. This notional value is not delivered as principal. Rather, the counterparties would deliver or receive the net between the fixed interest rate applied to $10 million and the floating rate amount, so the claims that the counterparties might have on each other are far smaller than the notional value.

3. Estimates reported in Board of Governors of the Federal Reserve System (1993). For discussions of the activities of banks in OTC derivatives markets, see also Bank of England (1993), Bank for International Settlements (1992), Deutsche Bundesbank (1993), Commodity Futures Trading Commission (1993), General Accounting Office (1994), Group of Thirty (1993), and Goldstein and Folkerts-Landau (1993).

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

Treasury bond rates, Eurodollars, French government bonds (OAT), German Bunds, and Japanese government bonds.

The expansion in derivatives markets is reflected in the turnover statistics that have also increased substantially in recent years. Annual turnover of exchange-traded derivatives increased from an estimated 420 million contracts in 1989 to 774 million in 1993.[5] The estimated global net foreign exchange market turnover, comprising transactions in spot and forward foreign exchange and currency swaps and OTC options, was $880 billion per day in April 1992, compared with $620 billion in April 1989 (Bank for International Settlements 1993). Spot trades accounted for 47 percent of reported turnover, while foreign exchange swaps resulted in 39 percent of turnover. Trading in currency futures averaged $9.5 billion per day, and trading in currency options averaged approximately $28 billion, about 82 percent of which was OTC.

6.1.2 Hedging Foreign Exchange Exposure

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. Institutional investors play an important role in such investment. 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 totaled $19.6 trillion. The sizes of their exposures in absolute terms and even in relation to their total assets can be quite large.[6] 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.

The risks from such holdings are hedged or 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 currency to cover settlement, a forward or future sale, or the

5. See Goldstein and Folkerts-Landau (1994). Intertemporal comparisons of trading volume are only suggestive; no adjustment is made for changes in the composition of trading activity across contracts of different sizes.

6. For a discussion of the foreign holdings of institutional investors in industrial countries, see Goldstein et al. (1993).

acquisition of a put option or 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 seek to ensure a floor to the domestic currency value of the foreign currency component of its portfolio, but the portfolio remains subject to the risk of currency fluctuations while the portfolio value is above the floor.[7]

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.

6.1.3 Mechanics of Option Pricing and Dynamic Hedging

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.[8] 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.[9]

7. 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.*

8. For the development of this formula, see Garman and Kohlhagen (1983) or Grabbe (1983). 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 option-pricing formulas for currencies restricted by target zones as in the European exchange rate mechanism (ERM). However, the majority of options contracts are written for dollar transactions. In April 1992, 82 percent of net foreign exchange turnover involved the dollar on one side of the transaction; only 7 percent of total net turnover involved exchanges of one ERM currency for another (Bank for International Settlements 1993). In the OTC options market, 74 percent of transactions involved the dollar.

9. Most exchange-traded currency options, other than those traded on the Philadelphia Stock Exchange, are options on futures, for which the Garman/Kohlhagen formula for spot exchange options is inapplicable. However, since the OTC segment of the options market accounts for more than 85 percent of activity (see Bank for International Settlements 1993), the formula for options

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

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

where r_{DM} and $r_{\$}$ 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.[10] $N(d_1)$ is the value of the normal distribution function evaluated at the argument

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

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

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 one 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 $\exp[-r_{\$}T]X$. 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.

on spot exchange rates is more relevant to our discussion. In any event, since currency futures contracts are very sensitive to changes in the interest rate differential, the delta of an option on a currency future is more sensitive to interest rate changes than is the delta of an option on the spot exchange rate, which would tend to strengthen our conclusion.

10. 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 Hull 1993).

The foreign exchange exposure of the agent that sells the put is to the *possibility* of having to buy deutsche mark at the exercise price at date T. Under the assumptions underlying 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 almost certainly be exercised, to 0, for a deep out-of-the-money option that would never be exercised. 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 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 $[1 - N(d)_1)]\exp(-r_{DM}T)$ deutsche mark spot for dollars and buying $[1 - N(d_2)]\exp[-r_{\$}T]X$ 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.

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 also 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 (see, e.g., Cookson 1993).

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, 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.

6.2 Dynamic Hedging by Type of Institution

6.2.1 Currency Risk Management by Fund Managers

Managers of pension funds, mutual funds, and bank trust accounts typically manage their currency risk by dynamic hedging operations—including the use of 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 an annual basis—fund managers' performance, and therefore their compensation, is often 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.

A hedge can be established by simply shorting the currency through a forward or future sale in a static hedge, by replicating a put option synthetically, by using constant-proportion portfolio insurance, or by acquiring an actual put option, thereby shifting the dynamic hedging operation to the seller of the put. 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.[11] This method has

11. 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 the horizon of the hedging operation.

become typical for fund management. As indicated above, this buy-high, sell-low strategy ex post will 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.[12] Rather, it is driven entirely by price movements. For example, one realization of this strategy may aim at outperforming a 50 percent hedged position and would begin with a 50 percent hedge. A 1 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 mere jump in volatility.[13]

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.

6.2.2 Risk Management of Bank Foreign Exchange Books

Because of internal risk-control operations and regulation of 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.

Regulation on banks' net foreign exchange positions varies widely across industrial countries.[14] 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 position limits on the dealing book, and limits on the extension of credit to individual counterparties.

The dominance of the major dealing banks in the markets for foreigu ex-

12. This strategy is referred to by Leland, O'Brien and Rubinstein and Associates as a perpetual protection policy.

13. 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.

14. For a discussion on the regulatory and internal constraints on banks' foreign exchange trading, see Goldstein et al. (1993).

change options complicates the control of foreign exchange risk and makes banks major users of dynamic hedging techniques. In its study of foreign exchange market transactions in April 1992, the Bank for International Settlements (1993) found that only 10 percent of options trading was conducted on organized exchanges. Moreover, two-thirds of the banks' options transactions, measured by notional principal, had other banks or dealers as counterparties and only one-third involved a nonbank counterparty.

The high ratio of interdealer to customer business can be attributed in part to the dealers' hedging operations. 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 on 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. Because OTC options are by nature nonstandard, however, 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.

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 possible only 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 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 1.00 for $\$X$ at time T and long one European put option to sell DM 1.00 for French francs at T^*. If the bank uses the Garman/Kohlhagen formula, its deutsche mark position from its options book is

Option	DM Position
1. Short 1 put DM/$	$[1 - N(d_1)]\exp[-r_{DM}T]$
2. Long 1 put DM/Fr	$-[1 - N(d_1^*)]\exp[-r_{DM}T^*]$

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.

6.3 Hedging in a Crisis

Dynamic hedging strategies are not an entirely new activity—stop-loss trading had 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 has been 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—notably, those involved in option replication—may interact with central bank exchange rate and liquidity policies to undermine a defense of a fixed exchange rate system.

When a fixed exchange rate regime moves toward a crisis, speculation against the currency is generally channeled 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.[15] 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).

Likewise, 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

15. 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.

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 also imposes 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. 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 position.[16] 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.

6.3.1 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 of formula (1).[17]

16. Even if a nonbank seller of puts exists somewhere in the financial system. the selling bank seeking cover may not find the nonbank seller of puts through the banking system. In a crisis. gross volumes of trading 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 interbank credit lines fill. volume will tend to move to the more secure organized exchanges.

17. As Bill Branson has reminded us, differentiating delta with respect to r_{DM} yields an expression that is not easily signed. In numerical evaluations. delta is a downward-sloping convex function of r_{DM} for most parameter values. However. for options with long maturities or very low implied volatilities or that are deep in the money. the relation may turn positive. although relatively flat. after sufficiently large increases in the foreign interest rate. For example. for the parameters used in fig. 6.1 below. if the contract maturity was six months. the slope would turn positive after r_{DM} exceeds 39 percent. For very long options (e.g.. one year) with very low volatilities. delta may be everywhere increasing in the foreign interest rate.

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 delta or hedge ratio increases.[18]

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 interest rate jumps upward. 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 portfolio. 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 6.1 provides some indication of this effect. This figure plots the put option delta against the foreign interest rate for a one-month, at-the-money put and for an in-the-money put of equal maturity where the spot exchange rate is assumed to be 1 percent below the strike price. Delta is a declining, convex function of the

---

Such anomalies are likely to be unimportant for three reasons. First, Bank for International Settlements (1993) data on the maturity structure of forward contracts show that foreign exchange dealers' positions are strongly weighted toward the near term: 64 percent of contracts have maturities of less than a week, 99 percent are for less than a year, and ERM currencies have relatively short maturities compared to non-ERM currencies. In addition, futures and exchange-traded options transactions tend to be concentrated in contracts with maturities well below one year. Thus, the behavior of long-term options may not be very relevant. Second, central bank liquidity squeezes generally have their greatest effect on short-term interest rates, so increases in long-term rates are unlikely to be large enough to reverse the tendency toward an increase in the hedge ratio. In the United Kingdom, on 16 September 1994 six-month sterling deposit rates rose only twenty basis points, while one-week rates rose by thirty-five hundred basis points; during the ERM crises, six-month interest rate differentials against dollar LIBOR (London interbank offered rate) rates were highest for Sweden, and these reached only 23 percent. Finally, simulations using actual interest rates and historical volatilities for the currencies involved in the ERM crisis failed to yield any cases where the slope reversed over the range of observed interest rates. Since actual volatilities used in pricing options during a crisis can be expected to exceed historical volatilities, it is likely that the slope of the delta:r_{DM} relation was if anything more negative than that implied by either these simulations or fig. 6.1.

18. 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 effect on one-month, three-month, and even one-year interest rates, which are relevant to option pricing. As the maturity of the option lengthens, a given movement in the relevant interest rate will have a stronger effect on the value of option and on the delta.

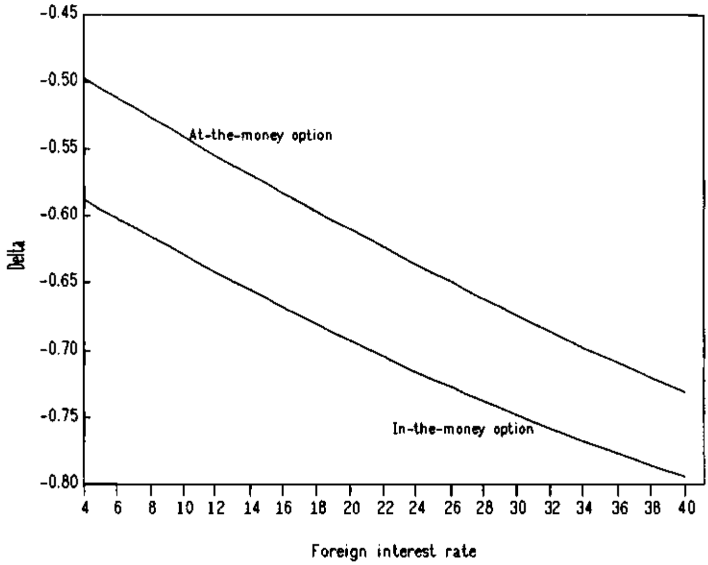

Fig. 6.1 Sensitivity of the put option delta to the foreign interest rate
Note: Assumptions: domestic rate of 3 percent, volatility of 15 percent, one-month option.

foreign interest rate. The response of dynamic hedging programs during the final days of a managed or fixed exchange rate regime can be inferred from such plots. 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.

In the United Kingdom, for example, on 16 September 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).[19] 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 sixteenth. Such an interest rate increase would result in a decrease in the delta (or an increase in the hedge ratio) of an at-the-money put of over 20 percent, from −0.54 to −0.66—a larger change than would have been obtained from a 1 percent depreciation at the initial interest rate. In the Swedish market, the increase in the marginal lending rate from 75 percent to 500 percent on 16 September led to an increase in the one-month

19. For descriptions of the European currency crisis of 1992–93, see Goldstein et al. (1993) and Group of Ten (1993).

STIBOR (Stockholm interbank offered rate) rate from 25 to 70 percent. An increase in rates of this magnitude would imply a 30 percent increase in the hedge ratio. For countries such as France and Italy where one-month interest rates were not as variable, the largest increases in delta that would be implied by the interest rate data are of an order of magnitude of 10 percent.

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.[20] The experiment conducted using the contracts illustrated in figure 6.1 suggests that the selling triggered by dynamic hedging programs during an interest rate defense can be significant. Since delta approximates the proportion of the portfolio to be hedged by short positions in the foreign currency, these examples suggest that short positions might be increased by 20 percent or more of the portfolio value in response to an aggressive interest rate increase. 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.[21] In effect, the hedging programs make the hedgers insensitive to the added costs of funding their weak currency sales.

20. 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 in his conference comments. 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 the existing hedges were constructed well before the interest rate defense was launched and with a relatively long maturity, they would have locked in longer-term finance, and the position would be immune from a short squeeze.

21. 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 selloff in the currency through dynamic hedging. During the European exchange rate mechanism crisis of September 1992, e.g., 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. It was a major factor in the lira market one week after the first devaluation and also in the Swedish krona market in 1992. Up to 10 percent of the sales were due to increases in interest rate spreads. In the case of the United Kingdom, on 16 September 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 hedging sales may also have been a source of some of the selling pressure observed on 12 August 1994, when the Italian lira depreciated sharply after the Banca D'Italia raised the discount rate by fifty basis points, although the consensus view is that markets reacted to a belief that the interest rate increases were fiscally unsustainable.

If the central bank has a credit line limit in foreign exchange or a self-imposed net reserve position limit, 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 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 the fixed exchange rate. Dominance by the mechanistic hedges 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 the actions both 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.

6.4 Conclusion

In their effect 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 rearguard 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, although ultimately to high levels.[22] 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 intraday beyond its position limits.

References

Bank of England. 1993. *Derivatives: Report of an internal working group.* London, April.

Bank for International Settlements. 1992. *Recent developments in international interbank relations.* Basle, October.

———. 1993. *Central bank survey of foreign exchange market activity in April 1992.* Basle, March.

Board of Governors of the Federal Reserve System. Federal Deposit Insurance Corporation. Office of the Comptroller of the Currency. 1993. Derivative product activities of commercial banks. Joint Study Conducted in Response to Questions Posed by Senator Riegle on Derivative Products. Mimeo. Washington, D.C., 27 January.

Brady Commission. 1988. *Report of the Presidential Task Force on Market Mechanisms.* Washington, D.C.: U.S. Government Printing Office.

Chiang, Raymond, and John Okunev. 1993. An alternative formulation on the pricing of foreign currency options. *Journal of Futures Markets* 13, no. 8:903–7.

Commodity Futures Trading Commission. 1993. *OTC derivative markets and their regulation.* Washington, D.C.

Cookson, Richard. 1993. Moving in the right direction. *Risk* 6, no. 10:22–26.

Deutsche Bundesbank. 1993. Off-balance-sheet activities of German banks. *Monthly Report of the Deutsche Bundesbank* 45, no. 10:45–67.

Dumas, Bernard, L. Peter Jennergren, and Bertil Näslund. 1993. Realignment risk and currency option pricing in target zones. Working Paper no. 4458. Cambridge, Mass.: National Bureau of Economic Research.

Garman, M., and S. Kohlhagen. 1983. Foreign currency option values. *Journal of International Money and Finance* 2:231–37.

22. "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.

General Accounting Office. 1994. *Financial derivatives: Actions needed to protect the financial system.* Washington, D.C.: U.S. Government Printing Office.
Gennotte, Gerard, and Hayne Leland. 1990. Market liquidity, hedging and crashes. *American Economic Review* 80:999–1021.
Goldstein, Morris, and David Folkerts-Landau. 1993. *International capital markets, part II: Systematic issues in international finance.* Washington, D.C.: International Monetary Fund.
———. 1994. *International capital markets developments, prospects and policy issues.* Washington, D.C.: International Monetary Fund.
Goldstein, Morris, David Folkerts-Landau, Peter Garber, Liliana Rojas-Suarez, and Michael Spencer. 1993. *International capital markets, part I: Exchange rate management and international capital flows.* Washington, D.C.: International Monetary Fund.
Grabbe, O. 1983. The pricing of call and put options on foreign exchange. *Journal of International Money and Finance* 2:239–53.
Grossman, Sanford J. 1988. An analysis of the implications for stock and futures price volatility of program trading and dynamic hedging strategies. *Journal of Business* 61, no. 3:275–98.
Group of Ten. 1993. *International capital movements and foreign exchange markets.* Rome.
Group of Thirty. 1993. *Derivatives: Practices and principles.* Washington, D.C.
Hull, John C. 1993. *Options, futures, and other derivative securities.* 2d ed. Englewood Cliffs, N.J.: Prentice-Hall.
Kroner, Kenneth, and Jahangir Sultan. 1993. Time-varying distributions and dynamic hedging with foreign currency futures. *Journal of Financial and Quantitative Analysis* 28, no. 4:535–50.
Melino, Angelo, and Stuart Turnbull. 1990. Pricing foreign currency options with stochastic volatility. *Journal of Econometrics* 45:239–65.
Naik, Vasanttilak. 1993. Option valuation and hedging strategies with jumps in the volatility of asset returns. *Journal of Finance* 98, no. 5:1969–83.
Perraudin, William R., and Bent E. Sorenson. 1992. Foreign exchange option pricing in a continuous time arbitrage pricing model with stochastic volatility and jumps. Birkbeck College, University of London. Mimeo.
Securities and Exchange Commission (SEC). 1988. *The October 1987 market break.* Washington, D.C.: U.S. Government Printing Office.

Comment Richard K. Lyons

This comment is intended to clarify assumptions embedded in the option hedging analysis of the Garber and Spencer paper. In particular, the authors state (in section 6.3.1) that "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."

Here, I demonstrate that this result is not unambiguous; rather, additional assumptions are required regarding the interest sensitivity of the underlying

Richard K. Lyons is associate professor in the Haas School of Business at the University of California, Berkeley, and a faculty research fellow of the National Bureau of Economic Research.

portfolio's value relative to the hedge's value. To do so, I present a transparent example using a money market hedge, which is a special case of their option foreign exchange hedge.[1] The analysis of Garber and Spencer spans this case since—assuming frictionless markets—a money market hedge is equivalent to a forward hedge, which is in turn equivalent to a put option hedge with a strike price of infinity.

Assumptions

1. Two-period investment horizon.
2. Equal borrowing and lending (investment) rates for the same maturity.
3. Foreign exchange hedge ratio is constant.

Notation

R_1^{DM} = one-period nominal deutsche mark interest rate.
R_2^{DM} = two-period nominal deutsche mark interest rate.

The Four Cases

Case 1: (i) Investment: R_2^{DM}
(ii) Hedge borrowing: R_2^{DM}
(iii) $\uparrow R_1^{DM} \Rightarrow$ no change in deutsche mark borrowing for hedge $\Rightarrow$ *no spot sale of deutsche mark*

Case 2: (i) Investment: R_1^{DM}
(ii) Hedge borrowing: R_1^{DM}
(iii) $\uparrow R_1^{DM} \Rightarrow$ no change in deutsche mark borrowing for hedge $\Rightarrow$ *no spot sale of deutsche mark*

Case 3: (i) Investment: R_2^{DM}
(ii) Hedge borrowing: R_1^{DM}
(iii) $\uparrow R_1^{DM} \Rightarrow \downarrow$ in deutsche mark borrowing for hedge $\Rightarrow$ *spot purchase of deutsche mark*

Case 4: (i) Investment: R_1^{DM}
(ii) Hedge borrowing: R_2^{DM}
(iii) $\uparrow R_1^{DM} \Rightarrow \uparrow$ in deutsche mark borrowing for hedge $\Rightarrow$ *spot sale of deutsche mark*

From these four cases it is clear that the Garber-Spencer effect on the spot market holds only in case 4. This may well be the relevant case for most investors, but that is an empirical matter. Note that if investors are using rolling hedges, as many do, then cases 2 and 3 might be more relevant. (Rolling hedges involve the rolling over of the hedge position because the hedging instrument has a shorter maturity than the cash flow being hedged.)

1. A money market hedge involves either borrowing or lending in the foreign currency to set up an offsetting foreign currency cash flow. Importantly, putting on (or changing) a money market hedge will also involve a transaction in today's spot market.