Memories, Heteroscedasticity, and Price Limit in Currency Futures Markets

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INTRODUCTION

One of the major issues in finance literature is the efficiency of various asset markets. In an efficient market, the changes in asset prices are independent over time and they react to the release of information instantaneously. However, empirical evidence thus far find price dependence in a number of asset markets. Several related issues are examined in spot and forward currency markets. Frenkel and Levich (1977), Geweke and Feige (1979), and Meese and Singleton (1982) investigate and find that the underlying process of exchange rate is well approximated by random walks. Another set of literature examine the statistical property of exchange rate changes. This issue centers on whether they can be described by independent, identical distributions (i.i.d.); whether they are from a distribution with either nonconstant means and/or nonconstant variances, or nonzero serial correlations. Studies by Friedman and Vandersteel (1982), Calderon-Rossell and Ben-Horim (1982), and Hsieh (1988, 1989a, 1989b) consistently reject the i.i.d. hypothesis. Hsieh (1988) is unable to find significant serial correlation in spot British pound, Canadian dollar, German mark, and Swiss franc. Finally, in an effort to detect a long-term irregular cycle in exchange rates, Booth, Kaen, and Koveos (BKK) (1982) employ the rescaled range analysis (R/S analysis) to examine spot rate for the British pound, French franc, and German mark. They find these currencies to exhibit positive long-term price dependence under a flexible exchange rate system and negative long-term price dependence under a fixed rate regime.

Contrary to the attention devoted to spot and forward exchange rates, the property of foreign exchange futures has yet to be examined extensively. Thus far, findings on the unbiasedness hypothesis are mixed [Hill and Schneewis (1981); Hodrick and Srivastava (1987); McCurdy and Morgan (1987); Kodres (1989)]. So (1987) shows that the distribution of currency futures returns is nonstationary. Glassman

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(1987) examines serial correlations in the British pound, Canadian dollar, German mark, and Swiss franc futures. Significant serial correlations are detected on these currency futures when the entire return series are examined. However, she argues that limit moves in futures market distort the "observed" mean and variance and therefore induce serial correlation. To account for this impact, she adjusts the return time series by deleting "limit move days" from the series.[1] Serial correlations are no longer significant after this adjustment. In summary, existing literature on time series price dependence of financial assets are inconclusive. Since the presence of price dependence is clearly inconsistent with the prediction of market efficiency, further economic and/or technical justifications need to be explored to justify the findings of price dependence.

This article seeks to examine the nature of price dependence in the foreign exchange futures market. It is proposed that differences in the level of price dependence may be caused by traders possessing an heterogeneous information set and analytical skills (heterogeneous traders hypothesis) and/or differences in the degree of trading efficiency in various markets (transaction efficiency hypothesis). To examine the time series property of currency futures, a modified R/S statistic recently proposed by Phillips (1987) and Lo (1989) is used. Unlike previous studies, this methodology is sensitive to nonperiodic or irregular dependence that is not captured by measures such as autocorrelation analysis which assumes linear dependence in the series. It is modified to be robust to the heteroscedasticity often found in the futures prices. The modified test also allows differentiation between short-term and long-term dependence. Specifically, the detection of long-term memory implies that martingale models, such as random walks, do not hold for currency futures markets.

The evidence seems to suggest that previous findings of long-term dependence in foreign exchange spot rates are, in fact, short-term in nature. The misidentification is attributed to the shift in first moment of the return series. More importantly, it is shown that the short-term dependence cannot be fully explained by the price limit rule in the marketplace. The economic justification for the short-term dependence identified in this study, among other possible reasons, is more consistent with the heterogeneous traders hypothesis.

THE SOURCES OF PRICE DEPENDENCE

Since finding of price dependence is not implied by the efficient market hypothesis, possible justifications for the findings need to be identified. Based on Rao and Ma (1991), one possibility is that assumptions of market efficiency may be violated. Alternatively, price dependence may be caused by unique characteristics of various marketplaces. Similar to their arguments, the heterogeneous traders hypothesis and transaction efficiency hypothesis are proposed as possible justifications for the existence of price dependence.

A. Heterogeneous Traders Hypothesis

The efficient market hypothesis assumes the investors are endowed with equal intelligence and new information is available to all investors simultaneously. Copeland

[1]Glassman (1987) examines the British pound, Canadian dollar, German mark and Swiss franc from May 1972 to December 1981 and finds less than 2% of the price observations in the entire sample to be limit move days.

(1976) questions the instant availability of the equal information set and proposes that information is made available to various market participants sequentially. This sequential revelation of information is accompanied by a dependent sequence of prices and above-normal trading volume if informed traders do not trade instantly to the true equilibrium level. In support of this hypothesis, Morse (1980) shows that periods of unusually high volume are accompanied by serial correlation of return residuals.

On the issue of individual competence, Heiner (1983) argues that regularity of behavior is affected by both the environment uncertainty and the competence level of the agent. That is, behavior of a market participant is more predictable if the level of uncertainty in decision-making processes increases, or if he (she) has a low competence level. Given the same uncertainty level in the environment, Kaen and Rosenman (KR) (1986) examine the impact on the pricing process if market participants possess heterogeneous perceptual abilities. They state that, for a trade to occur, the "reliability ratio" of a market participant must exceed a minimum "tolerance level." This tolerance level is a function of the objective loss and profit potentials, and is invariant across all market participants. The tolerance level changes only when the information environment changes. The reliability ratio, on the other hand, is a measure of subjective confidence levels in making the right trading decision. The level of this ratio is positively related to the analytical ability of market participants and, therefore, is idiosyncratic in nature. Since the market is composed of participants with different competence levels, trading is triggered on a sequential basis—with more competent participants trading first, and less competent ones trading later. Setting such a motion in action, as KR argue, results in a noticeable price dependence. It should be noted that, since the advantage derived from the differential information set or from superior intelligence cannot exist among the market participants in the long run, price dependence generated from this cause should be short-term in nature.

B. Transaction Efficiency Hypothesis

Price dependence can also be a result of a different market transaction efficiency. Transaction efficiency can be described by the liquidity, the opportunity of leverage, the cost of transaction, and the speed of information dissemination in the marketplace. The degree of efficiency in a market may differ over time. It may also vary among financial markets. Therefore, informed traders would maximize their information advantage by trading in a market with the most transaction efficiency. This could lead to different degrees of price dependence in various financial markets, with shorter price dependence being observed in a more efficient market.

As compared to spot markets, derivative markets such as futures and options markets may be more efficient because they have significantly lower commission costs and impact higher leverage. Manaster and Rendleman (1982) and Ma and Rao (1988) posit that informed traders prefer to trade in the derivative asset market than in the spot market primarily because of the higher leverage opportunities. Jennings and Starks (1986) and Patell and Wolfson (1979) demonstrate that options markets react faster to news announcements and that options premia appear to anticipate stock price changes. Kawaller, Koch, and Koch (1987) show that, more often than not, price changes in the futures market lead similar changes in the spot market for various stock market indices.

To the extent that this collective evidence suggests that a greater proportion of informed and perceptive traders prefer to transact their business in the futures markets, it also implies that there is a greater potential for asymmetry in both information sets and competence levels among participants in the futures markets. This, in turn, provides the causes for price dependence. However, in contrast to the heterogeneous traders hypothesis, the difference in transaction efficiency can exist in the long run between various asset markets. Thus, the evidence of long-term price dependence would be consistent with the prediction from the transaction efficiency hypothesis.

THE FOREIGN EXCHANGE FUTURES MARKETS

Trading in currency futures began at the International Monetary Market (IMM) of the Chicago Mercantile Exchange in May 1972. The timing coincides with the collapse of the Bretton Woods fixed exchange rate system. Currently, futures trading in a few most widely used currencies are available on organized exchange markets in several countries including the United States.

Trading volume in foreign exchange futures has increased substantially over time. Part of the growth reflects the increased need for hedging as the result of rapid globalization of the business community and increased exchange rate uncertainty. Smaller hedgers are attracted to the futures market to take advantage of the standardized trading procedure and relative small contract size. Furthermore, unlike the forward market, speculative activities are encouraged in the futures market. Finally, increased interventions by central banks also help stimulate trading activities in currency spot, forward as well as futures markets. With the growing popularity of this market, it is desirable to investigate the time series property of currency futures contracts. The null hypothesis of this article states that return series of currency futures exhibits short-term price dependence.

THE CLASSIC R/S STATISTIC

The modified R/S analysis proposed by Phillips (1987) and Lo (1989) is employed in this study to determine if return series of currency futures exhibits long-term dependence. The classical R/S analysis was first developed by Hurst (1951, 1956) and subsequently applied to economic time series data in a series of studies by Mandelbrot and others [Mandelbrot and Wallis (1969); Mandelbrot (1971, 1972, 1975)].

As discussed in these earlier studies R/S analysis has an advantage over conventional techniques, such as the Autocorrelation Function (ACF) analysis, because it is capable of detecting long-term irregular cycles. To correct for these problems, Mandelbrot proposed an alternative method, namely, rescaled range analysis (R/S analysis). R/S analysis presents several advantages over the standard ACF. Irrespective of their marginal distribution, this method may differentiate the structure of dependence in various economic time series, especially long-run dependence, from the serial correlation. By dividing the entire sample period into intervals of various lengths, R/S analysis may identify the presence of short, medium, and long nonperiodic cycles which are not visible through ACF. Furthermore, R/S analysis is robust with respect to the problem of infinite variance, as shown by Mandelbrot and Wallis (1969a) and Greene and Fielitz (1977).

R/S Analysis and the Hurst Coefficient

In this section, the empirical procedure of R/S analysis is described and the estimate of price dependence is derived. Following standard notation in the literature, $R(t,s)$ is the cumulative range of a return-generating process between times $t+1$ and $t+s$ after removal of the sample average and $S(t,s)$ is the corresponding sample standard deviation. Let $X(t)$ represent the return-generating process at the discrete integer-valued time and $X^*(t)$ is the cumulative return process. Therefore, for any particular time interval, $s > 1$, $R(t,s)$ is defined by:

$$R(t,s) = \max_{0<u<s} [X^*(t+u) - [X^*(t) - (u/s)(X^*(t+u) - X^*(t))]] - \min_{o<u<s} [X^*(t+u) - [X^*(t) - (u/s)(X^*(t+u) - X^*(t))]] \quad (1)$$

and

$$S(t,s) = \left[(1/s)\sum_{u=0}^{s} X^2(t+u) - (1/s^2)\left[\sum_{u=0}^{s} X(t+u)\right]^2 \right]^{1/2} \quad \text{for} \quad 0 < u < s \quad (2)$$

$R(t,s)$ measures the range of the deviation from the linear approximation of the trend line in the given interval. Thus, the rescaled range for lag s is defined as

$$R/S = R(t,s)/S(t,s)$$

Mandelbrot (1972) shows that R/S asymptotically approaches CS^H, where c is a constant, and H is the Hurst coefficient which measures the persistence in time series.

To empirically estimate H, the entire sample period is first divided into n equal, nonoverlapping intervals with the length of lag s. An average R/S corresponding to the lag s is computed by averaging the n different R/S estimated from each interval. The same procedure is repeated for various lags which are specified in Wallis and Matalas (1970), and the Hurst coefficient is then estimated by applying the generalized least squares procedure to the following transformed model:

$$\ln(R/S) = a + H \ln(s) \quad (3)$$

The estimated slope, H, therefore indicates the direction and intensity of long-term dependence. Specifically, the time series is long-term independent if $H = 0.5$, the dependence is positive if $0.5 < H < 1$, and negative if $0 < H < 0.5$. Intuitively, the level of H indicates the relative proportion of deviations on either side of the trend line. For example, the noise (deviation) with $H > 0.5$ indicates that some periods above or below the theoretical mean are extraordinarily long. In other words, prices move in one direction for some time and result in persistent patterns.

The R/S statistic was first applied to currency data by BKK. They uncovered positive long-term price dependence in spot British pound, French franc, and German mark during the floating exchange rate system (July 1973 to June 1979) and negative long-term dependence during the fixed rate system (July 1965 to June 1971). The method has also been used to analyze several assets including stocks [Greene and Fielitz (1977)], spot gold [Booth, Kaen, and Koveos (1982)], as well as agriculture futures [Helms, Kaen, and Rosenman (HKR) (1984)]. Positive long-term dependence was observed in all these assets.

However, the classical R/S analysis has been criticized by Milonas, Koveos, and Booth (MKB) (1985); Aydogan and Booth (1988); and Lo (1989). In particular, Lo shows that the method cannot distinguish between short- ("strong dependence") and long-term ("weak dependence") memory. This can be a severe drawback since short-term dependence of asset returns have been detected using the variance ratio test [Lo and MacKinlay (1988)]. Further, the method assumes stationary first and second moments for the return series [MKB (1985)]. Numerous empirical studies on several asset markets have found evidence in violation of this assumption. For example, variance of return from various futures contracts has been shown to exhibit seasonality and maturity effects [Anderson (1985); Milonas (1986); Kenyon et al. (1987)]. Mean and variance of spot exchange rates have also been observed to be nonconstant.

In a recent article, Lo (1989) presents a modified R/S statistic. The time series property of the statistic is discussed in detail in an earlier paper by Phillips (1987). The statistic is shown to be robust to many forms of heterogeneity and is capable of making a distinction between long- and short-term memory. Lo computes both a classical and a modified R/S statistic using daily, weekly, monthly, and annual stock returns indexes over several time periods. He obtains conflicting findings. Long-term memory in the stock index return series is detected when the classical statistic is computed. This finding is consistent with earlier studies. He finds the opposite result when the modified statistic is computed. Lo attributes this discrepancy to the two having different assumptions on the second moment of the distribution.

THE MODIFIED R/S STATISTIC

Following the same notations, let P_t represent the price of an asset at time t and define $X_t = \log P_t - \log P_{t-1}$ to be the continuously compounded single-period (from $t - 1$ to t) return. Assume the return-generating process is

$$X_t = \mu + \varepsilon_t \tag{4}$$

The null hypothesis depends on four assumptions on time series $\{\varepsilon_t\}$ as described by Lo (1989) and discussed in detail by Phillips (1987). They include the return-generating process being heteroscedastic and the presence of short-term serial dependence. Accordingly, the return series is said to be short-term price dependent if the null hypothesis is not rejected. The return series is said to be long-term price dependent if the null is rejected. The hypothesis stated is a joint one.

Based on assumptions for the null hypothesis and a sample of observations $X_1, X_2, \ldots, X_n$, Lo defines the modified rescaled range, Q_n, as[2]:

$$Q_n = (1/\sigma_n(q))\left[\max_{1\le k\le n}\sum_{j=1}^{k}(X_j - \overline{X}_n) - \min_{1\le k\le n}\sum_{j=1}^{k}(X_j - \overline{X}_n)\right] \tag{5}$$

where

$$\sigma_n(q) = 1/n\sum_{j=1}^{n}(X_j - X_n)^2 + 2/n\sum_{j=1}^{n} w_j(q)\left[\sum_{i=j+1}^{n}(X_i - X_n)(X_{i-j} - X_n)\right]$$

$$w_j(q) = 1 - j/(q + 1) \quad q < n \tag{6}$$

[2]As reported in Lo's article, critical values at 1%, 5%, and 10% significance levels are 2.098, 1.862, and 1.747, respectively.

and the modified R/S statistic is defined as[3]:

$$V_n(q) = (1/n)^{-1/2} Q_n \tag{7}$$

The limiting distribution of $V_n(q)$ is the range of a Brownian bridge on a unit interval with a mean of $\pi/2$. Fractiles of this limiting distribution is reported in Table 2a of Lo's article. The numerator of Q_n measures range of deviation from linear approximation of the trend line in a given interval. This is similar to the classical R/S statistic. The major improvement of the modified statistic is in the denominator of Q_n. The denominator of the classical statistic represents the sum of squared deviations of X_j; while a second term, the sum of weighted autocovariances (up to lag order q), is added to form the denominator of the modified statistic. As Lo points out, this term will be nonzero if $\{X_t\}$ exhibits short-term memory. It also allows the variance of the return series to be heteroscedastic.

However, a problem can arise when applying the modified R/S statistic to a return time series with a nonconstant mean; because, in the model, the mean of the series is implicitly (and incorrectly) assumed to be constant. This could lead to incorrect rejection of the null hypothesis. In other words, a return time series could be incorrectly identified as having long-term memory. It is imperative that the modified R/S analysis be conducted on a time series with a constant mean. Proper treatment of the time series data is necessary if the series experiences a major structural change during the observation period.

EMPIRICAL DESIGN

This study examines futures contracts in the British pound, German mark, Swiss franc, and Canadian dollar from the IMM. Daily closing prices of near-term contracts from November 1, 1979 to December 31, 1987 are obtained from Commodity Perspective Inc. Because most trading activities are concentrated in the near-term contract (the database assumes that rollover takes place one week prior to the expiration of the contract), its selection removes the potential impact of trading volume on variance of the return series. This time series is selected to avoid the chaotic period during the first few years after the collapse of the Bretton Woods fixed rate system[4] and to avoid the period of changes in the U.S. Federal Reserve policies during October 1979.

Daily price limits on currency futures were present during first few years of trading on the IMM. However, the IMM lifted price limits entirely on February 22, 1985 to be in line with the trading practice in spot and forward markets. Limit moves would induce serial correlation and affect first and second moments of the time series distribution [Kodres (1988); Chiang and Wei (1990)]. Since the R/S statistic assumes a constant mean in the time series distribution, it has the tendency to reject the null hypothesis if the series has nonconstant means. To account for this limitation, the study's time series is divided into a period where price limits are in place (November 1, 1979 to February 22, 1985) and a period of no price limits

[3]However, it should be pointed out that Mandelbrot suggests that X_n be replaced by the sample trend. Furthermore, the R/S memory is different from GARCH or chaos memory. In the later cases, the variances of the return prices is related to the level of the return, and the dependence is generated from the dependent variance.

[4]As discussed in footnote 3, while chaos also represents one type of dependence, it is basically different from the R/S memory that is investigated in this article. This is another reason why the pre-1989 period is excluded from the testing.

(February 25, 1985 to December 31, 1987). Also, since the "no price limit" period is much shorter than the period of "price limit," a third period that covers an equal number of days (April 19, 1982 to December 31, 1987) is used. Finally, to determine if the test statistic is robust to length of the time series, a fourth period that spans the second half of the "price limit" period (from July 1, 1982 to February 22, 1985) is used. In summary, the analysis is conducted for the following time intervals:

1. Mixed period (covers the entire "price limit" period and the entire "no price limit" period): November 1, 1979 to December 31, 1987.
2. Mixed subperiod (covers the last 722 days of "price limit" period and the entire "no price limit" period): April 19, 1982 to December 31, 1987.
3. Price limit period (covers the entire "price limit" period): November 1, 1979 to February 22, 1985.
4. Price limit subperiod (covers the second half of "price limit" period): July 1, 1982 to February 22, 1985.
5. No price limit period (covers the entire "no price limit" period): February 25, 1985 to December 31, 1987.

A modified R/S statistic, $V_n(q)$, is computed for each currency futures for the following maximum lag length (q): 0, 5, 10, 25, 50, 65, and 130. As defined in (3), the autocovariance term of $\sigma_n(q)$ drops out when lag value is set to equal to zero. Consequently, the modified R/S statistic falls back to the classical one. This enables a comparison of the two methods. Lag values of 5, 10, 25, and 50 are chosen because they were used in Lo's Monte Carlo experiment. Lags over 50 are used because Wallis and Matalas (1970) showed that the RS estimates are significantly upward if the lag is less than 50. Lag values of 65 and 130 are used because the time series covers such a long period. Summary of the test statistic for the mixed period and mixed subperiod are reported in Table I. Table II contains results for price limit period and price limit subperiod. Table III contains results for the no price limit period.

EMPIRICAL RESULTS

A. Mixed Period and Mixed Subperiod

Results on the whole mixed period are presented in panel A of Table I. The test statistic, i.e., $V_n(q)$ of the German mark, is 1.928 when lag value is zero. When other lag values are used, $V_n(q)$ ranges from 2.192 for lag of 5 down to 1.810 for lag of 130. These values are compared to fractiles for the limiting distribution, $V_n(q)$, reported in Table 2a of Lo's article. With lag value of 0, $V_n(q)$ is significant at the 5% level. $V_n(q)$ is significant at the 1% level when lag value is 5, 10, 25, or 50, at the 5% level when lag value is 65, and at the 10% level when lag value is 130.

The $V_n(q)$ values for Swiss franc futures are significant at the 5% level for lag values up to 65 (including lag value of 0), but insignificant for lag value of 130. In the case of British pound futures, it is significant at either the 1% or 5% levels for all lag values examined in this study. In general, the null hypothesis is rejected based on findings from these three currencies. However, none of the $V_n(q)$ values are significant for the Canadian dollar futures which exhibit short-term, not long-term, price dependence.

Since about two thirds of the observations in the whole mixed period is from the "price limits" period and the remaining one third is from the "no price limits"

Table I
TEST STATISTIC FOR THE R/S ANALYSIS, $V_n(q)$: MIXED PERIOD COVERING "PRICE LIMIT" AND "NO PRICE LIMIT" PERIODS

	q[a]						
Currency Futures	**0**	**5**	**10**	**25**	**50**	**65**	**130**
Panel A: Nov. 1, 1979 to Dec. 31, 1987 (n = 2062)							
German mark	1.928[c]	2.192[d]	2.169[d]	2.129[d]	2.112[d]	2.026[c]	1.810[b]
Swiss franc	2.025[c]	1.997[c]	1.982[c]	1.933[c]	1.935[c]	1.872[c]	1.718[c]
British pound	2.302[d]	2.096[c]	2.105[d]	2.214[d]	1.973[c]	2.075[c]	1.890
Canadian dollar	1.351	1.331	1.336	1.380	1.467	1.475	1.580
Panel B: Apr. 19, 1982 to Dec. 31, 1987 (n = 1444)							
German mark	2.167[d]	2.107[d]	2.034[c]	2.058[c]	2.079[c]	2.003[c]	1.758[b]
Swiss franc	2.045[c]	2.037[c]	2.002[c]	1.996[c]	2.006[c]	1.952[c]	1.749[b]
British pound	2.019[c]	2.005[c]	1.985[c]	2.007[c]	1.901[c]	1.841[b]	1.701
Canadian dollar	1.313	1.305	1.310	1.326	1.370	1.385	1.473

[a] q is the maximum lag used in the calculation.
[b] Significant at the 10% level.
[c] Significant at the 5% level.
[d] Significant at the 1% level.

Table II
TEST STATISTIC FOR THE R/S ANALYSIS, $V_n(q)$: "PRICE LIMIT" PERIOD

	q[a]						
Currency Futures	**0**	**5**	**10**	**25**	**50**	**65**	**130**
Panel A: Nov. 1, 1979 to Feb. 22, 1987 (n = 1340)							
German mark	0.979	1.230	1.253	1.230	1.294	1.312	1.417
Swiss franc	1.029	1.035	1.049	1.021	1.058	1.060	1.099
British pound	1.249	1.263	1.300	1.328	1.291	1.253	1.149
Canadian dollar	1.083	1.010	0.982	0.990	1.052	1.081	1.152
Panel B: Apr. 19, 1982 to Dec. 31, 1987 (n = 1444)							
German mark	1.318	1.100	1.076	1.104	1.180	1.209	1.258
Swiss franc	1.197	1.235	1.239	1.272	1.327	1.347	1.397
British pound	1.178	1.191	1.230	1.340	1.430	1.459	1.470
Canadian dollar	1.593	1.449	1.403	1.356	1.317	1.283	1.181

[a] q is the maximum lag used in the calculation.

period, the analysis is replicated on a mixed subperiod which consists of an equal number of observations from the "price limit" and the "no price limit" periods. Results are reported in panel B of Table I. The findings are consistent with the whole mixed period. The null hypothesis of short-term memory cannot be rejected

Table III
TEST STATISTIC FOR THE R/S ANALYSIS, $V_n(q)$: "NO PRICE LIMIT" PERIOD

Commodity	q^a 0	5	10	25	50	65	130
Feb. 25, 1985 to Dec. 31, 1987 (n = 722)							
German mark	1.155	1.157	1.158	1.313	1.516	1.529	1.587
Swiss franc	1.073	1.071	1.079	1.188	1.356	1.394	1.474
British pound	1.382	1.390	1.400	1.492	1.453	1.423	1.378
Canadian dollar	1.116	1.183	1.282	1.370	1.394	1.417	1.562

[a] q is the maximum lag used in the calculation.

with the exception of Canadian dollar futures. Furthermore, the test statistic is robust to the length of the time series.

As noted earlier, limit moves affect not only the variance but also the mean of the series. Even though the modified R/S statistic recognizes variance of the return series as being nonconstant, it assumes the series has a constant mean. As a result, the model has a tendency to reject the null hypothesis. To gain some insight on this, the "price limit" period and the "no price limit" period are examined separately.

B. Price Limit Period and Price Limit Subperiod

The price dependence issue is reexamined by isolating the "price limit" period. The price limit period consists of the entire "price limit" period, while the price limit subperiod consists of only second half of the same period. Results of the two periods are summarized in panels A and B of Table II, respectively. Contrary to findings from the two mixed periods, no significant $V_n(q)$ is found for any of the four currency futures. Further, $V_n(q)$ values for the four currencies are very similar. This confirms the conjecture that a structural change in the return-generating process takes place when daily price limits are lifted. Finally, findings from the price limit period and the price limit subperiod are consistent. This further confirms that the test statistic is robust to length of time series.

C. No Price Limit Period

Results from the subperiod after price limits are removed are presented in Table III. Similar to findings from the two price limit periods, $V_n(q)$ is insignificant for all four currencies. The null hypothesis cannot be rejected. Futures contracts on the German mark, Swiss franc, British pound, and Canadian dollar do not have long-term memory. Furthermore, $V_n(q)$ values from this subperiod are very similar to the ones reported in Table II. This implies that limit moves do not induce serial correlation at higher orders.

SUMMARY AND CONCLUSIONS

This study examines the time series property of four actively traded currency futures: the British pound, Canadian dollar, German mark, and Swiss franc. Modified R/S analysis, as proposed by Phillips and Lo, is employed to determine whether they exhibit long- or short-term price dependence. This model assumes the return series has constant mean, nonconstant variance and is serially correlated at lower orders. To account for possible change in mean induced by the removal of daily price limit, the entire time series is divided into "price limit" periods and "no price limit" periods. The R/S statistic for the two periods is computed separately. The statistic is computed also by combining the two periods. The modified statistic is robust to length of time series. When the mixed period is examined, the null hypothesis is rejected for three out of the four currency futures. When the two periods are examined separately, it is not possible to reject the null hypothesis for all four currency futures. This suggests that long-term dependence found in mixed period cases can be induced by nonconstant means in the return series. Therefore, one can conclude that currency futures on German mark, Swiss franc, British pound, and Canadian dollar exhibit short-term price dependence. Since the difference in transaction efficiency between markets cannot explain short-term dependence, the findings seem to be more consistent with the heterogeneous traders hypothesis.

The collective findings in this study suggest several implications. The evidence of short-term price dependence in currency futures market is consistent with both the heterogeneous traders hypothesis and the transaction efficiency hypothesis. Long-term price dependence disappears when price limits are accounted for. This implies that previous findings of long-term price dependence in the currency spot market may be spurious. Furthermore, the timing of the removal of price limits from the futures market generally coincides with the reversal of U.S. dollar value (from being a strong currency to a weak currency) in the spot market. This lends further support for the decision to control the shift in means.

It is well-known in the literature that interventions by central banks have limited impact on currency values. Central bank interventions can, at best, smooth out excessive short-term exchange rate volatility. They have not worked well as tools for pegging the level of currency value for an extended period of time. This is consistent with this article's argument of nonstationary mean and findings of short-term price dependence in futures contracts of the four currencies.

Finally, findings of significant short-term, and not long-term, price dependence from both limit and no limit periods provide important policy implications for the validity of price limit rules. Critics of price limit rules have long argued that price limits only delay the price adjustment process, and therefore, create artificial price dependence. The fact that short-term dependence exists regardless of whether or not price limit rules are in effect suggests that the impact of price limit removal on serial correlation is, at most, transitory in nature, if at all.

Bibliography

Anderson, R. (1985, Fall): "Some Determinants of the Volatility of Futures Prices," *The Journal of Futures Markets,* 5:331–348.

Aydogan, K., and Booth, G. (1988): "Are There Long Cycles in Common Stock Returns?," *Southern Economic Journal,* pp. 141–149.

Bilson, J. F. O. (1981, December): "The Speculative Efficiency Hypothesis," *Journal of Business,* 54:435–451.

Booth, G. G., Kaen, F. R., and Koveos, P. E. (1982, Spring): "Persistent Dependence in Gold Prices," *Journal of Financial Research,* 5:85–93.

Booth, G., Kaen, F., and Koveos, P. (1982, November): "R/S Analysis of Foreign Exchange Rates Under Two International Monetary Regimes," *Journal of Monetary Economics,* 10:407–415.

Calderon-Rossell, J., and Ben-Horim, M. (1982): "The Behavior of Foreign Exchange Rates," *Journal of International Business Studies,* 13:99–111.

Chiang, R., and Wei, K. (1990): "Price Limit in Taiwan and Risk Return Estimation," *Pacific-Basin Capital Market Research,* 1.

Copeland, T. E. (1976, September): "A Model of Asset Trading Under the Assumption of Sequential Information Arrival," *The Journal of Finance,* 31:1149–1168.

Cornell, B. (1977, August): "Spot Rates, Forward Rates and Exchange Market Efficiency," *Journal of Financial Economics,* 5:55–65.

Finnerty, J. E., and Park, H. Y. (1987a): "Empirical Evidence on Stock Index Arbitrage: The Case of Program Trading," BEBR faculty working paper, University of Illinois, Urbana-Champaign.

Finnerty, J. E. (1987b): "A Note on the Tail Wagging the Dog Effect in Stock Index Futures," Paper presented at the 1987 Eastern Finance Association meetings, Baltimore, MD.

Frankel, J. A. (1980): "Tests of Rational Expectations in the Forward Exchange Market," *Southern Economic Journal,* 46:1083–1101.

Frenkel, J. A. (1978): "A Monetary Approach to the Exchange Rate: Doctrinal Aspects and Empirical Evidence," in *The Economics of Exchange Rates: Selected Studies,* Frenkel, J. A., and Johnson, H. G. (eds.). Reading, MA: Addison-Wesley.

Frenkel, J. A., and Levich, R. M. (1977): "Transactions Costs and Interest Arbitrage: Tranquil versus Turbulent Periods," *Journal of Political Economy,* 85:1209–1226.

Friedman, D., and Vandersteel, S. (1982): "Short-Run Fluctuations in Foreign Exchange Rates," *Journal of International Economics,* 13:171–186.

Geweke, J., and Feige, E. (1979, August): "Some Joint Tests of the Efficiency of Markets for Forward Exchange," *Review of Economics and Statistics,* 61:334–341.

Glassman, D. (1987): "The Efficiency of Foreign Exchange Futures Markets in Turbulent and Non-Turbulent Periods," *The Journal of Futures Markets,* 7:245–267.

Greene, M., and Fielitz, B. (1977, September): "Long-Term Dependence in Common Stock Returns," *Journal of Financial Economics,* 4:339–349.

Hansen, L. P., and Hodrick, R. J. (1980, October): "Forward Exchange Rates as Optimal Predictors of Future Spot Rates: An Econometric Analysis," *Journal of Political Economy,* 88:829–853.

Heiner, R. A. (1983, September): "The Origin of Predictable Behavior," *American Economic Review,* 73:560–595.

Helms, B., Kaen, F., and Rosenman, R. (1984, Winter): "Memory in Commodity Futures Contracts," *The Journal of Futures Markets,* 4:559–567.

Hill, J., and Schneewis, T. (1981, May): "Forecasting Effectiveness of Foreign Currency Futures," *Business Economics,* 16:42–46.

Hodrick, R., and Srivastava, S. (1987): "Foreign Currency Futures," *Journal of International Economics,* 22:1–24.

Hsieh, D. (1988): "The Statistical Property of Daily Foreign Exchange Rates: 1974–1983," *Journal of International Economics,* 24:129–145.

Hsieh, D. (1989): "Modeling Heteroscedasticity in Daily Foreign-Exchange Rates," *Journal of Business and Economic Statistics,* 7:307–317.

Hsieh, D. (1989): "Testing for Nonlinear Dependencies in Daily Foreign Exchange Rates," *Journal of Business,* 62:339–368.

Hurst, H. (1951): "Long Term Storage Capacity of Reservoirs," *Transactions of the American Society of Civil Engineers,* 116:770–799.

Hurst, H. (1956): "Methods of Using Long Term Storage in Reservoirs," *Proceedings of the Institute of Civil Engineers,* 1:519–543.

Ireland, T. C., Simpson, W. G., and Wingender, J. R. (1987): "The Predictive Value of Stock Index Futures Contracts." Paper presented at the Midwest Finance Association Meetings, Chicago, IL.

Jennings, R., and Starks, L. (1986, March): "Earnings Announcements, Stock Price Adjustments, and the Exercise of Options Markets," *Journal of Finance,* 41:107–125.

Kaen, F. R., and Rosenman, R. E. (1986, March): "Predictable Behavior in Financial Markets: Some Evidence in Support of Heiner's Hypothesis," *American Economic Review,* 76:212–220.

Kawaller, I. G., Koch, P. D., and Koch, T. W. (1987, December): "The Temporal Price Relationship Between S&P 500 Futures and the S&P 500 Index," *Journal of Finance,* 42:1309–1330.

Kenyon, D., Kling, K., Jordan, J., Seale, W., and McCabe, N. (1987, February): "Factors Affecting Agricultural Futures Price Variance," *The Journal of Futures Markets,* 7:73–91.

Kodres, L. E. (1989): "Tests of Unbiasedness in Foreign Exchange Futures Markets: The Effects of Price Limits," *Review of Futures Studies,* 7:138–166.

Lo, A. (1989, May): "Long-Term Memory in Stock Market Prices," Working paper no. 2984, National Bureau of Economic Research.

Lo, A., and MacKinlay, C. (1988): "Stock Market Prices Do Not Follow Random Walks: Evidence from a Simple Specification Test," *Review of Financial Studies,* 1:41–66.

Ma, C. K., and Rao, R. P. (1988, February): "Information Asymmetry and Option Trading," *The Financial Review,* 23:39–52.

Manaster, S., and Rendleman, R. J. (1982, September): "Option Prices as Predictors of Equilibrium Stock Prices," *Journal of Finance,* 37:1043–1058.

Mandelbrot, B. (1971): "When Can Price Be Arbitraged Efficiently? A Limit to the Validity of the Random Walk and Martingale Models," *Review of Economics and Statistics,* 53:225–236.

Mandelbrot, B. (1972): "Statistical Methodology for Non-Periodic Cycles: From the Covariance to R/S Analysis," *Annals of Economic and Social Measurement,* 1:259–290.

Mandelbrot, B. (1975): "Limit Theorems on the Self-Normalized Range for Weakly and Strongly Dependent Processes," *Z. Wahrscheinlichkeitstheorie verw. Gebiete,* 31:271–285.

Mandelbrot, B., and Wallis, J. (1969): "Robustness of the Rescaled Range R/S in the Measurement of Noncyclic Long-Run Statistical Dependence," *Water Resources Research,* 5:967–988.

McCurdy, T. H., and Morgan, I. G. (1987): "Tests of the Martingale Hypothesis for Foreign Currency Futures," *International Journal of Forecasting,* 3:131–148.

Messe, R. A., and Singleton, K. J. (1982): "On the Unit Roots and the Empirical Modeling of Exchange Rates," *Journal of Finance,* 37:1029–1034.

Milonas, N. (1986, Fall): "Price Variability and the Maturity Effect in Futures Markets," *The Journal of Futures Markets,* 6:443–460.

Milonas, N., Koveos, P., and Booth, G. (1985, Spring): "Memory in Commodity Futures Contracts: A Comment," *The Journal of Futures Markets,* 5:113–114.

Morse, D. (1980, December): "Asymmetrical Information in Securities Markets and Trading Volume," *Journal of Financial and Quantitative Analysis,* 15:1129–1148.

Patell, J., and Wolfson, M. (1979, August): "Anticipated Information Releases Reflected in Call Option Prices," *Journal of Accounting and Economics,* 1:117–140.

Phillips, P. (1987): "Time Series Regression with a Unit Root," *Econometrica,* 55:277–301.

So, J. C. (1987): "The Sub Gaussian Distribution of Currency Futures: Stable Paretian or Nonstationary," *Review of Economics and Statistics,* pp. 100–107.

Wallis, J. R., and Matalas, N. C. (1970, December): "Small Sample Properties of H and K—Estimators of the Hurst Coefficient *h*," *Water Resources Research,* 6:1583–1594.