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Evidence of market inefficiency and exchange rate predictability in Ghana

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Abstract

The random walk behaviour of exchange rates in Ghana is explored by employing parametric and non-parametric variance ratio tests based on ranks and signs. The paper fills an important gap by using various time series techniques to investigate the efficiency of the foreign exchange market in Ghana. The conclusive evidence based on non-parametric variance ratio tests indicates that the behaviour of monthly Cedi/US dollar exchange rates is inconsistent with the random walk process and the weak-form efficient market hypothesis. This supports prior findings of the validity of long-run purchasing power parity and predictability of exchange rates in Ghana.

1. Introduction

The efficiency of foreign exchange markets continues to occupy an important place in monetary policy making (Sarno and Taylor, 2001). According to the Efficient Market Hypothesis (EMH), the ability of a market to incorporate freely and fairly relevant information in the price generation process is suggestive of its level of efficiency (Fama, 1970). The weak form of the proposition which claims that markets must follow an unpredictable or random walk trend has attracted a considerable amount of empirical research in the past few decades. Attributable to the unrelenting attempt by analysts and researchers alike to investigate this hypothesis a lot of controversy has been generated and leaves the matter far from settled.

Studies on the behaviour of exchange rates have serious implications for economic policy making, market efficiency and risk modelling. On one hand, the efficiency of the market prevents excess profitable opportunities in transactions. In such markets government interventions become minimal. Conversely, an efficient market makes it challenging for policymakers and financial analysts to develop models that best predict exchange rate movements. Market efficiency makes it daunting for policymakers to establish appropriate models to manipulate exchange rates, reduce excessive volatilities in the market and evaluate the outcomes of different economic policies.

Different techniques have been applied to model real exchange rates but the matter still remains mixed and scattered. A long tradition exists concerning tests for random walk (hereafter, RW) and stationarity hypothesis in the macroeconomics and finance literature. According to Sarno and Taylor (2002), three approaches used to test for stationarity of the real exchange rate are unit root tests, VR test, and fractional integration. Some previous studies have reported that the RW hypothesis cannot be rejected for the real exchange rates (Roll, 1979; Adler and Lehmann, 1983; Darby, 1983; and Huang, 1987). Despite this seeming consensus, Belaire-Franch and Opong (2005a, 2005b), Lee *et al.* (2001), Pan *et al.* (1996), Whitt (1992, 1989) and Huizinga (1987) have found evidence rejecting the RW hypothesis. It is claimed that the failure of many studies to reject the RW in the real exchange rate series is probably caused by the poor power of the tests applied rather than as evidence opposing the long-run validity of PPP (Hakkio, 1986; Abuaf and Jorion, 1990).

A class of tests based on the variance-ratio (hereafter, VR) methodology has gained tremendous popularity (see, for example, Campbell and Mankiw, 1987; Cochrane, 1988; Lo and MacKinlay, 1988; Poterba and Summers, 1988). Lo and MacKinlay (1988) show that the VR test is more powerful than unit root test, and Ayadi and Pyun (1994) also argue that VR has more appealing features than other procedures. The tests have been widely applied to stock returns in emerging markets (Chaudhuri and Wu, 2003; Chang *et al*., 2004 – for Latin America; Smith and Ryoo, 2003 – for Eastern Europe; Hoque *et al*., 2007; Kim and Shamsuddin, 2008 – for Asian markets; and Smith *et al*., 2002; Al-Khazali *et al*., 2007; Lagoarde-Segot and Lucey, 2008 – for African markets. For exchange rates, variants of the tests have been applied by Liu and He (1991), Fong *et al.* (1997), Wright (2000), Yilmaz (2003), Belaire-Franch and Opong (2005a, 2005b), Lima and Tabak (2007, 2008), Chen (2008), among others.

The present paper makes a contribution to the literature by examining the predictability of exchange rates in Ghana using a battery of techniques including the parametric and non-parametric VR tests. The issue has become very problematic for Ghana considering the threats posed by the excessive volatility of exchange rates to macroeconomic stability. The study is significant as it follows an empirically robust non-parametric VR test proposed by Wright (2000). A significant innovation in this is that to the best of our knowledge, this will be the first study that applies this powerful test to the Ghanaian exchange rates market not counting a few studies that have considered the PPP and exchange rates modelling in Ghana using unit root and cointegration approach (see, for example, Alagidede *et al.* 2008; Tweneboah, 2010, Iossifov and Loukoianova, 2007; among others); and (Bahmani-Oskooee and Gelan, 2006) through STAR techniques. More importantly, the heteroscedasticity-consistent test is robust to heteroscedasticity and to non-normality, considering that there is increasing evidence that exchange rates often exhibit time-varying volatilities and deviations from normality (see, Westerfield, 1977, Rogalski and Vinso, 1978, Hsieh, 1988, and Baillie and Bollerslev, 1989).

The remainder of the paper is organised as follows: Section 2 describes the modelling technique applied in the study. Section 3 is the empirical results for the tests and a discussion of the policy implications derived from the results. Section 4 is a summary and conclusion of the paper.

2. The VR Modelling Technique

The methodology follows Lo and MacKinlay's (1988; 1989) parametric and Wright's (2000) non-parametric VR tests to examine the behaviour of exchange rates in Ghana. According to Lo and MacKinlay (1988), if the natural logarithm of a time series follows a pure RW data generating process, increments in the variance of its q-differences is linear with the difference in a finite sampling interval. The methodology comprises a test for RW against stationary alternatives. This implies that, the variance of the q-period differences, $y_t - y_{t-q}$ of the time series, y_t, is q times the sample variance of the first difference, $y_t - y_{t-1}$, such that the variance computed at each individual lag interval q ($q = 2, 3, \ldots$) is unity for all horizons. A time series (in level) is said to be a non mean-reverting process if it has a variance significantly higher than unity at long horizons (see, Poterba and Summers, 1988). Application of the VR statistic is useful when conducting tests against alternatives to the RW model, most remarkably those hypotheses associated with mean reversion. The VR statistic is acclaimed to have optimal power against such alternative by proponents (see, Lo and MacKinlay, 1989; Richardson and Smith, 1991; Faust, 1992).

2.1 Lo-MacKinlay Parametric Tests

Basically, Lo and MacKinlay (1988, 1989) designed two VR tests for examining RW hypothesis; LM1 assuming homoscedasticity (i.e. independent and identically distributed process), and LM2 estimates robust against heteroscedasticity. If e_t is a time series consisting of T observations, $e_1, e_2, \ldots, e_T$ of exchange rates, the VR of the q-difference, VR(q) is defined as:

$$VR_{(q)} = \frac{\partial^2(q)}{\partial^2(1)} \qquad (1)$$

where $\partial^2(q)$ is the unbiased estimator of $1/q$ of the variance of exchange rates q-th differences under the null; $\partial^2(1)$ is the variance of the first difference of the exchange rates, q is the base lag ($q =$ 2, 4, 8 and 16 in this study). Under the null hypothesis of a RW data generating process, the variances for all q-th lags are expected to be equal to unity. According to LM (1988), the estimator

$$\partial^2(q) = \frac{1}{Tq}\sum_{t=q}^{T}(e_t + \ldots + e_{t-q+1} - q\overline{\mu})^2 \quad (1.a)$$

where $= \frac{1}{T}\sum_{t=1}^{T} e_t$ is the estimated arbitrary drift parameter. The unbiased estimator of the variance of the first difference,

$$\partial^2(1) = \frac{1}{T}\sum_{t=1}^{T}(e_t - \overline{\mu})^2 \quad (1.b)$$

Therefore, the null hypothesis of RW under the assumption of homoscedasticity, is normally distributed with zero mean, and unit variance,

$$LM_1(q) = \frac{VR(q) - 1}{f(q)^{1/2}} \quad (2)$$

where the homoscedastic asymptotic variance of the VR is given as

$$\Phi(q) = \frac{2(2k-1)(k-1)}{3k - T} \quad (2.a)$$

The second test, LM2 which is robust against heteroscedasticity and non-normalities is given as follows:

$$LM_2(q) = \frac{VR(q) - 1}{\Phi^*(q)^{1/2}} \quad (3)$$

with the corresponding hetereoscedasticity-consistent asymptotic variance for the test statistic defined as:

$$\Phi^*(q) = \sum_{j=1}^{q-1}\left[\frac{2(q-1)}{q}\right]^2 \delta_j \quad (3.a)$$

and

$$\delta_j = \frac{\sum_{t=j+1}^{T}(e_t - \overline{\mu})^2 (e_{t-j} - \overline{\mu})^2}{\sum_{t=1}^{T}(e_t - \overline{\mu})^2} \quad (3.b)$$

The two statistics proposed by Lo and MacKinlay (1988) for testing individual VR estimates are robust under homoscedasticity and heteroscedasticity. The tests examine the VR statistics for several q values and reject the null if it is rejected for some q's. However, Chow and Denning (1993) claim that this sequential procedure leads to an oversized testing strategy. This argument has led to the extension of the individual tests to multiple VR comparison tests (Chow and Denning, 1993) and Wald-type joint tests (Richardson and Smith, 1989; Cecchetti and Lam, 1994).

Again, other arguments premised on the fact that the LM and multiple VR tests are approximated by their limiting distributions, have led to some transformation of the traditional tests. Irrefutably, the asymptotic sampling distribution of the VR statistic can be far from normal in a finite sample exhibiting severe bias and right skewness. Cecchetti and Lam (1994) argues that the finite sample deficiencies may give rise to serious size distortions or low power, which can lead to misleading inferences, especially when the sample size is not large enough to justify asymptotic approximations. In order to avoid this, some transformations such as Wright (2000) – exact VR tests based on ranks and sign, Whang and Kim (2003) with a sub-sampling approach, Chen and Deo (2004, 2006) – a power transformed VR statistic, and Kim (2006) – a bootstrap method, among others have been proposed.

2.2 Non-Parametric VR tests based on Wright's Ranks and Sign

Based on the weaknesses associated with the conventional asymptotic sampling distributions, Wright (2000) proposes non-parametric tests that preference the use of signs and ranks to the differences in the LM tests. Wright argues that the non-parametric tests can have high power over a wide variety of models exhibiting serial correlation, including fractional integration. The ranks-based tests are exact under the IID assumption, while signs-based tests are exact even under conditional heteroskedasticity. Besides, Wright (2000) claims that under conditional heteroskedasticity ranks-based tests display low size distortion. Wright's proposed standardized rank (WR1) and van der Waerden rank scores (WR2), for T observations of exchange rates $\{e_1, e_2, ..., e_T\}$, are defined as follows:

$$WR_1(q) = \left(\frac{\frac{1}{Tq}\sum_{t=q}^{T}(r_{1t} + ... + r_{1t-q+1})^2}{\frac{1}{T}\sum_{t=1}^{T} r_{1t}^{\ 2}} - 1 \right) \times \varphi\,(q)^{-1/2} \tag{4}$$

where

$$r_{1t} = \left(\frac{r(e_t - \frac{T+1}{2}}{\sqrt{\frac{(T-1)(T+1)}{12}}} \right) \tag{4.a}$$

Also,

$$WR_2(q) = \left(\frac{\frac{1}{Tq}\sum_{t=q}^{T}(r_{2t} + ... + r_{2t-q+1})^2}{\frac{1}{T}\sum_{t=1}^{T} r_{2t}^{\ 2}} - 1 \right) \times \varphi\,(q)^{-1/2} \tag{5}$$

where

$$r_{2t} = \phi^{-1}\left(\frac{(r(e_t)}{T+1} \right) \tag{5.a}$$

and

$$(q) = \frac{2(2q-1)(q-1)}{3qT} \quad (5.b)$$

$r(e_t)$ is the rank of e_t among $e_1, e_2, ..., e_T$, and Φ^{-1} is the inverse of the standard normal cumulative distribution function.

In another development, a modification of the homoskedastic LM statistic was proposed by Wright in which each e_t is replaced by its sign as follows:

$$WS(q) = \left(\frac{\frac{1}{Tq}\sum_{t=q}^{T}\left(s_t(\bar{\mu}) + ... + s_{t-q+1}(\bar{\mu})\right)^2}{\frac{1}{T}\sum_{t=1}^{T} s_t(\bar{\mu})^2} - 1 \right) \cdot \phi(q)^{-1/2} \quad (6)$$

where $s_t = 2u(e_t, 0)$, $s_t(\bar{\mu}i) = 2u(e_t, \bar{\mu}i)$ and $u(x_t, q) = \begin{cases} 0.5, x_t > q, \\ -0.5, \text{otherwise} \end{cases}$

This statistic is valid under the martingale difference sequence (*MDS)* null, as well as under the assumption that $\mu = 0$, the exact sampling distribution may also be approximated using a permutation bootstrap.

3. Empirical Result & Analysis

3.1 Data and Preliminary Evidence

The behaviour of monthly nominal and real GHS/USD exchange rates is examined applying a battery of techniques. The data spans the period 1963:M3 to 2013:M5 giving us 603 observations. The nominal exchange rate data and the consumer price index for Ghana and the United States are obtained from the International Financial Statistics published by the International Monetary Fund (IMF). Figure 1 and 2 are plots of nominal and real exchange rates respectively. A summary of the descriptive statistics of the logarithm of the nominal and real cedi/dollar exchange rates (levels and returns) are reported in Table 1. Whereas there is a higher probability of decreases in the levels series, the returns indicate a possibility of large increases due to its positive skewness. The non-normality of the distribution both in the levels and returns series is confirmed by the highly leptokurtic nature especially in the returns series. These results seem consistent with the Jarque-Bera test of normality which rejects the null hypothesis of normal distribution. Further analysis of normality through the empirical distribution tests indicates that the series do not exhibit normal distribution. A comparison of the mean and standard deviation also reveal high volatility in the exchange rates.

Table 1: Descriptive statistics

	Mean	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis	JB	LBQ(12)
Levels-N	-4.70	0.68	-9.55	3.86	-0.02	1.33	0.00	7018.6*
Returns-N	0.02	2.39	-0.35	0.11	17.16	356.27	0.00	2.17
Levels-R	-0.78	0.32	-4.05	0.84	-1.59	5.38	0.00	6446.9*
Returns-R	0.00	2.33	-0.33	0.11	14.78	291.47	0.00	6.93

N=nominal, *R*=real and * denotes statistical significance at 1% level. JB is the *p*-values of Jarque-Berra statistic for normality. LBQ is the Ljung-Box test statistic for autocorrelation.

Figure 1: Plot of nominal GHS/USD exchange rates

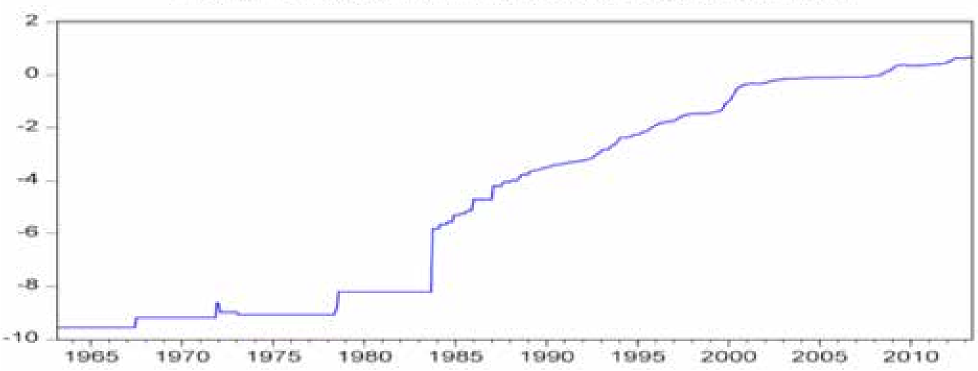

Figure2: Plot of real GHS/USD exchange rates

3.2 Evidence of nonlinearities in residuals of ARMA (1, 1) model

The ordinary least squares regression procedure was applied to fit an ARMA model to be able to test for additional properties of the data such as serial correlation, conditional heteroskedasticity, and nonlinear independence. The Ljung-Box

Q-statistic (LBQ) and Breusch-Godfrey Serial Correlation LM Test (LM)[6] are applied on the residuals of the model and the lag length selected based on the Akaike and Schwarz information criterion. The LBQ statistics and LM respectively show that all the series are not significantly serially correlated and do not exhibit conditional heteroskedasticity.

In order to examine further the properties of the data, we employed the nonlinear diagnostic tests for evidence of IID process through the technique described in Brock, *et al.* (1996). The results are shown in Table 2. We specify the epsilon as a fraction of pairs, since that is most invariant to different distributions of the series. Table 2 indicates all the test statistics are significantly greater than the critical values and strongly reject the null hypothesis of I.D.D. The results strongly suggest that the time series exhibit nonlinear serial dependence behaviour.

Table 2: BDS Independence Test

	Nominal				*Real*			
M	2	3	4	5	2	3	4	5
BDS	0.07	0.12	0.16	0.18	0.07	0.12	0.14	0.16
S.E.	(0.002)	(0.003)	(0.004)	(0.004)	(0.005)	(0.007)	(0.009)	(0.009)
Z-stat	11.76	12.85	13.33	14.51	14.68	14.83	15.38	16.44

Note: m represents dimension which is the number of consecutive data points to include in the set. The epsilon is set at 0.7. Standard errors are in parenthesis. The BDS statistics indicates that all the p-values under the null hypothesis of a serially iid process are zero. The bootstrap probabilities give similar results at 1000 reps.

As a portmanteau test for independence the BDS test can be used for testing against a variety of possible deviations from IID, non-linear dependence, or chaos. Under the assumption of independence, the statistic would be expected to be close to zero. Although, there is evidence of no statistically significant correlations in the series, the BDS test strongly rejects the null of linearity at the 1% level. All the *p*-values are zero, indicating strong departures from the IID condition. Alagidede (2011) claims that the presence of nonlinearities in African stock returns could imply evidence of return predictability as the successful application of technical trading rules require some form of nonlinearity in prices (Neftci, 1991), and also serves as a necessary condition for trading rules to have potential predictive power according to Mills (1997). Alagidede (2011) attributes the evidence of nonlinearities in African stock markets to market inefficiency, delayed responses to information, or different reactions of investors to price sensitive information.

[6] Results of LBQ and LM tests are available upon request

3.2 Parametric VR Tests

In Table 3 we report the Lo and MacKinlay VR test statistics for both the homoscedastic and heteroscedasticity robust assumptions. The Z-statistics are calculated for various *q*'s by using 1-month as our base horizon, and alternative *Z*-statistics calculated by matching the variance of the base interval with that of the 2-month, 4-month, 8-month, and 16-month periods. The VR(*q*) for each *q*, and the Var[VR(*q*)] are calculated and used to generate the corresponding Z-statistics, Z(*q*), for each of the *q*'s = 2, 4, 8, and 16. We report similar findings for monthly returns for both nominal and real exchange rates as well as for asymptotic and bootstrap probabilities.

Table 3: Lo-MacKinlay VR Estimates

q	2	4	8	16	CD	X^2
Nominal GHS/USD exchange rates						
VR(q)	1.00	0.99	1.01	1.05		
Z(q)	0.17	0.15	0.11	0.30	0.30 (0.99)	0.70(0.95)
Z^*(q)	0.98	0.03	0.59	1.14	1.36 (0.69)	
Real GHS/USD exchange rates						
VR(q)	1.03	1.06	0.99	0.97		
Z(q)	0.74	0.79	0.09	0.17	0.79(0.89)	3.20(0.52)
Z^*(q)	1.50	1.39	0.13	0.11	1.50(0.43)	

Note: VR(*q*) represents the VRs for *q*-monthly periods. Z(*q*) is the VR test statistics assuming homoscedasticity, and Z*(*q*) is the heteroscedasticity robust VRns. CD is the Chow-Denning multiple test statistics, with *p*-values in ( ).

From the results, both Z(*q*) and Z*(*q*) are not statistically significant, thus failing to reject the RW hypothesis. Test statistics based on the multiple VR test methodology by Chow and Denning (1993) as reported on the table also support the RW hypothesis. Again, when the tests were subjected to wild bootstrap probabilities as suggested by Kim (2006) the results were not different. Since the results are similar, it can be said that there is no autocorrelation or heteroscedasticity in the series. However, parametric tests are said to have low power compared to non-parametric tests (see, Lehmann, 1975; Luger, 2003).

3.3 Non-Parametric VR tests using Ranks and Signs

Wright's (2000) non-parametric VR test statistics based on ranks and signs are applied to further examine the RW and the MDS hypotheses. The variances presented in Table 4 provide strong evidence against the RW and MDS hypothesis. Again, the multiple/joint Chow and Denning and Richardson and Smith (1991) Wald (X^2) strongly reject the hypothesis. These results indicate that the behaviour of exchange rates is not consistent with the RW hypothesis.

Table 4: Wright's Rank and Sign Estimates

q	2	4	8	16	CD	X^2
Nominal GHS/USD exchange rates						
WR1	1.51	2.39	3.95	6.56	30.99	995.74
WR2	1.43	2.11	3.26	5.00	22.31	505.31
WS2	1.63	2.85	5.17	9.51	47.44	2462.99
Real GHS/USD exchange rates						
WR1	1.48	2.11	2.60	3.66	14.83	307.85
WR2	1.46	2.04	2.51	3.52	14.05	274.00
WS	1.39	1.89	2.26	3.02	11.59	181.33

Notes: WR1, WR2 and WS represent the rank scores and sign VRs. X^2 is the Richardson and Smith (1991) Wald (Chi-square) multiple VR test. The *p*-values (not reported) indicate that all the tests reject the null hypothesis at the 1% significance level.

The results of the non-parametric VR tests contradict the earlier findings based on conventional Lo-MacKinlay's parametric VR tests. However, given the improved size and power properties of Wright's (2000) rank and sign tests, the results of the ranks and sign tests are robust. Wright's tests do not rely on the asymptotic approximations to the sampling distributions of the statistics but the exact distributions approximations to sampling distribution of the statistics. Also, as mentioned earlier in this paper, it has been argued that non-parametric tests are generally more powerful and better specified than parametric tests. The rejection of the RW hypothesis in support of validity of long-run PPP is consistent with prior evidence by Alagidede *et al.* (2008), Tweneboah (2010), Oguanobi *et al.* (2010), among others. Bahmani-Oskooee and Gelan (2006) reports similar findings for Ghana within a nonlinear STAR framework.

Although this present paper combines data from both fixed and floating exchange rates systems, our analysis is valid and consistent with both theoretical underpinnings of exchange rates and previous empirical studies. This evidence against market inefficiency may be attributed to the small size of the foreign exchange market in Ghana. The small market has only a few active players with the Bank of Ghana as the most dominant player responsible for over 90 per cent of the total transactions in the market. In line with Ajayi and Karemera (1996), our evidence of rejection of the RW process in exchange rates provides support for the classical monetary models of exchange rates, which hold PPP as the long-run equilibrium model. Albeit, since increments in exchange rates increase with time under a RW process, our evidence holds crucial implications for the long-run validity of PPP.

4.0 Conclusion and policy implications

The RW behaviour of exchange rates in Ghana is explored by employing parametric and non-parametric VR tests. The paper fills an important gap by using various time series techniques to investigate the efficiency of exchange rates markets in Ghana. We make use of the conventional Lo and MacKinlay's individual VR test for homoskedastic and heteroskedastic RWs, and Wright's ranks and signs non-parametric VR tests to examine the behaviour of monthly GHS/USD exchange rates over the period of January, 1963 to May, 2013. We report interesting revelations from the empirical analysis. The descriptive statistics and preliminary tests indicate non-normalities in the levels and returns series which denote that the data generating process of the series contain autocorrelated increments. Again, the exchange rates are found to be characterised by excess kurtosis, large standard deviations, and inherent leptokurtic behaviour. Further results based on BDS provide evidence of non-linearity which casts doubt about the efficiency of the market.

The results of the non-parametric VR tests suggest that the behaviour of both nominal and real exchange rates violate the RW process, and are therefore not consistent with the weak-form efficient market hypothesis. Both the ranks and signs based test statistics consistently reject the RW and the MDS hypotheses at the 1% significance level wherein the VR increases as the horizon increases. This evidence of predictability of exchange rates suggests the possibility of gaining excess returns eventually through speculation. Whereas the rejection of the weak form efficiency is consistent with previous evidence on exchange rates modelling in Ghana, it grants support to the argument that financial liberalization agenda embarked upon to date have not been so significant to improve market efficiency.

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