Empirical Testing Of Random Walk Of Euro Exchange Rates: Evidence From The Emerging Markets

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ABSTRACT

This paper utilizes the new non-parametric variance ratio tests based on signs and ranks to examine the random walk hypothesis of Euro exchange rates for 10 Middle Eastern and North African (MENA) currencies. The results of the new- variance ratio tests reject the random walk hypothesis for all currencies except the Kuwaiti and the Emirate currencies. Given the improved size and power properties of Wright's (2000) ranks and signs tests, the results of the new variance ratio tests are robust to the results of the traditional LOMAC variance ratio tests.

INTRODUCTION

Using the U.S. Dollar as a direct quotation, many researchers have documented that the nominal exchange rate series follows a random walk process (see Messe and Singleton, 1982; Hsieh, 1988; and Baillie and Bollerslev, 1989). In a recent study, Franch and Opong (2004) provide evidence consistent with random walk behavior of Euro exchange rates for eight of ten major currencies.[1] While their results suggest that the behavior of the Euro exchange rates for the major trading currencies is weak form efficient, this may not necessarily be the case for lesser traded currencies. Thus, the aim of this study is to extend the current literature by examining the behavior of the Euro exchange rates for 10 Middle Eastern and North African (MENA) currencies: Bahrain, Egypt, Jordan, Kuwait, Morocco, Oman, Qatar, Saudi Arabia, Tunisia, and United Arab Emirates.[2]

Foreign exchange rate issues have become more important in recent years, especially in emerging markets, but international investors appear to look through exchange rate volatility to focus on key market opportunities. Furthermore, global markets are important to growth, and few firms in any geography, including emerging markets, forgo foreign investments because of exchange rate volatility. Exchange rate may come into play when assessing market opportunity; but it does not appear to be, in and of itself, a deterrent of investment, except in the case of outright currency crises. Franch and Opong (2004) stated that knowledge of the behavior of exchange rates, in the context of randomness, is of interest to all parties in the market such as academicians, practitioners, and regulators.

Empirical evidence for and against the random walk theory is in abundance in extant literature, and the interest in the random walk hypothesis remains strong. Earlier studies testing the random walk hypothesis focused primarily on large developed financial markets. Practically, all of the aforementioned empirical studies concerning the efficiency hypothesis of foreign exchange market have primarily focused on the U.S., European, and Japanese economies. However, the recent increased volume of activities in developing markets as well as the recent availability of reliable data on these markets prompted researchers to take another look at the random walk hypothesis.

Furthermore, no previous work investigating the hypothesis in the Middle Eastern and North African (MENA) currencies was found. Therefore, this paper applies the new non-parametric variance ratio tests based on ranks and signs introduced by Wright (2000) to examine the behavior of Euro exchange rates for the 10 currencies in the MENA countries.

The remainder of this paper is organized as follows. Section 2 discusses data and methodology used in this study. Section 3 presents and discusses the results and Section 4 concludes the paper.

DATA AND METHODOLOGY

We used daily nominal exchange rates for the Bahraini Dinar, Egyptian Pound, Jordanian Dinar, Kuwaiti Dinar, Moroccan Dirham, Omani Rial, Qatari Rial, Saudi Rial, Tunisian Dinar, and Emirate Dirham, all relative to the Euro. The daily nominal exchange rates were obtained from the Central Bank of each respective country for five years from January 2000 to December 2004.[3]

UNIT ROOT TEST

Testing for the presence of unit roots in an autoregressive time series evaluates two statistical properties, which require that the (a) estimated values of regression slope coefficients are unity and (b) all characteristics roots of the estimators lie within the unit circle (Meese and Singleton, 1982; Enders, 1989). In the presence of a single unit root, the estimated value of the slope coefficient may not be statistically different from unity. However, under the null hypothesis that the coefficient is unity, the non-stationarity in the time series means that standard confidence interval tests of *t* and *F* statistics are inappropriate (Enders, 1989).

The presence of a unit root in the series means that the first difference will be required to transform the series into a stationary process, while the presence of two unit roots requires second differencing to stationarize the series.

The unit root tests, developed by Fuller, 1976, Dickey & Fuller, 1979 & 1981, Said & Dickey, 1984, and later refined by Phillips & Perron, 1988, examine whether a time series is stationary by taking into account the heteroskedasticity in the time-series data. If the unit root hypothesis is rejected, it means that a time series is stationary. If the unit root hypothesis is not rejected, the series is non-stationary.

One can test the presence of one unit root by the augmented Dickey-Fuller model (Fuller 1976 and Dickey, and Fuller 1979, 1981):

$$\Delta x_t = \alpha + \beta x_{t-1} + \gamma_j \sum_{j=1}^{k} \Delta x_{t-j} + \varepsilon_t \tag{1}$$

where x_t is the variable being tested for unit roots, β is the regression coefficients, and ε_t is the random error term, which is normally distributed with a mean of zero and variance σ^2. The *t*-test statistic for the null hypothesis is H_0: $\beta = 1$ is $(\beta-1)/s(\beta)$, where $s(\beta)$ is the standard error of the regression coefficient β. Using the null hypothesis that β=0 versus the alternative of β< 0, for any *x*. The lag length *j* in the ADF test regressions is determined by the Akaike Information Criterion (AIC).

On the other hand, the Phillips & Perron (PP) test (1988) estimates $\Delta x_t = \alpha + \beta x_{t-1} + \varepsilon_t$ and tests the null hypothesis that β=0 versus the alternative of β< 0. Three variations of ADF and PP regressions are estimated: with intercept, trend and intercept, and neither trend nor intercept. The purpose of this approach is to insure that the test results are robust in the presence of drifts and trends. The PP test may be more appropriate if autocorrelation in the series under investigation is suspected. The statistics are transformed to remove the effects of autocorrelation from asymptotic distribution of the test statistic. The formula for transformed test statistics is given in Perron (1988). The lag truncation of the Bartlett Kernel in the PP test is determined by Newey and West (1987). The critical values for unit root test statistics that are found in Mackinnon (1991) will be used for the evaluation of ADF and PP tests. Accepting the null hypothesis means that the series under consideration is not stationary and a unit root is present. If the null hypothesis of a unit root in Euro exchange rates in a particular currency is not rejected, this result implies that the consecutive changes in exchange rates over the period are random. Accordingly, the foreign exchange market is weak-form efficient.

LOMAC SINGLE VARIANCE RATIO TEST

The traditional variance ratio (VR) test of Lo and MacKinlay (1988, 1989) is widely employed in testing the random walk hypothesis. This test is based on the assumption that the variance of the random walk increments in a finite sample is linear in the sampling interval. The variance ratio test is robust with respect to many forms of heteroskedasticity and non-normality of the stochastic disturbance term.

Furthermore, the VR test is derived from the assumption that if the natural logarithm of a time series x_t is a pure random walk, the variance of its *qth* difference grows proportionally with the difference q, that is the variance of its *qth* difference variable would be q times the variance of its first difference. Therefore, if we obtain $n + 1$ observations $x_0, x_1, x_2, x_3, \ldots\ldots, x_n$ at equally spaced intervals, $1/q$ of the variance of x_t, x_{t-q} is expected to be the same as the variance of $x_t – x_{t-1}$, for a time series characterized by random walks. The variance ratio at lag q, VR (q), is defined as:

$$VR(q) = \frac{\sigma_q^2}{\sigma_1^2} \tag{2}$$

$$\sigma_1^2 = \frac{1}{nq-1}\sum_{t=1}^{nq}(x_t - x_{t-1} - \hat{\mu})^2 \tag{3}$$

$$\sigma_q^2 = \frac{1}{m}\sum_{t=q}^{nq}(x_t - x_{t-q} - q\hat{\mu})^2 \tag{4}$$

where

$$\hat{\mu} = \frac{1}{nq}(x_{nq} - x_0) \tag{5}$$

and

$$m = q(nq - q + 1)\left(1 - \frac{q}{nq}\right) \tag{6}$$

where x_0 and x_{nq} are the first and last observations in the series. Under the assumption of homoskedasticity, the test statistics $z(q)$ will test the null hypothesis of a random walk and will obtain in the following format:

$$z(q) = \frac{(VR(q) - 1)}{[\phi(q)]^{1/2}} \sim N(0,1) \tag{7}$$

where

$$\phi(q) = \frac{2(2q-1)(q-1)}{3q(nq)} \tag{8}$$

Lo and MacKinlay (1988) also developed a heteroskedasticity-consistent version of this z-statistics, which takes the form

$$z^*(q) = \frac{(VR(q) - 1)}{[\phi^*(q)]^{1/2}} \sim N(0,1) \tag{9}$$

where

$$Q^*(q) = \sum_{j=1}^{q-1} \left[\frac{2(q-j)}{q} \right]^2 \hat{\delta}(j) \tag{10}$$

and

$$\hat{\delta}(j) = \frac{\left[\sum_{t=j+1}^{nq} (x_t - x_{t-1} - \hat{\mu})^2 (x_{t-j} - x_{t-j-1} - \hat{\mu})^2 \right]}{\left[\sum_{t=1}^{nq} (x_t - x_{t-1} - \hat{\mu})^2 \right]^2} \tag{11}$$

Consistent with Hamao, Masulis, and Ng (1990) and Huang (1995), we use an autoregressive conditional heteroskedasticity (ARCH) test to determine whether the heteroskedasticity-consistent estimator is required.[4]

RANK- AND SIGN-BASED VARIANCE TESTS

Wright (2000) stated that variance ratio tests using ranks and signs are more robust than LOMAC test when data are non-normal and non-stationary. Furthermore, Wright (2000) tests will be robust to many forms of conditional heteroskedasticity and ought to have power against a wide range of models of serial correlation such as autoregressive moving average and fractionally integrated alternatives with heavy tailed innovations. Thus, Wright (2000) modified the conventional VR to nonparametric VR based on ranks and signs. To derive the VR statistic using ranks, Wright substituted the time series (asset returns) used in the conventional VR statistic (Lo & MacKinlay, 1989) with two linear transformations of the rank of the variable in question as follows:

Let $r(p_t)$ be the rank of p_t among $p_1, p_2, \ldots\ldots\ldots p_n$

$$r_{1t} = \frac{\left(r(p_t) - \frac{N+1}{2} \right)}{\sqrt{\frac{(N-1)(N+1)}{12}}} \tag{12}$$

$$r_{2t} = \frac{r(p_t)}{\lambda(N+1)} \tag{13}$$

where λ is the standard normal cumulative distribution function. It should be noted that r_{1t} and r_{2t} are the most common forms of the ranks transformations of a series. To derive the VR based on ranks, we substitute r_{1t} and r_{2t} in place of p_t in the definition of the tests statistics Z_1 and Z_2 in equations 2 and 3. Thus, Wright's (2000) rank-based test statistics, R_1 and R_2, are:

$$R_1 = \left(\frac{\frac{1}{Nk} \sum_{t=k+1}^{N} (r_{1t} + r_{1t-1} \ldots\ldots + r_{1t-k})^2}{\frac{1}{N} \sum_{t=1}^{N} r_{1t}^2} - 1 \right) \times \left(\frac{2(2k-1)(k-1)}{3kN} \right)^{-1/2} \tag{14}$$

and

$$R_2 = \left(\frac{\frac{1}{Nk}\sum_{t=k+1}^{N}(r_{2t} + r_{2t-1} \ldots\ldots + r_{2t-k})^2}{\frac{1}{N}\sum_{t=1}^{N} r_{2t}^2} - 1 \right) \times \left(\frac{2(2k-1)(k-1)}{3kN} \right)^{-1/2} \tag{15}$$

Wright (2000) also shows that it is possible to construct another nonparametric VR test using signs of returns; his sign-based VR statistic, S_1 and S_2 is obtained by substituting the time series with the signs of the variable (instead of the rank). More specifically, for any series y_t, let $\omega(y_t, q) = 1(y_t > q) - 0.5.$ Thus, $\omega(y_t, 0)$ is ½ if y_t is positive and -½ otherwise. Let $s_t = 2\omega(p_t, 0) = 2\omega(\varepsilon_t, 0)$. Clearly, s_t is an iid series with a mean of 0 and a variance of 1. Each s_t is equal to 1 with a probability ½ and is equal to -1 otherwise. The VR statistic using S_1 is[5]

$$S_1 = \left(\frac{\frac{1}{Nk}\sum_{t=k=1}^{N}(s_t + s_{t-1} \ldots\ldots + s_{t-k})^2}{\frac{1}{N}\sum_{t=1}^{N} s_t^2} - 1 \right) \times \left(\frac{2(2k-1)(k-1)}{3kN} \right)^{-1/2} \tag{16}$$

Note that S_1 is based on the assumption that the mean = 0, and this assumption is relaxed under S_2. Both S_1 and S_2 provide valid and exact tests even under conditional heteroskedasticity, although S_2 is more conservative. Wright (2000) argues that the ranks and signs test are more powerful than the conventional VR test and that the rank test outperforms the signs test. It should be mentioned that Wright's S_2 test is not considered here, as his Monte Carlo simulation results clearly indicate that its size and power properties are far inferior to those of S_1.

EMPIRICAL RESULTS

Unit Root Test

The results of Dickey-Fuller test in Table 1 shows that the null hypothesis of a unit root is not rejected for all exchange rates in the MENA currencies. This means that the spot rates of all currencies under study have a random walk behavior. Furthermore, Table 1 reports the results of the Phillips-Perron (1988) heteroskedasticity-robust unit root tests. Using a non-parametric correction for serial correlation, the P-P approach evaluates the presence of a unit root from the first order regression of time series. Once the first order regression with a constant or a time trend is obtained, the P-P statistics are computed by removing the effects of serial correlation on the asymptotic distribution. The P-P statistics are then checked against the same critical values as those used for the Dickey-Fuller (D-F) tests (Mackinnon, 1991). The P-P unit root hypothesis can be rejected if the *t*- or *Z*-test statistics is smaller than the critical value. It is shown in Table 1 that in all cases, the test statistics is not significant even at the 10% level.

Table1: Unit Root Tests for 10 MENA Exchange Rates Quoted in Terms of Euro

Currency	ADF_a	ADF_b	ADF_c	PP_a	PP_b	PP_c
Bahrain	-0.75	-0.58	-0.86	-1.03	-1.25	0.86
Egypt	-0.64	-1.15	-0.79	-0.58	-1.05	1.14
Jordan	-0.97	-0.77	-0.67	-0.93	-1.13	1.14
Kuwait	-1.13	-0.96	-1.18	-1.02	-1.33	1.26
Morocco	-0.76	-0.89	-1.12	-1.31	-1.41	0.65
Oman	-0.68	-0.66	-0.94	-0.67	-0.83	-1.11
Qatar	-0.64	-0.89	-1.14	-0.67	-1.14	-1.18
Saudi Arabia	-0.42	-0.73	-0.36	-0.88	-0.77	-1.07
Tunisia	-0.29	-0.56	-0.44	-0.55	-0.67	-1.25
United Arab Emirates	-0.69	-0.67	-0.67	-0.45	-1.14	-1.17

Note: The ADF and PP are the Augmented Dickey Fuller and Phillips-Perron unit root tests with intercept (a), with trend and intercept (b), and with neither trend nor intercept (c), respectively.

In summary, the null hypothesis of a unit root is not rejected by the P-P tests for all MENA currencies under study. This means that when the effects of auto- or serial-correlation are removed, spot rates in these countries did have random walk patterns for the period under investigation.

LOMAC VARIANCE RATIO TEST

The variance ratio test designed by Lo and MacKinlay (1988, 1989) are more powerful than the Dickey-Fuller unit root test in detecting violations of spot rates from a random walk. However, the variance ratio tests are not necessary more powerful when compared to the Phillips-Perron unit root test for time series that contain large auto regression errors.

Under the null hypothesis that spot rates follow a random walk, the variance ratios are expected to be equal to 1. The random walk hypotheses for 10 MENA currencies are tested by calculating VR(q), $Z(q)$, and Z*(q) for cases: q = 2, 4, 8, and 16, with one week spot rate used as the base. Variance ratio values for cases q greater than 16 are not evaluated because the variance ratio may have a distorted empirical distribution when q is larger relative to the sample size.

The results from these calculations are presented in Tables 2 and 3. While the variance-ratios VR(q) are reported in the main rows in each table, the *Z*- and *Z** -statistics are given in the parentheses in Tables 2 and 3, respectively. It is shown in Table 2 that under the hypothesis of homoskedasticity for the entire period, there is evidence that random walk hypothesis can be rejected for the following currencies: Egyptian Pound at q = 4, for the Jordanian Dinar at q = 8, for the Moroccan Dirham at q = 4, and for the Tunisian Dinar at q =16. However, the hypothesis cannot be rejected for the other currencies.

Table 2: Estimates Of Variance Ratios [Var(Q)] And Homoskedasticityvariance Ratio Test Statistics [Z(Q)] Quoted In Terms Of Euro

Currency	q=2	q=4	q=8	q=16
Bahrain	0.945 (0.92)	0.973 (1.11)	0.966 (0.99)	1.054 (0.89)
Egypt	1.023 (1.13)	1.265 (2.34)**	1.074 (1.09)	0.975 (0.97)
Jordan	0.965 (0.78)	0.98 (1.11)	1.56 (3.89)***	1.08 (0.78)
Kuwait	0.985 (0.89)	0.953 (0.92)	1.011 (1.09)	0.98 (0.78)
Morocco	0.932 (1.09)	1.59 (2.33)**	0.973 (0.91)	1.055 (1.16)
Oman	0.983 (0.78)	1.023 (1.12)	1.08 (0.78)	1.062 (0.99)
Qatar	0.983 (0.78)	0.931 (0.67)	0.972 (0.87)	0.965 (1.03)
Saudi Arabia	1.013 (0.76)	0.982 (0.94)	0.954 (0.69)	1.062 (1.01)
Tunisia	0.933 (0.84)	0.964 (0.93)	0.983 (1.10)	1.36 (3.98)***
United Arab Emirates	0.961 (0.87)	0.982 (0.93)	0.991 (1.02)	0.983 (0.94)

***, ** Variance ratios are significantly at the 1% and 5% level, respectively.

The test statistics, Z(q), reported above are computed under the assumption of homoskedasticity of spot rates. Therefore, these results, specifically for Egypt, Jordan, Morocco, and Tunisia, may be induced by the presence of heteroskedasticity. Lo and MacKinlay (1988) suggest a correction for heteroskedasticity. The heteroskedasticity-consistent test statistics $Z^*(q)$ for lags q = 2, 4, 8, and 16 are reported in Table 3 for the 10 currencies. The test results indicate that Z*(*q*) is not rejected for all MENA currencies under study. After adjusting for the heteroskedasticity in the spot rate series, the results for the 10 MENA currencies shown in Table 3 support the random walk behavior hypothesis of foreign exchange rates.

Table 3: Estimates Of Variance Ratios [Var(Q)] And Heteroskedasticityvariance Ratio Test Statistics [Z^*(Q)] Quoted In Terms Of Euro

Currency	q=2	q=4	q=8	q=16
Bahrain	0.945 (0.81)	0.973 (0.89)	0.966 (0.73)	1.054 (0.68)
Egypt	1.023 (1.03)	1.265 (1.21)	1.074 (0.93)	0.975 (0.74)
Jordan	0.965 (0.65)	0.98 (1.01)	1.56 (1.12)	1.08 (0.57)
Kuwait	0.985 (0.67)	0.953 (0.73)	1.011 (0.86)	0.98 (0.58)
Morocco	0.932 (0.87)	1.59 (1.11)	0.973 (0.76)	1.055 (0.88)
Oman	0.983 (0.56)	1.023 (0.92)	1.08 (0.62)	1.062 (0.78)
Qatar	0.983 (0.52)	0.931 (0.42)	0.972 (0.61)	0.965 (0.83)
Saudi Arabia	1.013 (0.65)	0.982 (0.83)	0.954 (0.39)	1.062 (0.75)
Tunisia	0.933 (0.74)	0.964 (0.79)	0.983 (0.92)	1.36 (0.99)
United Arab Emirates	0.961 (0.75)	0.982 (0.85)	0.991 (0.82)	0.983 (0.78)

VARIANCE RATIO TESTS BASED ON RANKS AND SIGNS

The results based on ranks and signs are reported in Table 4. The results of Variance ratio test based on R_1 reject the random walk hypothesis of Euro exchange rates in Egypt, Jordan, Morocco, Qatar, and Saudi Arabia. However, the hypothesis cannot be rejected in the remaining exchange rates. When we apply R_2, the hypothesis can be rejected in all currencies except the Kuwaiti and the Emirate currencies. The results of sign-based variance ratio reject the hypothesis in five currencies namely: Jordanian, Moroccan, Qatari, Saudi Arabian, and Tunisian currencies.

In summary, the results for individual *k* values reported in Table 4 suggest that the null hypothesis of random walk can be rejected for all nominal exchange rates, with the exception of the Kuwaiti Dinar and Emirate Dirham. The results of the non-parametric variance ratio tests contradict the results of the traditional LOMAC variance ratio test. Given the improved size and power properties of Wright's (2000) rank and sign tests, the results of the new variance ratio tests based on ranks and signs are robust to the results of the traditional LOMAC variance ratio tests. Furthermore, Wright's tests do not rely on the asymptotic approximations to the sampling distributions of the statistics. This is because Wright's tests use the exact distributions or data-intensive approximations to sampling distribution of the statistics.

SUMMARY AND CONCLUSION

This paper employs the new non-parametric variance ratio test in addition to the traditional variance ratio test and unit root, to examine the behavior of Euro exchanger rates from January 2000 to December 2004. This paper tests whether spot rates for 10 currencies in the Middle East and North Africa (MENA) follow a random-walk process consistent with the weak form efficient market hypothesis.

Table 4: Estimates Of Variance Ratio Tests Based On Ranks And Signs

Currency	k=2	k=4	k=8	k=16
Bahrain				
R_1	0.966	0.969	0.971	1.041
R_2	0.667	0.569	2.771*	1.241
S_1	0.568	0.869	1.171	1.141
Egypt				
R_1	2.313*	2.954*	2.132*	1.251
R_2	0.613	3.155*	2.753*	0.565
S_1	1.113	0.715	1.153	0.865
Jordan				
R_1	0.971	2.269*	2.312*	2.352*
R_2	0.771	0.669	2.495*	1.173
S_1	0.761	0.819	2.345*	1.255
Kuwait				
R_1	0.963	0.971	1.021	0.968
R_2	1.163	1.371	1.121	0.568
S_1	0.863	1.171	1.432	0.668
Morocco				
R_1	0.967	1.08	3.246*	3.321*
R_2	0.467	2.673*	0.946	1.221
S_1	0.767	2.281*	0.834	1.321
Oman				
R_1	0.975	1.016	1.312	1.045
R_2	0.875	3.345*	1.131	1.145
S_1	0.775	1.216	1.021	1.212
Qatar				
R_1	0.991	0.945	2.268*	0.976
R_2	0.791	2.565*	0.928	1.276
S_1	0.879	2.845*	2.768*	1.034
Saudi Arabia				
R_1				
R_2	2.421*	3.011*	2.569*	1.036
S_1	1.123	0.791	3.671*	1.136
	1.221	0.891	2.649*	1.231
Tunisia				
R_1	0.963	0.971	0.971	1.027
R_2	0.763	2.571*	0.876	1.123
S_1	0.734	2.471*	2.556*	1.342
United Arab Emirates				
R_1	0.971	0.965	0.987	0.991
R_2	0.771	0.865	0.687	0.791
S_1	0.271	0.665	0.567	0.861

Note: * indicates significance at (individual) 5% level.

The results of Dickey-Fuller test show that the null hypothesis of unit root is not rejected for all exchange rates in the MENA currencies. Furthermore, when the effects of auto- or serial-correlation under Phillips-Perron test are removed, spot rates in these countries did have random walk patterns for the period under investigation.

Furthermore, the results of traditional variance ratio test under the assumption of homoskedasticity of spot rates show that the random walk hypothesis can be rejected for certain lags in Egypt, Jordan, Morocco, and Tunisia currencies. However, after adjusting for heteroskedasticity in the spot rate series, the results for 10 MENA currencies support the random walk behavior hypothesis of foreign exchange rates.

However, the results of variance ratio tests based on ranks and sign contradict the results of the traditional variance ratio test. The random walk hypothesis of the Euro exchange rates is rejected in all countries under study except for the Kuwaiti and Emirate currencies. Finally, our analysis shows that Wright's (2000) ranks and sign tests yield statistical inference that is relatively more powerful than what can be drawn from Lo-MacKinlay VR tests.

REFERENCES

1. Baillie, R. and Bollerslev, T. (1989). Common Stochastic Trends in a System of Exchange Rates. *Journal of Finance*, 44, 167-181.
2. Dickey, D. and Fuller, W. (1979). Distribution of the Estimators for Autoregressive Time Series with a Unit Root. *Journal of the American Statistical Association,* 74, 427-431.
3. ______. (1981). Likelihood Ratio Statistics for Autoregressive Time Series with a Unit Root. *Econometrica*, 49, 1057-1072.
4. Enders, W. (1989). Unit Roots and the Real Exchange before War World I: The Case of Britain and the USA.. *Journal of International Money and Finance*, 8, 59-73.
5. Franch, J. and Opong, K (2004). Some Evidence of Random Walk Behavior of Euro Exchange Rates Using Ranks and Signs. *Journal of Banking and Finance*, Forthcoming.
6. Fuller, W. (1976). *Introduction to Statistical Time Series.* (New York: John Wiley).
7. Hamao, Y., Masulis, R., and Ng, V. (1990) Correlation in Price Changes across International Stock Markets, *Review of Financial Studies* 3, 281-307.
8. Hsieh, D. (1988). The Statistical Property of Daily Exchange Rates: 1974-1983. *Journal of International Economics*, 24, 129-145.
9. Huang, B. (1995). Do Asian Stock Market Prices Follow Random Walks? Evidence from the Variance Ratio Test. *Applied Financial Economics,* 5, 251-256.
10. Lo, 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.
11. Lo, W. and MacKinlay, C. (1989). The Size and Power of the Variance Ratio Test infinite Samples: A Monte Carlo Investigation. *Journal of Econometrics,* 40, 203-238.
12. Mackinnon, J. (1991). Critical Values for Cointegration Tests, In R.F. Engle and C. W. Granger, eds,: *Long-Run Economics Relationships* (Oxford University Press), 267-276.
13. Meese, R. and Singleton, K. (1982). On Unit Roots and the Empirical Modeling of Exchange Rates. *Journal of Finance,* 37, 1029-1035.
14. Newey, W. and West, K. (1987). A simple Positive Semi-definite, Heteroskedasticity and Autocorrelation Consistent Covariance Matrix. *Econometrica*, 55, 703-708.
15. Perron, P. (1988). Trends and Random Walks in Macroeconomic Time Series: Further Evidence from a New Approach. J*ournal of Economic Dynamics and Control,* 12, 297-332.
16. Phillips, P. and Perron, P. (1988). Testing for a Unit Root in Time Series Regression. *Biometrica*, 75, 335-346.
17. Said, S.E. and Dickey, D.A. (1984). Testing for a Unit Roots in Autoregressive-Moving Average Models of Unknown Order. *Biometrica*, 71, 599-608.
18. Wright, J. (2000). Alternative Variance-Ratio Tests Using Ranks and Signs. *Journal of Business and Economics Statistics,* 18, 1-9.

ENDNOTES

1. The major countries examined in their study are: Australia, Canada, Japan, UK, US, New Zealand, Norway, Singapore, Sweden, and Switzerland. The random walk hypothesis is rejected in the Canadian and Singapore dollar.
2. On January 1, 1999, the Euro became the currency of 11 European countries.
3. The short historical data avaialble for the Euro may have some impact on the results.
4. The exchange rates in all countries under study are characterized by ARCH (1) model, suggesting that the heteroskedasticity-consistent *z*-score is appropriate. The results of ARCH (1) model are available upon request from the author.

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