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Long-Term Dependence in the Foreign Exchange Markets: International Evidence*

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This article examines seven Pacific-rim foreign exchange markets for evidence of long-term dependence using two different techniques: the modified R/S analysis and the GPH test. These empirical tests are conducted with weekly and monthly data during the post-Bretton Woods period from January 1974 to December 2004. Empirical results indicate that there is little evidence of long-term dependence in the nominal exchange rate returns, which is supportive of the efficient market hypothesis (EMH), but it is inconsistent with previous literature, which found significant evidence of long-term dependence in major foreign exchange markets. Therefore, the results of long-term dependence are sporadic and unstable in exchange rate markets.

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1. INTRODUCTION

Exchange rate dynamics have significant economic implications for both theoretical and empirical levels. For distributed (i.i.d.). However, a non-linear fashion states that each market participant has heterogeneous trading horizons. For example, when the information arrives at the markets, some people react to the information immediately, while others delay their reactions until a trend is well established and hence their actions are accumulated and suddenly erupt in the markets (Skjeltorp, 2000). Therefore, such non-linear behaviour gives rise to a question about the assumption of random walk hypothesis.

Additionally, the presence of long-term dependence indicates evidence of a predictable component for future returns. Predictability would question the validity of the weak-form efficiency of exchange rate markets because exchange rate returns having long-term dependence would allow market participants to anticipate future price movement and consistently earn abnormal returns. Thus, the presence or absence of long-term dependence may test the efficient market hypothesis (EMH), which postulates that all relevant information is fully reflected into prices.

Much literature has been dedicated to examine long-term dependence in exchange rate dynamics since the breakdown of the Bretton Wood system in 1973. However, existing studies on long-term dependence of exchange rates remain with inconclusive results. On the one hand, Booth *et al*. (1982) initially examine three major daily exchange rates using a classical rescaled range (R/S) analysis. They find significant evidence of positive long-term dependence during the flexible exchange rate regime and negative long-term dependence during the fixed exchange rate regime. Cheung (1993) and Pan *et al*. (1996) find convincing evidence of long-term dependence in five major weekly nominal exchange rates. They provide evidence of long-term dependence in weekly nominal exchange rates. These findings are inconsistent with the EMH. On the other hand, Barkoulas *et al*. (2003) find little evidence of long-term dependence in weekly nominal exchange rates for eighteen industrial countries. They conclude that exchange rates are best characterized as a short-term dependence process rather than a long-term dependence process. As a result, it is required to re-examine the presence or absence of long-term dependence in the exchange rate return dynamics.

The primary aim of this study is to re-examine long-term dependence in the nominal exchange rate returns for seven Pacific-rim countries, namely, Australia, Japan, New Zealand, Singapore, South Korea, Taiwan and Thailand. The focus on the Pacific-rim exchange rate markets is appropriate for two reasons. First, most existing studies has considered major developed exchange rate markets, while only a few papers have studied the Pacific-rim exchange rate markets due to different currency management regimes. However, the Pacific-rim exchange markets have been liberalized since the October 1997 Asian currency crisis. When a Russian default in its national debt drove the domestic currency market into turmoil, some of the Pacific-rim exchange markets faced the collapse of markets. The Asian currency crisis had an impact on investors to experience severe losses and some negative yields in their market portfolios. These markets are stated to recover after several months of negative records and heroic efforts by International Institution (IMF) and National Governments to re-establish reliability in exchange rate markets.[1] Thus, this study based on the Pacific-rim exchange rate markets may provide different implication on exchange rate dynamics in contrast to major exchange markets.

Second, the same region markets allow a comparison of the degree of market efficiency depending on the absence or presence of long-term dependence. For example, both Australian and Japanese exchange rate markets are relatively considered as an efficient market, while other Pacific-rim exchange rate markets are classified as inefficient due to the inability of information transmission. Thus, the presence of long-term dependence might suggest the criteria of market efficiency in the Pacific-rim exchange markets.

The rest of this study is organised as follows. The next section discusses two research methodologies, such as the modified rescaled range (R/S) analysis and fractionally differencing test. In particular, both techniques examine the null hypothesis of short-term dependence against long-term dependence as the alternative hypothesis. The third section details the data and presents the results. The final section provides brief conclusions.

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[1] See Joyce (2000) for more details.

2. MODEL FRAMEWORK

2.1. Modified R/S Analysis

The classical R/S analysis originally developed by Hurst (1951) is useful to detect long-term dependence in highly non-Gaussian distribution having heavy tail with infinite variance (Willinger *et al*., 1999). However, the most well-known weakness with classical R/S analysis is that it is sensitive to short-term dependence which can bias the estimate of the Hurst exponent. The effect of short-term dependence upwardly biases the empirical estimates of the Hurst exponent and then it is accumulated to accept that there is a long-term dependence process in a time series. To overcome this problem, Lo (1991) attempted to modify classical R/S analysis to seek to incorporate a generalised model of short-term dependence and proposed a modified R/S analysis which examines the null hypothesis of short-term dependence.

Let $\overline{X}$ represent the sample mean of exchange rate return series $\{X_1, X_2, \ldots, X_N\}$. The modified R/S statistic, denoted as Q_N, is given by the range of partial sums of deviations from the mean rescaled by its standard deviation.

$$Q_n = \frac{1}{(\sigma_n(q))}\left\{\max_{1\le k\le N}\sum_{n=1}^{k}\left(X_n - \overline{X}\right) - \min_{1\le k\le N}\sum_{n=1}^{k}\left(X_n - \overline{X}\right)\right\}, \qquad (1)$$

where

$$\begin{aligned}\sigma_n^2(q) &= \frac{1}{n}\sum_{n=1}^{n}\left(X_n - \bar{X}\right)^2 + \frac{2}{n}\sum_{n=1}^{q} w_n(q)\left\{\sum_{t=n+1}^{n}\left(X_t - \bar{X}\right)\left(X_{t-n} - \bar{X}\right)\right\} \\ &= \sigma_x^2 + 2\sum_{n=1}^{q} w_n(q)\gamma_n,\end{aligned} \qquad (2)$$

and σ_x^2 and γ_n represent the sample variance and autocovariances respectively. The weights $w_n(q)$ are given by

Table 1 Critical value of the distribution $F_V(\upsilon)$

$P(V<\upsilon)$	.005	.025	.050	.100	.200	.300	.400	.500
υ	0.721	0.809	0.861	0.927	1.018	1.090	1.157	1.223
$P(V<\upsilon)$	0.543	0.600	.700	.800	.900	.950	.975	.995
υ	$\sqrt{\frac{\pi}{2}}$	1.294	1.374	1.473	1.620	1.747	1.862	2.098

Note: The null hypothesis of short-term dependence is examined at the 95% level of confidence using the interval [0.809, 1,862] in table 1. The null hypothesis is H_0 = {short-term dependence, i.e., $H=0.5$ } against the alternative H_1 = {there is long-term dependence. i.e., $1/2<H<1$ }.

$$w_n(q)=1-\frac{n}{q+1}, \quad q<N \,. \tag{3}$$

Under the null hypothesis of short memory, Lo (1991) defined the modified R/S statistics, $V_n(q)$, by setting

$$V_n(q)=\frac{1}{\sqrt{n}}Q_n \overset{a}{\sim} V, \tag{4}$$

in which the distribution function F_V of V is given by

$$F_V(\upsilon)=1+2\sum_{k=1}^{\infty}\left(1-4k^2\upsilon^2\right)\exp^{\left(-2(k\upsilon)^2\right)}. \tag{5}$$

The critical values of significant levels are computed from equation (5) and tabulated for the purpose of the hypothesis test under the null hypothesis of short-term dependence against long-term dependence alternatives. Table 1 is reproduced from Lo (1991).

The only difference between the classical and modified R/S analysis is that 'the denominator in equation (1) normalises the range measure not only by the sample variance $(q = 0)$, as considered in the classical R/S analysis, but also by weighted sum of sample autocovariances for $q > 0$' (Cheung and Lai, 1995, p. 601).

2.2. Fractional Differencing Test

An alternative method of testing long-term dependence used in this study is that a fractionally integrated process is based on a fractionally differencing parameter d. The model of an ARFIMA process has been widely studied in literature (Granger and Joyeux, 1980; Hosking, 1981), and is described as

$$B(L)(1-L)^d y_t = D(L)\varepsilon_t, \quad \varepsilon_t \sim i.i.d.(0,\ \sigma_u^2), \tag{6}$$

where L is the backward-shift operator; $B(L) = 1 - \beta_1 L - \ldots - \beta_p L^p$ and $D(L) = 1 + \delta_1 L + \ldots + \delta q L^q$ are polynomials with stable roots; ε_t is white noise; d is the fractional order parameter and $(1-L)^d$ is a fractional differencing operator defined as

$$(1-L)^d = \sum_{r=0}^{\infty} \frac{\Gamma(r-d)L^r}{\Gamma(-d)\Gamma(r+1)}. \tag{7}$$

$\Gamma(\cdot)$ denotes the gamma function. The long-term dependence parameter d is allowed to take on any real value. The fractionally integrated process is stationary and invertible with $-0.5 < d < 0.5$. More precisely, the autocorrelation function of ARFIMA process slowly decays at a hyperbolic rate to zero rather than the exponential decay of the ARMA process (Hosking, 1981). While $|d| > 0.5$, this process is non stationary as it has infinite variance. For $0 < d < 0.5$, the ARFIMA process displays persistence. In contrast, the fractionally integrated process with $-0.5 < d < 0$ has anti-persistence.

To compute an estimate of the parameter d, let $I(\xi)$ be the periodogram of X at angular frequency, ξ defined by

$$I(\xi) = \frac{1}{2\pi T}\left|\sum_{t=1}^{T} e^{it\xi}(X_t - \overline{X})\right|^2 . \tag{8}$$

Then the least squares regression is defined by

$$\ln\{I(\xi_\lambda)\} = \beta_0 + \beta_1 \ln\left\{4\sin^2\left(\frac{\xi\lambda}{2}\right)\right\} + \eta_\lambda, \quad \lambda=1, \ldots, \nu, \tag{9}$$

where $\xi_\lambda = \frac{2\pi\lambda}{T}(\lambda = 0, \ldots, T-1)$ denotes the Fourier frequencies of the sample, T is the number of observations, and $\nu = g(T) < T$ is the number of low frequency peridogram ordinates included in the spectral regression. Here, β_0 is a constant, and η_λ is independently, identically distributed. Thus, the slope coefficient d is provided by the OLS estimator of $-\beta_1$. Theoretically, the variance of η_λ is equal to $\pi^2/6$ and $g(T)$ is commonly expressed as $T^{0.5}$. Geweke and Porter-Hudak (1983) suggest that the hypothesis test with regard to the value of d can be based on the *t*-statistics of the regression coefficient.

Since Geweke and Porter-Hudak (1983), several authors including Sowell (1992) have modified the GPH estimator due to its poor finite sample size. Agiakloglou *et al*. (1992) also argue that when either the autoregressive or moving average possesses non-zero value of parameters in the ARFIMA model, the periodiogram regression estimator of d presents bias and inefficiency. Nevertheless, the GPH test continues to be widely used in applied work (Cheung and Lai, 1993; Barkoulas *et al*., 1997) because of its computational simplicity, i.e. without the autoregressive and moving average parameters.

3. DATA AND EMPIRICAL RESULUTS

3.1. Preliminary Analysis of the Data

The data sets consist of US dollar nominal exchange rates for seven Pacific-rim countries: Australian dollar (AUD/USD), Japanese Yen (JPY/USD), New Zealand dollar (NZD/USD), Singapore dollar (SGD/USD), South Korean won (KRW/USD), Taiwan dollar (TWD/USD), and Thai baht (THB/USD). All sample exchange rates are obtained from the database of the Federal Reserve Bank of St. Louis for a selection of countries. The frequencies of observation are examined in two groups: weekly and monthly data. In order to avoid to a data aggregation issue in the studies of long-term dependence, this study constructs sample data as following. First, weekly exchange rate series represent Friday noon-time bid prices in New York City for cable transfers payable in foreign currencies. When Friday prices are not available, Thursday prices are used. Second, monthly exchange rate data consist of the last trading day of each month. Both weekly and monthly nominal exchange rate series provide more reliable results for testing the nature of long-term dependence rather than daily nominal ones because daily basis data generally exhibit significant autoregressive tendencies. Thus, these tendencies can bias the estimates of long-term dependence tests.

The sample period covers the post-Bretton Woods period, beginning in January 1974 through December 2004, 30 years of data. For some countries, data is only available for a sub-sample. This study considers a longer, broader recent sample than previous studies. All weekly and monthly price series are converted into the first logarithmic differences (returns) of the exchange rate series,

$$X_t = \ln\left(P_t \big/ P_{t-1} \right), \tag{10}$$

where X_t is the returns for foreign currency at time t, and P_t is the current price and P_{t-1} is the previous day's price. Figure 1 illustrates the weekly prices and returns of all sample exchange rates. Since October 1997, more large volatility has been observed and volatility tends to persist for a prolonged period.

Table 2 presents the preliminary analysis for both weekly and monthly nominal exchange rate returns. In particular, the skewness and kurtosis of sample returns are computed. Skewness measures the extent to which a distribution is not symmetric about its mean value and kurtosis measures how fat the tails of the distribution are. For a normal distribution, skewness and kurtosis coefficient are zero and 3, respectively.

As shown in table 2, both the weekly and monthly nominal exchange rate returns display a similar pattern of results. In the case of skewness, the distributions of the weekly nominal returns for Japan and New Zealand are negatively skewed, others are positively skewed. The distributions of the monthly nominal returns for Japan, New Zealand, and Singapore are negatively skewed, others are positively skewed. In the case of kurtosis, all returns are highly greater than normal one. The statistics of Jarque-Bera test also confirm that the null hypothesis of normality should be rejected at the 5% significant level. Such excess kurtosis and skewness are common characteristics in return distribution, which appear to be leptokurtosis. Although non-normality is inconsistent with the assumption of random walk hypothesis in exchange rate returns, it can be not related with the long memory property, but due to exogenous shocks, such as the central bank intervention or monetary policy, which lead to market structural breaks in the foreign exchange markets.

In addition, the Ljung-Box test statistics are to check for serial correlation in both weekly and monthly nominal returns. Under the null hypothesis of no serial correlation, the $Q(5)$ and $Q(10)$ statistics are distributed asymptotically as a x^2 distribution (chi-square) with 5 and 10 degrees of freedoms respectively. According to the $Q(5)$ and $Q(10)$ statistics, there is significant evidence of serial correlation for five (Japan, Singapore, South Korea, Taiwan and Thailand) weekly nominal returns, while all monthly

Figure 1 Graphs of the sample exchange rate series

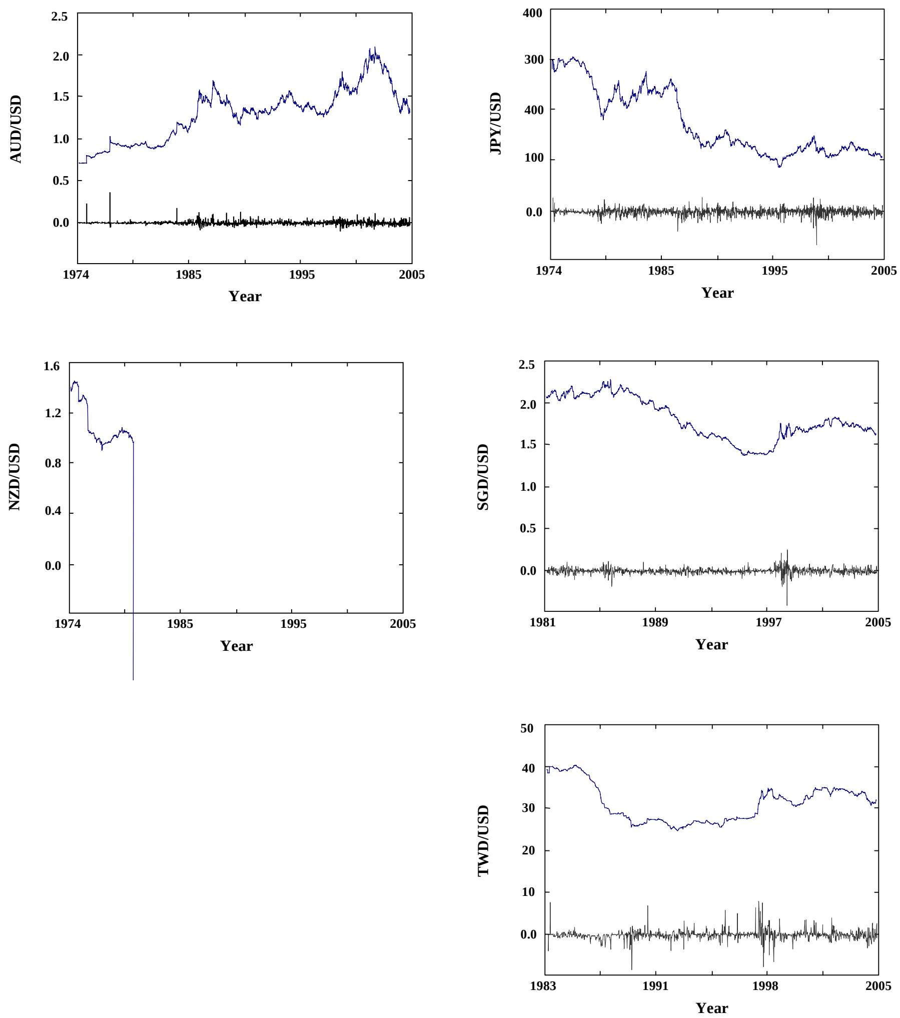

Table 2 Descriptive Statistics for All Nominal Exchange Rate Returns

Country	Mean	Std. Dev.	Skew	Kurt	J-B	$Q(5)$	$Q(10)$
(a) Weekly nominal exchange rate returns							
Australia	0.0004	0.014	3.20	39.54	92732**	6.02	7.77
Japan	–0.0006	0.015	–0.91	10.50	4009**	13.89**	17.62
New Zealand	–0.0004	0.015	–3.35	42.05	105774**	5.57	6.79
Singapore	–0.0002	0.007	0.95	22.27	19551**	18.56**	31.03**
South Korea	0.0003	0.015	8.66	214.7	2325989**	62.81**	205.96**
Taiwan	–0.0002	0.006	0.71	17.42	9856**	71.71**	90.54**
Thailand	0.0006	0.012	3.50	56.31	153937**	38.98**	52.96**
(b) Monthly nominal exchange rate returns							
Australia	0.0018	0.024	1.12	7.08	335**	32.20**	41.13**
Japan	–0.0028	0.029	–0.54	3.87	29**	48.04**	60.26**
New Zealand	–0.0018	0.026	–0.85	7.90	415**	48.22**	66.88**
Singapore	–0.0008	0.013	–0.06	6.31	130**	31.38**	38.56**
South Korea	0.0015	0.029	7.57	97.84	109148**	75.29**	86.25**
Taiwan	–0.0008	0.013	0.42	7.60	231**	55.06**	82.80**
Thailand	0.0022	0.027	2.96	28.52	8208**	23.17**	37.09**

Notes: This table describes several descriptive statistics, including mean, standard deviation, skewness, kurtosis, Jarque-Bera (J. B.) test and Ljung-Box test for exchange rate returns. Under the null hypothesis for normality, the Jarque-Bera statistic is distributed as x^2 (2). In the columns for $Q(5)$ and $Q(10)$, the Ljung-Box statistics for returns are reported up to 10^{th} order of serial correlation. Critical values are 11.1 and 18.3 for n =5 and 10, respectively, at the 5% significance level. ** indicates statistical significance at the 5% level.

nominal returns show strong evidence of serial correlation. Thus, such a serial correlation indicates significant short-tem dependence between exchange rate returns.

In order to check for stationarity, all exchange rate returns are subjected to three unit root tests, namely the ADF (augmented-Dickey-Fuller), PP (Phillips-Person) and KPSS (Kwiatkowski, Phillips, Schmidt and Shin). These tests differ in the null hypothesis: the null hypothesis of the ADF and PP tests is that a time series contains a unit root, $I(1)$ process, while the KPSS test has the null hypothesis of stationarity, $I(0)$ process. The latter serves as a complement to the ADF and PP tests. Comparing the results of unit root tests under the different null hypothesis is characterised by four possible outcomes (Barkoulas *et al.*, 1997): (1) when the null hypothesis of the ADF and PP tests is rejected and that of the KPSS test is not rejected, a time series is stationary. (2) Conversely, failure to reject a unit root by the ADF and PP tests and rejection stationary by the KPSS test supports that a time series is non-stationary. (3) Failure to reject a unit root and stationary null hypotheses shows that the series are not sufficiently informative with respect to the low-frequency properties. (4) Rejection of null hypotheses indicates that a series is not well represented as either $I(0)$ or $I(1)$, which indicates that the series appears to be a long-term dependence process.

Table 3 presents the empirical results of stationary tests for all nominal exchange rate returns. On the one hand, the ADF and PP tests have a unit root under the null hypothesis. The great negative values of the ADF and PP statistics, computing the statistics with and without trend, indicate that the non-stationarity under the null hypothesis is rejected at the 5% significance level. Thus, all nominal exchange rate returns are stationary. On the other hand, the results of the KPSS test, calculating the statistics with μ and τ respectively, are reported in table 3. The null hypothesis of stationarity is rejected for only weekly and monthly Taiwan nominal exchange rate returns at the 5% significance level.

Therefore, the results of stationary tests for only weekly and monthly Taiwan nominal exchange rate returns correspond to the fourth case, implying that they are neither $I(0)$ processes nor $I(1)$ processes. They might be a half way of both $I(0)$ processes and $I(1)$ processes, associated with long-term dependence properties.

Table 3 The Results of Stationary Test for All Nominal Exchange Rate Returns

Country	ADF		PP		KPSS	
	Without trend	With trend	Without trend	With trend	η_μ	η_τ
(a) Weekly nominal exchange rate returns						
Australia	–17.34**	–17.43**	–41.36**	–41.42**	0.303	0.056
Japan	–16.02**	–16.02**	–40.13**	–40.12**	0.089	0.070
New Zealand	–17.03**	–17.19**	–40.91**	–41.02**	0.567	0.072
Singapore	–14.86**	–14.86**	–37.58**	–37.57**	0.178	0.146
South Korea	–13.56**	–13.56**	–36.57**	–36.56**	0.104	0.106
Taiwan	–12.65**	–12.76**	–28.86**	–28.94**	1.103**	0.332**
Thailand	–15.01**	–15.00**	–32.29**	–32.28**	0.087	0.086
(b) Monthly nominal exchange rate returns						
Australia	–8.46**	–8.67**	–14.18**	–14.26**	0.412	0.077
Japan	–8.46**	–8.46**	–13.39**	–13.38**	0.128	0.080
New Zealand	–7.48**	–7.83**	–13.17*	–13.32**	0.781**	0.105
Singapore	–7.92**	–7.94**	–12.29**	–12.27**	0.242	0.203**
South Korea	–6.96**	–6.95**	–9.27**	–9.25**	0.113	0.117
Taiwan	–5.06**	–5.24**	–10.55**	–10.64**	1.022**	0.277**
Thailand	-6.29**	-6.28**	-12.90**	-12.88**	0.084	0.088

Notes: 1) The ADF and PP critical values without trend: –2.86 at the 5% significance level, the ADF and PP critical values with trend: –3.41 at 5% significance level. All of the estimated statistics above are smaller than the critical value, indicating that the weekly and monthly nominal exchange rate returns are stationary.

2) KPSS critical values are: (a) η_μ is 0.574 at the 5% significance level; (b) η_τ is 0.176 at the 5% significance levels. ** indicates significance at the 5% level.

3.2. EMPIRICAL RESULTS

3.2.1. Empirical results of the modified R/S analysis

The modified R/S analysis is performed on both weekly and monthly nominal exchange rate returns, and the results are reported in table 4. That table displays the classical R/S statistic with $q = 0$ and the modified R/S statistic with the optimal truncation lag for each nominal exchange rate returns (q). The classical R/S statistics are included for a comparative purpose.

Looking at the results from the classical R/S analysis, there is significant evidence of long-term dependence in only one weekly Taiwan nominal returns as well as in two monthly New Zealand and Taiwan nominal returns, implying that both exchange markets are relatively inefficient in the Pacific-rim region. However, the results from the modified R/S analysis can not

Table 4 Results of Modified R/S Analysis for All Nominal Exchange Rate Returns

Country	Weekly nominal returns			Monthly nominal returns		
	Classical R/S	Modified R/S	*q*-lag selected	Classical R/S	Modified R/S	*q*-lag selected
Australia	1.193	1.174	8	1.363	1.172	5
Japan	1.359	1.231	8	1.472	1.140	5
New Zealand	1.646	1.565	8	1.882**	1.448	5
Singapore	1.586	1.522	7	1.748	1.570	5
South Korea	1.632	1.381	7	1.609	1.276	5
Taiwan	2.328**	1.772	7	2.130**	1.495	5
Thailand	1.836	1.499	7	1.656	1.366	5

Note: ** indicates significance at the 5% level.

which allows several choices of low-frequency ordinates. These choices vary with the sample size T and are established in terms of $n = T^{\alpha}$ with α = {0.5, 0.525, 0.55, 0.575, and 0.6}. Table 5 shows the d estimates corresponding to $d(0.50)$, $d(0.525)$, $d(0.55)$, $d(0.575)$ and $d(0.60)$ when sample size $n = T^{0.5}$, $n = T^{0.525}$, $n = T^{0.55}$, $n = T^{0.575}$ and $n = T^{0.6}$ respectively. The estimates of long-term dependence parameter d are reported together with their t-statistics.

Additionally, to ensure for the statistical significance of the d estimates, the null hypothesis $(H_0 : d = 0)$ and the alternative $(H_0 : d \neq 0)$ are performed. As shown in table 5, the estimates d for weekly and monthly nominal returns have a similar pattern. Significant evidence of long-term dependence can be found in only a case of Taiwan returns. The Taiwan market is relatively inefficient in contrast to other Pacific-rim markets. The majority of exchange rate returns can not reject the null hypothesis of short-term dependence, indicating that exchange rate dynamics are random walk.

This finding is advocated by Barkoulas *et al*. (2003) who find little evidence of long-term dependence in eighteen currency returns.

In comparison with the earlier results from the modified R/S analysis, the results of the GPH test provide slightly more favourable evidence for long-term dependence in the weekly and monthly nominal exchange rate returns. Nevertheless, both results suggest that exchange rate dynamics of the Pacific-rim region markets are short-term dependence processes or martingale processes.

Theses findings are inconsistent with previous literature, which found significant evidence of long-term dependence in the major exchange rate markets (Booth *et al*., 1982; Cheung, 1993; Mulligan, 2000). There are two possible explanations for different agreements with previous literature. First, this study uses a longer, broader and more recent sample to provide more reliable statistical inferences. Second, the Pacific-rim exchange rate markets have recently been liberalized since Asian currency crisis (Wang, 2001). Therefore, the studies on the presence or absence of long-term dependence in exchange rate markets have been inclusive.

4. CONCULSION

This study has re-examined long-term dependence in the weekly and monthly nominal exchange rate returns for seven Pacific-rim countries during the post-Bretton Wood period, using Lo's modified R/S analysis and the GPH test. For conventional tests for all the nominal returns, they are not random or independent but correlated with others. Further, significant short-term dependence is presented, making it difficult to describe the nature of long-term dependence in nominal exchange rate returns. Hence, the modified R/S analysis and the GPH test are used to minimise short-term dependence in this study.

Using conventional stationary tests and the classical R/S analysis, although some evidence of long-term dependence is found in nominal exchange rate

Table 5 Estimates of the Fractional Differencing Parameter (d)

Country	$d(0.50)$	$d(0.525)$	$d(0.55)$	$d(0.575)$	$d(0.60)$
(a) Weekly nominal exchange rate returns					
Australia	0.039 (0.200)	–0.012 (–0.070)	–0.020 (–0.130)	–0.016 (–0.110)	0.047 (0.370)
Japan	0.192 (0.980)	0.189 (1.130)	0.181 (1.190)	0.072 (0.530)	0.030 (0.250)
New Zealand	0.112 (1.040)	0.009 (0.090)	0.049 (0.550)	0.037 (0.460)	0.057 (0.820)
Singapore	0.005 (0.050)	–0.013 (–0.130)	–0.038 (–0.430)	–0.043 (–0.550)	0.027 (0.350)
South Korea	–0.086 (–0.300)	–0.110 (–1.790)	–0.043 (–0.760)	–0.042 (–0.840)	–0.025 (–0.570)
Taiwan	0.347** (2.830)	0.257** (2.130)	0.291** (2.740)	0.238** (2.580)	0.278** (3.150)
Thailand	0.062 (0.550)	0.097 (0.900)	0.032 (–0.430)	–0.033 (–0.430)	–0.033 (–0.500)
(b) Monthly nominal exchange rate returns					
Australia	0.032 (0.270)	–0.096 (–0.870)	–0.097 (–1.070)	–0.105 (–1.340)	–0.066 (–0.990)
Japan	–0.021 (–0.200)	0.018 (0.170)	0.056 (0.620)	0.108 (1.290)	0.101 (1.310)
New Zealand	0.105 (0.440)	0.161 (0.780)	0.122 (0.680)	0.115 (0.780)	0.100 (0.760)
Singapore	0.275 (1.770)	0.218 (1.670)	0.168 (1.440)	0.079 (0.720)	0.106 (0.740)
South Korea	–0.014 (–0.100)	–0.025 (–0.100)	0.005 (0.060)	–0.022 (–0.250)	–0.024 (–0.300)
Taiwan	0.281 (1.500)	0.248 (1.650)	0.336** (2.510)	0.365** (3.140)	0.405** (3.910)
Thailand	–0.187 (–1.580)	–0.166 (–1.710)	–0.104 (–1.150)	–0.068 (–0.790)	–0.039 (–0.470)

Note: $d(0.525)$, $d(0.55)$, $d(0.575)$ and $d(0.60)$ give the d estimates corresponding to the GPH spectral regression of sample $v = T^{0.50}$, $T^{0.525}$, $T^{0.55}$, $T^{0.575}$ and $T^{0.60}$ respectively. The *t*-statistics are given in brackets. ** indicates rejection of the null of the two-sided test (d=0) at the 5% significance level.

returns, it is not convincing. Likewise the results of conventional techniques, the results from the modified R/S statistics can not reject the null hypothesis of short-term dependence in all weekly and monthly nominal returns. In addition to the modified R/S statistics, the results from the GPH test suggest that there is no evidence of long-term dependence in all exchange rate returns, except for a Taiwan case. This indicates that exchange rate returns are a short-term dependence process or random walk, corresponding to the assumption of the EMH. Overall, exchange rate dynamics of the Pacific-rim exchange rate markets have become efficient due to market liberalization.

REFERENCES

Agiaklogou, C., P. Newbold, and M. Wohar, "Bias in an Estimator of the Fractional Difference Parameter," *Journal of Time Series Analysis*, 14, 1992, pp. 235-246.

Baillie, R. T. and T. Bollerslev, "Common Stochastic Trend in a System of Exchange rates," *Journal of Finance*, 44, 1989, pp. 167-181.

Barkoulas, J., C. Baum, M. Caglayan, and A. Chakraborty, "Persistent dependence in foreign exchange rates? A reexamination," *global financial markets*: Issues and policies, Westport, CT: Greenwood Press, 2003.

Barkoulas, J., W. C. Labys, and J. Onochie, "Fractional Dynamics in International Commodity Prices," *Journal of Futures Markets*, 17, 1997, pp. 161-189.

Booth, G. G., F. R. Kaen, and P. E. Koveos, "R/S Analysis of Foreign Exchange Rates Under Two International Monetary Regimes," *Journal of Monetary Economics*, 17, 1982, pp. 407-415.

Cheung, Y. W., "Long Memory in Foreign-Exchange Rates," *Journal of Business & Economic Statistics*, 11, 1993, pp. 93-101.

Cheung, Y. W. and K. S. Lai, "A Search for Long Memory in International Stock Market Returns," *Journal of International Money and Finance*, 14, 1995, pp. 597-615.

Geweke, J. and S. Porter-Hudak, "The Estimation and Application of Long Memory Time Series Models," *Journal of Time Series Analysis*, 4, 1983, pp. 221-238.

Granger, C. W. J. and R. Joyeux, "An Introduction to Long Memory Time Series Models and Fractional Differencing," *Journal of Time Series Analysis*, 1, 1980, pp. 5-39.

Hakkio, C. S., "Does the Exchange Rates Follow a Random Walk? A Monte Carlo Study of Four Tests for a Random Walk," *Journal of International Money and Finance*, 5, 1986, pp. 221-229.

Hosking, J. R. M., "Fractional Differencing," *Biometrika*, 68, 1981, pp. 165-176.

Hurst, H. E., "Long-Term Storage Capacity of Reservoirs," *Transactions of the American Society of Civil Engineers*, 116, 1951, pp. 770-799.

Joyce, J. P., "The Asian Crisis and the IMF: New Problems, Old Solutions?," *The Journal of the Korean Economy*, 1, 2000, pp. 109-124.

Lo, A. W., "Long-Term Memory in Stock Market Prices," *Econometrica*, 59, 1991, pp. 1279-1314.

Mulligan, R. F. and G. A. Lombardo, "A Fractal Analysis of Foreign Exchange Markets," *International Advances in Economic Research*, 6, 2000, pp. 33-50.

Pan, M. S., L. Y. Angela, and H. Bastin, "An Examination of the Short-Term and Long-Term Behavior of Foreign Exchange Rates," *Financial Review*, 31, 1996, pp. 603-622.

Skjeltorp, J. A., "Scaling in the Norwegian Stock Market," *Physica A*, 283, 2000, pp. 486-528.

Sowell, F., "Maximum Likelihood Estimation of Stationary Univariate Fractionally Integrated Time Series Models," *Journal of Econometrics*, 53, 1992, pp. 165-188.

Wang, Y. J., "Does the Sequencing Really Matter? : The Korean Experience in the Capital Market Liberalization," *The Journal of the Korean Economy*, 2, 2001, pp. 35-67.

Willinger, W., M. S. Taqqu, and V. Teverovsky, "Stock Market Prices and Long-Range Dependence," *Finance and Stochastics*, 3, 1999, pp. 1-13.