FORD RESEARCH LABORATORY
Mark P. Everson , Christophe G. E. Mangin , Suzhou Huang, Cody Stumpo and JoAnn M. Schwartz

Evaluating Strategies for Foreign Exchange Risk Reduction

A B S T R A C T

Ford has a significant risk to its profits from changes in foreign exchange (FX) rates, due primarily to the international flows of parts and vehicles. Risk due to foreign exchange rates can be reduced using market-based instruments. For example, one market instrument, the forward, allows the locking-in of a future exchange rate. This provides insurance against adverse currency moves. The goal of Ford's foreign exchange hedging program is to reduce the company's FX risk to an acceptable amount in the most efficient manner.

We have used the value-at-risk (VaR) methodology to evaluate the risk of foreign exchange portfolios. Value-at-risk measures the worst expected loss of a portfolio under normal market conditions, for a given confidence level, over a given time period. Based on VaR, we have developed an optimization framework for evaluating the risks and benefits of different hedging strategies. The best strategy is to hedge an identical percentage of each FX exposure with forwards. Our results validate the Company's current basic strategy for FX risk reduction efforts.

INTRODUCTON

A global Company, such as Ford, engages in many transactions involving future commitments in different currencies. For example, Ford may sign a contract to build a factory in Mexico expected to cost 1 billion pesos one year from now. The current plan is to pay $100 million dollars at today's exchange rate. The exchange rate, however, fluctuates, and one year from now, the market may value the peso at 9 to the dollar instead of the currently assumed 10. In such a case, the plant would cost $111 million one year from now. In this case, Ford runs the "risk" of incurring an $11M unanticipated cost, one year from now. The source of this risk is called the foreign exchange (FX) **exposure**, in this case $100M. Of course, it is roughly equally likely the peso could move in the other direction relative to the dollar and the Company would stand to gain. The latter instance is the essence of currency speculation for profit. The Company, on the other hand, is not interested in speculation for profit, but rather in avoiding losses to core activities due to currency fluctuations. In the parlance of the trade, the Company engages in "risk-management". In the FX area this is the job of the Foreign Exchange Strategy Department in the Treasurer's Office. Risk management involves two general problems, the first is measurement of the risk and the second is undertaking actions to reduce the risk to acceptable levels.

The need to determine this risk is driven not only by business, but by legal requirements. In 1997, the Securities and Exchange Commission introduced an annual reporting requirement whereby certain corporations (Ford among them) are required to report several types of market risk including foreign-exchange risk. Corporations were allowed a choice between several approaches that would allow investors to gauge the company's risks. One very common approach in the financial community to report risk is to calculate a number, called the value-at-risk (VaR). Further discussion of VaR (1) follows below. In words, the VaR is a single value summarizing the maximum loss on a portfolio at some level of confidence over a certain time period. Ford has used a method developed by J.P. Morgan, called RiskMetrics, and in its 1998 annual report, Ford stated a VaR from foreign exchange of approximately $300M with a monthly risk horizon at 99% confidence. We will discuss the meaning of the risk horizon and confidence level shortly.

Risk measurement depends on the essential assumption that the fluctuations in exchange rates are random and can be described quantitatively by their statistical properties. If one takes the fluctuations of exchange rates to have a normal (gaussian) distribution there are two important resulting ideas. The first is that the risk for a single currency is related to the magnitude of the fluctuations as measured by the standard deviation of the currency value. The standard deviation, in financial terms, is also called the **volatility**. The second idea is that the overall profit (loss) is the sum of the contributions from all currencies. The volatility of this sum involves a combination of the volatilities associated with the individual currencies and the coupling in movements between the currencies, as measured by their **correlation**. Two independent random variables (uncorrelated) have correlation = 0; currencies moving in lock-step have perfect positive correlation (+1); and currencies moving precisely out-of-phase have perfect negative correlation (-1). In modern theories of financial diversification, also called portfolio management, the lack of perfect correlation between assets is the reason why mixtures of holdings have lowered risk. This is because on many occasions, losses in one area will be offset by gains in another. Offsets of losses never occur for two asset types with perfect positive correlation, whereas they always occur for perfect negative correlation. In between the two extremes, offsets of losses happen with higher frequency as the correlation coefficient moves from positive correlation to negative correlation. The use of the statistical properties and the estimation of parameters for the purposes of calculating the actual Company risk, for example in dollars, raises many issues discussed below. The important point to be made next, however, is not just that risk can be calculated, but that something can be done to mitigate it.

Risk reduction, known as **hedging** in the financial community, can be approached by two basic methods in the currency area. Essentially the Company takes out various types of "insurance" against these risks. The first, called a **forward**, is to reduce the uncertainties by "locking in" a future exchange rate. A forward is a contract, signed with an institution, to buy or sell a certain currency at a certain rate in the future. For example, consider the case above of using dollars to pay for a factory addition in Mexican pesos. If a bank or other institution were willing to contractually guarantee to provide a billion Mexican pesos in exchange for $100 million in one year, then the currency risk associated with the factory expansion would be eliminated. This is essentially what a forward does. The only proviso is that the actual exchange rate used is set by the market. So although the company might project a future rate of 10:1, the market might have determined some other rate at which participating institutions are willing to provide the one-year forward contracts. Since forward contracts are structured to exchange currencies at a market-determined fair price, entering into a forward contract has no up-front cost.

The second major type of instrument used in risk management are **options**. FX options, like forwards, contain a future exchange rate, called the strike rate. But unlike forwards, one party in the transaction has the choice of whether or not the exchange will occur. The party with this choice will only exercise the option if it has a positive value at the date the option takes effect. Because one party in the option transaction is protected from any loss, the other party requires an up-front payment to enter into the contract. In the hedging of an exposure, options allow the purchaser to reduce or eliminate their risk, without compromising the possibility of gain. Of course this potential gain comes at the price of having to purchase the option.

The aim of corporate risk-management programs is to devise a selection of hedging actions which "efficiently" reduce the profit risk to the company. The management choices, however, are not simple because of the many currencies involved, the somewhat unpredictable amount of each exposure, and certain general business constraints that will be discussed in more detail below.

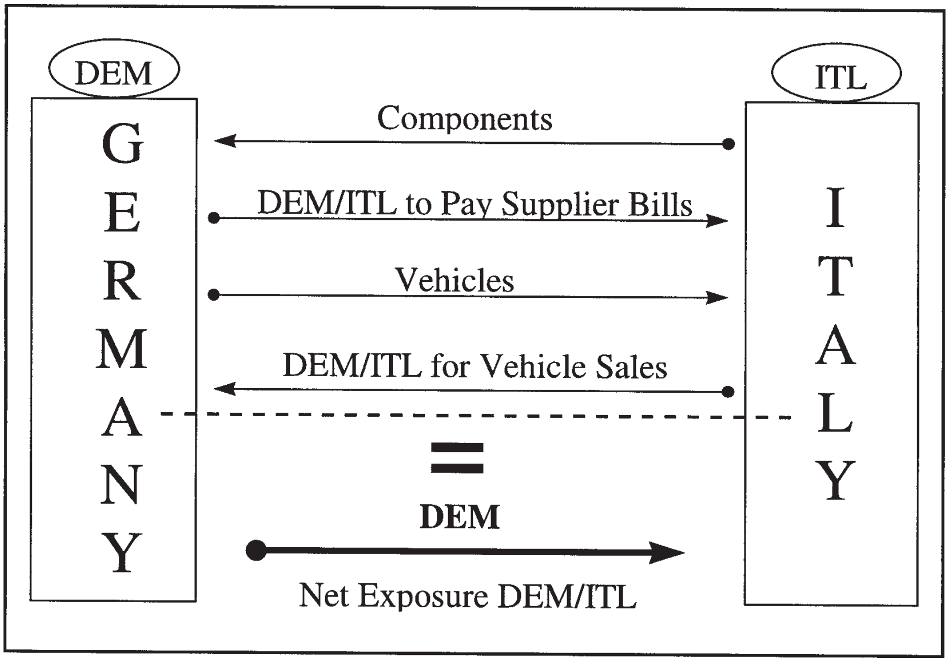
RESEARCH PROBLEM STATEMENT

The Company's current risk-reduction strategy for foreign exchange is basically to hedge an equal percentage of every exposure. For instance, hedging 50% of a $100 million $/peso exposure would be accomplished by buying a forward with base value of $50 million that locked in the future exchange rate. Hedging half of an exposure reduces the risk by half. The hedging is done primarily with forwards. The primary reason for this approach is that hedging each exposure completely (100%) is considered a desirable goal, but would be very difficult to implement because of institutional costs. This is because some predicted foreign exchange exposures can change substantially over time. Accounting rules penalize the Company for having an exposure greater than 100% hedged, which could happen often if exposures previously hedged at 100% shrunk in size.

Given that the currency pairs associated with each exposure can have different volatilities, and different correlations between currency pairs, it was not clear at the beginning of this work whether hedging every exposure at an equal percentage was the best way to protect the Company. Our goal was to use the value-at-risk methodology to determine the risk of a variety of potential hedging strategies. Previous to this work the only studies undertaken on the risk reduction expected from the current hedging strategy were calculations based on historical results over time periods of several years.

There were three major areas of interest we wished to explore. First, is value-at-risk a reasonable approach for estimating the Company's foreign

FIGURE 1 *Example of the types of currency translations that go into figuring the value of an exposure. In this case we look at flows between Germany and Italy.*



exchange risks? Second, is the basic strategy of hedging every exposure at an equal percentage the best one to use? And third, when exceptions are considered to the basic strategy for operational or other reasons, what is the best way to measure the tradeoffs between risk and predicted returns? This would help in the evaluation of whether modifications to the strategy are worthwhile or not.

One example of when modifying the basic strategy could be justified would be when acting on behalf of a foreign subsidiary that for competitive reasons may have a desire to limit its hedging. For instance, hedging can lock in an uncompetitive cost structure for the subsidiary (with respect to companies based in the foreign country). This is because for countries with high interest rates, the market will only issue forwards with an exchange rate where the high-interest-country's currency is of substantially lower value. So, in buying a forward to hedge the exposure, that potentially disadvantageous future exchange rate is locked in for an affiliate in that country since the affiliates are ultimately responsible for hedging costs associated with their business. If exchange rates do not follow the market-predicted path, then the affiliate would be paying higher rates for everything it imports. This would make its products more expensive, and reduce profits. It would be valuable to have an effective way to compare the tradeoffs between costs of a given hedging strategy to the subsidiary, with the change in risk to which the Company is exposed.

Our benchmarking and literature studies have lead us to conclude, with some caveats, that VaR is a reasonable way to measure the Company's FX risk. We have developed a novel framework for looking at FX risk from a corporate perspective, using value-at-risk as a base. We have used that framework to study and fundamentally validate the current foreign exchange risk management practice at Ford. These results have been reported to, and accepted by, senior Treasury management. We will discuss our new risk-management framework, and the results that have come from it, after some further discussion of several areas important to the understanding of the FX risk-management problem.

FX EXPOSURES

As introduced above, the Company is exposed to significant risk from changes in currency values. The business plan requires cash flows between currencies at various times to convert revenues from one country into another country's currency to pay suppliers and employees, satisfy contracts and commitments, purchase other companies, etc. If exchange rates have moved from the forecast exchange rates for that time period, the company will realize either a gain or loss on the currency translation. At the root of the FX risk problem are the Company's exposures.

Exposures are generally forecast for the coming six quarters. The exchange rates which are used for this calculation are from the Ford Corporate Economics and Strategic Issues Department forecasts. Figure 1 presents some examples of goods and money flows between Germany and Italy resulting, in this particular case, in a net exposure in the German currency (DEM for Deutschemark) compared to the Italian currency (ITL for Italian Lira). In the example the Company produces vehicles in Germany and purchases components from Italian suppliers who need to be paid in German and/or Italian currencies. At the same time, the Italian market is buying Ford vehicles and the revenues from these sales are paid out to suppliers in either German or Italian currencies.

Since exposures are based on predictions of both future sales and exchange rates, the initial predictions are only a current best estimate of the final value. We will assume the forecasts for exposures are correct predictions that do not vary with time in this study, but have removed this assumption in other studies (2). Those studies have found, based on limited data, that predicted exposures between selected currency pairs can fluctuate by amounts as large as 35% per quarter, at a 67% confidence level. The hardest-to-predict currency pairs can actually change in sign as well as magnitude over a year's time. So any hedging strategy needs to take into account these fluctuations in predicted exposures. Once the exposures are predicted, and their potential changes over time noted, a hedging strategy can be pursued using financial instruments such as forwards and options.

HEDGING INSTRUMENTS

There are a large variety of financial instruments available to the company for hedging FX risk. The most common among these are FX forwards, and options (3), as was mentioned in the introduction. A forward guarantees a future exchange rate (the forward rate) at which the currencies will be traded on a particular date. A forward is called a linear instrument, since its value tracks the underlying exchange rate proportionally. The specific approach to statistical handling of financial instruments in the VaR model we have used in this study is only rigorously correct for linear instruments, like forwards. An Option gives the purchaser the right, but not the obligation, to trade at a determined exchange rate (the strike rate) at some future date(s). For this privilege the purchaser must pay the issuer. Options are non-linear instruments because the purchaser has the choice of whether or not to exercise them. Non-linear instruments need to be handled by a Taylor series approximation when calculating their contribution to risk in the VaR formalism we have used.

The exchange rates used for forwards and options are determined by the currency markets. These market rates are in some sense a forecast that integrates all information currently available to the market. In the case of forward rates there is substantial academic discussion on whether or not a forward rate is the "market's forecast" of future exchange rates, and of the quality of that forecast (4). Some of this discussion is reviewed in reference 4. We simply take the market-determined forward rate as one reasonably objective forecast for the future value of a currency. What hedging with forwards does allow, is a form of insurance against changing currency values. This insurance is very inexpensive if one considers the forward rate as being relatively close to the expected future value for the exchange rate.

VALUE-AT-RISK

Once the exposures in the portfolio have been determined, and alternative hedging actions have been identified, we can estimate the risk of the hedged portfolio using a value-at-risk calculator. The ultimate choice of hedging actions is then a decision which rests on the tradeoffs between risk and total corporate profits. Here the corporate profits are taken to include estimated opportunity costs of hedging, such as those for developing-country affiliates as discussed in the Research Problem Statement. In practice, the hedging strategy needs frequent evaluation because of the changing market dynamics and exposure forecasts. For this purpose, Ford has chosen a risk-calculator system, called RiskManager, which uses the RiskMetrics (5) approach to VaR, developed by J. P. Morgan.

This methodology uses a set of relatively simple assumptions about the future behavior of the markets to determine estimated currency fluctuations, and their correlations. These estimates are then coupled with the Company's estimated exposures to determine the overall risk. Because the VaR methodology includes correlations between positions, as well as their individual expected fluctuations, it gives a measure of risk that includes the diversification benefit.

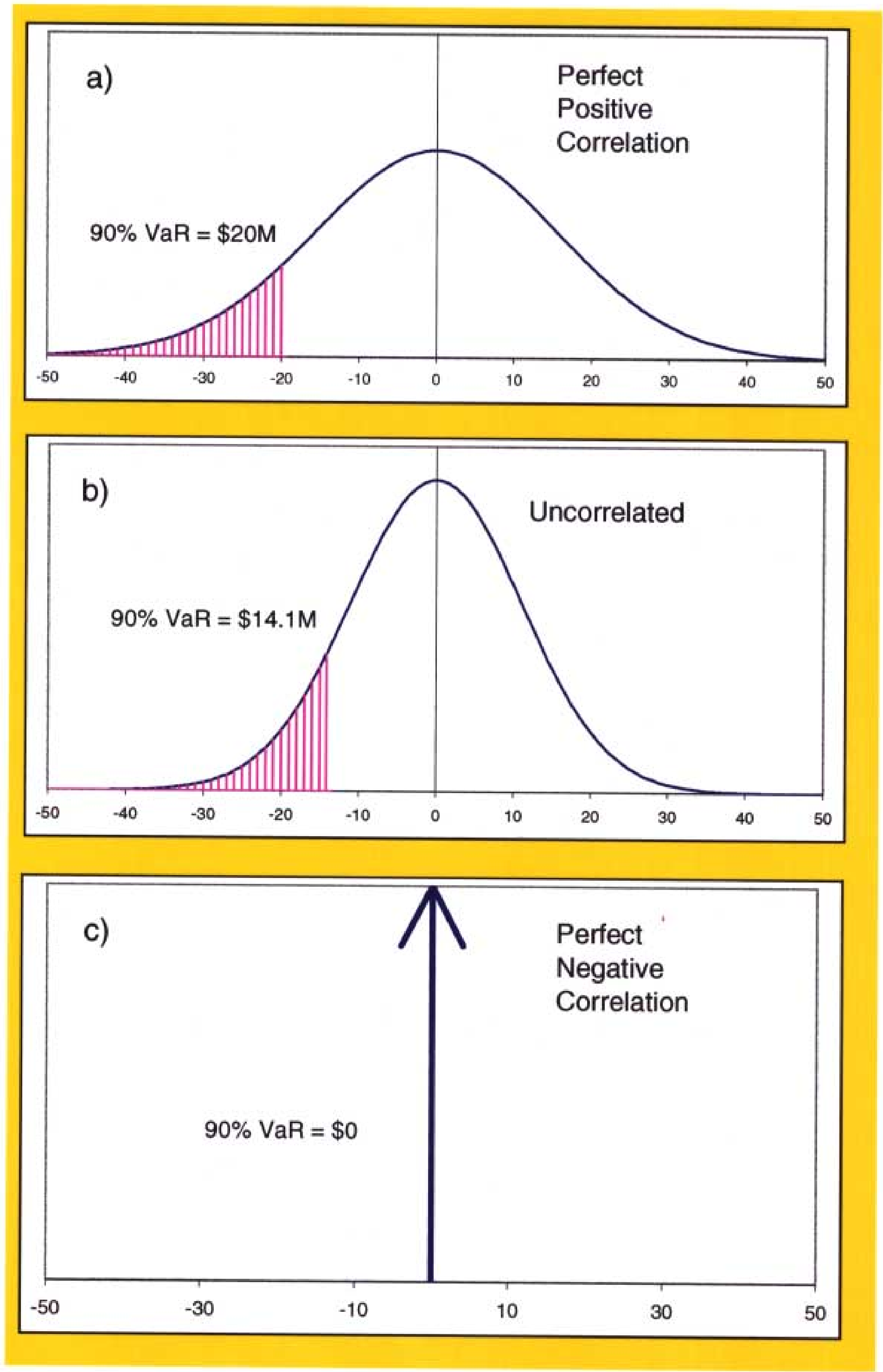
Value-at-risk provides a single value summarizing the maximum loss on a portfolio of financial instruments at some level of confidence (e.g. 99%) over a certain time period. VaR singles out, from an estimated distribution of potential future outcomes, the loss (say, in $U.S.) associated with a given likelihood (confidence level). For instance, a portfolio having a 1-month horizon, 99% confidence level, VaR of $1 million indicates that in one month's time there is a 1% chance that losses will equal or exceed $1 million. The distribution of potential outcomes is generated using a set of rules describing how future prices might evolve from current prices. There are many possible value-at-risk approaches that differ in many areas, including the assumptions used to project the statistical properties of future exchange rates.

The RiskMetrics approach to VaR was developed by J.P. Morgan, primarily for use in banking risk evaluation. The approach makes a number of assumptions about the statistical properties of financial variables, like foreign exchange rates. There are two critical assumptions of the methodology. The first is the use of historical data over approximately the prior six months to estimate the future fluctuations (volatilities) of financial variables and also their correlations. The second assumption is that the natural logarithm of the return of each underlying financial variable (in our case FX exchange rates) follows a normal distribution with an expected average value similar to that in the recent past. (Footnote: The use of the natural logarithm of returns rather than just the returns themselves is necessary because returns from two consecutive time periods are not additive, but multiplicative. Use of the logarithm gives this correct property to the returns since adding logarithms is equivalent to multiplication. It also ensures an asset's value can never go below zero. The only complication added by using the log approach is that the final log return needs to be exponentiated to obtain the actual return.) So the future evolution of the value of each financial position is taken to be a normal distribution whose volatility (standard deviation) is based on that position's fluctuations in the recent past. The RiskMetrics value-at-risk approach combines the volatility of each instrument with the correlations between instruments in a portfolio to determine a normal distribution which predicts the expected evolution of the value of the portfolio. The final VaR number represents the dollar value loss that corresponds to the selected confidence interval for risk measurement.

In order to understand the research questions underlying the foregoing discussion, the statistical meaning behind the value-at-risk needs to be clarified. Let us consider, first, the case of a single foreign currency's value versus the U.S. dollar. We are interested in how much the value of a holding in that currency might change over time, so we will use the return on our investment as the item of fundamental concern. If we use information from the FX markets to calculate the log returns at the end of each day over some time period, like a quarter, we will get about 75 points. If we organize the return axis into 'bins' and make a histogram showing log returns on the x axis, and frequency on the y axis, we will get a roughly gaussian curve (a normal distribution). The time dependence of the fluctuations of returns in the currency markets gives approximately the same type of result that one would get for a physical process, specifically a one-dimensional random walk.

A random walk is a stochastic process for which there is a well-developed theoretical foundation. Intuitively, we can envision schematically that the "random" motions of currency returns, as new economic information becomes known to the market, approximately follows a one-dimensional random walk. From this

FIGURE 2 *Illustration of the value at risk for the case of a two-asset portfolio where each asset alone has a VaR of $10M. The shaded area of each curve shows the part of the normal distribution where losses are greater than or equal to the VaR. The area fraction that is shaded is 10% of that under the curve, giving a 90% confidence VaR. Changing the correlation between the two asset classes gives dramatic changes in the value at risk, as discussed in the text.*



assumption, it follows that the fluctuations in a financial asset in general, and foreign exchange rates in particular, are log-normally distributed, i.e. the logarithm of the return is normally distributed. So the time evolution of currency returns can be modeled exactly the same as the time evolution in a one-dimensional random walk. The use of this analogy drastically simplifies the calculation of value-at-risk without greatly increasing the error.

The assumption that all assets (in our case hedged exposures of pairs of currencies) behave in a gaussian fashion makes calculating the distribution that represents the total portfolio value fairly straightforward. This is because the distribution representing the sum of a group of variables with gaussian dependence (assuming a mean of 0) is itself a gaussian distribution whose characteristics are completely determined by the standard deviations of each variable, and their correlations. To get the portfolio's expected future distribution, we just combine the amount and volatility of each asset, and its correlation with the other assets, in a big matrix multiplication.

Having obtained the volatility of the entire portfolio, the calculation of the VaR reduces to finding the value of the loss corresponding to the desired confidence level. For instance, if we are calculating a 90% confidence value-at-risk we will find the portfolio value, in dollars, beneath which 10% of the area is found. Figure 2a shows one example of the relationship between the area under the gaussian curve and the VaR.

Figure 2 diagrams the results of several simple VaR calculations. It shows the effect that correlation between positions has on the calculated distribution of future outcomes for the case where there are only two elements in the portfolio. The two individual positions in the portfolio are taken to each have the same VaR (= $10M) by themselves, and only the correlation between them is varied. As is seen from the figure the distribution is widest, and the risk largest, when the two assets are perfectly correlated. Some diversification benefit (reduction in VaR) is realized when the two assets are un-correlated. (The diversification benefit becomes more substantial when a large number of un-correlated asset types are added together in a portfolio.) Finally, when the two assets are perfectly anti-correlated, the risk goes to zero. This last case is what occurs when an exposure is coupled with a hedge like a forward, as discussed above. So long as the hedging instrument moves in value precisely opposite to the change in value of the underlying exposure, the risk will be zero.

FX HEDGING EVALUATION AND OUR APPROACH

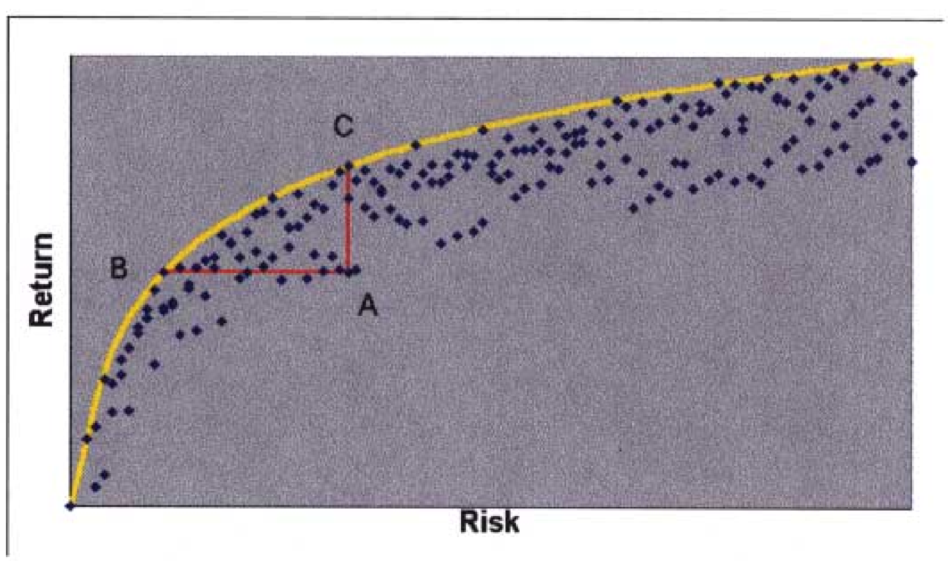
The details of an FX hedging strategy typically specify the types of hedging instruments, and the amount of each exposure that is hedged. Such a strategy can be determined using an optimization procedure to find portfolios that have attractive characteristics. The characteristics will likely be low risk combined with some other parameter. The other parameter might be, for instance, low hedging cost, high expected return, or low opportunity cost. There are some standard approaches from the finance literature that are potentially applicable to FX hedging evaluation. We will discuss one such approach, modern portfolio theory, before introducing our approach to the FX hedging problem.

MODERN PORTFOLIO THEORY AND THE EFFICIENT FRONTIER

Modern portfolio theory provides a consistent way to explore the risk-return properties of portfolios of financial assets (6). The mean (average) expected return of each portfolio is plotted vs. the predicted risk (volatility) of the portfolio value in the future. See figure 3 for an

FIGURE 3

Diagram illustrating the efficient frontier in modern portfolio theory. Each diamond represents an individual portfolio plotted for its risk vs. return. Only a limited number of possible portfolios are shown for clarity. The efficient frontier is plotted as a yellow line. If an investor's portfolio is not on the efficient frontier, then it is always possible to generate a portfolio that has better return at the same risk, and/or lower risk at the same return. See the section on modern portfolio theory for further discussion.



example. The risk of the portfolio is usually calculated using historical volatilities and co-variances among the asset classes, just as in value-at-risk. Modern portfolio theory includes the diversification benefits discussed above. One major historical importance of modern portfolio theory is that it highlighted the significant risk-reduction opportunities available through diversification, both across asset classes, and within them.

Modern portfolio theory allows investors with different levels of risk aversion each to find a portfolio with optimal return. After performing a mean-variance-based optimization on a universe of portfolios, the best return for each level of risk is identified. The curve consisting of all these optimal points is called the efficient frontier (EF). In figure 3 the efficient frontier is shown as a yellow line. Investors should hold the portfolio that is on the efficient frontier that matches their risk tolerance. For instance, suppose an investor were to hold a portfolio below the efficient frontier, represented by portfolio A in figure 3. By changing to portfolio C that investor can, at the same risk, achieve a greater return. Alternately, by changing to portfolio B, the investor could achieve the same return at a significantly lower risk. Clearly, regardless of risk aversion, the investor should prefer Any portfolio on the efficient frontier along the chord BC to the portfolio A. Each point along that chord has both higher return and lower risk than portfolio A.

One disadvantage of Modern portfolio theory for FX portfolio optimization is that if one takes the market-determined forward rates as a forecast of the future exchange rate, the efficient frontier collapses to a horizontal line. This is because the average return is always the same for an exposure and the forward that hedges it. With no reward in return for taking on extra risk the investor or corporation would always fully hedge each position, giving the lowest risk available. Thus effective use of Modern portfolio theory for FX hedging evaluation requires taking a view other than the forward rate as the future value, and using the mean return from the view. This would be an appropriate approach for a profit-center hedging activity with a mission to make money from the currency markets. However it is inappropriate if, as in the case of the Company, the goal is primarily one of reducing risk. Our formulation of the foreign exchange hedging problem, which we describe next, gets around the problem of having a flat efficient frontier by proposing an alternative criterion to replace the return.

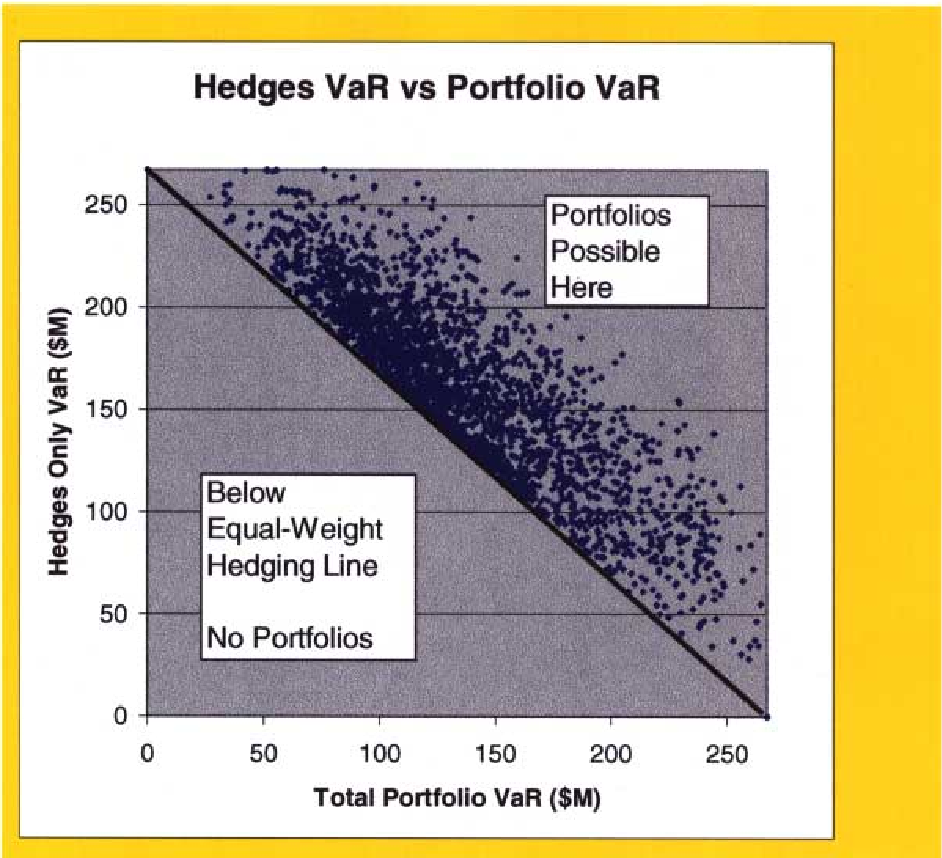
OUR APPROACH

So what is the method we have used to address the problem of the most efficient way of hedging the Company's foreign exchange risks? First we need to cover one more factor involved in risk management. In addition to its primary function of risk reduction, a hedging strategy is also judged by how much money it makes or loses. In any particular financial quarter the hedges that mature contribute to the accounted profit or loss of a company. Although losses in the hedges are typically offset by gains in the exposures, hedging losses themselves frequently come under scrutiny. When a hedging program consistently loses a company money over a several-year period, it can result in great pressure at the higher levels of that company to reduce or eliminate the hedging program. It frequently happens that foreign exchange rates will drift in a particular direction for long periods of time, up to several years. If the drift in exchange rates is such that the hedges for that company's portfolio of exposures always end up losing money, the question will surely be raised as to whether the hedging program is needed. Clearly, in this case, controlling and understanding potential losses in the hedging program are potentially vital to the program's future survival. Because of this importance of controlling hedging losses, we have included the potential size of those losses in our approach to hedging optimization. As would be expected from the discussion in most of the preceding paper, we have selected the VaR of a potential hedged portfolio as the parameter of primary importance in determining the risk of a particular hedging strategy. It is certainly the factor of greatest importance to the Company. However, in addition to the risk of the total portfolio we have selected a secondary parameter in our analysis to be the VaR of the hedging instruments alone. One can consider the VaR of the hedges as a measure of the magnitude of potential losses generated by the hedging program itself.

Our optimization prescription is to first consider a given level of risk in a hypothetical hedged portfolio. For a given value of risk in the portfolio an optimal solution will be one that has a minimum risk associated with the hedges alone. So, *given two portfolios that are equal in the value-at-risk of the total portfolio* we prefer the "safer" one, the one that has the smallest potential for loss on the hedges alone. This is similar to the way the risk-return trade-off is handled in modern portfolio theory, but is instead a trade-off between two different types of risk. Applying this procedure to all levels of portfolio risk will map out an efficient frontier, again analogous to that in modern portfolio theory.

Our approach can be used to model either hedging with forwards or options. In the case of options one should use the actual option cost instead of the VaR of the hedges that we have described above. However, forwards are the preferred hedging instrument used in the hedging program, since options have a significant up-front cost to purchase them. Also, from our analysis, forwards were found to be at least as effective for purposes of risk reduction

FIGURE 4 *Analysis of 4th quarter 1997 Ford Motor Company exposures. Each point in the figure is a single hedged portfolio with from 0-100% of each exposure hedged using forwards. Note the well-defined boundary beyond which no portfolios can exist. This is the equal-weight hedges line. We used monthly variances and covariances from a RiskMetrics data set for 12/31/1997. (Ref. 7) Both value-at-risk numbers were calculated for a one month risk horizon at a 99% confidence level. See the text for further discussion.*



as options. For these reasons, we will focus on just forwards for the remainder of this article.

When using forwards, fully "covering" (hedging) an exposure reduces that exposure's value-at-risk to zero since any losses in the exposure are offset by gains in the hedge, and vice versa. Therefore, in our approach, we only consider the percentage at which each exposure is covered by a forward. We allow this percentage to range from 0 to 100%. Going beyond this range would be an attempt to make money through speculation in the currency markets.

Finding the efficient frontier for our approach to FX hedging is the goal, since if we have the efficient frontier we can immediately compare the current strategy to the best achievable. Optimization techniques can be used to locate our methodology's efficient frontier for a given portfolio. The search spaces involved in these problems can, however, be huge, of order 10^{30} or larger given the company's FX exposures. Due to the size of the search space we have used an intelligent search technique called genetic algorithms (7) to find the efficient frontier for this problem.

APPLYING OUR FRAMEWORK TO FX HEDGING STRATEGY

Finding the efficient frontier for a realistic corporate FX portfolio hedged with forwards is quite manageable using our methodology. We use here the historical FX exposures for 4Q 1997 as an example of the approach. The exposures, provided by FX Hedging Strategy, run in quarterly increments for six quarters, 1Q1998 through 2Q1999. There are 230 total exposures listed. The gross value for all the exposures in this portfolio exceeds $10B. For this portfolio the VaR of the exposures alone was calculated to be $268M for a one month horizon at 99% confidence. This VaR number contains a substantial diversification benefit due to the large number of different currency pairs in the exposures. The exposures were hedged with forwards of the same duration as the exposures.

The result for the whole Ford portfolio is shown in figure 4. Each point on the plot in figure 4 represents a portfolio with the hedged exposures each set to some number from 0% to 100% of the original exposure. The graph plots the VaR of the total (exposures and hedges) portfolio on the X axis and the VaR of the forwards used for hedging on the Y axis. The efficient frontier consists of the portfolios which have a minimal VaR of the hedges (Y axis) at a given total portfolio VaR (X axis). So generally a portfolio more towards the lower left of the plot is a better hedging strategy.

Our optimization framework examined the space of possible portfolios and found some of the best portfolios to allow us to trace out the efficient frontier. The efficient frontier in this case is seen to be approximately a downward sloping 45 degree line. Portfolios on the efficient frontier line were found to have the property **that each of the exposures is hedged in approximately equal percentage**. The hedging percentage for the exposures varies smoothly from all exposures hedged at 0% (essentially un-hedged) at the lower right end of the line, to all exposures hedged at 100% (fully covered) at the upper left of the line. We'll refer to this line as the equal-weight-hedges line. For hedging with forwards it is true in general, and can be proven mathematically, that the portfolios at the efficient frontier satisfy the equation of the equal-weight-hedges line. Out of our moderately complicated framework has come the simple prescription that the best hedging strategies are those which hedge every exposure at the same percentage.

THE EQUAL-WEIGHT-HEDGES LINE

For the 4Q1997 exposures the efficient frontier was a well-defined diagonal line. We have examined approximately 15 portfolios of exposures hedged with forwards in this study. To calculate the VaR for these we have used four different sets of RiskMetrics data containing historical variance and covariance information. In all of these cases the efficient frontier has been on a diagonal line. The diagonal line of optimality is a line on which there are portfolios where **every** exposure is hedged at **the same** percentage.

Intuition provides one explanation for why the equal-weight hedging line could be the efficient frontier in our formalism. As is well-understood from modern portfolio theory, placing a set of not-completely-correlated instruments together into a portfolio provides a diversification benefit. Uneven hedging of a portfolio of linear instruments can reduce disproportionately some of the "natural" diversification benefit. Also, uneven hedging can lower the diversification benefit present in the portfolio of hedges alone (the potential losses due to a hedging strategy). So, at a first look, it is not unreasonable that the hedging strategy which hedges each position equally could be the best within our framework. This suspicion can be proven to be true mathematically. The efficient frontier is always the equal-weight hedges line.

Depending upon the specific exposures, volatilities, and correlations used, some portfolios with very far from equal weights can be found arbitrarily close to the equal-weight-hedging line. Such imbalanced portfolios can also be optimal or near-optimal under certain cases. However, if the underlying correlations change, as sometimes happens in the currency markets, such portfolios can become very much worse than optimal, whereas the equal-weight-hedging solution will remain optimal. The value-at-risk of the portfolio at a specific point on the line may change, but the hedged portfolio is still optimal under the new conditions. The robustness of the equal-weight-hedging solution with respect to changes in market conditions is one of the factors that makes it attractive as a tool for use in designing a hedging strategy.

The previous statements need to be modified somewhat to be rigorously correct. The equal-weight hedges line is always the efficient frontier in our approach provided that no limitations are placed on how much of an exposure can be hedged in the 0% to 100% range. If, for instance, a strategic decision is made not to hedge a certain currency, then the efficient frontier will no longer be the equal-weight hedges line. We will discuss this case briefly below. But first we need to discuss how the insights gained from our analysis can be use in deciding upon a hedging strategy.

EQUAL-WEIGHT HEDGING AS A BASIS FOR A HEDGING STRATEGY

We asked in the introduction whether one could use our approach to discern the outlines of an optimal hedging strategy. Clearly, moving hedging portfolios that lie off the efficient frontier onto it will result in portfolio VaR reductions, hedge portfolio risk reductions, or both. An equal-weight-hedging methodology is relatively straightforward to implement, and insures the protection of the natural diversification benefit present in the portfolio of exposures.

One difficulty in applying optimization methods to market-risk problems is that the solutions tend to not be robust with respect to changes in the behavior of the underlying market variables. For instance, if the volatilities and correlations of the underlying instruments changes, a previously optimal solution can be ruinous. Generally the only way to take care of this effect is to continuously rebalance the hedging portfolio to take account of the new market data. For portfolios as large as Ford Motor Company's, to rebalance at, say, biweekly intervals is impractical because of both transaction costs for obtaining the hedges, and the cost in "man-hours". The equal-weight hedging solution does not require continuous rebalancing. As previously discussed, it's result is optimal for any volatilities, correlations, and position sizes. Therefore the equal-weight-hedging method removes the possibility of the hedging strategy being invalidated by future market behavior. The only rebalancing needed when using our approach is that due to a change in size of the exposure. Only a large change in the exposure would require rebalancing since a small change would result only in moving from optimal to near-optimal.

When considering modifications to an equal percentage strategy, the equal-weight-hedges line can serve as a measure of how much additional risk is being taken on. For instance, one can fix the hedging percentage for given currency pairs according to the view being investigated, say not hedging certain exposures. Given the new positions a new efficient Frontier can be calculated. The distance between the new efficient Frontier and the equal weight hedges line on the VaR (risk) axis can be used as a measure of the risk associated with making that modification in the strategy. We have not yet pursued this idea in depth, but initial results look promising.

FUTURE DIRECTIONS

Extension of this methodology to nonlinear instruments such as FX options gives intriguing results that are an important area for future work. The equal-weight-hedging strategy no longer applies when nonlinear instruments like options are part of a portfolio. Preliminary results suggest however, that forwards are on average as good or better a deal than options for risk reduction. Another future modification to the methodology involves so-called earnings at risk. VaR does not always accurately reflect the risk to quarterly profits for a corporation, because of the accounting treatment for hedges and other factors. To correct for this one should use an earnings-at-risk framework. Earnings-at-risk is a VaR-like methodology that takes into account the timing and accounting treatment of cash flows. One obvious extension of our methodology would be to use earnings at risk instead of VaR. We are currently determining the modifications necessary to estimate earnings at risk in a VaR calculation framework. This will allow us to investigate this area until commercial earnings-at-risk packages are available (expected 1Q2000).

CONCLUSIONS

Our approach is a new way to look at the tradeoffs involved in foreign exchange hedging. It includes two risks involved in hedging. The risk to the Company's bottom line is the most important. Additionally it considers the potential cost of the hedging program when using forwards. For our formalism, the efficient frontier is on the equal-weight-hedges line for forward-only hedges. This is a general result. Optimization of portfolios so that they lie on the efficient frontier will result in reduced risks on the hedges for a fixed amount of total portfolio risk. The equal weight result is optimal for any market conditions, so we are protected against having our estimates of correlations invalidated by future market behavior. This makes our approach less "brittle" than other optimization strategies.

Our recommendation to Foreign Exchange Hedging Strategy based on this approach is already somewhat similar to the current FX hedging strategy. We are now addressing two issues with senior Treasury management. The first is the use of VaR in general in strategic risk management decisions in Treasury. The second is the use of our approach as a basis for the foreign exchange hedging strategy.

REFERENCES

1. Philipe Jorion, Value at Risk: The New Benchmark for Controlling Market Risk, Chicago, Irwin Professional Publishing, 1997.
2. Suzhou Huang, Sandra L. Winkler, and David P. Chock, "An Optimal Risk Management Scheme Using Forward Contracts for Foreign Currency Exchange Hedging" ,FRL Technical Report SRL-1999-0058.
3. For more complete definitions of forwards, options, and other financial instruments, with examples, we direct the interested readers to Hull. The reference also contains mathematical formulas for the value of these instruments. John C. Hull, Options, Futures, and Other Derivatives, third edition, Upper Saddle River, NJ, Prentice-Hall, 1997.
4. Jongwoo Kim, Allan M. Malz, Jorge Mina, LongRun Technical Document, New York, RiskMetrics Group, 1999.
5. RiskMetrics Technical Document, New York, Morgan Guarantee Trust Co., 4th edition, 1996.
6. H. Markowitz, Efficient Diversification of Investments, New York: John Wiley & Sons, 1959, and Mean-Variance Analysis in Choice and Capital Markets, Oxford: Basil Blackwell Ltd, 1987.
7. David E. Goldberg, Genetic Algorithms in Search, Optimization, and Machine Learning, Reading, MA, Addison-Wesley, 1989.