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INTERVENTION, EXCHANGE-RATE VOLATILITY, AND THE STABLE PARETIAN DISTRIBUTION

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I. Introduction

We wish to know if the United States' decision to cease intervention after March 1981 had a perceptible influence on the day-to-day behavior of exchange rates. To this end, we calculate volatility measures for spot exchange rates, six-month-forward exchange rates, and certain other asset prices. We then compare behavior of these measures in a period of frequent U.S. exchange-market intervention (March 1, 1980, to February 28, 1981) with their behavior during a period of no U.S. intervention (April 1, 1981, to March 31, 1982). We also compare the behavior of the spot exchange rates to that of the other asset prices over the two periods.

Westerfield (1977) and Rana (1981) have found that log approximations of percentage changes in exchange rates exhibit kurtosis and caution against volatility comparisons based on the assumption that the observed data are normally distributed. Westerfield and Rana find that the data conform to a symmetric, stable Paretian distribution. In addition, we find that percentage changes in the exchange rates and in other asset prices exhibit skewness. Consequently, we follow Koutrouvelis (1980 and 1981) and Koutrouvelis and Bauer (1982) and derive measures of volatility consistent with a more general form of the stable Paretian distribution that includes a parameter for skewness. We then take our estimates of the location parameters, the scale parameters, and the characteristic exponents of the Paretian distributions in each time period as our measures of volatility, and we compare them across periods. Generally, the results suggest no perceptible change in the behavior of the exchange rates over the two periods considered, but we observed some interesting exceptions.

II. Intervention in an Efficient Market

Most analysts regard exchange markets as highly efficient, incorporating all available information into current quotes, including expectations about future events. Changes in exchange rates reflect the market's interpretation of unanticipated information or "news."

While exchange markets are highly efficient, they probably are not perfectly efficient. At times, information is costly to obtain and slow to be disseminated to all concerned parties. Speculative bubbles can occur for short periods, even in rational, efficient markets.

In such cases, official intervention might reduce the volatility of foreign-exchange rate: if it improved the dissemination of information in the foreign-exchange market, or if it provided new information to the market.[1] If intervention successfully improved the flow of information to the foreign-exchange market, one would expect the day-to-day volatility of exchange rates to increase during sustained periods of no intervention, other things being equal.

III. Measures of Volatility

Analysts have suggested many alternative measures for exchange-rate volatility (see Greene [1984]). We choose day-to-day percentage changes in exchange rates and in other asset prices. Many other studies also have used percentage changes in exchange rates (or their log approximation) to measure volatility (see Bergstrand [1983]); Frenkel and Mussa [1980], Rana [1981]; and Westerfield [1977]). Day-to-day percentage changes in exchange rates seem good proxies for volatility stemming from "news" in the market, and comparisons of percentage changes in exchange rates over two periods seem a good way to gauge the relative uncertainty associated with that news over two periods. If day-to-day percentage changes in exchange rates do reflect uncertainty in the market, and if intervention affects the flow of information to the market, one would expect exchange-rate volatility to increase, other things being equal, when monetary authorities do not intervene.

We investigate the percentage changes in both the spot and six-month-forward exchange rates. The exchange rates are dollar rates against the French franc, German mark, Japanese yen, British pound, and Canadian dollar. We consider the forward exchange rate in the belief that the degree of volatility in the forward rate provides a direct proxy for the uncertainty associated with hedging near-term volatility in the spot rate.

In a highly efficient, forward-looking market, one would expect asset prices to be volatile as they adjust to news. Questions about the volatility of exchange rates, then, center on their relative volatility. Do exchange rates exhibit greater volatility than other asset prices? To investigate this question, we include the daily percentage changes in short- and long-term U.S. Treasury securities, gold prices, and the DOW and NYSE stock indexes. A difference between the volatility of other asset prices and the volatility of exchange rates over the two periods suggests that some unique factors influence each.

IV. The Time Frame

We examine the volatility of daily exchange rates from March 1980 through February 1981, relative to that of April 1981 through March 1982. The United States intervened heavily in foreign-exchange markets during the first period, but did not intervene during the second period. We dropped March 1981 from the samples because policy changed during this month.

We can attribute any changes in exchange-rate volatility to intervention patterns only to the extent that other factors that might affect exchange rates remained constant over the two periods considered. Since we do not take account of other factors formally in the analysis, a quick review of developments over these two periods might be useful.

Political and economic uncertainty were hallmarks of March 1980 through February 1981. Early in 1980, the Iranian hostage situation and the Soviet invasion of Afghanistan raised political uncertainties. Continued OPEC price increases heightened expectations of inflation. The fear of recession in the face of rapid price advances and the fear of weakening real economic activity were growing.

Nominal money demand had been very strong because of rising prices. Under a new operating procedure that focused on the rate of growth in bank reserves rather than on a federal funds rate target, the Federal Reserve moved to constrain the growth of bank reserves.' Interest rates began rising to unprecedented levels. In March 1980, the Carter administration, under the Credit Control Act of 1969, imposed credit controls. The tightening of monetary policy and the sharp rise in U.S. interest rates resulted in an initial dollar appreciation.

The United States experienced a recession in 1980, which briefly weakened U.S. interest rates and the dollar. The recession, however, did not lower inflationary expectations, and the Federal Reserve continued to restrict the growth of reserves. Interest rates in the United States rose steeply once again. Foreign monetary authorities, concerned about persistent economic weakness in their countries, were reluctant to raise interest rates. Favorable interest-rate spreads and an improving U.S. current account produced a sharp appreciation in the dollar.

Between March 1980 and February 1981, the dollar rose 6.4 percent on a trade-weighted basis, and the United States continued to intervene heavily in foreign-exchange markets. The System conducted approximately $14 billion in gross intervention transactions. On a net basis, the System sold nearly $10 billion, mostly for German marks. The dollar purchases were concentrated in April, May, and June of 1980. Foreign central banks also intervened heavily, selling dollars net.

A rapid appreciation of the dollar ensued during the second period under consideration--April 1981 through March 1982. Monetary policy tightened, and U.S. interest rates remained high. In contrast, economic activity abroad remained very sluggish, making foreign monetary authorities reluctant to allow their interest rates to rise. The U.S. current account continued to improve, while the current accounts of many European countries, notably Germany, deteriorated. Inflation in the United States began to abate.

In August 1981, the dollar began to reverse part of its substantial appreciation. U.S. economic activity started to weaken, and market participants began to expect the Federal Reserve System to alter policy in response to growing criticisms about the level of U.S. interest rates, which eased somewhat. European monetary authorities began to raise their interest rates because inflation in many European countries had not slowed. Market participants also forecasted a deterioration in the U.S. current account to a deficit in 1982. The current accounts in Germany and in Japan had swung back to surpluses.

Late in 1981, the dollar once again started to appreciate. Although U.S. interest rates continued to decline, international interest-rate spreads favored investments denominated in dollars. Economic activity in Europe continued to weaken, and foreign monetary authorities lowered their interest rates, as U.S. rates fell.

On balance, the trade-weighted dollar appreciated 13.8 percent between April 1981 and March 1982. The United States did not intervene for its own accounts during this period, but foreign central banks increased their dollar intervention. On a gross basis, foreign central banks replaced approximately 66 percent of the reduction in U.S. intervention from the March 1980 to February 1981 period.

In summary, one cannot identify many factors that would alter the volatility of the data in the second period, relative to the first period. Economic activity generally remained weak in both periods, and the operating procedure for U.S. monetary policy did not change. Inflation was reduced over the period. Because the volatility of inflation seems to decline as the rate of inflation falls, this could have some influence on volatility of exchange rates over the two periods.

The most obvious change was in U.S. intervention policy. The United States did not intervene from April 1981 through March 1982. Although foreign intervention did increase in the second period, it did not completely offset the reduction in U.S. intervention, and it most likely was not always directed at the same exchange-rate objectives as U.S. intervention.

V. The Stochastic Process Generating Exchange Rates

When studying the volatility of exchange rates, one is interested in the entire distribution of the volatility measure. We want to know the probabilities of very large exchange-rate changes, as well as the central tendencies of these changes. Many studies of volatility consider only the average tendencies of their volatility measure (for example, average daily or weekly percentage changes), or assume that the volatility measure has a normal distribution.[3] An advantage of assuming a normal distribution is that the first two moments of the volatility measure completely describe the distribution.

Westerfield (1977) and Rana (1981), however, have demonstrated that log approximations to percentage changes in exchange rates are not always drawn from a normal distribution.[4] In such cases, moments of an order greater than 1 do not exist, and volatility comparisons relying on the assumption that these measures are normally distributed could be inaccurate.'

Before investigating the volatility of our exchange rates and asset prices, we tested to see if they were drawn from a normal distribution. Tables 1, 2, and 3 present calculations of the mean, standard deviation, skewness, and kurtosis for each of the spot and forward exchange rates and for each of the asset prices.

Skewness indicates if the data are distributed symmetrically around the mean. Under a normal distribution, we expect no skewness in the data. Our estimate of skewness is:

$$B_1 = [n/(n - 1)(n - 2)]\sum(x_i - \bar{x})^3/S^2$$

where S^2 is the sample variance.[6] The B_1 statistic is normally distributed with a standard deviation of approximately $[\sqrt{(6/N)}]$. As tables 1, 2, and 3 indicate, we found B_1 was significantly different than zero in nearly all cases for the spot and forward exchange rates and for the other asset prices.

Kurtosis measures the fatness of the tails of the distribution--the likelihood of finding extreme observations. We estimate kurtosis by:

$$B_2 = [n(n + 1)/(n - 1)(n - 2)(n - 3)]$$
$$* \sum(x_i - \bar{x})^4/(S^4) - 3(n - 1)^2/(n - 2)(n - 3).$$

Under a normal distribution, B_2 should equal zero.' The B_2 statistic is normally distributed with a standard deviation of approximately $[\sqrt{(24/N)}]$. As tables 1, 2, and 3 indicate, nearly all of our B_2 estimates are significantly different than zero. All of the B_2 estimates are positive, which suggests that the data series tend to be fatter in the tails than one would expect under a normal distribution.

The Kolmogorov D statistic provides a further test of the distribution for large samples. To compute the D statistic, we calculate the cumulative frequency function from the sample and compare it with the cumulative frequency function from a normal distribution. The D statistic is the largest difference between the frequency distributions (see Kendall and Stuart [1961]). We next calculate the probability of finding a greater D value when the sample distribution truly is a normal distribution. If the calculated probability is less than 0.01, we reject the hypothesis that the data are drawn from a normal distribution. According to this measure, many of the exchange-rate series are not drawn from a normal distribution. Other exchange-rate data and many of the asset prices are borderline cases ($\leq$ 0.15).

Considering our measures of skewness, kurtosis, and the D statistic, we generally confirm the findings of Westerfield (1977) and Rana (1981) that percentage changes in exchange rates are not always normally distributed. These results suggest that we should heed Westerfield's warning and adopt measures of volatility that do not depend on the normal distribution, but that can accommodate a normal distribution. Following Mandelbrot (1963), Westerfield suggests that exchange-rate changes conform to a more general class of frequency functions called stable Paretian distributions or Stable Laws.

VI. The Stable-Paretian Function

The general form of the characteristic stable Paretian distribution is:

$$\log \Phi(t) = \exp\{i\delta t - |ct|^{\alpha} [1 + i\beta \operatorname{sgn}(t)\, w(t,\alpha)]\}$$

where

$$w(t,\alpha) = \begin{cases} \tan(\pi\alpha/2) & \text{for } \alpha \neq 1 \\ 2/\pi \log|t| & \text{for } \alpha = 1 \end{cases}$$

The parameter α is the characteristic exponent and measures the fatness of the tails; δ is the location parameter; c is the scale parameter; and β is the measure of skewness. The domains of these parameters are:

$$0 \leq \alpha \leq 2$$

$$-\infty < \delta < +\infty$$

$$c \geq 0$$

$$-1 \leq \beta \leq 1$$

For the case where $\alpha = 2$, and $\beta = 0$, $\Phi(t)$ corresponds to a normal distribution. This is the only stable Paretian distribution for which the variance and higher moments exists. Generally, only moments of the order r, r < α exist. When $\alpha = 1$, and $\beta = 0$, $\Phi(t)$ corresponds to a Cauchy distribution.

It is a fairly simple task to estimate the parameters of the stable Paretian distribution when the sample data are symmetric (see Mandelbrot [1963]; Fama [1963] and [1965]; Fama and Roll [1971]; and Wiener [1975]). Applications of symmetric stable Paretian distribution have been made to studies of the volatility of stock-market prices (see Mandelbrot [1963]) and exchange rates (see Westerfield [1977] and Rana [1981]).

The stable Paretian distribution, however, is much more difficult to estimate when the sample data exhibit skewness. Consequently, analysts seem to ignore the problem of skewness when applying the stable Paretian distribution to measures of exchange-rate volatility. Westerfield (1977, p. 183, footnote 4) adopts a unfamiliar measure of skewness, which seems to offer a necessary, but not a sufficient, criterion for determining skewness in data. Rana does not adjust for skewness because most of his volatility measures exhibit no skewness; however, *many* of his measures do exhibit skewness. Nearly all of our volatility measures indicate skewness. Parameter estimates that do not account for the skewness in the observed data will be biased and could result in false conclusions about the relative volatility of the exchange-rate series.

Statisticians have provided a few methods for estimating the general form of the stable Paretian distribution (see Du Mouchel [1971]); Press [1972]; and Paulson, Holcomb, and Leitch [1975]). We followed the methodology described by Koutrouvelis (1980, 1981); and Koutrouvelis and Bauer (1982).

Koutrouvelis (1980) notes that, for a set of random numbers X_1, X_2, X_3, ..., X_n, and a (the characteristic root) not equal to zero, one can write the characteristic function of the Paretian distribution as:

$$\Phi(t) = C(t) + i\, S(t),$$

where $C(t)$ and $S(t)$ are the real and imaginary parts of $\Phi(t)$, respectively. Koutrouvelis (1980) then shows that:

$$\log(-\log|\Phi(t)|^2) = \mu + a \log|t|,$$

and

$$[S(t)/C(t)] = \tan[\delta t - \beta c^{\alpha} \tan(\pi\alpha/2)\, \mathrm{sgn}(t)\, |t|^{\alpha},$$

where

$$\mu = \log(2c^{\alpha}).$$

Building on this, Koutrouvelis and Bauer (1982) offer a regression procedure for estimating the parameters a, c, 6, and ß. To use this procedure, one must first standardize the data with initial estimates of the location parameter, 6, and the scale parameter, c. Following Fama and Roll (19711, the initial estimate of the location parameter, δ_0, is taken as the mean of the middle 25 percent of the sample observations, and the initial scale parameter is defined as:

$$c_0 = (X_{.72} - X_{.28})/1.654,$$

where

X_f is the f sample quantile. The data are standardized according to:

$$X'_j = (X_j - \delta_0)/c_0$$

Next, we estimate μ and a in the model:

$$y_k = \mu + \alpha w_k + \varepsilon_k, \quad k = 1,2,3, \ldots 9,$$

where

$$y_k = \log(-\log|\Phi_n(t_k)|^2),$$

$$= \log[-\log([1/n \sum\cos(t_k X'_j)]^2 + [1/n \sum\cos(t_k X'_j)]^2)],$$

$$w_k = \log|t_k|,$$

$$t_k = (\pi k)/25,$$

ε_k = uncorrelated error term with mean equal to zero.

We based the choice of the values for k and t_k on an iterative regression process discussed in Koutrouvelis (1980). K = 9 seemed optimal for our data. Then α_0 is the estimated coefficient on w_k from the regression and is our initial estimate of the characteristic root of the Paretian distribution. We know that $\mu = \log(2c^{\alpha})$; therefore, Koutrouvelis and Bauer estimate the scale parameter $\hat{c} = c_, * c_1$ where :

$$c_1 = (e^{\mu}/2)^{1/\alpha}.$$

We next need to estimate the skewness parameter, ß, and we re estimate the location parameter, 6. First, however, Koutrouvelis and Bauer standardize the data according to:

$$X''_j = X'_j/c.$$

Koutrouvelis and Bauer estimate 6 and $ß_0$ from:

$$Z_{\ell} = \delta\mu_{\ell} - ß \tan(\pi\alpha/2)\ \mathrm{sgn}(u_{\ell})(u_{\ell})^{\alpha} + \lambda_{\ell},$$

$$\ell = 1,2,3, \ldots 9$$

where

$$Z_{\ell} = \mathrm{Arctan}[(\sum\sin(u_{\ell} X''_j))/(\sum\cos(u_{\ell} X''_j))],$$

$$u_{\ell} = (\pi\ell)/50.$$

The estimate of the skewness parameter is $\hat{ß}$, the regression coefficient obtained from this equation. The regression coefficient $\hat{\delta}$ is used to obtain a final estimate of the location parameter, $\hat{\delta} = 60 + \hat{c}\delta_1$.

We have now obtained estimates of the parameters of the Paretian distribution. We also need estimates of their variance to make volatility comparisons over two time periods. Koutrouvelis and Bauer estimate the asymptotic variances of the parameter from:

$Var_n(c) = (c^2/2\alpha^2)[V'_1AV_1 - 2(\log c)V'_1AV_2 + (\log c)^2 V'_2AV_2]$.

$Var_n(\alpha) = V'_2AV_2/2$.

$Var_n(\delta) = 0.5\ u'D_0u/(u'u)^2$.

In these equations, V is a (k x 2) matrix such that:

$V'_1 = d^{-1}\ [W_2 - w W_1, W_2 - w W_1, \ldots, W_2 - w_kW_1]$

$V'_2 = d^{-1}\ [Kw_1 - W_1, Kw_2 - W_1, \ldots, Kw_k - W_1]$,

where

$W_1 = \sum w_k$,

$W_2 = \sum w_k^2$,

$d = KW_2 - W_1^2$.

A is a (k x k) matrix, such that the (k,ℓ) element is defined as:

$$a_{k\ell} = c^{-2\alpha}\ |t_k\ t_\ell|^{-\alpha}\{h(t_k,t_\ell:\alpha,c)$$
$$* \cos[p(t_k,t_\ell;\alpha,\beta,c)]$$
$$+ h(t_k,-t_\ell;\alpha,c) \cos[p(-t_k,t_\ell;\alpha,\beta,c)]$$
$$- 2\},$$

D is an (ℓ x ℓ) matrix, such that the (k,ℓ) element is defined as:

$$d_{k,\ell} = -h(u_k,u_\ell;\alpha,c) \cos[p(u_k,u_\ell;\alpha,\beta,c)]$$
$$+ h(u_k,-u_\ell;\alpha,c) \cos[p(-u_k,u_\ell;\alpha,\beta,c)]$$

where

$$h(t,u;\alpha,c) = \exp[c^\alpha(|t|^\alpha + |u|^\alpha - |t + u|^\alpha)]$$

$$P(t,u;\alpha,\beta,c) = c^\alpha\beta[|t|^\alpha \operatorname{sgn}(t)w(t;\alpha)$$
$$+ |u|^\alpha \operatorname{sgn}(u)w(u,\alpha)$$
$$- (t+u|^\alpha \operatorname{sgn}(t+u;\alpha)w(t+u);\alpha].$$

Koutrouvelis and Bauer note that the estimates of α c, δ, and β all have asymptotic normal distributions.

VII. The Results

Tables 4, 5, and 6 present the estimated parameters of the stable Paretian distribution for the daily percentage changes of the spot exchange rates, forward exchange rates, and asset prices, respectively. In a few cases, we truncated the estimated values of β at 1 or -1 following Koutrouvelis (1980). The variance of the estimates for location, scale and the characteristic exponent appear in parentheses below the relevant parameter.

Although daily percentage changes in the exchange rates and in the other asset prices were not drawn from a nornal distribution, the estimated parameters of the stable Paretian distribution (a, 6, c, and β) are asymptotically normally distributed. Consequently, we test for change in the estimates of a, 6, and c over the two time periods using a standard t-statistic. The results appear in tables 7, 8, and 9. Using the same procedure, we also compared the volatility of the spot rates against forward rates and the spot rates against the other asset prices. These results appear in tables 10 and 11.

Generally, the tests indicate that these spot exchange rates were not more volatile between April 1, 1981, and March 31, 1982, than between March 1, 1980, and February 28, 1981. With only three exceptions, the parameters are not statistically different over the two periods. These three exceptions, however, all suggest more volatility in the period of no intervention.

The dollar-mark exchange rate is the most important rate in the experiment, because it is often the target of U.S. intervention, and because of its importance for international commerce. For the daily percentage changes in the dollar-mark, δ and c were not significantly different over the two periods at the 0.05 level. (However, the scale parameter, c, is marginally significant at the 0.1 level.) These are the most important parameters; they are akin to the mean and the standard deviation in the normal distribution. The characteristic root, a, did prove to be larger in the second period, relative to the first period. This suggests a tendency toward a few, very large (relative to the mean) observations in the second period than in the first.

The U.S. dollar-Canadian dollar exchange rate and the dollar-yen exchange rate showed no tendency to exhibit greater volatility in the second period relative to the first by any measure. Canada and Japan are our two most important trading partners.

For daily percentage changes in the French franc and the British pound, the location parameter was unchanged, but the scale parameter was significantly larger in the second period. This indicates that while one would expect to find similar daily percentage changes over both periods, there was greater chance of observing larger changes in the second period. The British pound and the French franc, therefore, seem more volatile in the second period.

The forward exchange rates produced roughly similar results. The characteristic exponent of the German mark exchange rate was larger in the second period, suggesting a slightly greater tendency to observe a few large fluctuations. The scale parameters for the French franc and for the British pound exchange rates, again, were larger in the second period, suggesting more volatility. A final difference in the forward rates is that the location parameters for the Japanese yen and the British pound are different over the two periods. This results only because both currencies appreciated in the first period and depreciated in the second period, on average. If we ignore the sign of the parameter, there is no statistical difference in their magnitude.[8]

Table 10 compares the volatility of the spot and forward exchange rates for each currency. In no case, were the location parameters, the scale parameters, or the characteristic exponents of the spot or forward exchange rates significantly different.

In contrast to the behavior of the spot and forward exchange rates, when we measure volatility by the scale parameter, the other asset prices were uniformly less volatile during the second period under investigation relative to the first period (see table 9). The location parameters and the characteristic exponents of the daily percentage changes in interest rates, gold prices, and stock indexes were generally not different over the two periods. (The DOW stock index was the exception.) The scale parameters were significantly smaller in the second period, for all of the asset prices. Anything that contributed to greater volatility in exchange rates during the second period than in the first period would seem to be unique to the exchange markets.

In table 11, we compare the volatility of the spot exchange rates with that of the various asset prices. We measure volatility only in terms of the scale parameters. The results generally suggest the exchange rates were was less volatile than other asset prices in all cases, except for the stock indexes during the second period. That is, although the volatility of the other asset prices declined in the second period, while the volatility of the mark did not decline, the volatility of the mark remained significantly less than the volatility of the other asset prices. This result is consistent with the work of Bergstrand (1983) and is not consistent with claims made by some in the early 1980s that exchange rates were excessively volatile.

VIII. Conclusion

This paper has extended previous work on exchange-rate volatility by constructing measures of volatility that account for both the observed kurtosis and skewness of the sample data.

The results do not substantiate the argument that exchange rates were more volatile when the United States did not intervene in the foreign-exchange market than they were when the Federal Reserve intervened heavily in the exchange market. One must be careful, however, in drawing conclusions about the appropriateness of exchange-market intervention from this result, because we do not directly control for all possible contingencies. It is possible that the U.S. decision not to intervene did cause more volatility, but that some other variable changed in such a way as to offset this volatility in the second period. There was no change in monetary policy regimes, however, over the period studied. Although foreign intervention did increase in the second period, it did not completely offset the decrease in U.S. intervention, and it probably was not always targeted in the same manner as U.S. intervention.

Interest rates, gold prices, and stock indexes tended to be less volatile from April 1, 1981, to March 30, 1982, compared to the first period, but we found that exchange rates were less volatile than the other asset prices in both periods. Exchange rates did not appear, therefore, to exhibit "excessive" volatility. We found no difference between the volatility of spot and forward exchange rates in either period.

Notes

1. Theory suggests that official intervention can alter exchange rates by 1) changing relative money stock growth rates, 2) inducing portfolio adjustments across assets denominated in different currencies, and 3) providing information and altering expectations. Of these, only the third seems a likely channel of influence for U.S. intervention. The effects of U.S. intervention on the money stock are routinely offset by the open-market operations, although exchange-rate considerations have influenced U.S. monetary policy on occasion. Moreover, empirical evidence does not find support for the portfolio-adjustment channel of influence. For a discussion and references, see Humpage (1986).

2. The Federal Reserve System altered its operating procedure in October 1979. We make our volatility comparisons in a period when the operating procedure did not change. A change in operating procedure from a focus on interest rates to reserve growth could affect exchange-rate volatility.

3. See Bergstrand (1983); Hakkio (1984); Frenkel and Mussa (1980); Greene (1984); and Levich (1981).

4. Mandelbrot (1963) first observed that stock-price changes did not follow a normal distribution. Subsequent work on asset-price volatility builds on his work.

5. As Fama (1963, p. 421) notes, "From a purely statistical standpoint, if the population variance of the distribution ... is infinite, the sample variance is probably a meaningless measure of scale. Moreover, if the variance is infinite, other statistical tools ... which are based on the assumption of finite variance will, at best, be considerably weakened and may in fact give very misleading answers."

6. For a description of B,, see SAS Institute Inc. (1982, Chapter 17)

7. For a description of B,, see SAS Institute Inc. (1982, Chapter 17).

8. For volatility studies, we should not care about the sign of the daily change, only the magnitude of the change.

Table 1 Daily Percentage Changes and the Normal Distribution
Spot Exchange Rates

Spot rates	Mean	Standard deviation	Skewness	Kurtosis	D-normal	Prob. > D
1. March 1, 1980, to February 28, 1981; n = 252:						
German mark	-0.0709	0.7334	0.6781"	2.6186"	0.0856[b]	< 0.01
French franc	-0.0724	0.6837	0.7979"	3.0166"	0.0815	— — 0.01
Japanese yen	0.0743	0.7237	0.4572"	1.3312"	0.0777	— — 0.01
Britishpound	-0.0124	0.5825	-0.2196	1.6968"	0.0606	= 0.023
Canadian dollar	-0.0181	0.2797	0.6457"	2.3533"	0.0439	> 0.15
2. April 1, 1981, to March 31, 1982; n = 252:						
German mark	-0.0524	0.8120	0.0320	0.1360	0.0451	> 0.15
French franc	-0.0893	0.8997	0.3170"	3.4452"	0.0636	= 0.014
Japanese yen	-0.0610	0.7381	0.5401"	1.4150"	0.0495	= 0.135
British pound	-0.0874	0.8384	-0.3093"	1.5872[a]	0.0432	> 0.15
Canadian dollar	-0.0145	0.2649	0.0224	0.7910"	0.0460	> 0.15

a. Reject null hypothesis that estimated statistic equals zero at the 0.05 confidence level.

b. Reject the null hypothesis that the data are drawn from a normal distribution.

Table 2 Daily Percentage Changes and the Normal Distribution
Six-Month-Forward Rates

Forward rates	Mean	Standard deviation	Skewness	Kurtosis	D-normal	Prob. > D
1. March 1, 1980, to February 28, 1981; n = 252:						
German mark	-0.0804	0.6581	0.5336"	3.1810"	0.0956"	< 0.01
French franc	-0.0712	0.6087	0.7717[a]	3.1800"	0.0967[b]	< 0.01
Japanese yen	0.0773	0.7265	0.2947"	1.2535"	0.0740[b]	< 0.01
Britishpound	-0.0012	0.5155	-0.3721"	1.4915"	0.0736 ‒	‒ 0.01
Canadian dollar	-0.0233	0.2658	0.5736"	3.2533"	0.0628	= 0.017
2. April 1, 1981, to March 31, 1982; n = 252:						
German mark	-0.0453	0.7487	0.0338	0.4345	0.0439	> 0.15
French franc	-0.1057	0.8810	-0.4749"	2.9550"	0.0688	< 0.01
Japanese yen	-0.0577	0.6863	0.5100"	1.6824"	0.0491	= 0.143
British pound	-0.0886	0.7722	-0.4921"	2.2432"	0.0546	= 0.067
Canadian dollar	-0.0142	0.2675	0.1661"	7.8087"	0.0737 ‒	‒ 0.01

a. Reject null hypothesis that estimated statistic equals zero at the 0.05 confidence level.

b. Reject the null hypothesis that the data are drawn from a normal distribution.

Table 3 Daily Percentage Changes and the Normal Distribution of Asset Prices

Asset price	Mean	Standard deviation	Skewness	Kurtosis	D-normal	Prob. > D
1. March 1, 1980, to February 28, 1981; n = 249:						
3-month T-bill	0.0410	2.6510	0.0543[a]	0.5083[a]	0.0490	> 0.15
20-year T-note	0.0427	1.3375	-0.4144[a]	0.5719[a]	0.0597	= 0.03
Gold price	-0.0733	2.5175	0.1541"	1.4439"	0.0481	> 0.15
NYSE stock index	0.0637	1.0286	-0.2838"	0.5788"	0.0460	> 0.15
DOW stock index	0.0537	1.0026	-0.1515"	0.7074"	0.0573	= 0.045
2. April 1, 1981, to March 31, 1982; n = 252:						
3-month T-bill	0.0499	2.2431	0.4686"	2.6240"	0.0627	= 0.018
20 year T-note	0.0347	1.1509	0.1792"	0.1314"	0.0473	> 0.15
Gold price	-0.1748	1.6100	-0.0704"	0.5126"	0.0269	> 0.15
NYSE stock index	-0.0737	0.8438	-0.0729"	0.8875"	0.0498	= 0.133
DOW stock index	-0.0761	0.8380	0.1276"	0.3659"	0.0311	> 0.15

a. Reject null hypothesis that estimated statistic equals zero at the 0.05 confidence level.

Table 4 Stable-Laws Parameters for Percentage Changes in the Spot Exchange Rate
(asymptotic variance in parenthesis)"

Spot rates:	Location δ	Scale C	Skewness β	Characteristic exponent α
1. March 1, 1980, to February 28, 1981; n = 252:				
German mark	-0.04861	0.42594	-0.63583	1.76013
	(0.00669)	(0.00337)		(0.00914)
French franc	-0.04433	0.38088	-0.66103	1.70961
	(0.00513)	(0.00269)		(0.00134)
Japanese yen	0.10369	0.44078	-0.84834	1.80724
	(0.00531)	(0.00281)		(0.00967)
British pound	-0.01855	0.36877	0.38617	1.86447
	(0.00395)	(0.00246)		(0.00756)
Canadian dollar	-0.01504	0.18811	-1.000000[b]	1.95726
	(0.00117)	(0.00202)		(0.00844)
2. April 1, 1981, to March 30, 1982; n = 252:				
German mark	-0.05338	0.57007	0.20627	1.99402
	(0.01052)	(0.00421)		(0.00483)
French franc	-0.1048	0.55565	0.21137	1.85656
	(0.01046)	(0.00456)		(0.00708)
Japanese yen	-0.04578	0.48939	0.05919	1.92960
	(0.00805)	(0.00277)		(0.00572)
British pound	-0.09723	0.54636	0.716056	1.90899
	(0.01140)	(0.00486)		(0.00358)
Canadian dollar	-0.01583	0.17105	0.110863	1.87972
	(0.00091)	(0.00312)		(0.00661)

a. The variance in parenthesis equals the estimated variance of the coefficient, divided by the number of observations.

b. Estimated β truncated to 1 or -1.

Table 5 Stable-Laws Parameters for Daily Percentage Changes in the Six-Month-Forward Rates
(asymptotic variance in parenthesis)[a]

Forward rates:	Location δ	Scale c	Skewness β	Characteristic exponent α
1. March 1, 1980, to February 28, 1981; n = 252:				
German mark	-0.0767	0.348	-0.051	1.635
	(0.00143)	(0.00324)		(0.01012)
French franc	-0.1045	0.326	-0.170	1.662
	(0.00124)	(0.00334)		(0.01010)
Japanese yen	0.1007	0.449	-0.336	1.830
	(0.00185)	(0.00182)		(0.00802)
British pound	-0.0137	0.318	0.277	1.823
	(0.00099)	(0.00254)		(0.00801)
Canadian dollar	-0.0234	0.170	-0.221	1.899
	(0.00027)	(0.00325)		(0.00600)
2. April 1, 1981, to March 30, 1982; n = 252:				
German mark	-0.0467	0.513	0.046	1.962
	(0.00215)	(0.00086)		(0.00326)
French franc	-0.1123	0.534	0.179	1.830
	(0.00256)	(0.00167)		(0.00832)
Japanese yen	-0.0455	0.448	-0.562	1.911
	(0.00172)	(0.00126)		(0.00557)
British pound	0.1003	0.485	0.325	1.865
	(0.00208)	(0.00153)		(0.00717)
Canadian dollar	-0.0123	0.149	-0.041	1.689
	(0.00031)	(0.00589)		(0.00993)

a. The variance in parenthesis equals the estimated variance of the coefficient, divided by the number of observations.

Table 6 Stable-Laws Parameters for Percentage Changes in Asset Prices (asymptotic variance in parenthesis)[a]

Asset prices:	Location δ	Scale c	Skewness β	Characteristic exponent α
1. March 1, 1980, to February 28, 1981; n = 252:				
3-month T-bill	-0.0579	1.770	-0.354	1.928
	(0.0337)	(0.0239)		(0.00514)
20-year T-note	-0.0625	1.317	0.535	1.917
	(0.00665)	(0.00221)		(0.00549)
Gold price	-0.0626	1.561	0.063	1.776
	(0.0240)	(0.0120)		(0.0100)
NYSE stock index	0.0416	0.683	1.000[b]	1.919
	(0.00396)	(0.00152)		(0.00531)
DOW stock index	0.0867	0.672	-1.630	1.934
	(0.00262)	(0.00170)		(0.00686)
2. April 1, 1981, to March 30, 1982; n = 252:				
3-month T-bill	0.0440	0.884	-0.813	1.928
	(0.01599)	(0.00661)		(0.00963)
20-year T-note	0.0447	0.783	-1.000[a]	1.984
	(0.00502)	(0.00147)		(0.00183)
Gold price	-0.2146	1.096	0.499	1.963
	(0.0102)	(0.0034)		(0.0031)
NYSE stock index	0.0567	0.544	0.481	1.878
	(0.00378)	(0.00140)		(0.00464)
DOW stock index	-0.0754	0.567	-0.586	1.949
	(0.00268)	(0.00114)		(0.00390)

a. The variance in parenthesis equals the estimated variance of the coefficient divided by the number of observations.

b. Estimated β truncated to 1 or -1.

Table 7 Tests for a Change in the Parameters
(daily percentage changes in the spot rates)

Currency	Parameter	t-statistic
German mark	6	0.03636
	c	-1.6555
	α	-1.97893[a]
French franc	δ	0.48438
	c	-2.05250[a]
	α	-1.60146
Japanese yen	6	1.29316
	c	-0.65074
	α	-0.98630
British pound	6	0.63503
	c	-2.07562"
	α	-0.42181
Canadian dollar	6	0.01723
	c	-0.23797
	a	0.63206

a. Reject null hypothesis that the parameters are equal in both periods at the 0.05 confidence level.

Table 8 Tests for a Change in the Parameters
(daily percentage changes in the six-month-forward rate)

Currency	Parameter	t-statistic
German mark	δ	-0.501
	c	-2.577
	α	-2.827[a]
French franc	δ	0.127
	c	-2.939[a]
	α	-1.237
Japanese yen	δ	2.449[a]
	c	-0.018
	α	-0.695
British pound	δ	-2.057[a]
	c	-2.618[a]
	α	-0.341
Canadian dollar	δ	-1.482
	c	0.220
	α	1.664

a. Reject null hypothesis that the parameters are equal in both periods at the 0.05 confidence level.

Table 9 Tests for a Change in the Parameters
(daily percentage changes in asset prices)

Currency	Parameter	t-Statistic
3-month T-bill	δ	-0.457
	c	5.072[a]
	α	0.0
20-year T-bond	δ	-0.992
	c	8.803[a]
	α	-0.783
Gold price	δ	0.822
	c	3.747[a]
	α	-1.634
NYSE stock index	δ	-0.172
	c	2.572[a]
	α	0.411
DOW stock index	δ	2.227[a]
	c	1.970[a]
	α	-0.145

a. Reject null hypothesis that the parameters are equal in both periods at the 0.05 confidence level.

Table 10 Comparison of the Volatility of Spot and Forward Exchange Rates
(data are t-values)

1. March 1, 1980, to February 28, 1981

	Location	Scale	Characteristic exponent
German mark	-0.312	-0.959	-0.902
French franc	-0.754	-0.707	-0.445
Japanese yen	-0.035	0.121	0.171
British pound	0.069	-0.718	-0.332
Canadian dollar	-0.220	-0.249	-0.485

2. April 1, 1981, to March 30, 1982

	Location	Scale	Characteristic exponent
German mark	-0.059	-0.959	-0.902
French franc	-0.754	-0.707	-0.445
Japanese yen	-0.035	0.121	0.171
British pound	0.069	-0.718	-0.332
Canadian dollar	-0.220	-0.249	-0.485

Table 11 Comparison of Scale Parameters for Spot Exchange Rates and Asset Prices
(data are t-values)

	German mark	French franc	Japanese yen	British pound	Canadian dollar
1. March 1, 1980, to February 28, 1981; n = 249:					
3-month T-bill	-8.139"	-8.519"	-8.133"	-8.631[a]	-9.826"
20-year T-bond	-11.920"	-13.373"	-12.367"	-13.876"	-17.357"
Gold	-9.156"	-9.737"	-9.205"	-9.915"	-11.595"
NYSE index	-3.676"	-4.656"	-3.681[a]	-4.981[a]	-8.318"
DON index	-3.456"	-4.394"	-3.443"	-4.701[a]	-7.934"
2. April 1, 1981, to March 31, 1982; n = 252:					
3-month T-bill	-3.018"	-3.107"	-4.074"	-3.152"	-7.221"
20-year T-bond	-2.825"	-2.928"	-4.509"	-2.974"	-9.032"
Gold	-6.029"	-6.056"	-7.723"	-6.047"	-11.455"
NYSE index	0.348	0.151	-0.846	0.030	-5.547"
DON index	0.042	-0.150	-1.241	-0.266	-6.066"

a. Reject null hypothesis that the parameters are equal at the 0.05 confidence level.

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