

Optimal Portfolios of Foreign Currencies

Trading on the forward bias.

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Market intuition suggests that forward exchange rates should be unbiased predictors of future spot rates. This idea is known as the “unbiased expectations hypothesis.” A long-standing puzzle in financial markets is that this intuition does not hold up in reality. If forward exchange rates were accurate predictors of spot exchange rates that are actually observed in the future, then currencies with lower nominal interest rates should on average appreciate against currencies with higher nominal interest rates. In reality, however, currencies with lower nominal interest rates tend to *depreciate*, violating the unbiased expectations hypothesis.

One implication of this observation for currency market investors is that a trading strategy that is consistently long currencies with high nominal interest rates and short currencies with low nominal interest rates should earn positive excess returns. Consider, for example, the cumulative returns on a hypothetical trading strategy: 1) Begin with one U.S. dollar at the start of 1988, and 2) at the beginning of every month invest the wealth accumulated previously in one-month bank deposits denominated in the currency that has the highest one-month LIBOR (U.S. dollar, German deutschemark, Japanese yen, British pound or Swiss franc).

Exhibit 1 plots the cumulative returns on this strategy from November 1989 through June 1999. The strategy would have higher returns than a strategy that rolls over one-month dollar deposits every month; the mean excess return of this strategy is 3.5% for a standard devi-

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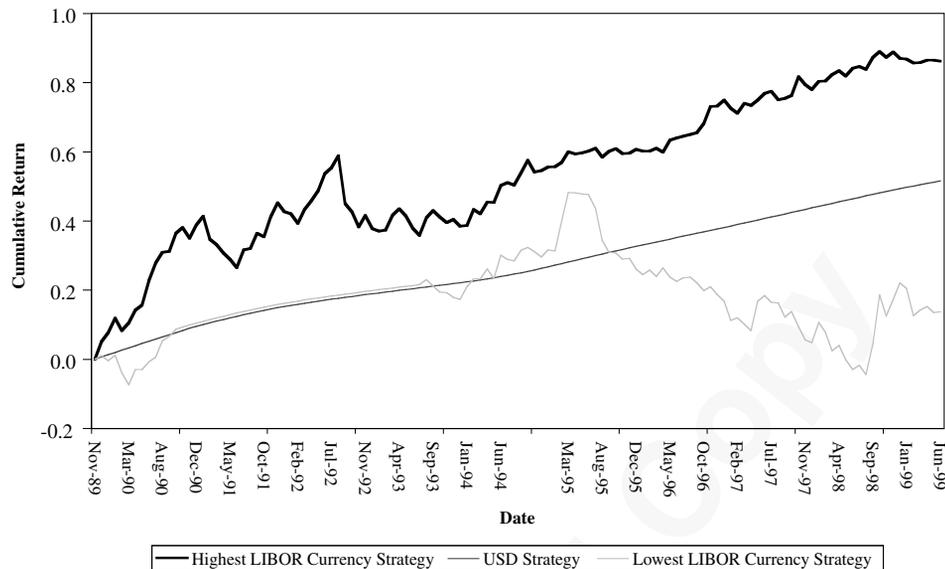
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EXHIBIT 1

CUMULATIVE RETURN FROM INVESTING IN HIGHEST LIBOR CURRENCY



ation of 10.2%. A strategy that is consistently long the currency with the lowest interest rate significantly underperforms the dollar deposit strategy. Indeed, its mean excess return is -4% for a standard deviation of 11.3%. These returns over and under U.S. dollar LIBOR returns are an indication of the forward bias.

Our purpose is to rigorously assess the risk-return performance of the trading strategies that seek to take advantage of the forward bias. We address three questions:

1. Assuming that forward exchange rates are not unbiased predictors of future spot rates, how can an investor form portfolios of currencies that benefit from the forward bias and that trade off risk and return optimally?
2. What kind of returns would be realized if one follows the optimal strategies?
3. How does the performance of these strategies depend on different ways of estimating risk-return parameters?

The contributions of our analysis are twofold. First, we show how to apply mean-variance analysis to construct an optimal portfolio of currencies. The key assumption is that exchange rates behave as random walks. This assumption is motivated by the fact that exchange rate changes do not seem to be predictable using any plausible set of macroeconomic variables. This methodology results in

stable portfolio weights over time, and does not require exogenous constraints on weights.

We find that optimal currency portfolios invested in DEM, JPY, GBP, and CHF with the U.S. dollar as the risk-free asset generate an average excess return of 2.79% per year over the period November 1989 through June 1999. The Sharpe ratio on these returns is better than that on a U.S. Treasury index and on a global Treasury index (unhedged for currency risk). Moreover, the returns are uncorrelated with major fixed-income and equity indexes.

These findings suggest that our methodology could be a useful benchmark for fund managers interested in optimal currency overlays.

FORWARD BIAS, CURRENCY RISK PREMIUM, AND PREDICTABILITY OF CURRENCY RETURNS

We first illustrate why the presence of a forward bias (or the absence of it) has important implications for the expected profitability of currency investments. This leads to a simple model of the risk premium on currencies.

An investor seeking to earn this risk premium must balance the premium against the risks of currency fluctuations by choosing an appropriate portfolio of currencies. We discuss how these risks can be measured. With a workable model of risk and return in hand, we can use

the classic mean-variance methodology to form optimal currency portfolios.

Risk Premium on Currency Investments

A currency investment is an investment in short-term money market instruments of a foreign country. Consider a U.S. dollar-based investor. Suppose that this investor invests \$1 at date t in EUR-denominated bank deposits maturing at $t + \Delta$.¹ Let the annualized interest rate for deposits of maturity Δ years be $r_d(t)$ on date t . The dollar return to the investor over the period t to $t + \Delta$ is

$$r_f(t)\Delta + \ln S(t + \Delta) - \ln S(t)$$

where $S(t)$ denotes the spot exchange rate (U.S. dollar per EUR).

Let the expected (continuously compounded) change at time t (denoted $\epsilon_t[\ln S(t + \Delta) - \ln S(t)]$) be equal to $\alpha(t)\Delta$. The investor can also make a riskless investment in U.S. dollars over the period Δ by investing in USD-denominated bank deposits. On this investment, the investor earns a sure return of $r_d(t)\Delta$.

Thus, the risk premium on the currency investment per unit time (i.e., the expected rate of return on the EUR deposit less the USD riskless rate) is given by

$$r_p(t) = r_f(t) - r_d(t) + \alpha(t) \quad (1)$$

The only unobservable quantity in Equation (1) is the expected (continuously compounded) change in the spot exchange rate, $\alpha(t)$. A model of how currency values are expected to change will produce a value for the currency risk premium through this identity. One such model is the unbiased expectations hypothesis.

Forward Exchange Rates as Predictors of Future Spot Rates

One version of the unbiased expectations hypothesis states that the log of the Δ -year forward exchange rate at date t , $F(t, \Delta)$, is an unbiased predictor of the log of the spot exchange rate at date $t + \Delta$, $\ln S(t + \Delta)$. Covered interest rate parity implies that the one-year forward exchange rate at date t is equal to $F(t, \Delta) = S(t)[r_d(t) - r_f(t)]\Delta$, which in turn implies that $\ln F(t, \Delta) = \ln S(t) + [r_d(t) - r_f(t)]\Delta$. If $\ln F(t, \Delta)$ is an accurate predictor of $\ln S(t + \Delta)$ [i.e. if $\ln F(t, \Delta) =$

$E_t[\ln S(t + \Delta)]$], the foreign currency should be expected to strengthen (i.e., $S(t)$ should be expected to rise) if $r_d(t) > r_f(t)$. Moreover, from Equation (1), the unbiased expectations hypothesis implies that the risk premium on currency investment is zero.

The forward premium puzzle arises from the empirical observation that currencies with high nominal interest rates tend to strengthen instead of weakening as predicted by the unbiased expectations hypothesis. This can be seen from the results of the regression equation:

$$\begin{aligned} \ln[S(t + \Delta)] - \ln[S(t)] &= a + b[\ln F(t, \Delta) - \ln S(t)] + \epsilon(t + \Delta) \\ &= \alpha + \beta[r_d(t) - r_f(t)] + \epsilon(t + \Delta) \end{aligned}$$

If forwards are unbiased predictors of future spot rates, then estimates of b from this regression should be close to 1, and estimates of a should be close to zero. Estimates of a and b from historical observations tend to produce values that are inconsistent with the unbiased expectations hypothesis. As seen in Exhibit 2, most estimates of b tend to be negative. These results are confirmed by many empirical studies (see, for example, Fama [1984] or Schotman, Straetmans, and de Vries [1997]).

It should also be noted that interest rate differentials have no significant explanatory power for exchange rate changes. Indeed, the R^2 produced by these regressions tends to be less than 1%. Equivalently, the hypothesis that a and b are both zero cannot be rejected. This would imply that forwards are not particularly good predictors of future exchange rates. A related implication is that current exchange rates are better predictors of future exchange rates than forwards are.²

EXHIBIT 2
REGRESSIONS OF CHANGES IN LOG EXCHANGE RATES ON A CONSTANT AND THE INTEREST RATE DIFFERENTIAL ($\Delta = 1$ WEEK)

Currency	\hat{a} (std \hat{a})	\hat{b} (std \hat{b})	R^2 (%)
DEM	-0.0001 (0.0007)	-0.36 (1.14)	0.023
JPY	0.0014 (0.0010)	-2.42 (1.52)	0.530
GBP	0.0002 (0.0009)	0.37 (1.27)	0.016
CHF	0.0003 (0.0008)	-1.32 (1.28)	0.210

MODELING THE RISK PREMIUM AND RISK OF CURRENCY INVESTMENTS

If forwards are not particularly good predictors of future exchange rates, and the unbiased expectations hypothesis is not supported by the data, this also means that the risk premium on currency investments is unlikely to be zero as implied by this hypothesis.³ For constructing currency portfolios that optimally balance risk and return, therefore, one must look for alternative specifications of the risk premium.

Economic reasoning suggests that exchange rate changes should be related to national differentials in fundamental macroeconomic variables such as output growth, investment opportunities, savings rates, fiscal policies, inflationary expectations, and monetary policies. Indeed, it is possible that short-term interest rate differentials do not account for all the relevant macroeconomic variables, but no robust dependence of exchange rate changes and economic quantities has emerged so far.⁴

In the absence of a clear pattern of predictability of exchange rate changes using fundamental variables, we follow a simple model of currency fluctuations that is not rejected by the data. We assume that the *expected change in log exchange rates is zero*, or, equivalently, that log exchange rates follow a random walk. Such a model is not dominated by regression-based models in forecasting changes in exchange rates.

From Equation (1), this assumption implies that the risk premium on currency investments equals the *negative of the interest rate differentials*. Over short time intervals, this assumption implies that the best guess for where the future spot rate is going to be is the current spot rate, or that the spot rate is a random walk. The economic justification for our assumption as to the risk premium is that higher interest rate countries face higher inflation and business cycle risks.

Besides its simplicity, this model has the advantage that one does not need to estimate any parameters for the risk premium. In this way, we avoid the problem that estimating the drift of typical financial time series is inherently difficult because a precise estimation would require long episodes of unchanged economic conditions, clearly hard to come by. It should be noted, however, that high-frequency data are of little use in estimating the expected changes in exchange rates.

The assumption that (log) changes in exchange rates are unpredictable does not rule out the possibility

that exchange rates can be predicted using more elaborate models. It is quite conceivable that one can build prediction models incorporating macroeconomic variables and information regarding market sentiment, central bank behavior, investor risk aversion, and the positioning of stop-loss orders. Given that the information required by such models is difficult to obtain on a consistent basis, and that the construction of such models is also a difficult exercise, our analysis can be thought of as a benchmark against which currency allocations based on more elaborate models can be evaluated. It should also be noted that it is straightforward to incorporate one's views on exchange rates in the methodology we present just by using the appropriate value of $a(t)$ in place of zero.

Finally, to compute currency portfolios that optimally trade off return against risk, we need also to quantify the risk of exchange rate changes. Fortunately, this is easier than measuring the drift of exchange rates. The risk of currency fluctuations can be quantified by the estimate of the variance-covariance matrix of exchange rate changes. These estimates are straightforward to compute, and they improve with the use of high-frequency data on exchange rates.

CHOOSING AN OPTIMAL CURRENCY PORTFOLIO

Having established a model for currency fluctuations, we can address how we combine different currencies into one optimal portfolio. We assume an investor whose investment universe consists of short-term bank deposits in N foreign currencies. In the baseline model for exchange rate changes, the logarithm of currency values follows a random walk.⁵ We denote the $(N \times N)$ variance-covariance matrix of changes in (log) exchange rates by Σ . Also, we denote the $N \times 1$ vector of risk premium of each currency by r_p . Finally, we assume that there are no short sales constraints on the investor.

We can use the classic mean-variance approach of Markowitz, Sharpe, and Lintner for forming a risk-optimized portfolio of currency investments. The optimal portfolios minimize the variance of returns to an investor for a chosen level of expected returns in excess of the riskless rate. If the investor chooses to obtain expected excess returns of μ , and faces no short sales constraints, then the optimal weights on foreign currency deposits (the risky assets in our problem) are given by:

$$\left[\frac{\mu}{r_p' \Sigma^{-1} r_p} \right] \Sigma^{-1} r_p \quad (2)$$

The weight on domestic bank deposit (the riskless asset) is one minus the sum of the weights on the risky assets.

A NUMERICAL EXAMPLE

We can illustrate the formula in Equation (2) using a simple example involving investment in the USD and two other currencies, JPY and GBP. Take $\mu = 0.02$ and assume, as in the data, that

$$\Sigma = \begin{pmatrix} 0.020 & 0.005 \\ 0.005 & 0.010 \end{pmatrix}$$

and

$$r_p = \begin{pmatrix} -0.040 \\ 0.005 \end{pmatrix}$$

Then compute

$$\Sigma^{-1} = \begin{pmatrix} 77 & -38 \\ -38 & 115 \end{pmatrix}$$

and

$$\Sigma^{-1} r_p = \begin{pmatrix} -3.4 \\ 2.2 \end{pmatrix}$$

$$\left[\frac{\mu}{r_p' \Sigma^{-1} r_p} \right] = 0.14$$

and

$$\left[\frac{\mu}{r_p' \Sigma^{-1} r_p} \right] \Sigma^{-1} r_p = \begin{pmatrix} -0.46 \\ 0.30 \end{pmatrix}$$

Consequently, the optimal weights are -0.46 in the Japanese yen, 0.30 in the British pound, and $1 - (-0.46 + 0.30) = 1.16$ in the U.S. dollar.

PERFORMANCE VERSUS A BENCHMARK

An investor may be interested not in the performance of a portfolio per se but in the performance of a portfolio *relative* to a fixed benchmark portfolio (such as a global Treasury index). We can analyze this within the mean-variance framework by assuming the investor is minimizing the variance of the difference between portfolio returns and benchmark returns, called *tracking error variance*, for a given expected return relative to the benchmark or expected tracking error.⁶

We can easily characterize the composition of the portfolio that consists of the *difference* between the tracking error optimal portfolio and the benchmark portfolio (or the optimal tilt portfolio, as this difference is generally known). The weights on the risky assets in the optimal tilt portfolio are given by Equation (2), and the weight on the riskless asset is equal to minus the sum of the weights on the risky assets (which is also equal to one minus the weight on the riskless asset in the optimal mean-variance portfolio).

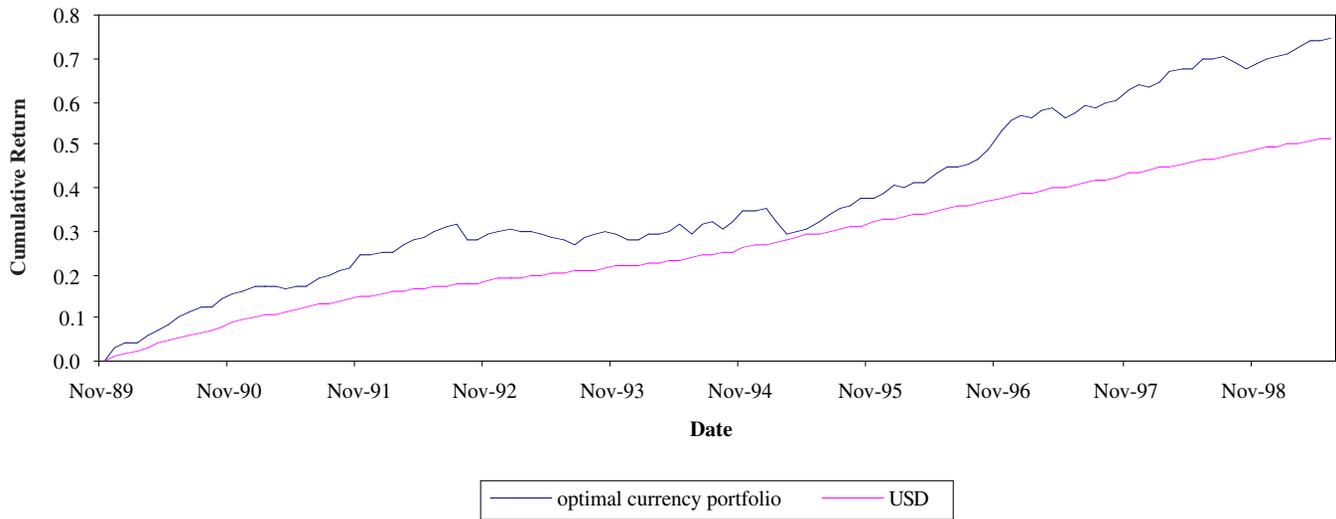
The remainder of our analysis can be reinterpreted in terms of the optimal tilt portfolio instead of the optimal mean-variance portfolio. We simply have to reinterpret the average excess return on the optimal mean-variance portfolio [μ in Equation (2)] as the average excess return required over the benchmark portfolio.

HISTORICAL ANALYSIS

How would investors have performed historically if they had chosen currency portfolios according to our model? We address this question by simulating an investment strategy using historical data for four currencies. We use weekly data on one-month LIBOR to construct one-, four-, twelve-, and fifty-two-week returns on money market accounts, assuming the term structure of interest rates is flat. Our sample is for the period November 1989 through June 1999.

The investor starts investing at the beginning of November 1989. The investment universe consists of money market accounts in DEM, JPY, GBP, and CHF. At the beginning of each period, the investor chooses the mean-variance optimal portfolio for the next period using Equation (2). She uses the current interest rate differen-

EXHIBIT 3
CUMULATIVE RETURN OF CURRENCY PORTFOLIO



tials to evaluate the risk premium vector, r_p , and estimates the variance-covariance matrix of exchange rate changes, Σ , using data in a prespecified window ending at the start of the holding period. Next period, the estimate of Σ is updated, and new values of interest rate differentials are used for r_p .⁷

This procedure generates a time series of realized returns on the simulated investment strategy. It is assumed in these calculations that the required excess return, μ , equals 200 basis points a year, and that the estimation window consists of two years of data.⁸

Distribution of Realized Returns

Optimal currency portfolios tend to have positive excess returns. This can be seen in Exhibit 3, which plots the cumulative return on our portfolio rebalanced every month. By emphasizing returns, Exhibit 3 is not informative about the risks that are taken, however. Exhibit 4 gives a more complete picture of the risk-return trade-off that is involved.

Panel A shows key statistics of the annualized returns on the portfolio using four different holding periods.

EXHIBIT 4
ANNUAL PORTFOLIO STATISTICS

Panel A. Currency Portfolio

Holding Period, Δ	Average Excess Returns (%)	Standard Deviation (%)	Sharpe Ratio	Skewness	Kurtosis
1 week	2.79	3.52	0.79	-1.03	6.75
4 weeks	2.38	3.96	0.60	-1.15	5.44
12 weeks	2.07	4.13	0.50	-1.02	5.34
52 weeks	1.59	2.31	0.69	0.30	1.57

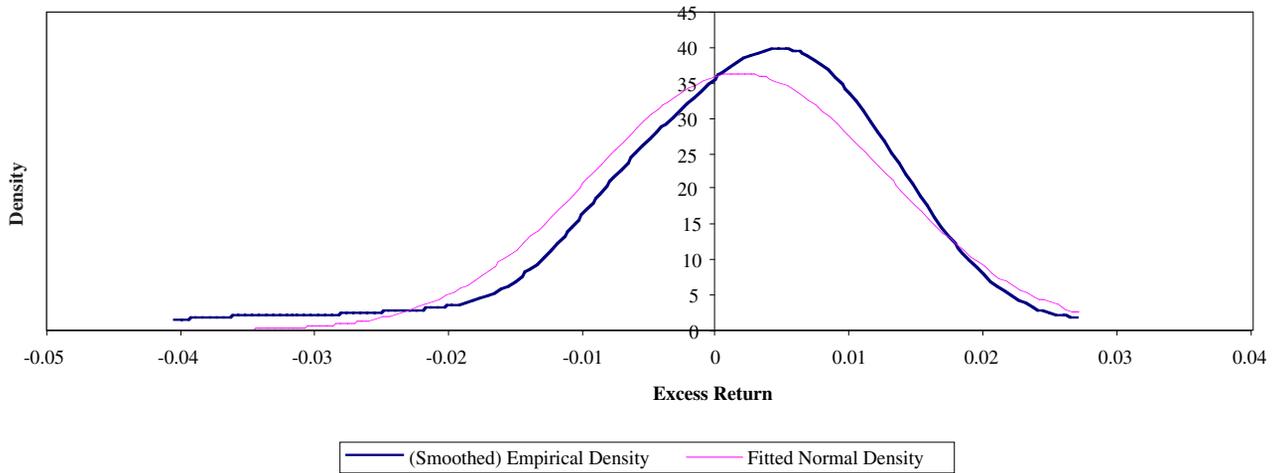
Panel B. Indexes

Index	Average Excess Returns (%)	Standard Deviation (%)	Sharpe Ratio	Skewness	Kurtosis
U.S. Treasury	2.29	4.31	0.53	-0.10	2.98
Global Treasury (unhedged)	2.85	5.81	0.49	0.12	3.33
Global Treasury (hedged)	2.78	3.45	0.80	-0.30	3.19
S&P 500	12.60	13.29	0.95	-0.74	5.06

Consider, for example, the returns for a holding period of four weeks. The average excess return is 2.38%, about 210 basis points above the average return on a USD money market account. The annualized standard deviation of excess return is 3.96%, yielding a realized Sharpe ratio of 0.60.

The statistics can be compared with those for alternative investments as displayed in Panel B. Optimal currency portfolios perform better than a portfolio indexed to the Lehman Brothers' U.S. Treasury Index or the Lehman Brothers Global Treasury Index (unhedged for cur-

**EXHIBIT 5
PROBABILITY DENSITY FUNCTION OF CURRENCY PORTFOLIO EXCESS RETURNS**



rency risk). The performance is comparable to that of Lehman Brothers Global Treasury Index (hedged for currency risk). Not surprisingly, the S&P 500 dominates our portfolio, as our sample period coincides with the long bull market of the 1990s.

Exhibit 4 also shows that the distribution of returns on currency portfolios has fat tails. Indeed, the kurtosis for the four-week portfolio is 5.44 compared to 3.00 for a normal distribution. This is also seen in Exhibit 5, which displays the (smoothed) empirical density of excess returns on currency portfolios together with the normal

density that has the same mean and variance. The probability of negative excess return is 37% (the area to the left of zero under the portfolio density curve).

Composition of Optimal Currency Portfolios

Exhibit 6 shows how optimal weights on currencies evolve over time. Exhibit 7 displays the means of weights over time and the standard deviations of changes in weights. Portfolio weights are reasonably stable over time. Note that the stability of weights is obtained without

**EXHIBIT 6
TIME SERIES OF PORTFOLIO WEIGHTS**

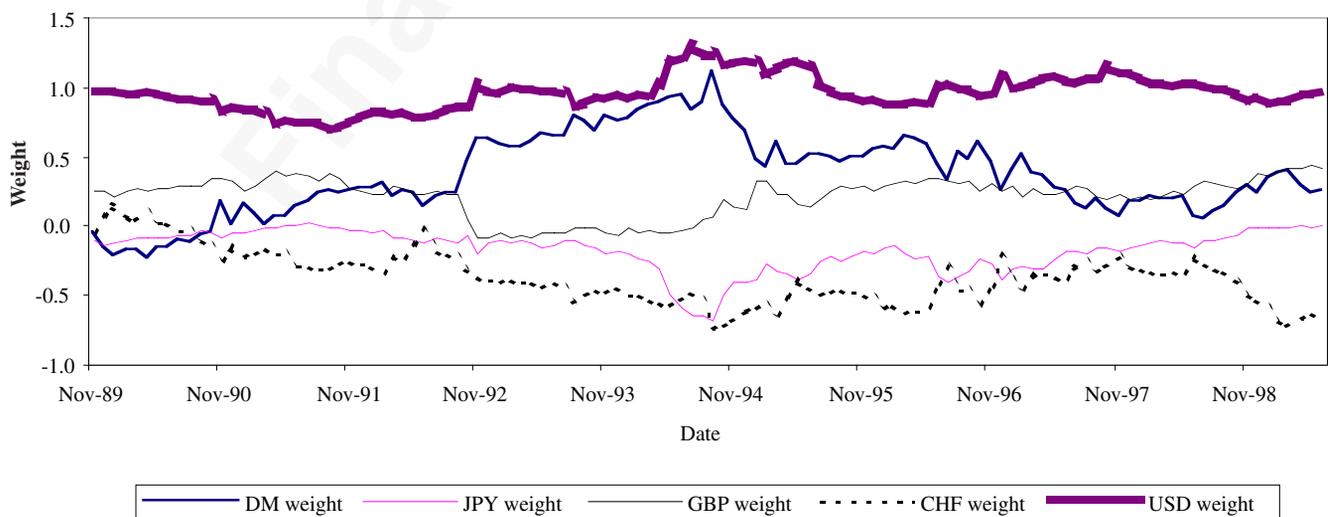


EXHIBIT 7**MEAN OF WEIGHTS AND STANDARD DEVIATION OF CHANGES IN WEIGHTS**

Currency	DEM	JPY	GBP	CHF	USD
Average Portfolio Weight	0.35	-0.17	0.21	-0.37	0.96
Standard Deviation of Change in Portfolio Weight	0.086	0.045	0.043	0.069	0.042

imposing any additional constraints in the portfolio choice problem. This is unlike application of the mean-variance methodology to equity and bond portfolios, which typically yields highly unstable weights (Best and Grauer [1991], Black and Litterman [1992]).

Equation (2) shows that such instability in weights may result from three factors. First, the estimated risk premium, r_p , may be very unstable. Assuming that log exchange rates follow a random walk avoids this problem because the risk premium follows the interest rate differential, which is very persistent. Second, the estimated variance-covariance matrix, Σ , may vary consistently over time. This is not the case here since our estimation procedure based on a rolling window generates a persistent Σ . Finally, Σ may be close to singular, yielding a very large Σ^{-1} . Consequently, small changes in r_p will be highly amplified. This does not seem to be a problem here.⁹

A number of observations present themselves. First, as expected, the portfolio tends to be long currencies whose interest rates are above the U.S. interest rate (and vice versa). For example, the portfolio is short JPY throughout the sample. Also, it tends to be long GBP except for the period 1993-1994. In 1993-1994, the weights on GBP are small, reflecting the increased volatility caused by the speculative attack on the pound in 1992 and its exit from the ERM. Post-1995, this episode is no longer taken into account as the variance-covariance matrix is estimated using only two years of data.

Next, long and short positions in DEM and CHF tend to offset each other. This reflects the high correlation between these two currencies and the lower CHF interest rates. Finally, the weight on the USD is close to one, which makes the foreign currency positions self-financing.

Correlation of Currency Returns with Other Assets

An interesting feature of the currency portfolio is how its returns are related to returns on other assets. We report in Exhibit 8, Panel A, the betas of portfolio returns

with respect to the returns on four widely used indexes of financial assets: the Lehman Brothers U.S. Treasury Index, the Lehman Brothers Global Treasury Indexes (unhedged and hedged for currency risk), and the S&P 500. The numbers show that currency returns are essentially uncorrelated with the returns on the indexes. As a consequence, our currency portfolio can be used to reduce interest rate risk (in the Treasury portfolios) and equity risk (in the S&P portfolio).

To illustrate this point, Panel B of Exhibit 8 shows the results of combining the indexes with our currency portfolio. We report key statistics of the annualized returns on a combination that is invested 95% in a given index and 5% in the currency portfolio. In all cases, the currency portfolio raises the Sharpe ratio on the index.

SUMMARY

The contributions of our analysis are twofold. First, we show how to apply mean-variance analysis to construct an optimal portfolio of currencies. The key assumption is that exchange rates behave as random walks. This assumption is motivated by the fact that exchange rate changes do not seem to be predictable using any plausible set of macroeconomic variables. This methodology results in stable portfolio weights over time and does not require exogenous constraints on weights.

Second, we find that optimal currency portfolios invested in the German deutschemark, the Japanese yen, the British pound, and the Swiss franc with the U.S. dollar as the risk-free asset generate an average excess return of 2.79% per year over the period November 1989 through June 1999. The Sharpe ratio on these returns is better than that on a U.S. Treasury index and that on a global Treasury index (unhedged for currency risk). Moreover, the returns are uncorrelated with major fixed-income and equity indexes. These findings suggest that the methodology can provide a useful benchmark for fund managers interested in optimal currency overlays.

EXHIBIT 8
COVARIATIONS OF RETURNS ON CURRENCY PORTFOLIOS

Panel A. Beta of Currency Portfolio Against Indexes

Index	Beta (standard deviation)
U.S. Treasury	-0.026 (0.083)
Global Treasury (unhedged)	0.027 (0.061)
Global Treasury (hedged)	-0.072 (0.103)
S&P 500	-0.014 (0.027)

Panel B. Portfolio Invested 95% in an Index and 5% in Optimal Currency Portfolio

Index	Average Excess Returns (%)	Standard Deviation (%)	Sharpe Ratio	Skewness	Kurtosis
U.S. Treasury	2.31	4.09	0.57	-0.10	2.98
Global Treasury (unhedged)	2.84	5.53	0.51	0.12	3.37
Global Treasury (hedged)	2.77	3.27	0.85	-0.31	3.20
S&P 500	12.10	12.62	0.96	-0.74	5.11

ENDNOTES

The authors thank Arun Muralidhar and David Prieul for their comments and suggestions.

¹We assume that bank deposits are not subject to default risk.

²*A priori*, the relation between exchange rate changes and interest rate differentials need not be linear (as postulated in the regressions). One could look for a *non-linear* relation between these variables. Bansal [1997] reports evidence in favor of a non-linear specification, but these models again tend to have weak explanatory power (R^2 on the order of 1%–2%). Moreover, results do not seem to be robust across sample periods.

³See Meese and Rogoff [1983], Meese [1990], and Sercu and Uppal [1995].

⁴See Merton [1980].

⁵Explicitly, changes in log exchange rates of the i -th currency are given by:

$$r_j(t)\Delta + \ln S(t + \Delta) - \ln S(t)$$

where σ is the annualized volatility of changes in the exchange rate, and the random currency shock, $\epsilon_i(t + \Delta)$, is assumed to be a standard normal variable. The correlation coefficient of shocks across currencies i and j is assumed to be given by ρ_{ij} . Together with Equation (1) and a mathematical result known as Ito's lemma, this equation implies that the excess (over the riskless rate) expected return on an investment in the short-term bank deposits denominated in the i -th currency (discretely

compounded) equals $r_i(t) - r_d(t) + \frac{1}{2}\sigma_i^2(t)$ where $r_i(t)$ is the (annualized) short-term interest rate, and σ_i is the (annualized) volatility for the i -th currency.

⁶See Roll [1992].

⁷To capture market expectations, we use the volatility implied from currency options to build a second estimate of Σ . We obtain similar results over the same sample period.

⁸A property of the Sharpe ratio is that it is invariant to leverage and therefore independent of μ . Of course realized returns and weights of the portfolio do depend on μ . The window length does not affect the results substantially.

⁹See Green and Hollifield [1992] for how this problem arises in a portfolio of equities.

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