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Do Gold Market Returns Have Long Memory?

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Abstract

This study examines the long memory behavior in gold returns during the post-Bretton Woods period using a new rescaled range technique. Unlike the conventional rescaled range analysis, the new rescaled range analysis is robust to short-term dependence and conditional heteroscedasticity found in the gold data. Statistical results suggest that the long memory behavior in gold returns is rather unstable. When only few observations corresponding to major political events in the Middle East, together with the Hunts event, in late 1979 are omitted, little evidence of long memory can be found.

Introduction

A growing body of literature has explored the long memory (or long-term dependence) property of financial price series (e.g., [5, 9, 10, 12, 15, 21, 28, 32, 42]). The long memory property describes the intertemporal dependence between observations at long lags. Short memory series, which include standard autoregressive moving average processes, have the property that observations far apart in time exhibit little or no statistical dependence. For long memory series, however, they display persistent dependence even between distant observations; such series are characterized by nonperiodic long cycles. An oft-cited example of the long memory series is the class of fractionally differenced processes [15, 19, 20, 38].

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Short memory in asset prices can arise, for example, from stop-loss orders and margin calls. A decrease in the price can trigger stop-loss orders and margin calls, which lead to selling and further price declines. Short memory can also result from extrapolative expectations and noisy trading [6]. On the other hand, long memory in asset prices can arise from alternative sources. Kaen and Rosenman [28] extend Heiner's [23] competence-difficulty (C-D) gap hypothesis of human behavior to explain possible long memory in asset prices. The C-D gap measures a spread between the investor's competence to make optimal decisions and the complexity of decision problems under uncertainty. When the C-D gap is wide, investors are likely to follow some rule-governed behavior, which can produce persistent price movements in the same direction. Kaen and Rosenman [28] argue that, due to the irregular arrival of new important information to the market, persistent price movements will at times reverse direction suddenly, thereby yielding nonperiodic price cycles. The Kaen-Rosenman analysis has often been used to explain the potential presence of long memory in many speculative markets, including those of foreign exchanges, stocks, and gold. Furthermore, models of metal price dynamics developed by Chan and Mountain [11] and Heal and Barrow [22] suggest that changes in gold prices are a function of the lagged values of gold prices and the interest rate, among others. A recent empirical study by Shea [42] reports that interest rates display long memory dynamics. If the Chan-Mountain and Heal-Barrow models are relevant, changes in gold prices are expected to show long memory dynamics as well, reflecting similar dynamics in the interest rate.

Recent studies by Fama and French [17], Lo and MacKinlay [33], and Poterba and Summers [40] report that stock returns display positive correlation over short horizons and negative correlation over long horizons. The results point to the possible presence of long cycles and potentially predictable components in long-horizon stock returns. Lo [32] illustrates that the reported negative correlation at long lags can be a symptom of long memory dynamics.

In this paper we investigate the long memory behavior of gold returns. Empirical evidence on the presence of long memory in gold returns has been presented by Booth et al. [9]. The study employs the classical rescaled range, or R/S analysis, first proposed by Hurst [27] and later refined by, e.g., Mandelbrot [35, 36] and Mandelbrot and Wallis [38]. Mandelbrot [35, 36] demonstrates the robustness of R/S analysis relative to other usual methods such as autocorrelation and variance ratio analyses in detecting long-term dependence. A problem with the classical R/S analysis is that the distribution of its test statistic is not well-defined, and the analysis can be sensitive to heterogeneities of the underlying data-generating process. As a result, reliable statistical inferences are hard to make. The problem of heterogeneously distributed processes is relevant, since gold prices have been found to display conditional heteroscedasticity (Akgiray et al. [3] and Frank and Stengos [18]). The finding of conditional heteroscedasticity is common among many financial prices (Bollerslev [8] and Hsieh [24, 25, 26]). Moreover, Aydogan and Booth [5] and Milonas et al. [39] discuss the sensitivity of R/S analysis to nonstationarity. The concern about stationarity is important, since the long memory phenomenon can be spuriously caused by shifting means in the data process (e.g., [7, 29]). The preciseness of the classical R/S analysis has also been called into question by Aydogan and Booth [5] for the problem of preasymptotic behavior. Further, gold returns appear to display short-term dependence (see Booth et al. [9] and Solt and Swanson [44]), which can bias the classical R/S test toward finding long memory too often.

This study reevaluates the finding of long memory in gold returns using a new modified R/S technique suggested by Lo [32]. Unlike the classical R/S procedure, the modified one has well-defined distributional properties and is robust to short-term dependence and conditional heteroscedasticity. The modified R/S procedure can therefore circumvent some of the drawbacks associated with the conventional one.

A brief review of the related literature on financial price behavior is provided in the second section. The modified R/S test is discussed in the third section. The fourth section describes the data, and the fifth section contains the test results. The sixth section reports further analysis of the results. The seventh section contains some concluding remarks.

Some Related Studies

Many studies have examined the distributional properties of asset returns over short horizons and identified the type of stochastic processes consistent with these properties (e.g., [1, 2, 30, 31, 43, 44, 45]). Analyses of stock returns, gold returns, and exchange rate changes generally report significant departures from normality; empirical return distributions are leptokurtic and fatter-tailed than the normal distribution. Different probability distributions have been explored to model the empirical return distributions, including the stable Paretian, scaled-*t*, and compound normal distributions. Some of the distributional analyses also report evidence of nonstationarity in the parameters of the return distributions (e.g., [43]). Akgiray and Booth [2] and Tucker [45] further show that changes in exchange rates and stock prices can well be described by mixed diffusion-jump models. All these models of distributions assume, however, that data observations represent independent realizations of some random variables. Such an assumption is not valid in the presence of temporal dependence in the market return data.

Analyses of nonlinear dependence in financial price series have enjoyed much attention in recent literature. The interest in nonlinear dynamics arises from the observation that the often wide fluctuations of financial prices cannot be adequately explained by linear models. Findings of leptokurtosis mentioned earlier may be a symptom of nonlinear dynamics such as ARCH (autoregressive conditional heteroscedastic) effects (Engle [16]). Scheinkman and LeBaron [41] note that ARCH processes can exhibit dependence similar to that of chaotic systems. Empirical evidence of chaotic dynamics or ARCH-type dependence has been reported for stock returns (Hsieh [26] and Scheinkman and LeBaron [41]), exchange rate changes (Hsieh [24, 25]), and gold and silver returns (Frank and Stengos [18]). To the extent that a long memory process generates nonperiodic cycles, long memory can be viewed as a specific form of nonlinear dependence. Mandelbrot [37] characterizes long memory processes as having "fractal dimensions." Lo [32] notes that some nonlinear system can exhibit the long memory property.

The above studies in general suggest that asset returns are characterized by nonnormality, ARCH effects, and possibly chaotic dynamics. Tests for long memory should therefore account for these elements. In this regard, the modified R/S test proposed by Lo [32] is attractive. The modified R/S test examines the null hypothesis of a short memory process against long memory alternatives. The test imposes little distributional structure on the data process. Specifically, short-term dependence, nonnormal innovations, and conditional heteroscedasticity are allowed for under the null hypothesis. Monte Carlo results reported by Cheung [13] support that the modified R/S test is robust to variance shifts and ARCH effects.

The Modified R/S Test for Long Memory

Let $\bar{x}$ be the sample mean of a given data series $\{x_t, t = 1, 2, \ldots, T\}$. The modified R/S statistic, denoted by Q_T, is given by the range of cumulative sums of deviations of the time series from its mean, rescaled by a consistent estimate of its standard deviation:

$$Q_T = R/s_T(q), \tag{1}$$

where R, the range of cumulative sums of deviations from the sample mean, is given by

$$R = \max_{1\leq i\leq T} \sum_{t=1}^{i} (x_t - \bar{x}) - \min_{1\leq j\leq T} \sum_{t=1}^{j} (x_t - \bar{x}), \tag{2}$$

and $s_T^2(q)$ is a heteroscedasticity and autocorrelation consistent variance estimator given by

$$s_T(q) = \left\{ \sum_{i=1}^{T} (x_i - \bar{x})^2/T + 2\sum_{j=1}^{q} \tau_j(q) \left(\sum_{i=j+1}^{T} (x_i - \bar{x})(x_{i-j} - \bar{x}) \right) \Big/ T \right\}^{1/2}, \tag{3}$$

with q being a truncation lag and $\tau_j(q) = 1 - j/(q + 1)$ for $q < T$. In the classical analysis $q = 0$ (e.g., [36]). For the optimal choice of q, Lo [32] applies Andrews's [4] data-dependent rule:

$$q = \mathrm{Int}[\xi_T],\ \xi_T = (3T/2)^{1/3} \{2\delta/(1 - \delta^2)\}^{2/3}, \tag{4}$$

where $\mathrm{Int}[\xi_T]$ denotes the integer part of ξ_T and δ is the first-order autocorrelation coefficient of the data. In addition, Andrews suggests an alternative weighting function given by

$$\tau_j(q) = 1 - |j/\xi_T|. \tag{5}$$

The numerator in equation (1) measures the memory in the series using cumulative sums of deviations from the mean. A long memory series will stay above or below its mean for a long period of time such that the range of the cumulative sums can become rather large. A major difference between the modified R/S statistic and the classical one lies in the normalization of the range measure. The denominator in equation (1) normalizes the range measure not only by the sample variance, which is considered in the classical R/S analysis, but also by a weighted sum of sample autocovariances for $q > 0$. The modification provides the robustness of the modified R/S analysis to both short-term dependence and heteroscedasticity. If $\{x_t\}$ displays short-term dependence, the estimator of the variance of the cumulative sums should include both the sample variance and the sample autocovariances of the individual terms.

The modified R/S analysis differs from the classical one in two other respects. First, in the modified R/S analysis the range of cumulative sums is based on deviations from a sample mean, whereas in the classical R/S analysis the range of cumulative sums is based on deviations from a sample trend. Second, the modified R/S test is based on R/S values computed using the entire series directly, while the classical R/S test is regression-based, which examines estimates of the Hurst [27] coefficient obtained from regressing R/S values of different subseries on their corresponding length. In contrast to the classical one, the modified R/S test statistic thus constructed has a well-defined distribution, useful for statistical inference. Mandelbrot [36] examines an R/S statistic similar to the modified R/S statistic applied in this paper, but without the adjustments for short-term dependence and conditional heteroscedasticity. Although Mandelbrot [36] shows the consistency of the classical R/S statistic, its distributional property is not derived. To get around the problem, the classical R/S analysis examines least squares estimates of the Hurst coefficient, which relates the R/S statistic with the series length.

The Q_T statistics can be operationally constructed in several steps. The return series $\{x_t\}$ of T observations is transformed as a series of deviations from mean $\{x_t - \bar{x}\}$. The cumulative sums of the $\{x_t - \bar{x}\}$ series is next calculated. The largest and the smallest elements of the cumulative sum series thus obtained are identified, and the range measure R is constructed using equation (2). To obtain the variance estimate, first choose the value of the lag parameter q. Then, use the series $\{x_t - \bar{x}\}$ to compute $s_T(q)$ according to equation (3). In the case where Andrews's lag selection rule is applied, the lag parameter is determined by equation (4) and the value of $s_T(q)$ is computed using equations (3) and (5). Under the short-memory null hypothesis, the statistical distribution of the standardized statistic, $Q_T\sqrt{T}$, has been derived by Lo [32].

Data and Some Preliminary Analysis

The data examined in this study are weekly spot prices in the London gold market during the post-Bretton Woods period. The entire sample, from the first week of July 1973 to the last week of December 1987, consists of 756 point-in-time observations. The gold price series is drawn from the *International Monetary Market Yearbook* and is based on the London afternoon fixing on Wednesday. When a data point fell on a holiday, the price quotation on the next business day was used. The data series is transformed into a weekly return series by taking first differences in the logarithms of the prices. Booth et al. [9] consider a different data set that covers the period from February 1969 to March 1980 and consists of daily returns computed from the Handy and Harman price quotations. For daily data, the observations are not uniformly spaced in the time scale (because the market is closed on Saturday and Sunday), and the so-called "weekend effect" may possibly exist and distort statistical tests. The use of weekly data in this paper can minimize this problem and still provides a chronologically (though not observationally) longer data series. In addition, little relevant data information is lost in using weekly instead of daily data, since we are interested in the low-frequency dynamics only. The use of a long data set is also desirable in that the long memory behavior, if it exists, can presumably take a long time span to manifest itself in the data.

Some preliminary data analysis of the gold return series is conducted, with particular attention paid to evidence concerning autocorrelation and conditional heteroscedasticity. The first- to tenth-order autocorrelations are computed, and they are given by 0.0227, 0.0162, 0.0950, 0.0385, 0.0422, −0.0166, −0.0218, 0.0463, −0.0457 and −0.0524. We can observe a significant autocorrelation coefficient at the third lag. The skewness and kurtosis of the sample distribution of gold returns are given respectively by 0.2678 and 4.8129, suggesting a much flatter tail than the normal distribution. Further analysis is carried out by fitting to the gold return data an autoregressive (AR(p)) model given by

$$x_t = c_0 + \sum_{j=1}^{p} c_p x_{t-j} + u_t. \tag{6}$$

The lag parameter p is determined using a model selection procedure based on the Schwarz information criterion. The squared residual series is tested for possible ARCH (autoregressive conditional heteroscedastic) effects using the standard Lagrange multiplier test [16]. Table 1 contains the estimation and test results, which indicate the presence of significant (third-order) autocorrelation and ARCH effects. The results are independent

TABLE 1

Short-Term Dependence and Conditional Heteroscedasticity

An AR(p) model is estimated for the gold return series x_t with and without a time trend. The lag parameter p of the model is selected using the standard Schwarz information criterion, with a maximum lag equal to 10 allowed. The regression residuals are checked for serial correlation and ARCH effects. Figures in parentheses are t-statistics, computed using standard errors obtained from White's [46] heteroscedasticity-consistent covariance matrix estimator. The distribution of the Ljung-Box statistic, LB(s), is approximately $\chi^2(s)$ under the null hypothesis of no serial correlation in the residual. The ARCH(r) statistic, obtained as TR^2 from regressing the squared residual on a constant and its lagged values at r lags, is distributed asymptotically as $\chi^2(r)$ under the null hypothesis of no ARCH effects. An asterisk (*) indicates significance at the 5 percent level.

Constant	Trend	x_{t-1}	x_{t-2}	x_{t-3}	x_{t-4}	LB(5)	LB(10)	ARCH(5)	ARCH(10)
0.2597	−0.0003	0.0167	0.0125	0.0932	0.0344	1.067	9.560	50.30*	64.26*
(0.9661)	(−0.4857)	(0.3097)	(0.2686)	(2.2312)*	(0.7479)				
0.1591		0.0170	0.0127	0.0935	0.0346	1.093	9.523	50.37*	64.42*
(1.2693)		(0.3146)	(0.2741)	(2.2362)*	(0.7532)				

of the inclusion of a linear trend in estimation, and the trend variable is not statistically significant. The finding of ARCH effects is consistent with those reported in [3] and [18]. The results call for the use of the modified R/S test for its robustness to short-term dependence and conditional heteroscedasticity.

Results of Long Memory Analysis

To check the sensitivity of test results to the sample period, the modified R/S test for long memory is performed on both the full sample series and overlapping subseries. The subseries are chosen according to forward-rolling and backward-rolling procedures. For the forward-rolling procedure, the test is first performed on data for the period from the first week of July 1973 through the last week of December 1976. The weekly data for the year of 1977 is then added, and the test for long memory is conducted on the new subseries. The process continues by updating the sample period by one year at a time until the end of the sample period is reached. The backward-rolling procedure starts with a subperiod from the first week of January 1984 to the last week of December 1987. The subseries is expanded by going back one year at a time until the beginning of the sample period is reached. These two recursive procedures may provide information about the stability of the statistical behavior of gold returns over time. In particular, the backward-rolling estimation can offer out-of-sample (post-1980 sample) tests of the statistical evidence of long memory reported by Booth et al. [9].

The results of the modified R/S test for forward-rolling and backward-rolling analyses are reported, respectively, in Tables 2 and 3. The column labeled "*A*" reports the estimates based on Andrews's [4] lag selection rule and weighting function. The lag selection rule generally suggests $q > 0$ be employed to construct the R/S statistic. This is consistent with the presence of short-term dependence and conditional heteroscedasticity, reported earlier in the preliminary data analysis. To check the sensitivity of the $Q_T/\sqrt{T}$ statistic to the lag length, the statistic is also computed using different values of q ($q = 0$, 1, and 3). As shown in Tables 2 and 3, the modified

TABLE 2

Results of the Modified R/S Test (Forward-Rolling)

This table provides the results of Lo's R/S test on the gold return data following a forward-rolling procedure. The test is first conducted on data for the period from the first week of July 1973 through the last week of December 1976. The weekly data for the year of 1977 is then added, and the test for long memory is performed on the new subseries. This process continues by updating the sample period by one year at a time until the end of the sample period is reached. T is the sample size. The column beneath A gives the modified R/S statistic based on Andrews's data-dependent rule (equation (4)) and weighting scheme (equation (5)). Critical values at 10 percent and 5 percent are respectively given by 1.620 and 1.747. Significance levels for the one-sided test for long memory are indicated by an asterisk (*) for 10 percent and by a double asterisk (**) for 5 percent.

Sample Period	T	$q = 0$	$q = 1$	$q = 3$	A	[A-Lag]
6/73–12/76	182	1.4566	1.4549	1.4422	1.4566	[Lag = 0]
6/73–12/77	234	1.4043	1.4028	1.3807	1.4043	[Lag = 0]
6/73–12/78	286	1.4510	1.4225	1.3829	1.4341	[Lag = 1]
6/73–12/79	338	1.7490**	1.7032*	1.6169	1.7075*	[Lag = 1]
6/73–12/80	390	1.7172**	1.6704*	1.5721	1.6711*	[Lag = 1]
6/73–12/81	443	1.9180**	1.8749**	1.7799**	1.8797**	[Lag = 1]
6/73–12/82	495	1.7514**	1.7245*	1.6449*	1.7350**	[Lag = 1]
6/73–12/83	547	1.8175**	1.7872**	1.7108*	1.7954**	[Lag = 1]
6/73–12/84	599	1.8886**	1.8592**	1.7790**	1.8677**	[Lag = 1]
6/73–12/85	651	1.8611**	1.8335**	1.7669**	1.8417**	[Lag = 1]
6/73–12/86	703	1.8049**	1.7798**	1.7155*	1.7880**	[Lag = 1]
6/73–12/87 [Full Sample]	755	1.7542**	1.7346*	1.6743*	1.7455*	[Lag = 1]

TABLE 3

Results of the Modified R/S Test (Backward-Rolling)

This table contains the results of Lo's R/S test on the gold return data following a backward-rolling procedure. The procedure starts with a subperiod from the first week of January 1984 to the last week of December 1987. The subseries is expanded by going back one year at a time until the beginning of the sample period is reached. T is the sample size. The column beneath A gives the modified R/S statistic based on Andrews's data-dependent rule (equation (4)) and weighting scheme (equation (5)). Critical values at 10 percent and 5 percent are respectively given by 1.620 and 1.747. Significance levels for the one-sided test for long memory are indicated by an asterisk (*) for 10 percent and by a double asterisk (**) for 5 percent.

Sample Period	T	$q = 0$	$q = 1$	$q = 3$	A	[A-Lag]
1/84–12/87	207	1.2098	1.2535	1.3149	1.2486	[Lag = 1]
1/83–12/87	259	1.5167	1.5307	1.5977	1.5167	[Lag = 0]
1/82–12/87	311	1.2028	1.2227	1.2388	1.2106	[Lag = 1]
1/81–12/87	364	1.0934	1.1174	1.1407	1.1108	[Lag = 1]
1/80–12/87	416	1.2131	1.2307	1.2640	1.2203	[Lag = 1]
1/79–12/87	468	1.8471**	1.8323**	1.7563**	1.8471**	[Lag = 0]
1/78–12/87	520	1.8861**	1.8585**	1.7807**	1.8699**	[Lag = 1]
1/77–12/87	572	1.9509**	1.9224**	1.8384**	1.9330**	[Lag = 1]
1/76–12/87	624	1.9701**	1.9328**	1.8551**	1.9372**	[Lag = 1]
1/75–12/87	677	2.0295**	1.9965**	1.9126**	2.0032**	[Lag = 1]
1/74–12/87	729	1.8092**	1.7886**	1.7119**	1.7989**	[Lag = 1]
6/73–12/87 [Full Sample]	755	1.7542**	1.7346*	1.6743*	1.7445*	[Lag = 1]

R/S test indicates significant evidence of long memory in gold returns when the entire sample is used in estimation. However, the statistical results from rolling subperiods apparently show instability over time, and the variations in the modified R/S test statistic display an interestingly consistent pattern over time. For both forward- and backward-rolling results, a prominent feature is that the $Q_T/\sqrt{T}$ statistics are all not significant at the standard levels of significance for subseries during either the 1973–78 or the 1980–87 period. However, as the data subperiod extends either forward or backward to include the year 1979, there are noticeable rises in the values of the statistics at all lags (by about 20 to 50 percent), and the $Q_T/\sqrt{T}$ statistics become generally significant for rolling subperiods thereafter. Note that, in contrast to the Booth et al. [9] result for the pre-1980 series, no significant evidence of long memory in gold returns for the post-1980 series can be found.

These noticeable rises in the values of the $Q_T/\sqrt{T}$ statistics as the 1979 data are included deserve a closer examination. An explanation for the finding may be that the modified R/S test has much lower power for small samples than for large samples. As a result, significant long memory can be detected for large samples and not for small samples. However, it is not evident that such consideration of differences in test power can adequately account for the sudden substantial increases in the values of the test statistics between two overlapping subperiods, which differ little in the sample size between them.

Another possible explanation is that the gold return series underwent significant structural changes due to some aberrant events in 1979. The concern about the stability of the data process is important, since the long memory phenomenon can be spuriously caused by structural changes (e.g, [7, 29]). If the structural changes were unusually drastic and were not realizations of the underlying process governing gold returns, the data points corresponding to the transition period of the structural changes can be viewed as extreme observations or outliers. The presence of such outliers can possibly create spurious long memory.

Further Discussion of the Results

As gold has always stood for the ultimate hedge against political instability (and inflation), movements in the gold price can be significantly influenced by political events. Late in 1979, a sequence of major political events, that one may consider unusual events, occurred and brought continual sharp rises in the gold price in the last two months of 1979. We look closely at this episode, which coincides with the political turmoil in the Middle East. In mid-November 1979, a surge of gold buying was spurred by concern about the unsettled Iranian crisis, worries over possible imposition of currency control following the U.S. freeze on Iranian assets, and the prospect of still higher oil prices. The combination of worries pushed investors to diversify their holdings of paper currencies into more tangible gold. Then the attack on the Grand Mosque in Mecca made Middle Eastern investors, who had vast holdings of Petrodollar, nervous of the risk on instability in Saudi Arabia. At the end of December 1979, these fears were compounded by the Soviet invasion of Afghanistan. The result was that the gold price exploded upward by more than 25 percent over this month only.

The Middle East crisis came also at the time the Hunt brothers attempted to corner the silver market. Beginning from October 1979, the ongoing heavy buying of the Hunts artifically drove up the silver price for several months, with little change in the market fundamentals. The rise in price was particularly dramatic in December 1979 and early January 1980, and the silver price peaked in mid-January 1980. Because of possible feedback interactions between the silver and gold markets [11, 34], the Hunts event would have a bullish influence on the gold price, thus magnifying the impact of the Middle East crisis on the gold market.

To the extent that the late-1979 crisis in the Middle East, coupled with the Hunts event, can drastically alter the data-generating process, the effects of the corresponding data points on the statistical significance of the modified R/S statistic should be taken out. Otherwise, misleading or incorrect statistical inference can occur. A strategy to deal with the problem is to examine how the test result is affected when those observations are excluded in estimation. Accordingly, the modified R/S test is performed on the gold return series for the full sample period, but omitting the four observations corresponding to December 1979. Such a strategy makes it possible to separate out the effects on test results of a small number of potential outliers from the rest of the data. At the same time, the strategy can minimize the possible role of differences in the test power in explaining the test results, since the full series and the series with omitted observations are of about the same length.

Table 4 contains the results of the modified R/S test with the potential outliers being omitted. When the four observations for December 1979 are omitted, the values of the modified R/S statistics fall considerably by about 11 percent or 0.2 in magnitude, making the statistics at all lags not significant at any usual level of significance. When four more observations for November 1979 are also discarded, given that the Middle East crisis along with the Hunts event began its impact on the gold market in mid-November 1979, the values of the statistics fall by another five percent. It thus appears that once the effects of the late-1979 episode are separated out from the gold data, there is little evidence of long memory in gold returns.

The question then is why just a few extreme observations can bias the R/S analysis toward finding spurious long memory. An explanation comes from the way that the R/S statistic is constructed. The R/S statistic, be it the classical or the modified one, is basically derived from a range measure of cumulative price movements. In general, the range is commonly known to be a simple but unsatisfactory measure of data fluctuations because of its great sensitivity to extreme observations. The range measure in our case is equal to the largest cumulative price movements minus the smallest cumulative price movements. Since the measure depends on the largest and smallest values only, sharp rises in the market price, even for a short period, can significantly push up the value of the R/S statistic and generate the appearance of long memory dynamics. It is this linkage that explains how the aberrant events in 1979 could be responsible for the long memory finding. In this regard,

TABLE 4

Results of the Modified R/S Test with Omitted Observations

This table reports the results of the modified R/S test on the full sample return series, but with the few observations corresponding to the major political events in the Middle East, along with the Hunts event, in late 1979 being omitted. Row (a) = the series with no observations omitted. Row (b) = the series with the four observations for December 1979 omitted. Row (c) = the series with the eight observations for November–December 1979 omitted. An asterisk (*) indicates significance at the 10 percent level. A double asterisk (**) indicates significance at the 5 percent level.

Sample Period		T	$q = 0$	$q = 1$	$q = 3$	A	[A-Lag]
6/73–12/87	(a)	755	1.7542**	1.7346*	1.6743*	1.7445*	[Lag = 1]
	(b)	751	1.5578	1.5550	1.5550	1.5578	[Lag = 0]
	(c)	747	1.5023	1.5008	1.4914	1.5023	[Lag = 0]

the rolling subsample results are instructive. The $Q_T/\sqrt{T}$ statistic is equal to about 1.22 for the 1980–87 period, but its values jump to about 1.85 when the sample period extends to include 1979. This represents an increase of about 50 percent, and it pushes the statistic up above the critical value of the R/S test.

The extreme observations were apparently generated by drastic structural changes associated with the anomalous events in 1979. An analysis based on dummy-variable regression indicated that the mean of the observations for the late-1979 period is significantly different from that of the rest of the sample period, pointing to the presence of mean nonstationarity. The result does not suggest that the nonstationarity is in mean only. Indeed, variance nonstationarity should be present as well. Nonetheless, the modified R/S test is robust to variance, though not mean, nonstationarity. Monte Carlo results reported by Cheung [13] show that the modified R/S test is sensitive to mean but not variance shifts. The results reflect the fact that the modified R/S test assumes a constant mean but allows for changing variances under the null hypothesis. Hence, if the long memory test picks up nonstationarity in the return process, it is likely to be mean nonstationarity and not variance nonstationarity, even though both types of nonstationarity exist.

The above analysis in general suggests that the long memory result reported in the previous section can be spurious. After adjusting for possible mean nonstationarity by dropping few observations, there is no longer any significant evidence of long memory in the gold return series. The distinction between mean nonstationarity and long memory should be clear analytically. A genuine long memory series is characterized by cycles of long periods and persistent dependence even for far apart observations. A series with a mean shift but no long memory, in contrast, exhibits no long cycles and no persistent dependence. Finally, the empirical failure to find long memory in gold returns does not completely deny its presence (see also the negative findings of long memory in stock returns reported by Aydogan and Booth [5] and Lo [32]). If long memory are in fact present in gold returns, new supportive evidence is apparently needed to confirm their empirical relevance.

Concluding Remarks

The R/S technique has often been used to study the long-term dependence in financial prices. In this paper, a new R/S test is employed to reexamine the long memory behavior in gold returns during the post-Bretton Woods period. Unlike the conventional R/S analysis, the new R/S analysis is robust to the short-term dependence and conditional heteroscedasticity that are both shown to exist in the gold return series. Although the test result for the full sample period (1973–87) seems to suggest the presence of long memory in gold returns, the recursive subsample results indicate substantial instability in the gold return process. Specifically, no significant evidence of long memory can be found for the subsample series corresponding to the years either before or after and not including 1979. An interpretation of the rolling sample results is that something drastic might have happened to the gold return process in 1979 that could be responsible for the finding of long memory. A closer examination of the finding is thus conducted. It is shown that when just a few observations corresponding to the major political events in the Middle East, along with the Hunts event, in late 1979 are omitted, we can no longer find significant evidence of long memory in gold returns. This suggests that the unusual events in 1979 may be responsible for the spurious finding of long memory dynamics in gold returns.

The results are suggestive in that the R/S test can be quite sensitive to extreme observations, which cause the test to spuriously find long memory. Such sensitivity of the R/S test reflects the fact that the R/S statistic is based on a range measure, which by construction is sensitive to extreme observations. Of course, the R/S technique can still be a potentially useful tool to detect long memory behavior in time series, though the present analysis provides a cautionary note on interpreting findings of long memory based on the R/S technique.

The long memory dependence examined in this paper represents a type of temporal dependence in the first moment of the time series data. Possible temporal dependence in the second moment and other nonlinear dependence can exist in gold returns, independent of whether long memory can be found in the gold data. For example, Akgiray et al. [3] and Frank and Stengos [18] report evidence of ARCH effects, a form of temporal dependence in the second moment, in both gold and silver returns. Their findings of ARCH-type dependence are confirmed in our analysis of the gold data. Frank and Stengos [18] further provide evidence of chaotic structures in addition to ARCH effects, suggesting the presence of more nonlinear dependence in gold returns. In contrast, Hsieh [25, 26] reports that nonlinear dependence in stock and foreign exchange returns can be adequately captured as ARCH-type dependence. Nonetheless, in view of the finding that gold returns are chaotic, the empirical results of our analysis should be interpreted carefully, since little is known about the effects of chaotic dynamics on tests for long memory. Future research work on the robustness of long memory tests to chaotic dynamics is warranted.

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