Murali Ramaswami
Salomon Brothers, Inc.

Active Currency Management

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Active Currency Management

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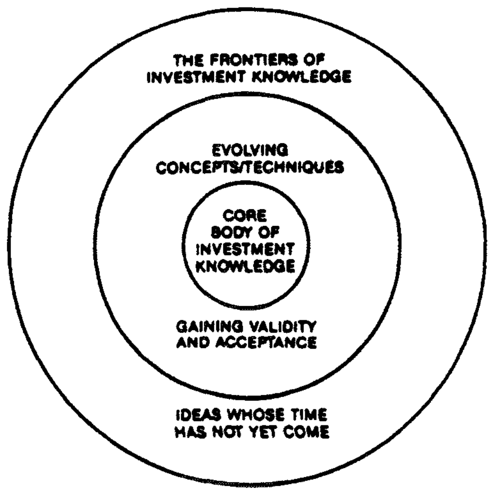

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Foreword

Is the active management of currency assets in a portfolio rewarding? Do the returns from trading strategies justify their use? If active currency management is not profitable, if the risk in currency strategies is systematic or not diversifiable internationally, investors may well demand a premium for bearing that risk.

To be rewarding, as author Murali Ramaswami points out, the return to currency as an asset must be nonzero over some definable time period. Whether it is or not, however, is controversial. Therefore, Ramaswami for this study set out to discover (1) what empirical evidence tells us about the characteristics of currency as an asset and (2) how well the predictive models perform in suggesting trading rules or strategies for making a profit in currency trading.

The data for the empirical study are the performance of seven major world currencies, a currency index, and an equity index. The time period is 1978 through 1991, and this period is examined as a whole and in two subperiods—one characterized as weak dollar, the other as strong dollar. Daily, weekly, monthly, and longer returns are tabulated and studied. In addition, inclusion of the indexes allows a comparison of the currency markets' behavior with the behavior of the U.S. domestic equity market.

Ramaswami's conclusion is that currency returns, on the whole, are efficient; they can be characterized as a random walk process. The return process is nonlinear, however, which allows the design of profitable trading rules.

With the characteristics of the return distributions and the currency markets identified, the study turns to examining those rules and the models on which they are based. A major contribution of the study is to ground what should be the approach of active currency management in the realities of currency-return behavior patterns. In particular, findings related to trends and reversals in returns have significant implications for investment horizons, costs, and strategy choices. The author proposes specific improvements in the models and the practices being followed in currency management. A worthwhile model and trading rule must, for example, take the nonlinear nature of the returns into account.

The globalization of investment management has increased the importance of knowing how to manage currency as part of a total portfolio strategy or as a hedge for some foreign investments in a portfolio. At the same time, the system of floating exchange rates has increased uncertainty in the foreign exchange network. The Research Foundation is, therefore, particularly pleased to make available this study at this time.

Readers interested in other research funded and published by the Research Foundation of the Institute of Chartered Financial Analysts may peruse the list on page ii. Seminar proceedings from the Association for Investment Management and Research—along with ordering information for all publications—are presented on pages 55–56.

Katrina F. Sherrerd, CFA

Active Currency Management

The belief that currency returns may be nonzero over varying periods of time is controversial, as is recognized in the literature.[1] If currency risk is systematic or internationally nondiversifiable, risk-averse investors would demand a premium for bearing currency risk. Moreover, the risk premium itself could be time varying, possibly reflecting changing investment opportunities (McCurdy and Morgan 1992). More recently, a technical reason (the "Siegel's paradox") has been suggested as a possible reason to expect a nonzero currency return (Black 1989).[2]

Notwithstanding the theoretical reasoning behind a zero expected currency return, what has been the empirical evidence from the recent past? For active currency management to be rewarding, the return to currency as an asset must be nonzero (net of transaction costs) during a definable period. Existence of trends, mean reversions, or identifiable trading patterns in currency returns ensures the success of technical models. This study examines the historical performance of seven major currency markets, with the objective of understanding their distributional characteristics. The study also uses a currency index, comprising these seven currencies, and an equity index to compare the behavior of the currency markets with that of the domestic equity market. Another objective of the study is to determine the prospects for success of predictive models of the currency markets.

The currencies studied are the Japanese yen (¥), the British pound (£), the German deutsche mark (DM), the French franc (FFr), the Swiss franc (SFr), the Australian dollar (A$), and the Canadian dollar (C$). The indexes are a

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[1] See Perold and Shulman (1988) for a discussion of the empirical work and theoretical arguments regarding this point.

[2] Perold and Schulman (1988) discuss the nonzero expected currency returns due to nonlinearity inherent in the compounding of nominal returns with currency movements and/or changes in price deflators.

composite equity-markets-weighted currency index (FxIndx) and the Standard & Poor's (S&P) 500 equity index.[3] The study period is 1978 to 1991; it is also divided into two seven-year subperiods—1978 to 1984, when the U.S. dollar was strong, and 1985 to 1991, when the dollar was weak. Daily, weekly, monthly, and longer period returns were used to determine the potential for success of various predictive models and investment strategies that are based on a presumption of imbedded trends or return reversals in the currency markets.

Interactive Data Corporation (IDC) is the data source for all the currency returns.[4] Wednesdays were chosen for weekly returns to avoid weekend effects and because few holidays occur on that day. Different statistical techniques were used to determine the presence or absence of trends or return reversals in the seven currencies and the currency and equity market indexes.[5]

Statistical Properties of Foreign Exchange Rates, 1978 to 1991

The annual returns from investing in the seven currencies and the two market indexes during the past decade (1980–91) are shown in Table 1.

Mean annual returns for the currencies varied from 5.41 percent for the yen to −3.16 percent for the Australian dollar. Approximate annual risk ranged from 17 percent (the French franc) to 4 percent (the Canadian dollar). Although the currency index had an annual risk of 13.73 percent, similar to the equity index during this period, its mean return was an anemic 2.25 percent compared to the equity index's mean return of 12.65 percent. This difference suggests the possibility of uncompensated risk in owning currency assets as opposed to

[3] FxIndx is a composite currency index created by the author. The equity market weights used in this index are the Morgan Stanley Capital International Europe/Australia/Far East country weights for 1978 to 1986 and those of the Financial Times Europe and Pacific (FT-EUROPAC) countries for 1986 to 1991.

[4] The IDC daily foreign exchange rates form the basis for weekly and monthly return calculations. Missing daily rates (for weekdays) were interpolated based on the immediately preceding and succeeding rates. The data for the composite FxIndx and the S&P 500 cover the 1980–91 period only. Daily S&P 500 prices are from FACTSET (for the 1987–91 period) and from IDC (for the 1980–86 period). The weekly currency rates are based on Wednesday's close, and the S&P 500 weekly returns are based on Friday's close.

[5] The data source for the exchange rates of the individual currencies composing the currency index is Goldman Sachs and Morgan Stanley International, and the source for the seven individual currencies is IDC. This difference in data sources could lead to minor inconsistencies between the index values and those built up from the seven component currencies, as in Table 1.

TABLE 1. Annual Returns to Currencies and Market Indexes, 1980–91

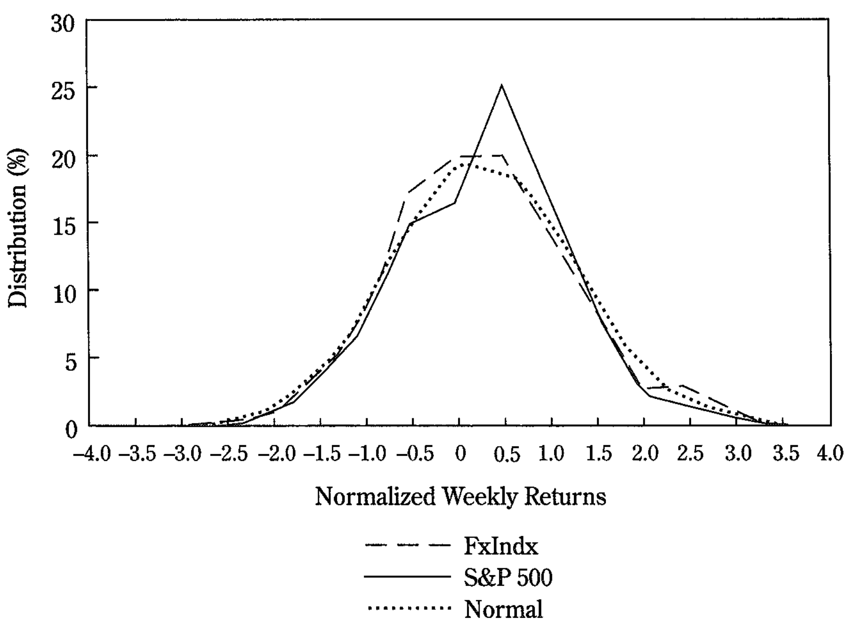
	¥	£	DM	FFr	SFr	A$	C$	FxIndx	S&P 500
1980	16.24%	−13.52%	7.93%	−11.92%	−11.24%	5.68%	−2.20%	2.91%	25.77%
1981	−7.57	−12.47	−22.34	−22.63	−0.24	−3.81	0.75	−11.65	−9.73
1982	−6.29	−5.97	−16.71	−16.95	−11.63	−13.89	−3.60	−10.88	14.76
1983	0.77	−14.37	−11.77	−21.96	−8.84	−8.72	−1.27	−7.25	17.27
1984	−8.02	−14.11	−21.61	−13.84	−16.57	−8.63	−5.98	−11.07	1.40
1985	22.61	25.36	22.04	24.48	21.93	−19.10	−5.62	21.85	26.33
1986	22.98	23.62	2.16	15.64	24.22	−2.61	1.35	16.91	14.62
1987	27.04	20.21	23.67	18.48	24.30	8.20	5.78	27.05	2.03
1988	−2.17	−11.12	−2.75	−11.92	−15.72	17.89	8.94	−3.97	12.40
1989	−14.85	4.53	−11.71	4.47	−3.35	−9.05	2.74	−9.48	27.25
1990	5.90	12.03	17.59	12.47	19.02	−2.20	−0.17	9.26	−6.56
1991	8.28	−1.49	−3.16	−1.88	−6.03	−1.74	0.17	3.30	26.31
Mean	5.41	1.06	−1.39	−2.13	1.32	−3.16	0.07	2.25	12.65
Standard deviation	14.06	15.57	16.34	16.70	16.26	10.08	4.37	13.73	13.14
Maximum	27.04	25.36	23.67	24.48	24.30	17.89	8.94	27.05	27.25
Minimum	−14.85	−14.37	−22.34	−22.63	−16.57	−19.10	−5.98	−11.65	−9.73

Source: Interactive Data Corp.

domestic equity. In 6 of the 12 years, currency returns were negative, but only 2 years were down years for the equity market.

Distribution Characteristics. The distribution of actual currency and equity weekly returns for the 1978–91 period are shown in Figure 1, along with a normal distribution of returns. The distribution of currency index returns is fatter at the tails, especially on the positive return side, than both the S&P 500 and a standard normal distribution, implying the existence of trends. The flat middle of the currency returns curve suggests the existence of reversals as well. Both conclusions are verified with autocorrelation analysis in the next section. Descriptive statistical properties and the distributional characteristics of the daily, weekly, and monthly currency returns were investigated separately for the 1980s and the two subperiods. Tables 2 through 10 provide summary statistics for the seven currencies and two indexes.

FIGURE 1. Distribution of Actual Weekly Exchange Returns, 1978–91



For the 1978–91 period, as shown in Tables 2, 3, and 4, none of the currencies or the currency index had a statistically significant nonzero mean daily, weekly, or monthly return. The equity index had highly significant positive returns—12.62 percent, annualized and averaged over the daily, weekly, and monthly returns.

TABLE 2. Distributional Characteristics of Daily Foreign Exchange Returns, 1978–91 and Subperiods

Characteristic	¥	£	DM	FFr	SFr	A$	C$	FxIndx[a]	S&P 500[a]
1978–91									
Observations	3,687	3,687	3,687	3,687	3,687	3,687	3,687	3,034	3,061
Mean percent	0.018	0.000	0.009	−0.003	0.011	−0.011	−0.001	0.006	0.044
Standard deviation	0.674	0.720	0.794	0.747	0.881	0.584	0.272	0.595	1.073
Annual	12.792	13.656	15.069	14.165	16.714	11.075	5.167	11.291	20.362
Skewness[b]	0.205	0.168	0.598	0.043	0.278	−2.236	0.458	0.397	−3.349
Kurtosis[b]	4.339	4.703	19.015	9.628	10.261	41.061	13.273	5.715	72.471
t-statistic for mean	1.627	-0.023	0.689	−0.244	0.789	−1.155	−0.220	0.523	**2.252**
1978–84									
Observations	1,847	1,847	1,847	1,847	1,847	1,847	1,847	1,305	1,305
Mean percent	−0.002	−0.024	−0.019	−0.037	−0.010	−0.017	−0.010	−0.035	0.039
Standard deviation	0.683	0.668	0.778	0.763	0.850	0.462	0.279	0.546	0.938
Annual	12.965	12.681	14.770	14.481	16.131	8.759	5.301	10.350	17.802
Skewness[b]	0.166	−0.092	0.883	−0.175	−0.085	−6.265	0.970	0.350	0.261
Kurtosis[b]	4.642	4.795	30.242	13.648	5.542	179.36	20.432	1.824	1.273
t-statistic for mean	−0.140	−1.565	−1.061	**−2.092**	−0.513	−1.579	−1.466	**−2.297**	1.520
1985–91									
Observations	1,826	1,826	1,826	1,826	1,826	1,826	1,826	1,729	1,756
Mean percent	0.038	0.026	0.040	0.034	0.035	-0.005	0.007	0.036	0.047
Standard deviation	0.659	0.764	0.804	0.722	0.908	0.685	0.265	0.628	1.164
Annual	12.513	14.493	15.259	13.706	17.223	12.995	5.019	11.923	22.078
Skewness[b]	0.206	0.343	0.367	0.349	0.590	−0.864	−0.130	0.384	−4.688
Kurtosis[b]	3.937	4.472	9.708	4.752	13.985	5.881	4.615	7.194	91.054
t-statistic for mean	**2.476**	1.466	**2.128**	**2.000**	1.660	−0.294	1.167	**2.388**	1.686

Note: Numbers in bold are significant at the 99 percent level.

[a]FxIndx is a composite equity-markets-weighted currency index, and S&P 500 is the Standard & Poor's 500 U.S. equity market index. Data for these indexes cover the 1980–91 period.

[b]The standard error for skewness is $\sqrt{6/N}$ and for kurtosis $\sqrt{24/N}$. For 1978 to 1991, the standard errors for skewness and kurtosis are 0.040 and 0.081, respectively; for 1978 to 1984, they are 0.057 and 0.114, respectively; for 1985 to 1991, they are 0.057 and 0.115, respectively.

TABLE 3. Distributional Characteristics of Weekly Foreign Exchange Returns, 1978–91 and Subperiods

Characteristic	¥	£	DM	FFr	SFr	A$	C$	FxIndx[a]	S&P 500
1978–91									
Observations	736	736	736	736	736	736	735	624	624
Mean percent	0.086	0.040	−0.005	−0.018	0.053	−0.057	−0.007	0.026	0.207
Standard deviation	1.529	1.578	1.595	1.586	1.783	1.311	0.608	1.305	2.201
Annual	11.027	11.377	11.500	11.440	12.858	9.456	4.386	9.412	15.873
Skewness[b]	0.533	0.114	0.054	0.185	0.180	−1.910	0.096	0.316	−0.526
Kurtosis[b]	1.372	0.766	1.880	2.407	0.622	12.344	2.310	0.774	3.073
t-statistic for mean	1.526	0.681	−0.083	−0.315	0.806	−1.183	−0.307	0.499	**2.346**
1978–84									
Observations	369	369	369	369	369	369	369	261	261
Mean percent	−0.012	−0.103	−0.127	−0.189	−0.056	−0.088	−0.050	−0.156	0.165
Standard deviation	1.483	1.439	1.384	1.538	1.745	0.900	0.620	1.148	2.196
Annual	10.697	10.378	9.979	11.094	12.580	6.491	4.469	8.278	15.832
Skewness[b]	0.626	0.244	0.011	0.405	0.243	−4.779	0.232	0.403	0.398
Kurtosis[b]	0.947	0.748	0.924	4.592	0.793	54.886	1.972	0.064	0.900
t-statistic for mean	−0.150	−1.379	−1.760	**−2.366**	−0.615	−1.881	−1.549	**−2.200**	1.211
1985–91									
Observations	366	366	366	366	366	366	366	364	364
Mean percent	0.189	0.198	0.128	0.168	0.176	−0.026	0.040	0.152	0.232
Standard deviation	1.566	1.666	1.751	1.587	1.788	1.626	0.592	1.396	2.207
Annual	11.291	12.015	12.625	11.442	12.894	11.722	4.267	10.065	15.913
Skewness[b]	0.451	0.090	0.098	0.112	0.226	−1.246	−0.042	0.199	−1.174
Kurtosis[b]	1.786	0.406	1.728	0.525	0.277	4.719	2.960	0.891	4.721
t-statistic for mean	**2.315**	**2.271**	1.403	**2.027**	1.884	−0.307	1.291	**2.080**	**2.007**

Note: Numbers in bold are significant at the 99 percent level.

[a]FxIndx is a composite equity-markets-weighted currency index, and S&P 500 is the Standard & Poor's 500 U.S. equity market index. Data for these indexes cover the 1980–91 period.

[b]For 1978 to 1991, the standard errors for skewness and kurtosis are 0.090 and 0.181, respectively; for 1978 to 1984, they are 0.128 and 0.255, respectively; for 1985 to 1991, they are 0.128 and 0.256, respectively.

TABLE 4. Distributional Characteristics of Monthly Foreign Exchange Returns, 1978–91 and Subperiods

Characteristic	¥	£	DM	FFr	SFr	A$	C$	FxIndx[a]	S&P 500
1978–91									
Observations	168	168	168	168	168	168	167	144	144
Mean percent	0.388	0.196	−0.011	−0.059	0.232	−0.244	−0.027	0.119	0.939
Standard deviation	3.766	3.671	3.527	3.530	4.138	2.848	1.254	3.122	4.804
Annual	13.045	12.716	12.219	12.227	14.335	9.864	4.343	10.815	16.642
Skewness[b]	0.148	−0.043	0.255	−0.179	0.032	−1.103	−0.408	0.062	−1.017
Kurtosis[b]	0.231	0.569	0.664	0.682	0.771	4.021	0.877	−0.587	4.863
t-statistic for mean	1.334	0.691	−0.040	−0.218	0.726	−1.111	−0.279	0.457	**2.345**
1978–84									
Observations	84	84	84	84	84	84	84	60	60
Mean percent	−0.056	−0.479	−0.591	−0.854	−0.302	−0.386	−0.217	−0.671	0.730
Standard deviation	3.881	3.504	3.126	3.374	4.268	2.003	1.325	2.760	4.290
Annual	13.445	12.139	10.827	11.689	14.784	6.940	4.591	9.560	14.859
Skewness[b]	0.347	0.310	0.115	0.007	0.180	−1.367	−0.188	0.375	0.210
Kurtosis[b]	0.899	1.112	−0.426	0.898	1.544	4.944	0.983	−0.312	0.597
t-statistic for mean	−0.132	−1.254	−1.734	**−2.319**	−0.650	−1.765	−1.500	−1.884	1.318
1985–91									
Observations	84	84	84	84	84	84	83	84	84
Mean percent	0.831	0.871	0.570	0.735	0.766	−0.102	0.165	0.683	1.088
Standard deviation	3.616	3.729	3.818	3.522	3.957	3.502	1.153	3.256	5.160
Annual	12.526	12.918	13.228	12.200	13.709	12.130	3.996	11.280	17.876
Skewness[b]	−0.030	−0.406	0.191	−0.429	−0.084	−1.035	−0.622	−0.213	−1.541
Kurtosis[b]	−0.342	0.796	1.000	1.153	0.055	2.601	1.013	−0.482	6.416
t-statistic for mean	**2.106**	**2.140**	1.367	1.913	1.775	−0.268	1.303	1.924	1.932

Note: Numbers in bold are significant at the 99 percent level.

[a]FxIndx is a composite equity-markets-weighted currency index, and S&P 500 is the Standard & Poor's 500 U.S. equity market index. Data for these indexes cover the 1980–91 period.

[b]For 1978 to 1991, the standard errors for skewness and kurtosis are 0.189 and 0.378, respectively; for 1978 to 1984, they are 0.267 and 0.535, respectively; for 1985 to 1991, they are 0.267 and 0.535, respectively.

Based on weekly returns, the average annualized volatility of 11.79 percent of the European currencies was higher than the 11.03 percent for the Japanese yen; the Australian and Canadian dollars had even lower volatilities of 9.46 and 4.39 percent, respectively. Significant low or negative correlations among the currencies were indicated by the much lower annualized volatility of 9.4 percent for the currency index.

Using daily returns, the mean annualized volatility of the European currencies was 14.9 percent—much higher than the 12.79 percent volatility of the yen. Again, the composite volatility of the currency index was lower at 11.29 percent, suggesting low or negative correlations among the currencies. Similar conclusions were reached using the strong- and weak-dollar subperiods.

The currency index had significant positive kurtosis, indicating a statistically significant peaked "fat-tailed" (or leptokurtic) distribution, at the daily and weekly intervals, but not at the monthly interval.[6] This suggests the existence of trends in the daily and weekly currency returns. Individual currencies exhibited even stronger trends in their daily and weekly returns during this period. Also, the degree of kurtosis declined as the return interval increased from daily to weekly. The evidence on skewness is similar: daily and weekly returns exhibited significant positive skewness.[7] At the individual currency level, the distribution was significantly skewed to the right for the yen and the European currencies; it was left-skewed for the Australian dollar, which might be explained by the relatively high Australian interest rate throughout the 1980s.[8] These conclusions are similar to those found in other studies that used data from the 1970s.[9]

The equity index daily, weekly, and monthly returns also exhibited significant excess kurtosis during the 1980s, which implies significant trends in equity returns at all intervals. Moreover, the returns at all intervals showed significant

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[6] Positive values of kurtosis indicate that a density is more peaked around its center than the density of a normal curve (implying trends), and negative values indicate that a density is more flat around its center than the density of a normal curve (implying reversals).

[7] A skewness to the right, or a positive value, indicates that large increases are more probable than large declines. A skewness to the left, or a negative value, indicates that large declines are more probable than large increases.

[8] Given the current (1990–91) significantly lower inflation and interest rates in Australia relative to the United States and the Organization for Economic Cooperation and Development countries, the left-skewness of the Australian dollar may not persist into the 1990s.

[9] Boothe and Glassman (1987), for example, used data for the period January 1973 to August 1984.

negative skewness, suggesting large equity declines are more probable than large increases relative to a normal distribution of returns.

Did these distributional characteristics differ between the strong- and weak-dollar subperiods? During the strong-dollar subperiod (1978–84), the mean daily, weekly, and monthly currency index returns were significantly negative, but the individual currencies (except the French franc) were not statistically significant from zero. During the weak-dollar subperiod (1985–91), returns for the index and the individual currencies generally were significantly positive. The currencies had higher annualized volatility during the weak-dollar subperiod, compared to the strong-dollar subperiod. The Australian dollar doubled its volatility in the weak-dollar subperiod relative to the strong-dollar one. In comparison, the mean equity returns were not significant during the subperiods even though they were positively significant during the entire period. Like the currencies, equity volatility was higher in the latter half of the 1980s than in the first half, possibly because of the October 1987 stock market crash.

In summary, during a full cycle of foreign exchange returns, mean monthly returns to the currencies were not significant. During the strong- and weak-dollar subperiods, however, individual currencies produced statistically significant expected positive or negative mean returns. All the currency daily and weekly returns exhibited trends (leptokurtosis); the evidence was not definitive for monthly returns. Currency volatility was higher during the weak-dollar subperiod than the strong-dollar subperiod. This was especially true for the Australian dollar. The Canadian dollar had stable, low volatility—only one-third as much as the other currencies—which is not surprising because the Canadian and U.S. dollars (and economies) are closely correlated. During the 1980s, the yen was the strongest currency; the U.S. dollar tended to be significantly weak against the yen during the dollar's weak phase and not significantly strong during its strong phase, and the French franc was the weakest against the dollar. During this period, the strong currencies (the yen, deutsche mark, and Swiss franc) had higher probabilities of large positive returns than large negative returns, and the Australian dollar had the opposite—negatively skewed distribution—which could be a result of the persistently high Australian interest rate during the 1980s. Data for the 1970s indicated similar conclusions on the kurtosis of the distributions, suggesting these results have held for at least two decades.

Autocorrelations. The analysis of distributional characteristics of the seven currencies suggested the existence of trends in the daily and weekly returns. Analysis of the autocorrelations in currency returns data can be used to confirm or negate existence of such trends.[10] Autocorrelation coefficients with lags of up to 10 periods were tested on the daily, weekly, and monthly returns of all the currencies for the 1978–91 period and the two subperiods. The Akaike information criterion and the Schwarz criterion also were used to determine the lag length suggested by the data set.[11] The results of the autocorrelation analysis are presented in Tables 5 through 7.

The Box-Pierce Q-statistic was used to test the joint hypothesis that all of the autocorrelation coefficients are zero.[12] This statistic was highly significant for the daily returns of the yen and the European currencies (except the pound) using a lag length of 10 days, which suggests the existence of autocorrelations of one or more lags up to 10 days. Moreover, the Central European currencies (the deutsche mark, French franc, and Swiss franc) showed significant one-day lagged negative autocorrelations, or reversals. Unlike the other European currencies, the pound showed no autocorrelations. The currency index exhibited significant autocorrelations.

The significance of the autocorrelations varied between the subperiods. The French franc appeared to have no autocorrelations during the weak-dollar subperiod, but it was very significantly autocorrelated (negatively) during the strong-dollar subperiod. For the currency index, the level of confidence declined between the strong-dollar and the weak-dollar subperiods, although for each, the autocorrelations were not significant. For perspective, autocorrela-

[10] When observations (for example, currency returns) from different (usually adjacent) time periods are correlated, the observations are autocorrelated or serially correlated. Negative serial correlation suggests reversals in returns; positive serial correlation indicates prevalence of trends.

[11] The lag length is selected by minimizing the following function for the maximum lag:

Akaike: $(RSS + 2K\,\sigma^2)/T$,

and

Schwarz: $[RSS + K(\log T)\sigma^2]/T$,

where K is the number of regressors and T is the number of observations. Results of this analysis are available from the author.

[12] The Box-Pierce Q-statistic is

$$Q = T\sum_{k=1}^{K}\hat{\rho}_k^2$$

distributed as chi-square with K degrees of freedom.

TABLE 5. Autocorrelation Coefficients, Daily Returns, 1978–91 and Subperiods

Number of Lags	¥	£	DM	FFr	SFr	A$	C$	FxIndx	S&P 500
1978–91									
Lag 1	0.009	−0.002	**−0.113**	**−0.082**	**−0.077**	0.001	−0.057	0.005	**0.055**
Lag 2	0.014	−0.004	0.013	0.007	0.016	−0.032	−0.012	−0.008	**−0.040**
Lag 3	**0.046**	0.010	**0.040**	**0.040**	0.011	−0.006	0.022	0.046	−0.028
Lag 4	0.008	−0.002	0.002	0.025	0.017	−0.009	0.013	−0.005	**−0.044**
Lag 5	0.004	0.015	−0.022	−0.026	−0.004	0.011	−0.003	0.021	**0.053**
LOC, Q-statistic (10)[a]	95.612	20.048	100.000	100.000	99.990	78.304	95.970	87.370	100.000
1978–84									
Lag 1	−0.001	−0.053	**−0.172**	**−0.164**	−0.039	**−0.127**	−0.147	−0.039	**0.093**
Lag 2	−0.012	−0.014	0.034	0.013	0.024	−0.011	−0.015	−0.002	0.034
Lag 3	0.014	0.041	**0.048**	**0.051**	0.006	−0.003	0.032	0.028	−0.019
Lag 4	0.027	−0.006	0.001	0.047	0.016	0.001	0.028	0.022	−0.035
Lag 5	−0.005	0.007	−0.039	**−0.054**	−0.037	0.004	0.025	0.015	0.005
LOC, Q-statistic (10)[a]	59.006	93.449	100.000	100.000	65.653	99.991	100.000	34.000	92.330
1985–91									
Lag 1	0.017	0.031	**−0.066**	0.003	−0.118	0.061	0.044	0.025	0.036
Lag 2	0.044	0.000	−0.010	−0.007	0.007	−0.042	−0.015	−0.014	**−0.077**
Lag 3	**0.084**	−0.017	0.032	0.026	0.013	−0.007	0.010	0.052	−0.033
Lag 4	−0.014	−0.005	−0.001	−0.005	0.014	−0.013	−0.004	−0.024	**−0.047**
Lag 5	0.011	0.020	−0.014	−0.003	0.023	0.014	−0.039	0.017	**0.076**
LOC, Q-statistic (10)[a]	97.101	64.418	72.138	8.236	99.984	92.415	49.688	61.040	100.000

Note: Numbers in bold are significant at the 95 percent level.

[a]The level of confidence (LOC) for the Box-Pierce Q-statistic of order 10 (or 10 lags).

TABLE 6. Autocorrelation Coefficients, Weekly Returns, 1978–91 and Subperiods

Number of Lags	¥	£	DM	FFr	SFr	A$	C$	FxIndx	S&P 500
1978–91									
Lag 1	**0.081**	0.014	0.041	0.006	0.041	0.003	−0.016	0.059	0.007
Lag 2	**0.090**	0.008	**0.079**	**0.099**	0.044	0.034	−0.007	0.073	0.042
Lag 3	**0.063**	0.026	−0.012	−0.004	0.023	−0.007	−0.016	0.035	−0.032
Lag 4	0.012	0.024	0.006	0.003	0.007	**0.093**	−0.015	0.043	0.025
Lag 5	0.040	0.023	−0.002	−0.012	0.028	−0.022	0.001	0.028	−0.020
LOC, Q-statistic (10)[a]	98.785	23.412	87.831	89.435	30.870	85.400	12.115	81.710	55.000
1978–84									
Lag 1	0.088	0.018	0.091	−0.004	0.083	0.051	−0.082	0.057	−0.029
Lag 2	**0.116**	−0.032	0.020	0.070	−0.044	**0.128**	0.035	0.027	−0.024
Lag 3	0.048	0.039	0.023	0.034	0.069	0.089	0.038	0.052	−0.043
Lag 4	0.070	0.069	0.021	0.001	0.020	−0.014	−0.062	0.030	0.046
Lag 5	0.015	0.031	−0.036	−0.051	0.015	0.064	−0.029	0.006	−0.015
LOC, Q-statistic (10)[a]	92.402	17.587	58.933	63.659	42.690	90.625	53.105	32.350	29.900
1985–91									
Lag 1	0.071	−0.002	−0.009	−0.007	−0.006	−0.011	0.056	0.039	0.011
Lag 2	0.068	0.019	**0.115**	**0.111**	**0.109**	0.005	−0.070	0.067	0.068
Lag 3	0.069	0.015	−0.048	−0.049	−0.017	−0.042	−0.095	0.010	−0.044
Lag 4	−0.044	−0.006	−0.005	0.008	0.004	**0.126**	0.018	0.030	0.017
Lag 5	0.056	0.014	0.016	0.001	0.041	−0.053	0.014	0.024	−0.008
LOC, Q-statistic (10)[a]	81.352	29.114	77.281	66.333	68.148	84.662	55.938	47.900	50.710

Note: Numbers in bold are significant at the 95 percent level.
[a]The level of confidence (LOC) for the Box-Pierce Q-statistic of order 10 (or 10 lags).

TABLE 7. Autocorrelation Coefficients, Monthly Returns, 1978–91 and Subperiods

Number of Lags	¥	£	DM	FFr	SFr	A$	C$	FxIndx	S&P 500
1978–91									
Lag 1	0.033	0.035	−0.034	−0.018	0.011	0.059	−0.021	0.014	0.042
Lag 2	−0.002	0.048	0.125	0.142	0.043	0.139	−0.146	0.084	−0.064
Lag 3	0.099	0.013	0.042	0.113	0.044	−0.099	0.001	−0.011	−0.079
Lag 4	0.062	0.035	0.023	0.065	0.006	**−0.194**	0.006	0.079	−0.081
Lag 5	0.072	0.058	0.053	0.069	0.028	−0.070	0.107	0.030	0.119
LOC, Q-statistic (10)[a]	50.760	4.408	38.656	73.176	29.879	95.366	92.434	30.460	58.690
1978–84									
Lag 1	0.052	0.055	−0.018	−0.042	−0.024	0.183	−0.115	−0.006	−0.003
Lag 2	−0.219	0.038	−0.070	−0.033	−0.081	−0.048	−0.203	−0.129	0.062
Lag 3	0.090	0.043	0.041	0.076	0.065	−0.096	0.000	0.001	−0.059
Lag 4	0.004	−0.065	−0.115	−0.057	−0.126	−0.199	−0.059	−0.222	0.159
Lag 5	0.036	**0.228**	0.002	−0.002	−0.038	0.106	0.121	0.082	0.138
LOC, Q-statistic (10)[a]	23.923	9.677	4.991	0.403	16.120	49.656	35.982	49.340	3.520
1985–91									
Lag 1	0.015	−0.005	−0.038	−0.021	0.022	0.030	−0.010	−0.069	0.053
Lag 2	0.102	−0.026	0.144	0.117	0.069	0.145	−0.123	0.127	−0.091
Lag 3	0.021	−0.007	0.020	0.050	0.042	−0.104	−0.037	−0.057	−0.094
Lag 4	0.070	0.082	0.045	0.060	0.113	−0.207	0.032	0.093	−0.182
Lag 5	0.059	−0.065	0.027	0.001	0.005	−0.127	−0.079	−0.028	0.084
LOC, Q-statistic (10)[a]	39.954	12.557	39.282	42.856	50.031	58.929	36.631	52.660	49.170

Note: Numbers in bold are significant at the 95 percent level.

[a]The level of confidence (LOC) for the Box-Pierce Q-statistic of order 10 (or 10 lags).

tions up to 10-day lags were highly significant for the equity index daily returns during the entire period and the two subperiods.

The trends (positive autocorrelations) in weekly returns generally were less significant than the reversals (negative autocorrelations) in daily returns (see Tables 5 and 6). The trends for the yen, however, were highly significant at various lags, and the European currencies (except the pound) showed significant trends in weekly returns. As before, the autocorrelations for the pound were insignificant. As with daily returns, the significance of autocorrelations changed with the subperiods. The trends for the currency index were as significant with weekly returns as the reversals were with daily returns. The autocorrelations for the equity index weekly returns were insignificant for all the periods—a dramatic change compared to the daily autocorrelations for returns. The monthly returns autocorrelations were not significant for any currency or either index for the entire period or for the subperiods. Table 7 presents the monthly returns autocorrelations.

In summary, except for the pound, daily and weekly currency returns during the 1980s exhibited significant autocorrelations. The daily return autocorrelations suggested reversals, the weekly return autocorrelations indicated existence of trends, but the monthly currency returns showed no significant trends or reversals. These results apply to the individual currencies and the composite currency index.[13] These conclusions are similar to those of the analysis of distributions, except for the trends found in daily returns based on the kurtosis of the distributions. Comparing the performance of the two indexes, the currency index had significant daily reversals and weekly trends and the equity index had significant daily trends and reversals. This difference was also examined with variance ratios computed for different holding period returns.

The implication for dynamic trading strategies, such as currency option replication strategies, is that although trends may exist in the weekly and daily returns for holding periods larger than a day or a week, dynamic strategies regimented to rebalance daily will suffer from significant whipsaw costs. This suggests the use of appropriate "filter rules" in the synthetic replication of currency options to minimize these wasteful costs.

Randomness. Another measure to detect the presence of trends or reversals in currency returns is the runs test. A run is one or more identical occurrences preceded or followed by a different occurrence. An unusually small

[13] A portfolio, or index, of currencies will generally have a smaller autocorrelation than the individual currencies (downward bias in the autocorrelation). This is similar to the downward bias in the variance of a portfolio relative to its component variances.

or large number of runs in a sequence indicates nonrandomness (i.e., a systematic pattern in the sign of the returns).[14]

Considering a positive currency return as one kind of occurrence and a negative currency return as the alternative occurrence, the null hypothesis of randomness was tested for the seven currencies and the two indexes. Table 8 provides results from the runs tests for the daily, weekly, and monthly currency returns for the 1978–91 period and the two subperiods.

TABLE 8. Runs Test, Z-Statistics, Daily, Weekly, and Monthly Returns, 1978–91 and Subperiods

Period	¥	£	DM	FFr	SFr	A$	C$	FxIndx	S&P 500
Daily									
1978–91	−3.03	−2.31	−0.67	−1.90	−1.85	−4.99	−6.06	−0.60	−1.93
1978–84	−1.97	−1.69	−1.23	−2.39	−2.09	−3.68	−3.29	−0.32	−2.10
1985–91	−2.20	−1.52	0.40	−0.26	−0.46	−2.96	−4.87	6.05	3.00
Weekly									
1978–91	−2.63	−2.06	−2.76	−2.18	−1.69	−2.70	0.04	−1.36	0.03
1978–84	−1.83	−3.38	−2.86	−2.65	−2.81	−3.75	1.58	−1.57	−0.15
1985–91	−0.82	0.87	−0.24	0.36	0.66	0.47	0.52	−0.06	0.27
Monthly									
1978–91	−1.21	−2.00	−2.17	−2.15	−2.01	−0.08	−0.33	−0.67	−1.15
1978–84	−0.70	−1.70	−1.93	−1.45	−0.79	0.08	0.26	−0.10	−1.54
1984–91	−0.86	−0.76	−0.56	−0.38	−1.48	−0.05	0.55	−0.11	−0.03

A significant negative (positive) Z value, less than (greater than) $-(+)1.96$, indicates the presence of significant trends (reversals). By this reckoning, the daily returns for the currencies (except the deutsche mark) showed significant trends; although the level of significance varied between the two subperiods, the trends in returns also existed in both. At the currency index level, daily returns showed no significant trends. As with autocorrelations, weekly returns showed highly significant trends for most currencies. The currency index did not indicate statistically significant trends in weekly returns. Except for the

[14] In the present use, let n_1 = number of times the currency return is positive, n_2 = number of times the currency return is negative, n_r = number of runs in the sequence, and $n_r = n_1 + n_2$. The mean number of runs is $\mu_r = (2n_1n_2/n_r) + 1$, the standard deviation of the number of runs is $\sigma_r = \sqrt{[2n_1n_2(2n_1n_2 - n_r)]/[n_r^2(n_r - 1)]}$, and the test statistic, sample $Z = (n_r - \mu_r)/\sigma_r$. See Bowen and Starr (1992, pp. 579–81).

European currencies, no significant trends or reversals existed for the monthly returns. The equity index showed significant trends with daily returns but no significant trends or reversals with the weekly or monthly returns.

The conclusions from runs tests are similar to the results suggested by the analysis of the return distributions. Except for the suggestion of trends in daily returns, conclusions from runs tests are also similar to the results of the autocorrelation analysis.

Trends and Reversals for Different Investment Horizons

The horizons over which significant trends or return reversals occur can be estimated through variance ratio tests. Variance ratios determine the extent to which a return series follows a random walk. For example, if the ratio of the variance of six-month returns divided by 6 times the variance of one-month returns is 1.0, then the returns do not exhibit any trends or return reversals (mean reversions) over a six-month return horizon. If, however, such a ratio is less than 1.0, then the returns exhibit return reversals. Autocorrelations will be negative for such a series. Mean reversions may exist because of subsequent corrections of divergences from fundamental values. For such a series, above-average returns tend to follow below-average returns and vice versa. Similarly, if the variance ratio is greater than 1.0, then the returns series exhibits a trend. For such a series, a positive return is typically followed by another positive return and a negative return by another negative return.

Using weekly returns for the 1978–91 period, the variance ratio statistic was computed for the seven currencies and both currency and equity indexes.[15] Table 9 contains variance ratios estimated for holding period returns of 3, 6, 9, 12, 18, 24, and 36 months. This statistic converges to unity if returns are uncorrelated through time.[16]

An inspection of the variance ratios suggests trends existed in the weekly returns for all the currencies (except the Canadian dollar) for the spectrum of holding periods ranging from 3 to 36 months. Z scores of all the variance ratios

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[15] The variance ratio is $VR(K) = [Var(R_t^K)/K]/Var(R_t)$, where $R_t^K = \sum_{i=0}^{k-1} R_{t-i}$ and R_t denotes the return in month t. See Poterba and Summers (1988b).

[16] Small-sample bias can be corrected by dividing $VR(K)$ by $E[VR(K)]$, where $E[VR(K)]$ is computed using the expected value of the jth sample autocorrelation, $E(\hat{\rho}_j) = -1/(T - j)$, where T is the number of data points and j is the jth lag of the autocorrelations: $E[VR(k)] \approx 1 + 2\sum_{j=1}^{k-1}[(k-j)/k]E(\hat{\rho}_j)$. See Poterba and Summers (1988b, note 5) and Kendall and Stuart (1976).

TABLE 9. Variance Ratios, Weekly Returns, 1978–91

Holding Period	¥	£	DM	FFr	SFr	A$	C$	FxIndx	S&P 500
3 months	1.16	1.12	1.07	1.06	1.11	1.16	0.84	1.12	1.08
6 months	1.56	1.35	1.39	1.45	1.35	1.16	0.87	1.46	1.16
9 months	1.49	1.28	1.41	1.48	1.33	1.02	0.80	1.42	1.11
12 months	1.70	1.42	1.75	1.83	1.48	1.15	1.00	1.76	1.13
18 months	1.88	1.43	2.19	2.21	1.71	1.12	1.23	2.12	0.99
24 months	1.98	1.45	2.39	2.42	1.82	1.21	1.47	2.36	0.74
36 months	2.46	1.48	2.46	2.53	1.77	1.18	1.88	2.74	0.56

(except the equity index) were found to be highly significant.[17] Also, for the equity index, note that although trends may exist up to the 12-month investment horizon, during longer horizons (18 to 36 months), equity returns exhibit reversals (Poterba and Summers 1988a).

The use of overlapping periods in the variance ratio analysis may make the standard statistical tests of significance inappropriate (Sharpe 1989). For each currency and the two indexes, Monte Carlo tests were used to assess the significance of these variance ratios by rearranging randomly the weekly returns and computing a new set of ratios. One thousand trials were performed for each currency and for each holding period of 3 to 36 months. The bootstrap probabilities of variance ratios greater than (for variance ratios greater than 1.0) or less than (for variance ratios less than 1.0) the corresponding variance ratios in Table 9 are given in Table 10. The smaller the value of the bootstrap probability, the more significant the corresponding variance ratio indicated in Table 9 for the investment horizon.

The bootstrap probabilities are similar to the levels of significance in hypothesis testing. Figure 2 illustrates bootstrap probabilities for the yen, pound, and deutsche mark. These are the results of 1,000 Monte Carlo simulations of variance ratios for the three currencies. In about 22 percent of

[17] A standardized Z-statistic under homoscedasticity can be computed to test the significance of the variance ratios $VR(k)$ using the following formula:

$$Z \cong \sqrt{nk}[VR(k) - 1]\left[\frac{2(2k-1)(k-1)}{3k}\right]^{\frac{1}{2}} \sim N(0, 1),$$

where nk = number of observations. See Lo and MacKinlay (1987).

A standardized Z-statistic where the asymptotic variance of the variance ratio is heteroscedastic is given in Liu and He (1991).

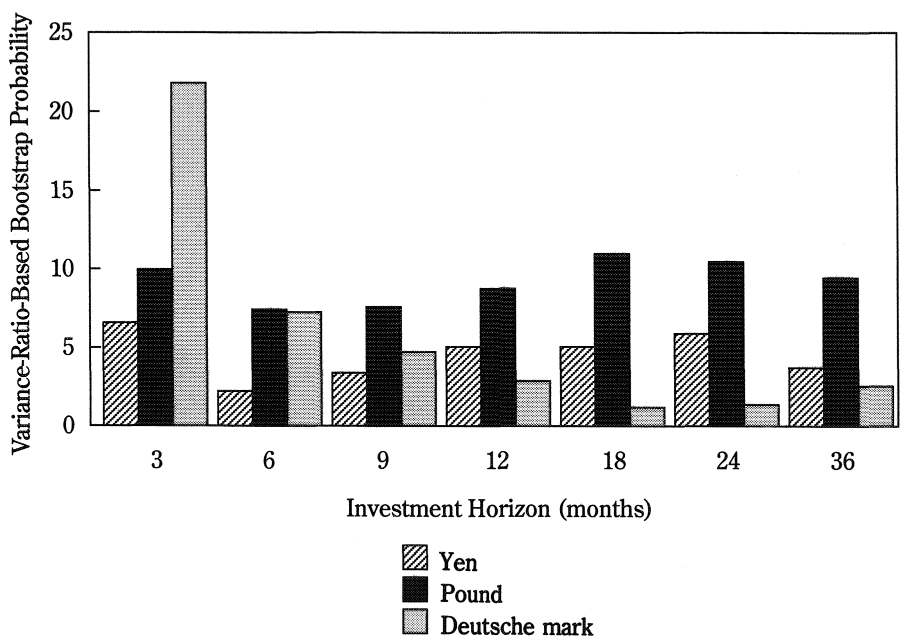
TABLE 10. Bootstrap Distributional Probabilities of Variance Ratios, Weekly Returns, 1978–91

Holding Period	¥	£	DM	FFr	SFr	A$	C$	FxIndx	S&P 500
3 months	6.8	10.5	21.8	22.9	13.3	3.4	7.1	12.6	31.0
6 months	2.5	7.6	7.3	3.7	8.2	23.0	17.9	4.9	46.7
9 months	3.3	7.6	4.7	2.5	6.7	29.4	24.6	4.5	45.0
12 months	4.9	8.9	2.7	1.7	9.5	22.1	44.5	2.7	53.7
18 months	4.8	11.0	1.2	0.4	7.0	22.7	21.5	1.5	33.3
24 months	5.6	10.6	1.4	0.3	7.1	14.3	11.4	1.2	19.3
36 months	3.5	9.4	2.1	0.6	10.2	11.7	3.7	1.1	13.7

Note: Variance ratios and bootstrap probabilities based on monthly returns of the currencies are very similar to those estimated using weekly returns.

the 1,000 trials involving the randomly selected deutsche mark weekly returns, the three-month variance ratio was higher than the 1.07 value shown in Table 9. This implies that because the 1,000 trials came from a random process, the probability is about 22 percent that the variance ratio of 1.07 actually obtained

FIGURE 2. Bootstrap Probabilities for Variance Ratios, Weekly Returns, 1978–91

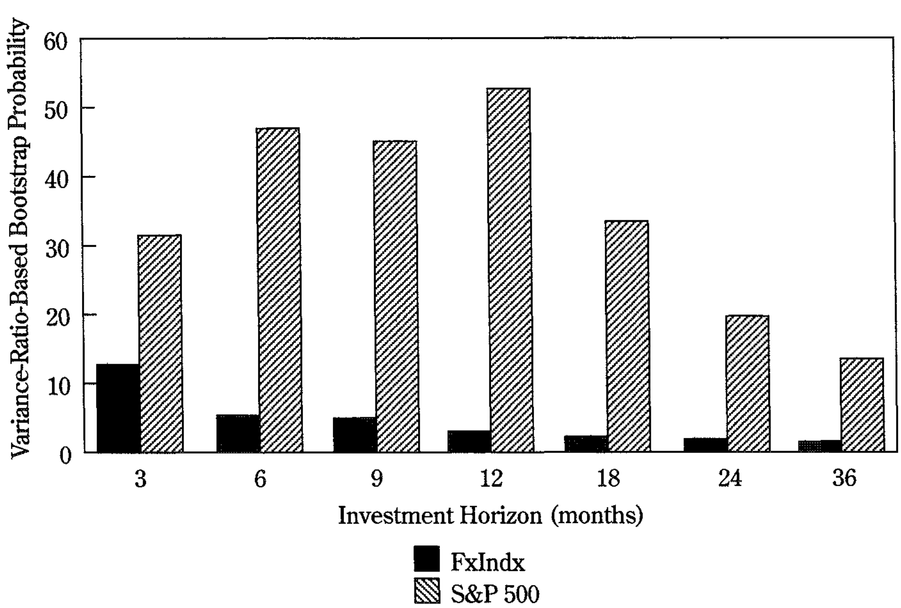


for the three-month deutsche mark return was attributable to chance. Although the three-month deutsche mark variance ratio is, therefore, not significant, the pure chance probability for the deutsche mark rapidly declines to less than 2.5 percent during investment horizons exceeding one year. In fact, it is as low as 1.2 percent for the 18-month investment horizon. Figure 2 indicates that the yen and deutsche mark, but not the pound, exhibit statistically significant trends in their returns for holding periods exceeding one year. The French franc and the currency index appear to possess significant (with a 95 percent confidence limit) trends in returns for holding periods between 12 and 36 months, as shown in Table 10.

Figure 3 shows the results of 1,000 Monte Carlo simulations of variance ratios for the two indexes. Although the trends in the currency composite were significant for horizons greater than six months, the equity index had statistically insignificant trends during short investment horizons (less than a year) and significant reversals during longer horizons (greater than three years).

In summary, the variance ratio statistic computed for the various currencies indicates the presence of significant trends for the currency index, the yen, and the European currencies for investment horizons longer than six months and lasting as long as three years. The pound exhibited a less significant trend

FIGURE 3. Bootstrap Probabilities for FxIndx and S&P 500, Weekly Returns, 1980–91



during this period. The Australian and Canadian dollars did not show significant trends or reversals, although the Canadian dollar had significant reversal over three-year horizons. These conclusions were confirmed with a Monte Carlo, or bootstrap, simulation performed to check the validity of the variance ratio tests.

The significance of trends for holding periods longer than three months for the yen, deutsche mark, Swiss franc, Australian dollar, and the equity index are also substantiated by the significance of the mean returns for holding periods longer than three months, as shown in Table 11. For the currency index, mean holding period returns beyond 12 months appeared to be significant.

Forecasting Expected Returns

Despite the implications of the purchasing power parity theorem[18] and interest rate differential theorem,[19] several empirical papers have suggested that both the nominal and real exchange rate changes are unpredictable.[20] Nominal exchange rates appear not to move to offset differences in inflation rates on a month-to-month, quarter-to-quarter, or even year-to-year basis. As a result, variation in nominal exchange rates is primarily the result of variation in real exchange rates. Neither past historical changes in real rates nor changes in macroeconomic variables such as domestic and foreign money supplies, real incomes, interest rates, and current or trade accounts appear systematically to explain changes in real rates.[21]

Although currency returns may be unforecastable in a statistical sense, determinations could be made as to whether reactions to unusual events (large positive or negative currency moves) were predictable and whether the adjustments from such events lasted long enough to formulate profitable investment strategies. Moreover, if daily, weekly, and monthly currency returns cannot be forecast but trends appear to exist for investment horizons of

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[18] Exchange rates are predicted to maintain, in the long run, a parity in the ability to purchase a basket of commodities.

[19] Exchange rates are predicted to adjust to the interest rate differential between two countries; the higher interest rate currency is predicted to devalue over time relative to the lower interest rate currency.

[20] See Wasserfallen (1988), Meese and Rogoff (1988), Adler and Lehman (1983), and Cumby and Huizinga (1990).

[21] See Wasserfallen (1988), Levich (1985), Backus (1984), Meese and Rogoff (1983), and others who agree on the results that the macroeconomic variables mentioned in the text are not systematically related to changes in exchange rates. Cumby and Huizinga (1990), however, suggest that their tests indicate changes in real exchange rates are predictable.

TABLE 11. Mean Holding Period Returns, Weekly Returns, 1978–91

Holding Period	¥	£	DM	FFr	SFr	A$	C$	FxIndx	S&P 500
3 months	**1.09%**	−0.09%	**0.47%**	−0.21%	**0.59%**	**−0.60%**	−0.05%	0.31%	**2.48%**
6 months	**2.29**	−0.21	**0.94**	−0.55	**1.19**	**−1.33**	−0.09	0.62	**5.60**
9 months	**2.97**	−0.31	**1.29**	−0.82	**1.59**	**−1.93**	−0.11	0.76	**7.74**
12 months	**3.99**	−0.36	**1.99**	−1.07	**2.14**	**−2.85**	−0.08	**1.21**	**10.83**
18 months	**6.12**	−0.47	**3.41**	−1.16	**3.65**	**−4.29**	−0.00	**2.41**	**15.74**
24 months	**8.29**	−1.38	**4.32**	−1.70	**4.54**	**−5.85**	0.03	**3.68**	**21.65**
36 months	**14.89**	**−4.17**	**4.93**	**−4.17**	**5.25**	**−9.27**	0.04	**8.03**	**36.99**

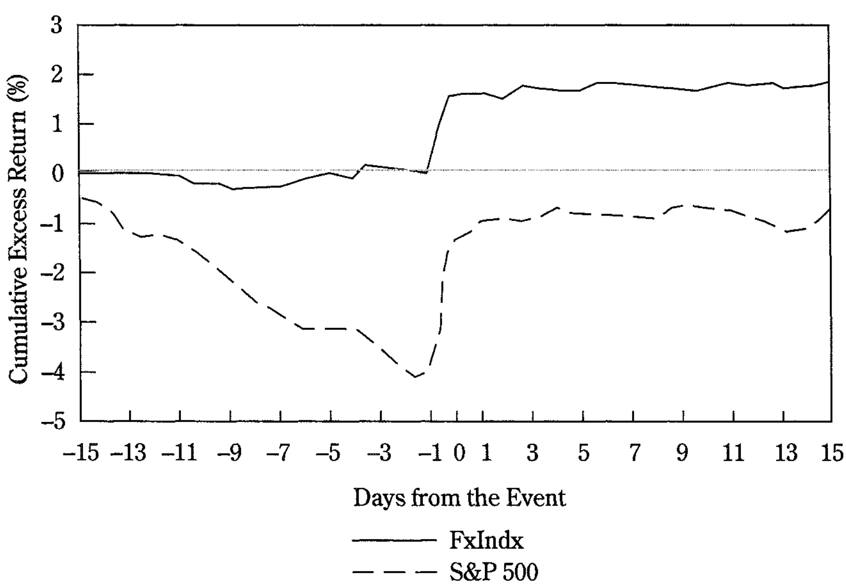
Note: Numbers in bold are significant at the 99 percent level.

six months or longer, as was found in the previous section, then option-based strategies that are "informationless" (do not require daily or weekly return forecasts), but are able to benefit from any trends in the currency assets over longer investment horizons, are appropriate. First, consider the reactions of currency returns to unusual events.

Reactions to Unusual Events. An "unusual event" is defined as a daily return that is one or two standard deviations above or below the mean daily return. The question is whether the markets are efficient before and after an unusual event. If after a significant rise (fall) the currency continues to rise (fall) or revert over several days, then profitable trading rules can be formulated.

Figure 4 shows the average cumulative excess return (i.e., more than two standard deviations in excess of the mean daily return) accrued from 15 days prior to the event day (day 0) and continued for 15 days after the event. Between 1978 and 1991, 89 such event days, out of 3,131 daily returns, occurred for the currency index and 61 such event days for the equity index. The mean event day excess return was 1.63 percent for the currency index and 2.79 percent for the equity index. If they both had been perfectly normal distributions, the event day average excess return would have been 2.0 percent for both indexes.

FIGURE 4. Cumulative Daily Return before and after Significant Event



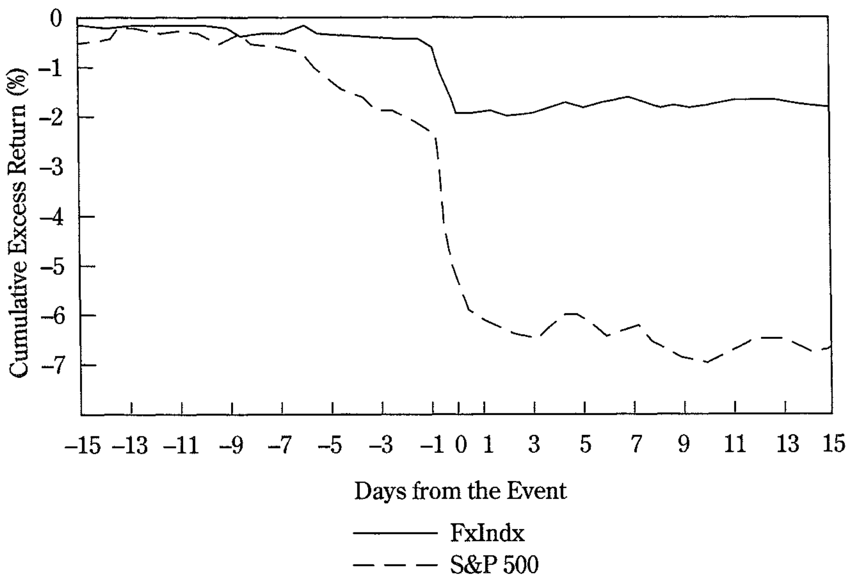
Market efficiency implies that the cumulative excess return is insignificantly different from zero up to the event day and thereafter stabilizes at a higher (or lower) level of cumulative excess return. By this criterion, the currency index return is remarkably efficient for a two-standard-deviation event whereas, for the equity market, a dramatic increase of two standard deviations in market returns appears to be preceded by equally dramatic cumulative declines in the prior 15 days. In other words, for the equity market, although large increases in daily returns are caused by reversals from a prior period's declines, in the currency market, large market moves appear to be unanticipated. This conclusion is also corroborated for a positive one-standard-deviation event. Individual currencies (the yen, pound, and deutsche mark) exhibited efficient market behavior for positive one- and two-standard-deviation events similar to that described for the currency index.

Figure 5 shows the cumulative excess returns for the currency index and the equity index before and after a negative two-standard-deviation event (a large decrease in currency or equity return). As in a large increase in daily return event, the currency market appears efficient in that the large negative return event day is unanticipated and the daily excess returns after the event are almost zero. During the 1978–91 period, 70 negative two-standard-deviation event days occurred for the currency market and 52 such event days for the equity market. The equity market appeared to anticipate the impending large decline in daily return about six days before the event day but did not fully assimilate the information. The individual currencies, as before, were efficient with respect to event days with large declines in returns. Similar conclusions were obtained with respect to event days of one standard deviation decline in daily returns.

In summary, the currency market is efficient with respect to unusual return event days, which implies that no profitable strategies can be formulated based on an anticipated large decline or increase in daily currency returns. For perspective, such profitable trading strategies appear to be feasible in the equity market.

Existence of Linear and Nonlinear Trends. Although the currency markets appear to be efficient with respect to unusual event days (they exhibit linear unpredictability), the daily returns of currencies exhibited trends and reversals. Also possible is that even though the currencies may show efficiency in linear trends (the correlation of returns between two points in time may be insignificant), nonlinear trends in higher dimensions (the correlation of returns among more than two points in time) may exist. Also, although currency returns

FIGURE 5. Cumulative Daily Return before and after Significant Event



(x_t) may be serially uncorrelated, nonlinear functions of currency returns (x^{2_t}) may be correlated (Manas-Anton 1986).

Nonlinear dependence in exchange rates may imply that exchange rate changes are deterministic processes that appear random—the "chaotic systems" that researchers have begun to investigate (Scheinkman and LeBaron 1989). Hsieh (1989) investigated nonlinear dependence in exchange rate changes arising from a stochastic nonlinear dependence on their own past. He used the BDS statistic to test directly for nonlinear dependence.[22] Examples of nonlinear stochastic systems include the nonlinear moving average model, the threshold autoregressive model, the bilinear time series model, and the familiar autoregressive conditional heteroscedasticity (ARCH) model and its variations.

Using daily closing bid prices of five major foreign currencies (the yen, pound, deutsche mark, Swiss franc, and Canadian dollar) for the period January 2, 1974, to December 30, 1983, Hsieh (1989) reported the BDS statistics, which indicate substantial nonlinear dependence in the data. A similar BDS statistic test was used in this study to detect nonlinear dependence in daily

[22] The BDS statistic was proposed by Brock, Dechert, and Scheinkman (1987).

currency returns data for the period 1978 to 1991.[23] Table 12 presents the BDS statistic (four dimensions and two proximity distances) for the seven currencies and the two indexes using daily returns. Proximity distance, *l*, is set in terms of the standard deviation of the data (i.e., $l = 1$ implies it is one standard deviation of the data).

TABLE 12. Brock, Dechert, Scheinkman Test, Daily Currency Returns, 1978–91

N[a]	l^b	¥	£	DM	FFr	SFr	A$	C$	FxIndx	S&P 500
2	0.50	11.89	10.17	7.93	9.54	6.04	24.06	15.58	2.13	0.85
3	0.50	14.82	12.68	10.15	13.69	7.70	30.69	18.57	3.35	1.13
5	0.50	23.21	16.83	15.18	23.86	11.11	44.59	25.31	6.87	2.59
7	0.50	37.73	25.45	20.92	41.48	16.29	73.67	39.23	9.78	3.82
2	1.00	10.83	10.19	10.03	8.31	6.97	22.76	13.52	2.43	2.78
3	1.00	13.07	12.35	11.00	11.28	8.35	26.61	15.79	3.48	3.43
5	1.00	17.67	15.30	12.97	17.08	11.38	32.24	19.61	6.83	4.82
7	1.00	22.87	18.78	14.78	23.05	14.75	38.92	23.72	9.52	6.11

Note: The BDS statistic has a standard normal distribution.
[a]Dimensions.
[b]Proximity distance.

The BDS statistics in Table 12 confirm for the more recent period (1978–91) Hsieh's findings regarding nonlinearity in currency returns for the 1974–83 period. The data exhibit substantial nonlinear dependence, but generally, the BDS statistics for the more recent period are smaller than those estimated by Hsieh (Hsieh 1989, p. 347). BDS statistics for the two indexes were also computed. For the currency index, although nonlinear dependence exists, it is somewhat muted compared to the individual currency components. The reduced degree of nonlinear dependence could be attributable to lower cross-correlations in higher dimensions. The BDS statistic for the equity index suggests less nonlinear dependence in the equity markets relative to the currency markets. Hsieh (1989, p. 1,358) obtained similar values of the BDS statistic for the daily equity index for the period 1983 to 1989. After rejecting structural changes and low-complexity chaotic behavior as reasons for the nonlinear dependence in stock returns, Hsieh concluded that a flexible variance

[23] This statistic is described in detail in Hsieh (1989).

exponential generalized autoregressive conditional heteroscedastic (EGARCH) model captures all nonlinear dependence in stock returns.[24] The implication for modeling stock returns is that efforts are better directed at modeling conditional heteroscedasticity rather than conditional mean changes, which include chaotic dynamics. Similar considerations guide the modeling of currency returns described in subsequent sections.

Nonlinearity in currency returns as revealed by significant BDS statistics also suggests that momentum/reversal-based trading strategies that are essentially nonlinear in nature may prove to be profitable.

Profitability of Nonlinear Trading Rules. If trends and reversals are present in the currency markets but no simple linear currency forecasting model exists, then profitable trading rules may have to be formulated only in a nonlinear form. We tested the profitability of simple "filter rules" that would be characterized as "technical" trading or "momentum" trading but are essentially nonlinear decision rules expressed as functions of currency returns. The presence of such profitable trading rules during the 1978–91 period offered confirmatory evidence of nonlinear dependence in the currency returns data.

In formulating and testing nonlinear trading rules, the methodology suggested by Sweeney (1986) was followed. The filter rule is based on Fama and Blume (1966): "Buy when the dollar value of the foreign currency rises *R* percent above its previous local low; sell when it falls *F* percent from its previous local high." Further, we set *R* and *F* equal and did not "optimize" to improve the trading rule performance. The buy-and-hold strategy was used as the standard of comparison to evaluate the profitability of the filter rules; filter returns in excess of buy-and-hold were determined. The sampling distribution of excess returns will be normal if standard deviations of currency returns exist (Sweeney 1986).[25]

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[24] Hsieh (1989) fitted to stock returns the following general EGARCH model, which has a stochastic term in the variance equation:

$$x_t = \sigma_t z_t,$$

where z_t is an individually and independently distributed (IID) random variable, and σ_t evolves according to $\log \sigma_t = \beta_0 + \Sigma_i \beta_i \log \sigma_{t-1} + v_t$, where v_t is IID, independent of z_t.

[25] Define X, filter returns in excess of buy-and-hold, as follows:

$$X = \overline{R}_F - \overline{R}_{BH} + f\overline{R}_{BH},$$

where $\overline{R}_F$ is the sample mean of filter returns over the 1981–91 period, $\overline{R}_{BH}$ is the arithmetic average buy-and-hold return over the sample period, and f is the fraction of the days in the sample

Table 13 shows excess returns before and after transaction costs. Excess returns net of transaction cost (number of round-trips multiplied by the per-round-trip cost) assume a round-trip cost of 12 basis points (Sweeney and Lee 1985). A few salient conclusions emerge from Table 13. As expected, presence of nonlinear dependence in currency returns resulted in profitable trading rules; the annualized excess return (before transaction costs) to filter rules ranged from a high of 5.3 percent for the yen to a low of −0.6 percent for the Australian dollar. The composite currency index showed positive excess returns for each filter rule. For the 0.5 percent and 1.0 percent filter rule strategies, the currency index had statistically significant 5.2 and 3.0 percent annualized excess returns. Even after accounting for transaction costs, the filter rules produced highly significant 3.1 and 2.0 percent annualized excess returns for the currency index.

Among the currencies, the yen showed the most gains (net of transaction costs), and the four major currencies—the yen, pound, deutsche mark, and Swiss franc—yielded significant excess returns from filter rule strategies. The French franc was profitable but not statistically significant. In general, the smaller filter bands (rules) appear more profitable than the larger ones, although considering the distribution of the t-statistics of the various filter rules for the seven currencies individually, all filter rules of 8 percent and less were highly statistically significant.[26]

In comparing the currency and equity indexes, the equity market did not afford any profitable trading rules, perhaps because the rules were based on conditional means of the asset returns. The nonlinearity in stock returns may have been caused by the presence of conditional heteroscedasticity rather than

that the filter rule model takes the investor out of the foreign currency market and into the domestic currency. Assuming constant risk premiums for the currencies, the variance of X is $\sigma_x^2 = (\sigma_u^2/N)f(1 - f)$, where σ_u^2 is the variance of the foreign currency return. The sampling distribution of X will be normal. We also ignored the interest rate differentials and evaluated the filter rule's effect solely attributable to exchange rate appreciation. As explained in Sweeney, this is justified if the interest rate differential between the foreign and domestic country, on average, is the same for days in the foreign currency as for days out of the currency and in the domestic currency.

[26] See Sweeney (1986). Because the t-statistics should show no correlation across countries for the same filter, the overall significance of the profits across countries from any filter can be tested by looking at the average t-statistic, which is distributed:

$$N(0,\ 1/N^{1/2}),$$

where N is the number of currencies (seven in this case). The t-statistics for the currencies are available from the author.

TABLE 13. Profitability of Filter Rule Strategy, Daily Returns, 1978–91

Filter Rule	¥	£	DM	FFr	SFr	A$	C$	FxIndx	S&P 500
Gross Profitability									
0.5%	**4.2%**	**2.9%**	2.1%	0.9%	**3.4%**	1.4%	0.2%	**5.2%**	2.6%
1.0	**5.3**	**3.7**	**4.6**	1.6	**4.5**	0.6	0.0	**3.0**	2.2
2.0	**3.0**	**3.0**	2.3	2.2	2.6	1.2	−0.2	2.2	−2.0
3.0	**2.5**	1.0	0.8	0.7	1.0	−0.6	0.6	2.4	**−5.1**
5.0	**3.2**	0.8	0.4	2.0	2.3	0.4	1.0	1.2	**−5.9**
8.0	2.0	1.9	1.5	1.5	2.6	−0.5	0.3	1.2	**−9.1**
10.0	0.5	1.5	1.6	0.5	1.8	0.2	0.4	1.1	**−8.3**
Net Profitability									
0.5	**0.8**	**0.1**	−0.9	−1.3	**−0.3**	0.0	−0.6	**3.1**	−2.6
1.0	**3.6**	**2.5**	**3.3**	0.6	**2.6**	−0.0	−0.3	**2.0**	−1.3
2.0	**2.3**	**2.5**	1.8	1.8	1.7	1.0	−0.3	1.8	−4.0
3.0	**2.1**	0.7	0.5	0.5	0.6	−0.8	0.6	2.2	**−6.4**
5.0	**3.0**	0.7	0.3	1.9	2.2	0.4	1.0	1.1	**−6.5**
8.0	1.9	1.9	1.5	1.5	2.6	−0.5	0.3	1.2	**−9.5**
10.0	0.4	1.4	1.6	0.5	1.7	0.2	0.4	1.1	**−8.6**

Note: Numbers in bold are significant at the 99 percent level.

the conditional mean. The performance differential of the trading rules between the two indexes also alludes to the perception of greater "efficiency" in the equity market, because the conditional means of equity returns are essentially random. From a market efficiency point of view, although the equity returns, on average, impound all available information at any given point in time, the currency returns may exhibit, in a complex way, vestigial effects of information disseminated in the past. This contrasts sharply with the conclusion reached through the event-day analysis described earlier. A compromise explanation is that the equity returns are largely efficient, linearly and nonlinearly, for normal returns but are inefficient for unusually large returns (one- or two-standard-deviation event days).

Hypotheses for Trading Rule Profits. Some interesting hypotheses have been suggested to explain the presence of filter rule profits in the currency markets. The excess returns are compensation for risk, in the sense of undiversifiable risk, as in the capital asset pricing model (CAPM); the higher the "beta" of a currency relative to the U.S. dollar, the higher the excess return. This argument, however, is not valid for the excess returns to filter rules reported in Table 13. These returns exceed the buy-and-hold returns and also the CAPM-implied expected excess returns to the filter over buy-and-hold returns, which should equal zero (Sweeney 1986).

Under the current managed-float regime of exchange rates, ill-conceived government intervention could lead to profit opportunities. A Federal Reserve summary of 10 staff studies concluded from the April 1983 "Report of the Working Group on Exchange Market Intervention" that coordinated intervention is more effective than intervention by a single country.[27] Reviewing another study by Lawrence (1983), the Federal Reserve summary concluded that the cumulative loss on U.S. dollar/deutsche mark intervention from 1973 to 1979 was $500 million, although the cumulative intervention activity, if measured from 1973 through 1981, was moderately profitable. Another study, by Taylor (1982), concluded that the central banks of Canada, France, Germany, Italy, Japan, Spain, Switzerland, the United Kingdom, and the United States jointly lost $12 billion during the 1970s in attempting to stabilize exchange rates.[28] To the extent that speculators bet against central banks, central bank losses

[27] Board of Governors of the Federal Reserve System (1983).

[28] Taylor's study used Friedman's profit criterion: The objective of a central bank when trying to stabilize foreign exchange markets should be the same as that of a private speculator—buy low, sell high. Thus, if a central bank is successful in stabilizing the foreign exchange market, it makes a profit; if unsuccessful, it suffers a loss.

became the "excess" returns to foreign exchange traders. Other studies also have concluded that some evidence suggests government intervention to "lean against the wind."[29] Such counterproductive government intervention offers a partial basis for generating excess returns in the currency market.[30]

Yet another reason for the excess returns to trading rules may be insufficient stabilizing speculation, which would be true by definition because with sufficient stabilizing speculative funds, both private and governmental destabilizing speculation would not lead to any excess returns. Restrictions on the open positions that commercial and investment bank exchange traders can take is often cited as the reason for the insufficiency of the private stabilizing speculative funds. Although data on daily exchange positions of banks are nonexistent, a conservative indication of the risk that banks lay off is given by a BankAmerica Options (a unit of Bank of America) estimate that about 80 percent of the deutsche mark options written by Bank of America's San Francisco office are hedged on the Philadelphia Exchange (Bartlett and Ludman 1986). Some authors, such as McKinnon (1979), have argued that the reluctance of commercial banks and multinational corporations to take large net positions in either the spot or forward exchange markets for significant intervals of time (because of inadequate private speculative capital) is one reason for the increased volatility of exchange rates under the floating exchange rate system.

The existence of excess returns can be argued by a reference to time-varying risk premiums. This would preserve the efficient market hypothesis because the filter rule will, on average, put the investor "in" the foreign currency when the risk premiums, and hence the expected returns, are larger than average. In this view, excess returns do not reflect true profits but higher average risk borne. The problem with this hypothesis is that it is not testable. To estimate risk premiums, an asset pricing model, such as CAPM or the arbitrage pricing theory, must be specified; therefore, any test of market efficiency will be a joint test of the asset pricing model and market efficiency. What remains, then, is the assumption of market inefficiency as a possible explanation of excess returns. Such inefficiency could be attributable either to unincorporated information arising from nonlinearity in currency returns or to inadequate speculative capital to arbitrage away the excess returns.

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[29] Sweeney (1986) cites Dornbusch (1980) and Branson (1983).

[30] A partial basis because, even in the absence of government intervention if currency markets exhibit nonlinear determinacy in returns, as shown above, trading profit opportunities would exist.

Structural (Macroeconomic) Exchange Rate Models of Currency Return Forecasts. In the previous section, a technical model was used to forecast exchange rate returns; filter rules are simple examples of technical models. In this section, the success of structural models of exchange rate forecasts is investigated. Many structural models involving macroeconomic variables—such as money supply, real incomes, and inflation rates—are formulated as a function of expected values of fundamental variables.[31] Three types of economic models of exchange rate determination are: (1) portfolio balance and monetary models, which involve asset supply and demand that make up the total wealth in a multicountry world (e.g., noninterest-earning money and interest-earning domestic and foreign bonds);[32] (2) balance of payments flow models, which involve flows in the trade and capital accounts;[33] and (3) equilibrium models, such as the universal CAPM, which predict expected returns to currencies based on their betas to a world market portfolio and the implication of the mathematics of "Siegel's paradox," which postulates that the sum of the expected return of currency i relative to currency j and expected return of currency j relative to currency i does not equal zero.[34]

The various exchange rate models differ in their implications for investment strategy of changes in macroeconomic factors because of their predictions regarding the relationship of exchange rate movements to macroeconomic

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[31] As shown in Meese (1992), many structural exchange rate models can be written as

$$s_t = x_t + b[E(S_{t+1}) - S_t],$$

where s_t is the logarithm of the spot rate, x_t is a linear combination of fundamentals, and b is the elasticity of the current spot rate to its expected rate of change. The exchange rate equation can be solved to yield

$$S_t = \frac{1}{1+b} \sum_{i=0}^{\infty} \left(\frac{b}{1+b}\right)^i E(X_{t+i}).$$

Thus, the current spot rate is considered to be a function of the expected values of an appropriate set of fundamental or macroeconomic variables.

[32] An integrated model that contains the basic properties of the monetary model plus the impact of the relative bond supplies (domestic and foreign) to represent risk premium in the exchange market, captured in the portfolio balance model, is described in "The Portfolio Balance Approach to Exchange Rate Determination," *Merrill Lynch Capital Markets,* August 1990.

[33] For details on this type of model, see "The Balance of Payments Flow Approach to Exchange Rate Determination," *Merrill Lynch Capital Markets,* February 21, 1991.

[34] See Solnik (1974), Black (1990), and Meese (1992).

factors. The equilibrium models are more stylized and are used to indicate long-run behavior; the deviation of current values from long-run equilibrium suggests the direction of future exchange rate adjustments. These models also can be used to provide anchoring values for asset returns in an optimization context.[35] They could serve as guides to active forecasts of exchange returns or, in the absence of explicit forecasts, function as the default normative values of asset returns. As equilibrium models, they are untestable; their popularity as practical aids in constructing balanced optimal portfolios remains to be seen.

The implications of changes in macroeconomic factors, such as a rise in domestic activity or domestic interest rates, differ dramatically between the portfolio balance model and the balance of payments flow approach. A rise in the domestic interest rate, for example, *ceteris paribus,* leads to a fall in domestic currency value under the integrated portfolio balance approach because of an increase in the risk premium and to a rise in domestic currency value because of a rise in domestic real interest rates (Bartlett and Ludman 1986, and McKinnon 1979). Although the net effect depends on the relative magnitudes of the two contrasting pulls, the balance of payments approach implies an unambiguous rise in domestic currency value from a rise in the domestic interest rate attributable to increased capital inflows.

The various forms of the monetary approach and the portfolio balance approach have performed poorly in econometric tests.[36] In out-of-sample tests, the models perform poorly except when differences in money growth rates across economies are large. Random walk models (i.e., naive prediction that exchange rates will not change) do as well or better than the predictions of these more sophisticated models (Korajczyk 1992). Root mean square error—a measure of the out-of-sample explanatory power of models—of one-quarter-ahead forecasts of currencies based on random walk models are of the same or lower order of magnitude as the various monetary and portfolio balance models tested over the 1982–90 period (Meese 1992). In summary, the structural models of exchange rate determination have been poor predictors of currency returns.

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[35] See Black and Litterman (1991). The authors argue that the use of the expected returns associated with asset market equilibrium (ICAPM) as a reference point for investors is a unique feature of their otherwise traditional mean–variance optimization approach to asset allocation.

[36] See Boughton (1988), Dornbusch (1980), Frankel (1984), Meese and Rogoff (1983), and Frenkel (1983).

Forecasting Expected Variance

Clearly, predicting expected returns (levels) of currency exchange rates can be difficult, as evident from the forecast accuracy of structural models. The next question is whether variances and correlations between currencies are predictable. Are they more determinate or stable?

Tables 14, 15, and 16 provide the cross-correlations of the daily, weekly, and monthly currency returns for the seven currencies for the entire study period and for the two subperiods of strong (1978–84) and weak (1985–91) dollars. In general, the daily, weekly, and monthly cross-currency correlations in the latter subperiod were larger than those in the former one. This upward

TABLE 14. Cross-Correlations of Daily Currency Returns, 1978–91 and Subperiods

Currency	¥	£	DM	FFr	SFr	A$	C$
1978–91[a]							
¥	1.00						
£	0.48	1.00					
DM	0.56	0.64	1.00				
FFr	0.56	0.64	0.77	1.00			
SFr	0.59	0.61	0.73	0.71	1.00		
A$	0.28	0.28	0.23	0.24	0.23	1.00	
C$	0.14	0.23	0.21	0.20	0.22	0.17	1.00
1978–84 and 1985–91[b]							
¥	1.00	0.59	0.64	0.68	0.63	0.27	0.16
£	0.35	1.00	0.72	0.77	0.68	0.29	0.27
DM	0.48	0.54	1.00	0.90	0.75	0.21	0.23
FFr	0.45	0.50	0.64	1.00	0.81	0.24	0.26
SFr	0.55	0.54	0.70	0.62	1.00	0.22	0.24
A$	0.31	0.26	0.26	0.25	0.27	1.00	0.22
C$	0.12	0.19	0.18	0.14	0.19	0.12	1.00

[a]Based on the number of observations (3,673) for the period, absolute value of the correlations exceeding 0.001 are statistically significant at the 5 percent level. Based on the sampling distribution of the sample correlation coefficient r, it can be shown that if the population correlation coefficient $\rho = 0$, then, and only then, the statistic $t = r\sqrt{n - 2/1 - r^2}$ has the Student t distribution with $v = n - 2$ degrees of freedom. See Bowen and Starr (1982, p. 432).

[b]The upper right triangle of the symmetric matrix contains the correlations for the period 1985 to 1991, and the bottom left triangle represents the period 1978 to 1984. Based on the number of observations (1,847) for the period, absolute value of the correlations exceeding 0.002 are statistically significant at the 5 percent level.

Table 15. Cross-Correlations of Weekly Currency Returns, 1978–91 and Subperiods

Currency	¥	£	DM	FFr	SFr	A$	C$
1978–91[a]							
¥	1.00						
£	0.50	1.00					
DM	0.63	0.75	1.00				
FFr	0.61	0.72	0.92	1.00			
SFr	0.65	0.70	0.89	0.84	1.00		
A$	0.25	0.27	0.22	0.23	0.24	1.00	
C$	0.01	0.01	0.00	−0.04	−0.01	0.06	1.00
1978–84 and 1985–91[b]							
¥	1.00	0.59	0.69	0.69	0.72	0.14	−0.02
£	0.38	1.00	0.82	0.83	0.81	0.21	−0.02
DM	0.56	0.64	1.00	0.98	0.95	0.13	−0.04
FFr	0.51	0.58	0.85	1.00	0.94	0.17	−0.04
SFr	0.57	0.57	0.83	0.74	1.00	0.15	−0.05
A$	0.48	0.41	0.42	0.38	0.43	1.00	0.09
C$	0.02	0.02	0.04	−0.05	0.00	0.01	1.00

[a]Based on the number of observations (735) for the period, absolute value of the correlations exceeding 0.005 are statistically significant at the 5 percent level.

[b]The upper right triangle of the symmetric matrix contains the correlations for the period 1985 to 1991, and the bottom left triangle represents the period 1978 to 1984. Based on the number of observations (368) for the period, absolute value of the correlations exceeding 0.01 are statistically significant at the 5 percent level.

drift of cross-currency correlations has been noted by others. Sorensen and Mezrich (1989) found that the median comovement rolling three-year correlations of nondollar currencies rose during the past few years to 0.83. They also found that this contrasts to the decline or downward drift in the median value of stock market comovements across 11 world equity markets. Estimated correlations can be used to form a consistent set of expected currency return forecasts. Such consistent forecasts have been found to lead to "balanced" optimal currency portfolios that are consistent with investors' views of the future and are internally consistent in a market equilibrium context.[37] The

[37] See Black and Litterman (1991) on asset allocation and combining investor views with market equilibrium.

TABLE 16. Cross-Correlations of Monthly Currency Returns, 1978–91 and Subperiods

Currency	¥	£	DM	FFr	SFr	A$	C$
1978–91[a]							
¥	1.00						
£	0.57	1.00					
DM	0.63	0.72	1.00				
FFr	0.65	0.72	0.95	1.00			
SFr	0.64	0.67	0.90	0.85	1.00		
A$	0.28	0.32	0.24	0.30	0.23	1.00	
C$	0.02	0.02	−0.01	−0.05	0.01	−0.01	1.00
1978–84 and 1985–91[b]							
¥	1.00	0.69	0.74	0.73	0.77	0.12	0.01
£	0.43	1.00	0.80	0.81	0.80	0.25	0.04
DM	0.51	0.60	1.00	0.99	0.95	0.12	−0.02
FFr	0.58	0.58	0.91	1.00	0.93	0.15	−0.02
SFr	0.52	0.53	0.86	0.78	1.00	0.10	0.02
A$	0.57	0.48	0.45	0.57	0.45	1.00	0.04
C$	0.00	−0.05	−0.04	−0.13	−0.04	−0.12	1.00

[a]Based on the number of observations (167) for the period, absolute value of the correlations exceeding 0.022 are statistically significant at the 5 percent level.

[b]The upper right triangle of the symmetric matrix contains the correlations for the period 1985 to 1991, and the bottom left triangle represents the period 1978 to 1984. Based on the number of observations (84) for the period, absolute value of the correlations exceeding 0.045 are statistically significant at the 5 percent level.

Canadian dollar had the least significant and, at times, insignificant or negative cross-correlations with other currencies. Thus, the Canadian dollar would be a choice candidate to provide diversification in a currency portfolio. This is also indicative of the low volatility of Canadian dollar returns, which is attributable to the similarity of the Canadian dollar to the U.S. dollar.

From the distributional characteristics tables (Tables 2, 3, and 4), the standard deviations of currencies (except the Australian dollar) appear to have been stable between the early and latter parts of the 1980s. Meese (1992) reached the same conclusions using a *t*-statistic to check the stability of the variances between the two halves of the 1980s. Some authors (Diebold and Nerlove 1989, and Hsieh 1989), however, have found the existence of an ARCH process in exchange rates, implying time-varying currency volatility. This process can account for most of the nonlinearity in the exchange rate data.[38] Thus, models to predict, explain, or determine short-term exchange rates must account for this conditional heteroscedasticity. More importantly, ARCH explains the clustering of volatility observed in the currency markets—that is, the phenomenon of large changes in exchange rates being followed by large changes of either sign and then by small changes, leading to contiguous periods of volatility and stability. The finding of random walks with ARCH disturbances implies that although expected exchange returns cannot be forecast, their changing variance can. Such volatility estimates would also permit construction of time-varying confidence intervals for point forecasts of exchange rate returns.

Univariate (or Single Currency) Analysis. The profitability of trading rules (filter rules) suggests the presence of nonlinearity in currency returns. As concluded earlier, currency returns, on the whole, are efficient because they can be characterized as a random walk process. The return process, however, permitted design of profitable trading rules, leading to a presumption of nonlinearity in the process. These two stylized facts must be accounted for in the design of any currency return analysis.

Nonlinearity could enter the return process through the mean or the variance of currency returns. The residual currency return—the unexplained part of the actual return—can have two types of nonlinear dependence with residual returns from previous periods: additive or multiplicative.[39] Both types imply that the variance of the process or of residual returns is correlated with its own lags. Multiplicative dependence, however, implies that the expected residual return for the current period is zero (a random walk) and additive dependence implies a nonzero expected residual return. Thus, the multiplicative dependence models would appear to best represent the currency process consistent with the stylized facts mentioned above. Nonlinear moving average

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[38] Hsieh (1989) shows that GARCH (1,1) can account for most of the nonlinearity in the data.

[39] See Hsieh (1989). If u_t is the residual currency return from an autoregressive model, the two types of nonlinear dependence in u_t are additive dependence,

$$u_t = v_1 + f(x_{t-1}, \ldots x_{t-k}, u_{t-1}, \ldots u_{t-k})$$

and multiplicative dependence,

$$u_t = v_{tf}(x_{t-1}, \ldots x_{t-k}, u_{t-k}),$$

where v_t is an IID random variable with zero mean and independent of past x_t's and u_t's, and f is an arbitrary nonlinear function of $x_{t-1}, \ldots x_{t-k}$ and $u_{t-1}, \ldots u_{t-k}$, for some finite k.

and threshold autoregression are examples of additive dependence, and the general form of conditional heteroscedasticity (ARCH, GARCH, EGARCH, etc.) is represented by multiplicative dependence. Note that ARCH-in-the-mean (ARCH-M) models are hybrids, because nonlinearity enters the process both through the mean and the variance. Therefore, multiplicatively dependent ARCH-type models were constructed to predict currency return variance.

Based on Diebold and Nerlove (1989), who modeled the dynamics of exchange rates with ARCH models, the following third-order autoregressive model was devised (assuming a nonzero mean currency return) with 10th-order linearly constrained ARCH disturbances:[40]

$$(1 - \rho_1 L - \rho_2 L^2)\Delta \ln S_t = \mu_1 + \varepsilon_t,$$

$$\varepsilon_t \mid \varepsilon_{t-1}, \ldots, \varepsilon_{t-10} \approx N(0, \sigma_t^2),$$

$$\sigma^2 = \alpha_0 + \theta \sum_{i=1}^{10} (11 - i)\varepsilon_{t-i}^2,$$

where L is the one-period lag operator, S_t is the exchange rate of the currency, and $\Delta \ln S_t$ is the change in the logarithm of the exchange rates or the currency return over the interval t and $(t - 1)$. Using weekly returns, the intercept, autoregressive, and ARCH parameters were estimated for each currency during the two subperiods, as well as the entire 1978–91 period (Table 17).[41] Strong evidence indicates the presence of conditional heteroscedasticity in all the currency returns, as evidenced by the uniformly high significance of the two parameters α_0 and θ for all the estimation periods. A GARCH-type model may be used to predict conditional variance of currency returns. As Hsieh (1989) observed, most researchers have concluded that GARCH fits most of the currencies. Therefore, using a GARCH (10,3) model on weekly yen currency returns from 1988 to 1991 (up to the third quarter), conditional variances and

[40] Diebold and Nerlove (1989) identified the order of the ARCH models to be no greater than 12 after considering information criteria.

[41] The log-likelihood function used for the estimation is:

$$\ln L(\rho, \alpha; \Delta \ln S) = \text{constant} - \sum_{t-1}^{T} \ln \sigma_t - \frac{1}{2}\sum_{t=1}^{T} \frac{\varepsilon_t^2}{\sigma_t^2}.$$

TABLE 17. ARCH Model Coefficients, Weekly Returns, 1978–91 and Subperiods

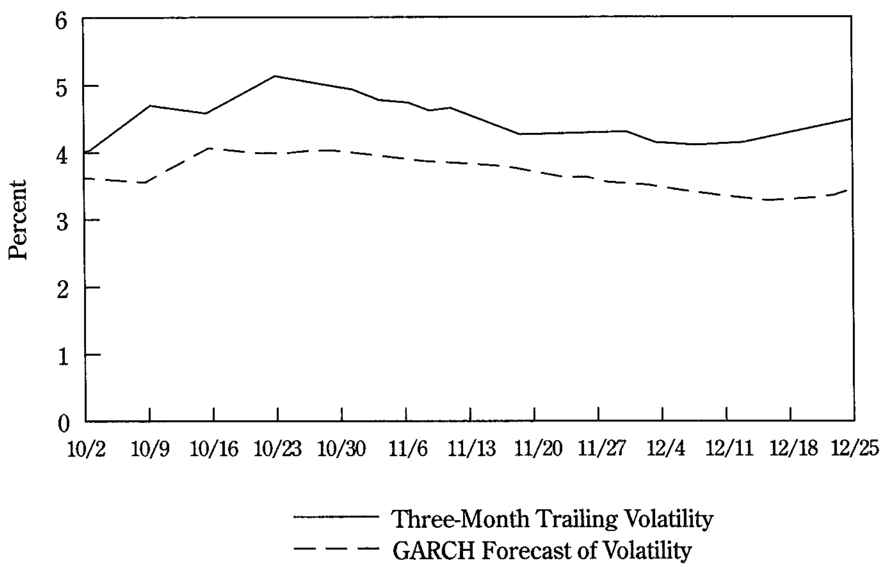
Coefficient	¥	£	DM	FFr	SFr	A$	C$
1978–91							
μ	0.055	−0.023	0.014	0.000	0.018	0.001	0.002
ρ_1	**0.075**	0.052	0.047	0.024	0.047	0.058	−0.030
ρ_2	**0.084**	0.025	**0.093**	**0.125**	0.065	**0.126**	−0.027
ρ_3	0.053	0.043	−0.002	0.017	0.024	0.090	−0.030
α_0	**1.582**	**1.040**	**1.117**	**1.122**	**1.634**	**0.144**	**0.164**
0	**0.006**	**0.011**	**0.010**	**0.011**	**0.008**	**0.026**	**0.011**
$-2\log\lambda$[a]	97.280	445.600	333.930	265.010	210.920	6440.300	375.260
1978–84							
μ	−0. 037	−0.114	−0.110	−0.139	−0.117	0.012	−0.056
ρ_1	0.075	0.077	0.090	0.044	0.098	0.095	−0.090
ρ_2	0.094	−0.015	0.021	0.083	−0.044	**0.176**	−0.012
ρ_3	0.015	0.022	−0.011	0.023	0.023	**0.172**	−0.004
α_0	**1.385**	**0.734**	**0.934**	**0.899**	**1.314**	**0.078**	**0.187**
0	**0.007**	**0.012**	**0.010**	**0.013**	**0.010**	**0.031**	**0.010**
$-2\log\lambda$[a]	68.398	260.820	168.950	250.650	174.090	2753.000	169.920
1985–91							
μ	0.160	0.121	0.200	**0.188**	**0.183**	0.042	**0.058**
ρ_1	0.058	0.025	−0.008	−0.013	−0.007	−0.003	−0.006
ρ_2	0.072	0.042	**0.130**	**0.129**	**0.138**	−0.039	−0.070
ρ_3	0.076	0.035	−0.016	−0.018	0.003	−0.041	−0.071
α_0	**1.801**	**1.625**	**1.443**	**1.264**	**1.889**	**1.435**	**0.135**
0	**0.005**	**0.008**	**0.009**	**0.009**	**0.007**	**0.006**	**0.011**
$-2\log\lambda$[a]	39.275	130.510	132.860	147.650	93.011	176.240	309.490

Note: Numbers in bold are significant at the 99 percent level.

[a]The statistic, $-2\log\lambda$, follows a chi-square distribution with six degrees of freedom. This statistic follows a chi-square distribution, where $-2\log\lambda$ is the likelihood ratio, L_0 is the likelihood function evaluated with all parameters (except the constant) set equal to zero, and L_{Max} is the maximum value of the likelihood function. Tabulated values for a chi-square variable with six degrees of freedom at 1, 2, and 5 percent level of significance are 16.812, 15.033, and 12.592, respectively.

means for the yen were forecasted for the last quarter of 1991.[42] Volatility implied by currency options offers a natural measure of comparison of the forecasted variance.[43] In its absence, forecasted variance for the fourth quarter of 1991 was compared to a time series of three-month trailing volatility of the yen during the same period. Figure 6 presents the forecasted conditional volatility of yen returns and a series of three-month trailing volatility of weekly returns (annualized).

FIGURE 6. GARCH Forecast of Volatility of Yen Weekly Return, Fourth Quarter 1991



The GARCH forecasts appear to have captured the declining volatility of yen returns in the last quarter of 1991. They also indicate a rising volatility toward

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[42] GARCH (10,3) is similar to the third-order autoregressive model described above, except that now the variance, σ^2, is assumed to be autocorrelated; that is,

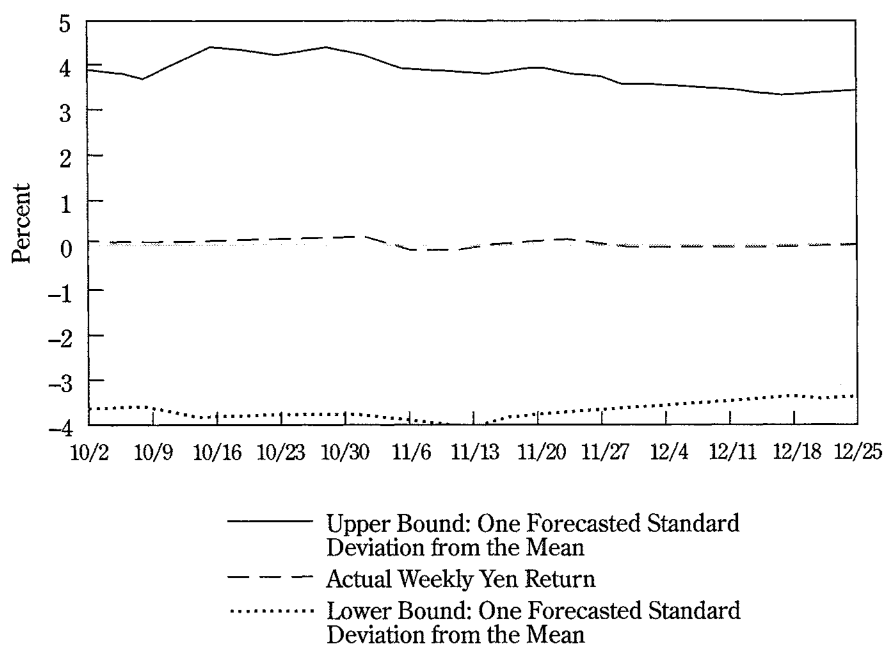
$$\sigma^2 = \alpha_0 + \theta_1 \sum_{i=1}^{10} (11 - i)\varepsilon_{t-1}^2 + \theta_2 \sum_{i=1}^{3} (4 - i)\sigma_{t-1}^2.$$

[43] Sorensen and Mezrich (1992) illustrate the predictive power of GARCH estimation of return volatility using S&P 500 returns. They also use option-based implied volatilities to make comparisons with the forecasts.

year-end and the beginning of the last quarter of 1991. More detailed analysis of the preciseness of the prediction is necessary before judging the economic profitability of trading strategies based on the predicted volatility. Another use of GARCH-predicted volatility is to determine the time-varying confidence intervals for point forecasts of currency returns. The GARCH model, like other exchange rate prediction models, was less successful in predicting the mean of the exchange rate process; however, a time-varying confidence band could be constructed around the predicted (less accurate) mean currency return using the superior forecasts of the standard deviation of currency returns. Such a band around the predicted mean return would be suggestive of a time-varying currency risk premium, and a forecast of the time-varying premium could potentially offer profitable cross-currency trading strategies based on relative risk premiums.

Figure 7 illustrates the confidence band around the point forecasts of yen return during the last quarter of 1991. The risk premium for the yen (vis-à-vis the dollar) appears to widen in mid- to late October and then narrow in November and December 1991. Presuming the normal risk premium prevailed

FIGURE 7. Time-Varying Confidence Band around the Point Forecasts of Yen Return, Fourth Quarter 1991



in September, November, and December (this can be established only by analyzing a longer time series of risk premiums for the yen), Figure 7 suggests the phenomenon of reversal in the risk premium or a tendency for the risk premium to move toward an equilibrium value. This presents a framework for forecasting the direction of yen return in the subsequent week(s). For example, in Figure 7, the forecasted high-risk premium for the latter half of October forecasts a higher-than-usual yen return for October, and the subsequent projected decline in risk premium for November and December presages a decline in yen return. A similar analysis for other currencies and a comparison of the magnitudes of the individual relative risk premium increments or decrements from their equilibrium values would offer a useful framework for cross-currency return forecasts.

Sorensen, Mezrich, and Thadani (1992) suggest some interesting applications of GARCH-based volatility forecasts. Their suggested investment strategies are based on the observed phenomenon of implied volatility of the S&P 500, reverting from the upper and lower bounds of volatility established from the GARCH model forecasts. Also, a comparison of volatility spreads (difference between the forecasted and the implied volatility) between two indexes (or assets) could suggest profitable option trading strategies in which the option on the asset with the higher-than-normal volatility spread is sold (with the presumption that the spread will narrow) and the option on the other asset with the lower-than-normal volatility spread is bought. Similar strategies can be conceived in the realm of the currencies.

Suggested model improvements involve a multivariate version of the univariate GARCH model used for the forecasts of currency return volatilities (Diebold and Nerlove 1989). This modification is based on the argument that covariances among the currencies are nonzero and time varying (similar to the individual currency return variance) and that the movement of currencies may reflect a common factor effect as all exchange rates react to the arrival of new information. Diebold and Nerlove (1989) proposed a multivariate latent-factor ARCH model and tested the variance predictions of such a model on the deutsche mark and the pound. They concluded that the two models have a high degree of coherence or similarity when the currency variance is explained to a large degree by a common factor (e.g., the deutsche mark in the early 1980s) and larger divergence in their predictions when the currency variation is minimally explained by a common factor (e.g., the pound).

Optimal Currency Asset Allocation

Presuming currency returns and volatilities can be forecast with some degree of comfort, the problem of constructing an optimal basket of currencies—either as part of a larger asset allocation process or to form a vehicle to hedge the currency exposure resulting from investing in assets of other countries—remains unsolved. Perold and Schulman (1988) and Lee (1987) suggested that currencies be treated as separate assets and therefore a multicurrency global portfolio be derived taking into account the correlations not only between the equity or bond foreign assets, but also between those assets and the foreign currencies. Interestingly, Lee (1987) shows that even in the absence of skillful currency forecasting, quadratic mean–variance optimization techniques that separate the assets and currencies to minimize total portfolio risk outperform those portfolios that do not separate assets and currencies. A minimum-variance multicurrency quadratic portfolio optimization problem can be formulated thus:

Minimize σ_p^2, subject to a minimum expected return constraint, $\mu_p = \mu_0$, and a no-borrowing constraint in which the portfolio variance, $\sigma_p^2 = \begin{pmatrix} a \\ x \end{pmatrix}^T V \begin{pmatrix} a \\ x \end{pmatrix}$, and the portfolio mean, $\mu_p = \begin{pmatrix} a \\ x \end{pmatrix}^T E \begin{pmatrix} R \\ C \end{pmatrix} = \mu_0$, and the no-borrowing constraint is defined as $\begin{pmatrix} a \\ x \end{pmatrix}^T \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} = 1, 1$ (i.e., the sum of the portfolio asset holdings and the currency holdings separately sum to the total initial investment amount). In this formulation, a and x represent the vector of asset and currency weights, respectively; R and C represent the vector of local asset returns plus forward premiums, respectively; V, the variance–covariance matrix of the assets and currencies; E is the expectation operator; and $(\ )^T$ is the transpose of a matrix. The optimal portfolio could also be customized to suit an investor's risk tolerance by reformulating the objective function to maximize $\mu_p = \lambda\ \sigma_p^2$, subject to the no-borrowing constraint, where λ characterizes the investor's risk tolerance or risk–return trade-off.

Strategies to use only premium currencies as hedging vehicles to provide yield pickup (Sorensen, Mezrich, and Thadani 1992) (i.e., premiums or the difference between forward and spot rates) to the overall international asset portfolio easily can be analyzed under the above framework by including an additional constraint, $\begin{pmatrix} a \\ x \end{pmatrix}^T \begin{pmatrix} 0 \\ F - S \end{pmatrix} \geq \phi_0$, where ϕ_0 is some minimum expected yield pickup for the optimal portfolio and $F - S$ is the currency risk premium/discount vector. Such strategies recently have become popular, as evidenced by J.P. Morgan's introduction of the "high-yield bond index," whose expected superior (to a broader bond index) return performance is predicated on the currency forward markets not being efficient in anticipating the future spot rates.[44] Other researchers (Eaker and Grant 1991) have found that a simple selective hedge strategy in which the high-yielding currencies (discount currencies) remain unhedged and premium currencies are hedged has proven to be profitable. According to Eaker and Grant, between August 1975 and December 1988, such a selective hedge strategy implemented on long-term government bonds would have resulted in incremental returns (over a näive total hedge) ranging from 2.14 to 0.34 percent depending on the fraction invested in international bonds.

Informationless Strategies

Hedging currency exposure greatly enhances diversification potential of foreign investments. For U.S. investors, the gain from hedging is as much in risk reduction as investing abroad, unhedged, in the first place (Perold and Schulman 1988). Perold and Schulman believe that aside from transaction costs, which appear to be minimal, a case that currency hedging reduces long-run expected returns is hard to make. In other words, currency risk appears to be uncompensated. Moreover, hedging unambiguously reduces risk if the observed correlation between the foreign asset and the exchange rate is positive. Additionally, the lower the volatility of the foreign asset relative to the exchange rate, the greater the hedging effectiveness for any observed cross-correlation.[45]

Given the less-than-sterling track record of currency return expectational models and the observation that hedging currency exposure enhances diversification and reduces risk, the logical question is whether passive, informationless—in the sense of not requiring forecasts of currency expected returns—hedging strategies exist that provide the necessary risk reduction in currency exposure resulting from foreign investments. Currency options provide the means to implement the informationless hedging strategies.

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[44] See "Investing in Foreign Bonds," J.P. Morgan, February 1992. The publication concludes that portfolios that overweight markets with high bond yields typically outperform global bond indexes and the U.S. bond market.

[45] See Benari (1991). Comparing the risks of unhedged and fully hedged portfolios, the author shows that hedging reduces risk provided

$$\rho > -\frac{1/2}{\sigma_r/\sigma_x},$$

where ρ is the correlation between the foreign asset and the exchange rate, σ_r is the risk of the foreign asset in local currency, and σ_x is the exchange rate volatility.

Option-Based Strategies. The statistical distributions of currency returns suggest the use of convex payoff strategies (options) to exploit the presence of trends in currency returns. Also, the simultaneous presence of reversals in daily returns argues for the use of appropriate "filters" in the synthetic implementation of options. The difficulty in forecasting currency returns and exploiting the nonlinear dependency in returns through use of filters also suggests the use of options to control risk.

Currency exposure of foreign investments can be hedged by purchasing a standard currency put option. At the end of the investment horizon, however, the investment in foreign equity or bonds may be under- or overhedged depending on the performance of the underlying asset. This uncertainty in the quantity of foreign currency generated by the performance of the foreign asset has led to a variable-quantity foreign exchange option of an asset-linked foreign exchange put.[46] The terminal payoff of the asset-linked currency put will be

$$S^{*T} \text{Max}[0, K - X^T],$$

where S^{*T} is the terminal value of the foreign asset in local currency, X^T is the terminal value of the exchange rate expressed as domestic currency per unit of foreign currency, and K is the preset strike price for the exchange rate. Such an option will be appropriate for an investor who desires protection from currency risk but is unconcerned with the foreign asset risk in local currency. A multicurrency generalization of these options involves treating the foreign asset as a portfolio of foreign assets denominated in various currencies and the currency as an asset-exposure-weighted basket of various currencies. The cross-currency correlations, the cross-asset currency correlations, the volatilities of individual currencies and assets, and the differential interest rates are parameters relevant in the pricing of such a multicurrency option and the related synthetic hedging portfolio.

Table 18 provides simulated results (currency returns) of hedging a multicurrency equity portfolio comprising countries in the FT-EUROPAC index with a multicurrency quantity-adjusting put option. Currency returns in Table 18 are net of transaction costs and are simulated using daily historical data. A fully hedged strategy involves the purchase and sale of baskets of currency forwards every month; the quantity of forwards is determined by the value of the underlying equity exposure. A rolling simple option strategy consists of buying or selling an appropriate number of individual simple currency put options as

[46] Contracts of this nature were originally discussed by Marcus and Modest (1986) and referenced in Reiner (1992).

determined by the performance of the equity investments every month. A quantity-adjusting option, or an equity-linked foreign currency put option, strategy is a dynamically implemented, formula-based hedging strategy involving the purchase and sale of currency forwards; the frequency of the transaction is governed by the "filter rules" adopted to adjust the actual hedge amount to the formula-recommended hedge quantity.

TABLE 18. Return Results for Currency Protection Strategies, 1980–91

Year	Unhedged	Fully Hedged	Rolling Simple Option	Quantity-Adjusting Option
1980	2.91%	2.27%	3.84%	−0.37%
1981	−11.66	4.70	−0.72	1.43
1982	−10.88	2.23	−3.52	−1.65
1983	−7.25	1.60	−5.53	−2.68
1984	−11.07	2.66	−3.15	−0.80
1985	22.30	0.21	16.21	14.87
1986	16.91	0.59	10.29	11.86
1987	27.05	1.84	19.55	22.13
1988	−3.97	2.68	−4.20	−2.77
1989	−9.48	2.03	−3.07	−3.11
1990	9.26	−0.24	6.14	7.16
1991	3.30	−3.18	−1.32	−0.52
Annualized mean	1.47	1.43	2.57	3.51
Standard deviation	10.84	0.58	6.89	6.16

Salient aspects of the currency markets emerge from an analysis of the results presented in Table 18. During the past 12 years, average annualized returns to hedged and unhedged strategies were similar, but the hedged strategy had about 1/20th the volatility of the unhedged strategy. This is evidence of the uncompensated volatility in the currency market. The incremental return (with incremental risk) of the rolling option strategy over the näive fully hedged strategy is attributable to the presence of trends in the currency returns that benefit option-based strategies. This conclusion of convex payoff strategies (i.e., options) benefiting from a persistence of trends in currency returns is suggested by an analysis of the return distributions. The incremental return of the quantity-adjusting option strategy over the rolling simple option strategy is caused by:

- The higher implied volatility cost of the simple option strategy arising from the use of a basket of individual currency options as opposed to the less expensive option on a basket of currencies used in the quantity-adjusting option strategy.

- The inadequate private speculative capital to maintain open option positions for longer time horizons, leading to implied option volatilities being higher than actual experienced volatilities.
- The "excess" profits generated from the filter-rule-based dynamic implementation of the quantity-adjusting option strategy.

This source of incremental profit is attributable to the trading rules benefiting from the presence of nonlinear dependence in currency returns. This is the active currency management component of an otherwise passive, information-less dynamic currency hedging strategy.

Returns to the passive, dynamically implemented quantity-adjusting option strategy could be further improved by:

- The use of volatility forecasts to construct better—in an *ex post* sense—optimal baskets of options to track the larger number of currency exposures from the foreign equity asset.
- Using forecasted volatility to construct better—in an *ex post* sense—formula-based hedges.
- Opportunistic cross-currency hedging arising from the breakdown of the uncovered interest rate parity phenomenon (i.e., high-yielding currencies not declining by as much as the forward markets expected).
- Opportunistic substitution of listed options during historically low-volatility periods.

Summary

This study concludes that the currency markets are largely "efficient" in the strict sense of not being linearly dependent. Significant nonlinear dependencies in current returns, however, lead to potential formulation of profitable trading strategies.

Analysis of daily, weekly, and monthly currency returns over a full cycle of 14 years (1978 through 1991) leads to the conclusion that no significant mean daily, weekly, or monthly returns occurred. During the strong- and weak-dollar subperiods, however, individual currencies produced the expected positive or negative statistically significant mean returns. During the 1980s, the yen was the strongest currency and the U.S. dollar tended to be significantly weak against the yen during its weak phase and not significantly strong during its strong phase. Each currency appeared more volatile during the weak-dollar subperiod relative to the strong-dollar one. The volatility of the Canadian dollar was less than half that of the other currencies.

During the 1980s, each currency showed significantly asymmetric returns (skewness), particularly with the daily returns. Although each currency showed positive skewness, the Australian dollar was most significantly negatively skewed, which could be because of persistently high relative Australian interest rates during the 1980s. The tests suggest the presence of significant trends in weekly returns and reversals in daily returns of currencies and the currency index. During longer investment horizons (more than six months), trends appeared to exist in all the currencies and the currency index. Other researchers have obtained similar results using the data from the 1970s.[47]

For comparative analysis, the equity daily returns exhibited significant trends and reversals; for longer investment horizons (weekly, monthly, or longer), no significant trends or reversals were found. For very long investment horizons (three years or longer), however, equity returns exhibited significant reversals.

The results of the analysis of currency returns offer the following implications for currency management:

- Synthetic currency options involving dynamic trading of currencies must use appropriate "filters" to minimize wasteful whipsaw costs attributable to significant return reversals in daily currency returns.
- Convex payoff strategies (e.g., option strategies) designed to benefit from the persistence of trends in currency returns should consider investment horizons exceeding six months and up to three years.
- Contrary to experience in the equity market, concave payoff strategies designed to benefit from expectations of mean reversions in currency returns should have very short (days and weeks) investment horizons.
- The suggested designs for profitable currency trading strategies are not inconsistent with the notion of zero expected returns to currencies in the long run—an investment horizon of 9 to 10 years.

Despite the prevalence of trends and reversals in currency returns, several researchers have concluded that currency returns may not be forecastable. Such a conclusion is based primarily on the absence of perceptible linear dependency in currency returns. Notions of currency market efficiency are further buttressed by the reactions of the currency market to unusual events, such as returns one or two standard deviations above or below the mean daily

[47] Using weekly returns from July 1973 to August 1985, Diebold and Nerlove (1989) found significant correlations for the deutsche mark and the yen. Also see Boothe and Glassman (1987), who used data from January 1973 to August 1984. More recently, Liu and He (1991), using exchange rates from August 7, 1974, to March 29, 1989, concluded that the weekly returns exhibited positive autocorrelations or trends.

return; market efficiency implies that cumulative excess returns be zero up to the event day and, thereafter, stabilize at a higher or lower level of cumulative return. By this criterion, the currency index return is remarkably efficient. For the currency index, large declines or increases in currency returns were largely unanticipated. As a matter of contrast, large increases (two-standard-deviation events) in the equity market appear to be forecastable because they are preceded by significant market declines lasting more than 15 days prior to the reversal.

Linear unpredictability, however, does not ensure the futility of return predictions. Currency returns appear to exhibit strong nonlinear dependence. Nonlinear dependence in exchange rates could imply that exchange rate changes are deterministic processes that look random—"chaotic systems." Statistical evidence of such nonlinearity suggests that nonlinear predictive models or trading strategies, such as momentum/reversal-based trading strategies, may prove profitable. Indeed, using daily currency returns for the 1978–91 period, simple nonlinear "filter" rules are shown to yield significant trading profits (about 3 to 3.5 percent annualized, net of transactions costs) for various currencies. Interestingly, the equity returns do not show any significant nonlinear dependence and, as a result, do not yield significant trading profits based on nonlinear trading rules. Because of unsuccessful attempts to forecast currency returns using linear macroeconomic (structural) models, investigation of nonlinear forecasting models appears to offer the best potential for success.

Forecasting currency variance appears to be a more rewarding undertaking. The finding that ARCH models adequately explain the currency return process also offers a medium for forecasting currency variances. Forecasted volatility (illustratively, for the yen) appeared to track historical trailing volatility reasonably well.[48] Moreover, the time-varying nature of forecasted volatility permits construction of time-varying currency risk premiums that could potentially lead to development of cross-currency trading strategies. Time-varying cross-currency correlations suggest the subsequent stages of analysis in this line of research: a multivariate—as opposed to individual currency, univariate analysis—common factor-based variance forecasting model.

Treating currency as a separate asset offers significant benefit in risk reduction of international portfolios. This arises from an asset allocation decision divorced from the implicit currency exposure acquired from the holdings of foreign assets.

[48] A more appropriate comparison, though not done in this study, would be to a time series of option-implied currency volatility.

Empirical abnormalities, such as the failure of the uncovered interest rate arbitrage theory (i.e., high-yielding currencies not depreciating as much as forward markets anticipated) offer yet another avenue for formulating profitable currency trading strategies.

Hedging currency exposure greatly enhances the diversification potential of foreign investments. Hedging, when used as a passive strategy (i.e., hedging decisions requiring no forecasts of currency returns), offers significant benefits. Currency options offer the route to achieve this end. Because options are informationless strategies, and the currency market is shown to contain significant trends, which benefit option-type convex payoff patterns, option-based strategies should perform well, even when viewed as active currency management strategies. The simulated performance of yen put options during the 1980–91 period bears out this conclusion; the option strategies yielded a 1 to 2 percent annual incremental return over the näive fully hedged or unhedged strategies. The synthetic implementation of the variable quantity option strategy is argued to possess an active currency management component, which results in an additional layer of incremental return because of the filter rules used in its implementation scheme. Inadequacy of private speculative capital in the currency markets is offered as a possible explanation to the apparent "free lunch" characteristic (i.e., higher mean return with lower volatility) of option-based strategies vis-à-vis the unhedged longer duration international portfolio.

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