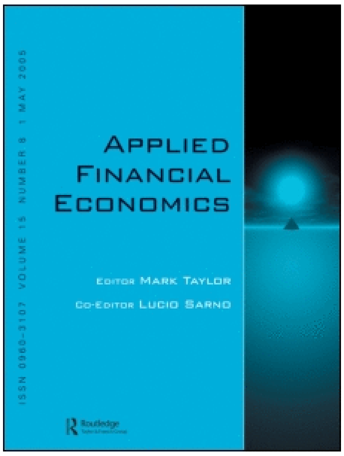

Applied Financial Economics
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713684415

A re-examination of variance-ratio test of random walks in foreign exchange rates

Yuanchen Chang [a]
[a] Department of Finance, National Chengchi University, Taipei, Mucha, Taiwan

Online Publication Date: 01 June 2004

To cite this Article Chang, Yuanchen(2004)'A re-examination of variance-ratio test of random walks in foreign exchange rates',Applied Financial Economics,14:9,671 — 679

To link to this Article: DOI: 10.1080/0960310042000233449

URL: http://dx.doi.org/10.1080/0960310042000233449

Applied Financial Economics, 2004, **14**, 671–679

A re-examination of variance-ratio test of random walks in foreign exchange rates

YUANCHEN CHANG

Department of Finance, National Chengchi University, Taipei, Mucha, Taiwan
e-mail: yccchang@nccu.edu.tw

This paper employs a variance ratio test to reexamine the random walk hypothesis for the Canadian dollar, French franc, Deutsche mark, Japanese yen and British pound. In addition to standard normal test statistics, the bootstrap resampling technique is used to calculate the significance levels of variance ratio statistics over the period 7 August 1974 to 30 December 1998. The results provide evidence rejecting the random walk hypothesis for the Japanese yen over the entire sample, while the results for the other four currencies are inconclusive. Furthermore, subperiod results show that from 1989 onwards the random walk hypothesis cannot be rejected for the Canadian dollar, French franc, Deutsche mark, and British pound.

I. INTRODUCTION

The issue of whether exchange rate returns are serially uncorrelated has generated considerable research interest in recent years, yet the existing empirical evidence on this issue shows conflicting results. Giddy and Dufey (1975), Cornell and Dietrich (1978), Logue *et al.* (1978), and Hsieh (1988) demonstrate that exchange rates contain uncorrelated increments. On the other hand, Liu and He (1991) provide evidence rejecting the random walk hypothesis for the Canadian dollar, French franc, Deutsche mark, Japanese yen, and British pound from 7 August 1974 to 29 March 1989. They suggest autocorrelations in these series are consistent with exchange rate overshooting or undershooting phenomenon. Wright (2000) uses non-parametric sign and rank-based variance ratio tests to examine the random walk hypothesis in five exchange rates. Though he finds strong evidence against the random walk hypothesis for all five currencies from 7 August 1974 to 29 March 1996, he did not provide subperiod results. Even so, non-parametric tests may be less efficient by transforming exchange rates into ranks and signs.

This study extends previous research by re-examining the random walk hypothesis of exchange rates using a bootstrap resampling procedure. This procedure, which is a distribution-free randomization technique, avoids sensitivity of results caused by possible non-normality, heteroscedasticity, and excess kurtosis in exchange rates. The results, based on this procedure, are consistent with the findings in Hsieh (1988) and Liu and He (1991), but are in contrast to the results in Wright (2000). The random walk hypothesis for the Japanese yen can be rejected for the entire sample period, but the results for the other four currencies are inconclusive. Furthermore, subperiod results show that from 1989 onwards the random walk hypothesis cannot be rejected for the Canadian dollar, French franc, Deutsche mark, and British pound.

The remainder of this article is as follows. Section II discusses the methodology and describes the data set used in this study. Section III reports the results of variance ratio tests for the entire sample and the sub-samples. Section IV discusses some economic implications of the empirical results. Section V concludes the paper.

II. METHODOLOGY

In testing the random walk hypothesis in five exchange rates, both homoscedastic and heteroscedastic variance ratios developed in Lo and MacKinlay (1988) are adopted.

Applied Financial Economics ISSN 0960–3107 print/ISSN 1466–4305 online © 2004 Taylor & Francis Ltd
http://www.tandf.co.uk/journals
DOI: 10.1080/0960310042000233449

In addition, a bootstrap method, which shuffles the data before computing the variance ratio for each run, is employed to provide another significant test. To check the robustness of the results, the entire sample is divided into three subperoids and calculate variance ratio statistics for each subperiod.

Variance ratio test

The variance ratio test developed by Lo and MacKinlay (1988) is based on the fact that the variance of q-differences of an uncorrelated series is q-times the variance of its first difference. Therefore, if one obtains $nq+1$ exchange rate observations $y_0, y_1, \ldots, y_{nq}$ at equally-spaced intervals, then the ratio of $1/q$ of the variance $y_t - y_{t-q}$ to the variance of $y_t - y_{t-1}$ would be equal to one. Based on this proportional relationship, the uncorrelated increment in a time series can be examined by estimating the variance ratio. If the estimated variance ratio is statistically different from one, then the uncorrelated hypothesis would be rejected. Both the homoscedasticity (Z) and heteroscedasticity-consistent (Z^*) statistics are calculated for various observation frequencies.

The formulae for calculating the variance ratio, the variance of the variance ratio, and the variance-ratio test statistics are given below in Equations 1 to 5.

$$VR(q) = \frac{V(r_{t-q})}{qV(r_t)} \tag{1}$$

where $r_{t-q} = \ln(y_t/y_{t-q})$ is the q-period return, $q = 2$, 4, 8, 16; $V(r_{t-q})$ is the variance of the q-period return; $V(r_t)$ is the variance of one-period return. The asymptotic variance of the variance-ratio under homoscedasticity, $\phi(q)$ is:

$$\phi(q) = 2(2q-1)(q-1)/3q(nq) \tag{2}$$

The standard normal test statistic under homoscedasticity, $Z(q)$ is:

$$Z(q) = \frac{VR(q)-1}{[\phi(q)]^{1/2}} \overset{a}{\sim} N(0,1) \tag{3}$$

The heteroscedasticity-consistent asymptotic variance of the variance ratio $\phi^*(q)$ is:

$$\phi^*(q) = \sum_{j=1}^{q-1}\left(\frac{2(q-j)}{q}\right)^2 \hat{\delta}(j), \quad \hat{\delta}(j) = \frac{\sum_{t=j+1}^{nq}(r_t^2 r_{t-j}^2)}{\left(\sum_{t=1}^{nq} r_t^2\right)^2} \tag{4}$$

The heteroscedasticity-consistent standard normal test-statistic $Z^*(q)$ is:

$$Z^*(q) = \frac{VR(q)-1}{[\phi^*(q)]^{1/2}} \overset{a}{\sim} N(0,1) \tag{5}$$

Lo and MacKinlay (1988) show that approximations (Equations 3 and 5) work well when q is small and nq is large. They suggest that it is necessary to examine the variance ratio tests for several selected values of q and the random walk hypothesis can be rejected when the test statistics are rejected for all q.

Bootstrap resampling technique

The small sample distribution of variance ratio test statistics cannot be derived analytically if exchange rate returns are non-normal and heteroscedastic. Although Lo and MacKinlay (1989) and Huang (1995) provide critical values based on Monte Carlo simulations for variance ratio statistics in finite samples, their methods are based on certain specifications of error terms. Following Pan *et al.* (1991) and Malliaropulos and Priestley (1999), this study uses a bootstrap resampling method to generate significant levels of variance ratio statistics that are free from distribution assumptions.

The standard bootstrap method shuffles the data before computing the variance ratio for each run and provides a distribution-free significant test statistic (Pan *et al.*, 1991). The random walk hypothesis can be tested by comparing the observed variance ratio test statistics ($VR(q)$) with the α-quantile of its sampling distribution. If $VR(q)$ is less than the lower α-quantile, then the null of a random walk can be rejected against the alternative of a mean-reverting process at the α per cent significance level. If, on the other hand, $VR(q)$ is higher than the upper $(1-\alpha)$-quantile, then the null of a random walk can be rejected against the alternative of a mean-averting process at the α per cent significance level.

Malliaropulos and Priestley (1999) show that a standard bootstrap method is neither consistent nor asymptotically unbiased under heteroscedasticity. They propose a heteroscedastic bootstrap method that weighs each original observation with random draws with replacement from a standard normal distribution. The advantage of this method is that it does not need to assume any particular form of heteroscedasticity in order to carry out significant tests. They show that the artificial data created in this way preserve the dependence in the original data set and can accommodate a broad class of non-constant volatility processes. The results reported in the next section are obtained from this method by bootstrapping the data 1000 times.

III. DATA AND EMPIRICAL RESULTS

Data and summary statistics

Tests are performed using nominal exchange rates for the Canadian dollar, French franc, German mark, Japanese yen and British pound, all against the US dollar over the period 7 August 1974 to 30 December 1998. The spot exchange rates, which are obtained from the Federal

Reserve Bank of Chicago, consist of daily noon buying rates in New York. For the analysis, the daily exchange rates are transformed into weekly rates of returns based on Wednesday's prices. When there is no trading on a given Wednesday, the last trading day before Wednesday is used to compute returns. Returns are constructed as the first differences of the log exchange rates. The data starts in 1974 due to the fact that most of the countries shifted into a flexible exchange rate regime around that time. Liu and He (1991) use similar data sets, but their data end at 1989.

Summary statistics of the return series are presented in Table 1. There were 1274 weekly observations in the sample period. The sample means for the five exchange rates are close to zero. The sample skewness, kurtosis, and Jarque-Bera statistics show that the return series are not normally distributed. Therefore, it is essential to use the bootstrap resampling scheme to calculate the significant levels of variance ratio statistics, especially for subperiod results where small sample properties are difficult to derive.

The first-lag correlations for five exchange rates are all positive and close to 0.05. The standard and adjusted Box-Pierce Q statistics show that the null hypothesis of a random walk can only be rejected for the Japanese yen at the 5% level. This is consistent with the findings in Hsieh (1988), who applies Box-Pierce Q statistics to five exchange rates from 1974 to 1983 and concludes that the null hypothesis of serial independence can only be rejected for the Japanese yen.

Results of the variance ratio test

Tables 2 and 3 report the results of variance ratio statistics over the entire sample for 2-week, 4-week, 8-week, and 16-week intervals. Results using the standard variance ratio statistics are reported in Table 2 and results based on the bootstrap resampling method are reported in Table 3.

As shown in Table 2, the $Z(q)$ statistics indicate that there is sufficient evidence to reject the random walk hypothesis for the Japanese yen at the 5% level. There are some cases whereby one can reject the random walk hypothesis for the Deutsche mark, the French franc, and the British Pound (two rejections out of four cases) and the Canadian dollar (one rejection out of four cases). Because these results are under the hypothesis of homoscedasticity, the rejection of the random walk hypothesis may either be due to heteroscedasticity or to serial correlation. To investigate this issue, the heteroscedasticity-consistent variance ratio test ($Z^*(q)$) is calculated, and it is seen that some of the rejections under homoscedasticity are not robust to heteroscedasticity. For example, all of the

Table 1. *Return series summary statistics*

	CAN	FF	DM	YEN	POUND
Mean	0.0004	0.0001	−0.0003	−0.0007	−0.0002
Std	0.0058	0.0142	0.0145	0.0145	0.0143
Skewness	0.3104	0.0346	−0.1112	−0.5842	−0.2765
Excess Kurtosis	2.7720	2.4986	1.9400	3.1179	3.5784
Jarque-Bera	428.35	331.66	202.43	588.52	695.97
Autocorrelations					
1	0.0579	0.0485	0.0352	0.0698	0.0499
2	0.0343	0.0768	0.0825	0.1062	0.0066
3	−0.0521	−0.0036	0.0037	0.0459	0.0081
4	−0.0129	0.0471	0.0332	0.0438	0.0599
5	−0.0135	−0.0181	0.0028	0.0141	0.0449
6	−0.0291	−0.0358	−0.0213	0.0046	0.0061
7	−0.0143	−0.0129	−0.0034	−0.0072	0.0178
8	0.0150	0.0501	0.0515	0.0108	0.0444
9	−0.0147	0.0066	0.0108	0.0186	−0.0250
10	−0.0355	0.0180	−0.0041	−0.0734	−0.0378
11	0.0496	0.0178	0.0118	0.0360	0.0037
12	0.0327	0.0297	0.0124	0.0541	0.0011
13	0.0220	0.0085	0.0006	0.0500	−0.0033
14	−0.0027	0.0357	0.0142	−0.0101	0.0153
15	−0.0236	0.0454	0.0204	−0.0079	0.0722
Box-Pierce	19.1078	21.8872	15.7482	42.1775**	23.5904
$Q(15)$	(0.2089)	(0.1108)	(0.3990)	(0.0002)	(0.0724)
Adjusted	15.3644	18.7223	12.8164	32.6865**	15.8263
Box-Pierce $Q(15)$	(0.4255)	(0.2266)	(0.6165)	(0.0052)	(0.3937)
Sample size	1274	1274	1274	1274	1274

Notes: ** significant at the 1% level, marginal significant levels in parentheses. Jarque-Bera is the Jarque-Bera (1987) normality test. Box-Pierce is the Box-Pierce (1970) Q statistics and Adjusted Box-Pierce is the heteroscedasticity-adjusted Box-Pierce Q statistics proposed by Diebold (1986).

Table 2. *Estimates of variance ratios statistics for entire sample*

Currency	Number of observations	Number q of base observations forming variance ratio			
		2	4	8	16
CAN/US$	1274	1.06	1.09	1.03	1.00
		(2.00)*	(1.72)	(0.42)	(−0.01)
		[1.58]	[1.40]	[0.35]	[−0.01]
FF/US$	1274	1.04	1.11	1.15	1.28
		(1.44)	(2.06)*	(1.85)	(2.25)*
		[1.31]	[1.77]	[1.58]	[1.97]*
DM/US$	1274	1.04	1.11	1.16	1.26
		(1.47)	(2.03)*	(1.92)	(2.15)*
		[1.34]	[1.76]	[1.64]	[1.87]
YEN/US$	1274	1.07	1.23	1.39	1.50
		(2.48)*	(4.48)**	(4.76)**	(4.08)**
		[1.92]	[3.65]**	[3.97]**	[3.48]**
POUND/US$	1274	1.04	1.07	1.19	1.29
		(1.59)	(1.35)	(2.26)*	(2.35)*
		[1.11]	[0.98]	[1.69]	[1.84]

Notes: ** indicates statistical significance at the 1% level. * indicates statistical significance at the 5% level. The estimates of variance ratios are shown in the main row, the $Z(q)$ statistics are in parentheses, and the $Z^*(q)$ statistics are in square brackets.

estimated $Z^*(q)$ statistics for the Canadian dollar, the Deutsche mark, and the British Pound are not statistically different from one at the 5% level. There are one and three out of four cases for the French franc and Japanese yen, respectively, for which one can reject the random walk hypothesis at the 5% level.

Table 3 reports significant levels of the variance ratio statistics based on the bootstrap resampling scheme. It is seen that the random walk hypothesis can be rejected for the Japanese yen at the 5% level for the entire sample. There are some cases that reject the random walk hypothesis for the Deutsche mark (three rejections out of four cases), the French franc, and the British Pound (two rejections out of four cases) and the Canadian dollar (one rejection out of four cases). These results show that there is only sufficient evidence to reject the random walk hypothesis for the Japanese yen, while the results for the other four currencies are mixed.

The variance ratio test for sub-periods

To check the robustness of the variance ratio test results, the test statistics are computed for three sub-periods: from 7 August 1974 to 10 October 1979; from 11 October 1979 to 29 March 1989; and from 30 March 1989 to 30 December 1998. Both standard and bootstrap methods are used to generate significant tests of the variance ratio statistics. The reason for choosing these cut-off points is to provide comparisons with results of Liu and He (1991), who use October 1979 as a cut-off point at which time the Federal Reserve changed its operating procedure. They suspect that the change of the Federal Reserve's policy might have caused some structural changes in the data. The sample period ends at 30 December 1998, because of data restriction.[1]

Results for sub-periods using standard variance ratio tests are presented in Table 4. In the first subperiod, there is more evidence leading to the rejection of the random walk hypothesis for the Canadian dollar and British pound for variance ratio statistics under homoscedasticity. After adjustment for heteroscedasticity, only one out of four cases are significant at the 5% level for the Canadian dollar and French franc, whereas none of the statistics for the Deutsche mark are significant at the 5% level. There are two out of four cases where the random walk hypothesis can be rejected at the 5% level for the Japanese yen.

In the second subperiod, the Japanese yen is the only currency that can reject the random walk hypothesis for all intervals at the 5% level. There are one out of four cases whereby the random walk hypothesis can be rejected for the French franc in this period. In the third subperiod, it is seen that the random walk hypothesis cannot be rejected for all five currencies based on heteroscedastic-consistent variance ratios.

Subperiod results based on bootstrap methods are reported in Table 5. The results in the first and second subperiods are in line with those reported in Table 4. There is in fact only conclusive evidence to reject the

[1] The Federal Reserve Bank of Chicago discontinued posting dollar exchange rates against the eleven currencies participating in the EMU upon the introduction of the euro on 1 January 1999.

Table 3. *The bootstrap resampling variance ratios statistics for entire sample*

		Number q of base observations forming variance ratio			
Currency time period	Number of observations	2	4	8	16
Panel A. Can/US$					
74/08/07-98/12/30	1274	1.06*	1.09	1.03	1.00
Mean		1.0001	0.9961	1.0013	0.9980
Std		0.0350	0.0632	0.1020	0.1408
1%-Quantile		0.9195	0.8513	0.7963	0.6870
5%-Quantile		0.9454	0.8928	0.8459	0.7767
95%-Quantile		1.0591	1.1018	1.1775	1.2372
99%-Quantile		1.0847	1.1534	1.2797	1.3198
Panel B. FF/US$					
74/08/07-98/12/30	1274	1.04	1.11*	1.15	1.28*
Mean		0.9978	1.0016	0.9999	0.9907
Std		0.0309	0.0619	0.0922	0.1384
1%-Quantile		0.9277	0.8692	0.8029	0.7185
5%-Quantile		0.9458	0.8989	0.8531	0.7716
95%-Quantile		1.0503	1.1030	1.1573	1.2159
99%-Quantile		1.0695	1.1555	1.2390	1.3637
Panel C. DM/US$					
74/08/07-98/12/30	1274	1.04	1.11*	1.16*	1.26*
Mean		0.9980	0.9962	0.9934	0.9967
Std		0.0303	0.0583	0.0941	0.1397
1%-Quantile		0.9271	0.8590	0.7936	0.7019
5%-Quantile		0.9477	0.9008	0.8465	0.7915
95%-Quantile		1.0481	1.0927	1.1569	1.2287
99%-Quantile		1.0677	1.1391	1.2330	1.3450
Panel D. Yen/US$					
74/08/07-98/12/30	1274	1.07*	1.23**	1.39**	1.50**
Mean		1.0004	0.9974	0.9941	0.9785
Std		0.0354	0.0656	0.0991	0.1390
1%-Quantile		0.9177	0.8575	0.7821	0.6988
5%-Quantile		0.9461	0.8877	0.8452	0.7767
95%-Quantile		1.0574	1.1039	1.1628	1.2146
99%-Quantile		1.0834	1.1551	1.2583	1.3397
Panel E. Pound/US$					
74/08/07-98/12/30	1274	1.04	1.07	1.19*	1.29*
Mean		0.9985	0.9984	0.9957	0.9951
Std		0.0380	0.0662	0.1070	0.1523
1%-Quantile		0.9082	0.8514	0.7734	0.6909
5%-Quantile		0.9365	0.8979	0.8325	0.7654
95%-Quantile		1.0626	1.1129	1.1809	1.2671
99%-Quantile		1.0867	1.1621	1.2704	1.3751

Notes: The table reports bootstrap variance ratio statistics proposed by Malliaropulos and Priestley (1999). Row 2 reports means and row 3 reports standard deviations. Rows 4 to 7 report 1%, 5%, 95%, and 99% quantiles of the bootstrap distribution of variance ratio statistics with the replication of 1000 times. ** indicates statistical significance at the 1% level. * indicates statistical significance at the 5% level.

random walk hypothesis for the Japanese yen in the second subperiod, but the results for the other four currencies are inconclusive.

The results in the third subperiod for the Japanese yen are slightly different from those in Table 4. Based on bootstrap methods, there are three out of four cases whereby the random walk hypothesis for the Japanese yen can be rejected at the 5% level in the third subperiod. The rest of the results confirm those in Table 4 that there is no rejection of the random walk hypothesis for the other four currencies from 1989 onward. Some economic implications derived from these results are presented in Section IV.

IV. ECONOMIC IMPLICATIONS

The results of the variance ratio tests suggest that the rejections of the random walk hypothesis for the Canadian dollar, French franc, and Deutsche mark are primarily due to heteroscedasticity in the return series. Though serial

Table 4. *Estimates of variance ratios statistics for sub-periods*

		Number q of base observations forming variance ratio			
Currency time period	Number of observations	2	4	8	16
Panel A. Can/US$					
74/08/07-79/10/10	271	1.14	1.34	1.34	1.25
		(2.38)*	(3.01)**	(1.87)	(0.92)
		[1.38]	[1.99]*	[1.42]	[0.78]
79/10/17-89/03/29	494	1.05	1.03	0.94	0.92
		(1.14)	(0.40)	(−0.42)	(−0.42)
		[0.96]	[0.34]	[−0.35]	[−0.36]
89/04/05-98/12/30	509	1.01	1.03	0.98	0.95
		(0.30)	(0.31)	(−0.16)	(−0.26)
		[0.26]	[0.27]	[−0.14]	[−0.24]
Panel B. FF/US$					
74/08/07-79/10/10	271	1.08	1.27	1.24	1.40
		(1.34)	(2.37)*	(1.35)	(1.51)
		[1.05]	[1.97]*	[1.17]	[1.33]
79/10/17-89/03/29	494	1.07	1.17	1.22	1.43
		(1.51)	(1.98)*	(1.68)	(2.17)*
		[1.43]	[1.84]	[1.57]	[2.04]*
89/04/05-98/12/30	509	0.99	1.00	1.04	1.05
		(−0.06)	(0.04)	(0.28)	(0.26)
		[−0.06]	[0.04]	[0.24]	[0.23]
Panel C. DM/US$					
74/08/07-79/10/10	271	1.12	1.26	1.21	1.36
		(1.92)	(2.29)*	(1.17)	(1.35)
		[1.34]	[1.69]	[0.94]	[1.14]
79/10/17-89/03/29	494	1.06	1.15	1.22	1.38
		(1.42)	(1.80)	(1.62)	(1.93)
		[1.38]	[1.66]	[1.48]	[1.79]
89/04/05-98/12/30	509	0.99	1.02	1.07	1.09
		(−0.13)	(0.20)	(0.54)	(0.45)
		[−0.12]	[0.18]	[0.46]	[0.40]
Panel D. Yen/US$					
74/08/07-79/10/10	271	1.07	1.28	1.57	1.85
		(1.15)	(2.45)*	(3.18)**	(3.18)**
		[0.70]	[1.58]	[2.12]*	[2.22]*
79/10/17-89/03/29	494	1.11	1.30	1.43	1.44
		(2.49)*	(3.57)**	(3.23)**	(2.22)*
		[2.01]*	[3.03]**	[2.88]**	[2.07]*
89/04/05-98/12/30	509	1.03	1.15	1.26	1.34
		(0.65)	(1.82)	(1.95)	(1.77)
		[0.53]	[1.56]	[1.67]	[1.53]
Panel E. Pound/US$					
74/08/07-79/10/10	271	1.10	1.25	1.62	1.97
		(1.65)	(2.21)*	(3.46)**	(3.61)**
		[1.37]	[1.90]	[3.05]**	[3.27]**
79/10/17-89/03/29	494	1.01	1.00	1.11	1.27
		(0.21)	(−0.03)	(0.81)	(1.37)
		[0.17]	[−0.03]	[0.67]	[1.15]
89/04/05-98/12/30	509	1.06	1.10	1.14	1.09
		(1.37)	(1.23)	(1.08)	(0.48)
		[0.85]	[0.82]	[0.75]	[0.36]

Notes: ** indicates statistical significance at the 1% level. * indicates statistical significance at the 5% level.

Table 5. *The bootstrap resampling variance ratio statistics for subperiods*

Currency	Number of observations	Number q of base observations forming variance ratio			
		2	4	8	16
Panel A. Can/US$					
74/08/07-79/10/10	271	1.14*	1.34*	1.34*	1.25
Mean		0.9884	0.9797	0.9596	0.9488
Std		0.0830	0.1476	0.2008	0.2807
1%-Quantile		0.7650	0.6653	0.5387	0.4314
5%-Quantile		0.8492	0.7241	0.6533	0.5486
95%-Quantile		1.1252	1.2249	1.3062	1.4662
99%-Quantile		1.1789	1.3596	1.5142	1.7546
79/10/17-89/03/29	494	1.05	1.03	0.94	0.92
Mean		0.9924	0.9949	0.9858	0.9652
Std		0.0499	0.1007	0.1575	0.2162
1%-Quantile		0.8754	0.7764	0.6650	0.5660
5%-Quantile		0.9093	0.8364	0.7536	0.6511
95%-Quantile		1.0728	1.1675	1.2750	1.3442
99%-Quantile		1.1038	1.2459	1.3983	1.6196
89/04/05-98/12/30	509	1.01	1.03	0.98	0.95
Mean		0.9988	0.9936	0.9925	0.9582
Std.		0.0506	0.0963	0.1451	0.2146
1%-Quantile		0.8806	0.7856	0.7065	0.5814
5%-Quantile		0.9168	0.8465	0.7672	0.6523
95%-Quantile		1.0834	1.1637	1.2504	1.3221
99%-Quantile		1.1101	1.2172	1.3477	1.5128
Panel B. FF/US$					
74/08/07-79/10/10	271	1.08	1.27*	1.24	1.40
Mean		0.9825	0.9714	0.9629	0.9557
Std.		0.0783	0.1330	0.1957	0.2872
1%-Quantile		0.7886	0.6748	0.5528	0.4390
5%-Quantile		0.8526	0.7670	0.6565	0.5421
95%-Quantile		1.1074	1.2001	1.3110	1.4696
99%-Quantile		1.1671	1.3017	1.4572	1.8113
79/10/17-89/03/29	494	1.07	1.17*	1.22	1.43*
Mean		0.9992	0.9985	0.9973	1.0002
Std.		0.0465	0.0915	0.1458	0.2051
1%-Quantile		0.8982	0.7963	0.6933	0.5953
5%-Quantile		0.9277	0.8613	0.7732	0.6925
95%-Quantile		1.0768	1.1537	1.2440	1.3710
99%-Quantile		1.1102	1.2259	1.3759	1.5239
89/04/05-98/12/30	509	0.99	1.00	1.04	1.05
Mean		0.9960	0.9990	0.9885	0.9630
Std		0.0469	0.0933	0.1457	0.2154
1%-Quantile		0.8877	0.7780	0.6935	0.5795
5%-Quantile		0.9154	0.8552	0.7578	0.6587
95%-Quantile		1.0724	1.1562	1.2390	1.3485
99%-Quantile		1.1029	1.2191	1.3365	1.5908
Panel C. DM/US$					
74/08/07-79/10/10	271	1.12	1.26*	1.21	1.36
Mean		0.9896	0.9836	0.9753	0.9357
Std		0.0818	0.1396	0.2139	0.3095
1%-Quantile		0.8005	0.6723	0.5816	0.4181
5%-Quantile		0.8522	0.7614	0.6709	0.5292
95%-Quantile		1.1219	1.2233	1.3564	1.4814
99%-Quantile		1.2001	1.3363	1.5892	1.8878
79/10/17-89/03/29	494	1.06	1.15*	1.22	1.38*
Mean		0.9945	0.9967	0.9945	0.9878
Std		0.0441	0.0874	0.1445	0.2089
1%-Quantile		0.8962	0.8009	0.6955	0.5939
5%-Quantile		0.9244	0.8585	0.7663	0.6774
95%-Quantile		1.0641	1.1421	1.2495	1.3742
99%-Quantile		1.0993	1.2033	1.3884	1.5501

(*continued*)

Table 5. (*continued*)

Currency	Number of observations	Number q of base observations forming variance ratio			
		2	4	8	16
89/04/05-98/12/30	509	0.99	1.02	1.07	1.09
Mean		0.9958	0.9964	0.9814	0.9584
Std		0.0471	0.0905	0.1501	0.2080
1%-Quantile		0.8823	0.8097	0.6631	0.5663
5%-Quantile		0.9216	0.8585	0.7441	0.6485
95%-Quantile		1.0752	1.1517	1.2353	1.3276
99%-Quantile		1.1057	1.2253	1.3649	1.5382
Panel D. Yen/US$					
74/08/07-79/10/10	271	1.07	1.28	1.57*	1.85*
Mean		0.9911	0.9991	0.9938	0.9856
Std		0.0928	0.1604	0.2453	0.3459
1%-Quantile		0.7392	0.6243	0.5093	0.3953
5%-Quantile		0.8379	0.7512	0.6396	0.5183
95%-Quantile		1.1426	1.2810	1.4465	1.6116
99%-Quantile		1.2151	1.4169	1.6501	1.9612
79/10/17-89/03/29	494	1.11*	1.30**	1.43**	1.44*
Mean		0.9973	0.9935	0.9884	0.9696
Std		0.0528	0.0965	0.1494	0.2074
1%-Quantile		0.8752	0.7775	0.6731	0.5460
5%-Quantile		0.9131	0.8403	0.7564	0.6548
95%-Quanitle		1.0815	1.1603	1.2636	1.3453
99%-Quanitle		1.1235	1.2371	1.3377	1.5215
89/04/05-98/12/30	509	1.03	1.15*	1.26*	1.34*
Mean		0.9982	0.9930	0.9880	0.9362
Std		0.0507	0.0924	0.1493	0.2046
1%-Quantile		0.8744	0.7809	0.6727	0.5594
5%-Quantile		0.9133	0.8469	0.7648	0.6293
95%-Quantile		1.0841	1.1485	1.2462	1.3277
99%-Quantile		1.1195	1.2182	1.3713	1.4930
Panel E. Pound/US$					
74/08/07-79/10/10	271	1.10	1.25*	1.62*	1.97*
Mean		0.9870	0.9837	0.9561	0.9248
Std		0.0743	0.1327	0.1959	0.2762
1%-Quantile		0.8177	0.6826	0.5831	0.4435
5%-Quantile		0.8683	0.7786	0.6673	0.5236
95%-Quantile		1.1101	1.2014	1.3143	1.4255
99%-Quantile		1.1728	1.3387	1.5284	1.6907
79/10/17-89/03/29	494	1.01	1.00	1.11	1.27
Mean		0.9946	0.9882	0.9846	0.9729
Std		0.0535	0.0968	0.1481	0.2191
1%-Quantile		0.8679	0.7655	0.6996	0.5557
5%-Quantile		0.9078	0.8292	0.7592	0.6579
95%-Quantile		1.0868	1.1499	1.2380	1.3590
99%-Quantile		1.1348	1.2264	1.3877	1.5568
89/04/05-98/12/30	509	1.06	1.10	1.14	1.09
Mean		1.0026	0.9928	0.9942	0.9593
Std		0.0613	0.1096	0.1718	0.2328
1%-Quantile		0.8529	0.7567	0.6583	0.5284
5%-Quantile		0.8992	0.8179	0.7477	0.6342
95%-Quantile		1.1031	1.1725	1.2957	1.3898
99%-Quantile		1.1572	1.2922	1.4431	1.5925

Notes: The table reports bootstrap variance ratio statistics proposed by Malliaropulos and Priestley (1999). Row 2 reports means and row 3 reports standard deviations. Rows 4 to 7 report 1%, 5%, 95%, and 99% quantiles of the bootstrap distribution of variance ratio statistics with the replication of 1000 times. ** indicates statistical significance at the 1% level. * indicates statistical significance at the 5% level.

correlation is small, there is strong evidence supporting significant autocorrelation of the Japanese yen in the sample period.

Since the variance ratio minus 1.0 is approximately $q-1$ times the weighted sum of the first $q-1$ autocorrelation coefficients, the estimated variance ratios that are higher than 1.0 for the Japanese yen suggest positive serial correlation in the return series. Dominguez and Frankel (1993) note that the Japanese yen began to abruptly depreciate against the US dollar at the end of 1978 and the Japanese authorities responded by selling US dollars quite heavily throughout 1979 and early 1980. They also report that the central bank of Japan intervened in support of the dollar in massive quantities, before and after the Louvre Accord (February 1987). Therefore, the findings are consistent with a possible undershooting phenomenon of the Japanese yen that was caused by the lean-against-the-wind intervention policy adopted by the central bank of Japan during this period. The results for the other four currencies are inconclusive. Though the findings show that there are some cases where one can reject the random walk hypothesis, the magnitude and significant levels are declining from 1989 onwards.

V. SUMMARY AND CONCLUSIONS

This study applies homoscedastic and heteroscedasticity-consistent variance ratio tests to five exchange rates over the period 7 August 1974 to 30 December 1998. In addition to standard normal test statistics, the bootstrap resampling technique is used to calculate the significance levels of variance ratio statistics.

Of all five currencies selected for inclusion in this study, the Japanese yen seems to be the only currency for which one can find sufficient evidence to reject the random walk hypothesis. The rejection of the random walk hypothesis for the Japanese yen could be related to the undershooting phenomenon caused by the lean-against-the-wind intervention policy adopted by the Bank of Japan. Subperiod results show that the random walk hypothesis cannot be rejected for the Canadian dollar, French franc, Deutsche mark, and British pound from 1989 onwards, which indicates that returns are not dependent on past returns for these currencies.

REFERENCES

Box, G. and Pierce, D. (1970) Distribution of residual autocorrelations in autoregressive-integrated moving average time series models, *Journal of the American Statistical Association*, **65**, 1509–26.

Cornell, B. W. and Dietrich, J. K. (1978) The efficiency of the market for foreign exchange under floating exchange rates, *The Review of Economics and Statistics*, **60**, 111–20.

Diebold, F. X. (1986) *Empirical Modelling of Exchange Rate Dynamics*, Springer-Verlag, New York.

Dominguez, K. M. and Frankel, J. A. (1993) *Does Foreign Exchange Intervention Work*?, Institute for International Economics, Washington, DC.

Giddy, I. H. and Dufey, G. (1975) The random behavior of flexible exchange rates: implications for forecasting, *Journal of International Business Studies*, **6**, 1–32.

Hsieh, D. (1988) The statistical property of daily foreign exchanges: 1974–1983, *Journal of International Economics*, **24**, 129–45.

Huang, B. (1995) Do Asian stock market prices follow random walks? Evidence from the variance ratio test, *Applied Financial Economics*, **5**, 251–6.

Jarque, C. M. and Bera, A. K. (1987) A test for normality of observations and regression residuals, *International Statistical Review*, **55**, 163–72.

Liu, C. Y. and He, J. (1991) A variance ratio test of random walks in foreign exchange rates, *Journal of Finance*, **46**, 773–85.

Lo, A. W. 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.

Lo, A. W. and MacKinlay, C. (1989) The size and power of the variance ratio tests in finite samples: a Monte Carlo investigation, *Journal of Econometrics*, **40**, 203–38.

Logue, D. E., Sweeney, R. J. and Willett, T. D. (1978) Speculative behavior of foreign exchange rates during the current float, *Journal of Business Research*, **6**, 159–74.

Malliaropulos, D. and Priestley, R. (1999) Mean reversion in Southeast Asian stock markets, *Journal of Empirical Finance*, **6**, 355–84.

Pan, M. S., Chiou, J. R., Hocking, R. and Rim, H. K. (1991) An examination of mean-reverting behavior of stock prices in Pacific-Basin stock markets, *Pacific-Basin Capital Market Research*, **2**, 333–43.

Wright, J. H. (2000) Alternative variance ratio tests using ranks and signs, *Journal of Business and Economic Statistics*, **18**, 1–9.