Do exchange rates follow random walks? A variance ratio test of the Zambian foreign-exchange market

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A B S T R A C T

The random-walk hypothesis in foreign-exchange rates market is one of the most researched areas, particularly in developed economies. However, emerging markets in sub-Saharan Africa have received little attention in this regard. This study applies Lo and MacKinlay's (1988) conventional variance ratio test and Wright's (2000) non-parametric ranks- and signs-based variance ratio tests to examine the validity of the random-walk hypothesis in the Zambian foreign-exchange market. The study utilises daily nominal United States dollar/Zambian kwacha (USD/ZMK) exchange-rate returns for data from August 2003 to December 2012. Both types of variance ratio tests reject the random-walk hypothesis over the data span. The implication is that technical and fundamental analysis can help traders and other investors to earn higher-than-average market returns.

Key words: variance ratio tests, random-walk hypothesis, exchange rates, market efficiency

Introduction

Many studies have been carried out to test the financial markets' efficiency ever since the seminal work by Fama (1970). Apart from stocks and equities, foreign-exchange is a key component of the financial market sector. The importance of the foreign-exchange market cannot be overemphasised. According to the Bank for International

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Settlements (BIS) statistics (2010) for the year 2010, the average daily foreign-exchange volume for the world foreign-exchange market was about US$4 trillion. Investment banks, commercial banks, local and multinational corporations, brokers and central banks are the major participants. Treasurers and fund managers keenly follow the exchange rate, as this helps them to manage or guard their exposures to other currencies and protect themselves against unfavourable exchange-rate movements using risk management tools. The foreign-exchange market is relevant not only to academics, but to central bankers and policy makers as well, since a clear understanding of the functioning of the markets will translate into better decision-making in terms of trade policy.

With increasing globalisation, nations are exposed to the international community, and trading in both goods and services will be affected to a large extent by movements in exchange rates. For instance, an appreciation of the local currency results in a loss of national competitiveness as exports become more expensive and trading partners switch to relatively cheaper sources. At the same time, traders benefit since imports become cheaper. Knowledge of the behaviour of exchange rates, in the context of randomness, is of interest to all parties including academics, practitioners and regulators (Belaire-Franch & Opong 2005). For many years, the random-walk hypothesis (RWH) has been topical; the theory has been challenged by academics and finance practitioners and as such has occupied an important place in finance (Rashid 2006). Whilst numerous studies have been conducted on the developed markets, little research has been carried out on relatively less-developed financial markets, particularly in sub-Saharan Africa. This paper contributes to the literature by extending the analysis to the exchange-rate market of the small but open commodity-exporting economy of Zambia.

An understanding of exchange-rate behaviour is important in formulating policies aimed at attaining macroeconomic stability in an economy, as exchange-rate uncertainty is certain to disturb set macroeconomic targets. Moreover, currency trading has become a huge source of revenue for the banking sector in Zambia. Understanding exchange-rate movements will therefore not only help in shaping macroeconomic policy, but also affect other foreign-exchange market participants such as currency traders and speculators. It is against this backdrop that this study aims to investigate the validity of the random-walk hypothesis for the United States dollar and Zambian kwacha (USD/ZMK) exchange-rate market, using Lo and MacKinlay's (1988) conventional variance ratio (VR) tests and Wright's (2000) ranks and signs test. Specifically, the study seeks to investigate whether successive daily nominal exchange-rate returns in the Zambian foreign exchange market follow a random-walk process.

This study will make a contribution in assisting to understand the pattern and behaviour of exchange-rate movements in Zambia. To the authors' best knowledge, there is no previous work investigating the random-walk hypothesis on the USD/ZMK exchange rate.

Brief institutional background of the exchange-rate mechanism in Zambia

The exchange-rate system in Zambia is broadly characterised by both fixed and floating exchange-rate policies. From independence in 1964 to 1982, and from 1987 to 1991, the monetary authorities adopted a fixed exchange-rate regime. This regime was sustained by an occasional adjustment of the exchange-rate system and other measures such as the issuing of import licences instead of official interventions in the exchange-rate market (Mkenda 2001). Between 1983 and 1985, the Zambian kwacha was pegged to a basket of its major trading partners' currencies with a monthly crawl of one per cent. The crawling peg was later revised to one and a half per cent due to the depressed economic conditions at that time. Towards the end of 1985, owing to conventional and political factors, the authorities introduced a floating exchange-rate regime whereby the central bank (Bank of Zambia) auctioned off foreign currency with the aim that the bidding system would guide the exchange rate (Chipili 2009). In 1992, the authorities abolished this system and a freely floating exchange-rate mechanism was introduced. The new system allowed commercial banks to trade foreign currency with the Bank of Zambia (BOZ) three times a week. This was later amended from three times a week to daily, in order to control the volatility in the exchange rate. Despite all these measures, Zambia, like many other commodity-exporting countries, witnessed an increase in exchange-rate volatility. As a result, a broad-based interbank foreign-exchange market (IFEM) system was introduced in July 2003 to address the weaknesses perceived in the previous exchange-rate regimes (Chipili 2009). According to the African Development Bank (ADB) (2007), the introduction of IFEM was considered an important step in improving efficiency in the market. This allowed commercial banks and other licensed agents to bid and offer foreign exchange on the interbank market, and corporates and individuals to sell and buy foreign exchange from commercial banks. The Zambian kwacha is freely tradable, and the liberalisation of the financial sector has attracted offshore investors, speculators and other traders.

The rest of the paper is organised as follows: the second section reviews the theoretical and empirical literature on financial market-price efficiency, discussing the Efficient Market Hypothesis (EMH) and the random-walk hypothesis (RWH);

the third section describes the data and the methodology used in this study; the results of the empirical work are presented and discussed in the fourth section; while the last section draws some conclusions.

Literature review

Theoretical framework

The Efficient Market Hypothesis (EMH) states that in an efficient market, asset prices fully reflect all available information about the asset, and investors therefore cannot consistently earn abnormal returns (Peirson, Bird, Brown & Howard 1995). In its weak form variant, the EMH implies that prices follow random-walk behaviour in which successive price changes have zero correlation (Trippi & Lee 1996). This weak form variant of the EMH is known as the random-walk hypothesis (Peirson et al. 1995). A random-walk model can be structured as follows: Let Y_t be a logarithm of the exchange rate at time t. The random-walk model for exchange rates states that Y_t follows a recursive equation,

$$Y_t = \delta + Y_{t-1} + \varepsilon_t \tag{1}$$

where δ is a drift parameter and ε_t is a white noise process. Owing to the EMH, foreign exchange rates are viewed as following random walks (Diebold & Nason 1990). In foreign-exchange markets, 'random walk' is understood to refer to the perceived random movements in financial prices, for instance exchange rates, whereby prices do not depend on past events but follow a random pattern. For the foreign-exchange market, this theory implies that traders and other market participants should not earn unusually higher returns than the market average through exploitation of past information. The existence of a random walk in a market confirms that current prices are independent of past prices, and thus the market is efficient.

Empirical literature

The seminal works of Poterba and Summers (1988) and Lo and MacKinlay (1988) have provided the foundation for VR tests of the random-walk hypothesis. This area has received significant research interest, but the literature on relatively less-developed markets is scanty. Despite a plethora of literature on the random-walk hypothesis in relation to developed markets, the results are still inconclusive. Gradojević, Djaković and Andjelić (2010) investigate the validity of the random-walk theory in the euro-

Serbian dinar exchange-rate market by applying Lo and MacKinlay's (1988) VR test and Wright's (2000) non-parametric ranks and signs tests to the daily euro–Serbian dinar exchange-rate returns. Both types of VR tests overwhelmingly reject the random-walk hypothesis over the data span.

Liu and He (1991) use five pairs of weekly nominal exchange-rate series (the Canadian dollar, British pound, Japanese yen, French franc and Deutsche mark, all relative to the US dollar) over the period from 7 August 1974 to 29 March 1989, to test the random-walk hypothesis using VR tests. In four out of five nominal exchange rates, the random-walk hypothesis is rejected. Vats and Kamaiah (2011) utilise both parametric and non-parametric tests to examine the behaviour of the weekly returns of eight currencies relative to the Indian rupee in the post-liberalisation period. The results show strong evidence rejecting random walk for the US and Hong Kong dollars relative to the Indian rupee. Furthermore, the results indicate mixed evidence of random walk for the Singapore dollar, but for the other five currencies, the random-walk hypothesis could not be rejected. Ajayi and Karemera (1996) examine the random-walk hypothesis using VR tests to examine the random-walk hypothesis for the currencies of eight economies of the Pacific Basin. The results show that the random-walk model is not consistent with market dynamics.

Chen (2009) examines the random-walk hypothesis for ten Pacific Basin foreign-exchange markets and rejects the RW hypothesis using the Lo-MacKinlay variance ratio tests. Al-Khazali, Ding and Pyun (2007) utilise non-parametric variance ratio tests to examine the empirical validity of the random-walk hypothesis in eight emerging markets in the Middle East and North Africa (MENA) region. The results show that a non-parametric VR test is appropriate for emerging stock markets. Lima and Tabak (2007) examine multiple variance ratio tests for emerging-market exchange rates that have recently adopted floating exchange-rate regimes on a daily and weekly frequency. The results support the random-walk hypothesis in both frequencies.

Swarna and Ghosh (1999) use daily data to examine the weak and strong forms of the EMH on the foreign-exchange markets of seven major currencies in Europe. The results rejected both forms of the market-efficiency hypothesis. Chen (2008) utilises Lo-MacKinlay's (1988) conventional VR test, Chow-Denning's (1993) simple multiple VR test, and Wright's (2000) non-parametric ranks- and signs-based variance ratio tests to test the random-walk hypothesis of the euro/US dollar exchange-rate market using data from January 1999 to July 2008. The results support the random-walk hypothesis and conclude that the euro/US dollar exchange-rate market is regarded as weak-form efficient. Rashid (2006) finds evidence for the random-walk hypothesis in Pakistan in five pairs of weekly nominal exchange rates using Lo and MacKinlay's (1988) VR tests. At best, the results on foreign-exchange market efficiency are mixed.

The study by Lo and MacKinlay (1988) is the foundation of the variance ratio test approach. It is by far the most important study on the random-walk hypothesis. However, the test focuses on testing one variance ratio at a time for a single observation interval. It is an individual hypothesis test. Other scholars (Chow & Denning 1993) have suggested that a proper test of the random-walk hypothesis should be based on multiple comparison of a set of variance ratios in order to have a correct overall size of the test, which requires a joint hypothesis test. This methodology is unpopular because it is valid only when sample autocorrelations of the random-walk increments are asymptotically uncorrelated, which might not be true due to the nature of some dependent time series. While many other tests have been developed over the years to try and remedy the possible shortcomings of earlier models, for instance the Whang-Kim subsampling test (Whang & Kim, 2003), wild bootstrap test (Kim, 2006) and non-parametric ranks and signs tests (Wright, 2000), the Lo and MacKinlay (1988) methodology still remains one of the most robust tests. Wild bootstrap test statistics are derived assuming that the underlying time series is conditionally homoscedastic. Owing to strong conditional heteroskedasticity observed in many financial time-series data, assuming a conditionally homoscedastic time series is a major weakness of this methodology (Kim 2006). While recent methodological advances in testing the random walk in exchange rates have been applied only to currencies of industrialised economies, this paper attempts to bridge this gap by employing variance ratio tests to examine the RWH for the USD/ZMK exchange rate. We contribute to the literature on the random-walk hypothesis by reporting findings based on these variance ratio tests. A further contribution is that, compared with most previous studies where samples end in the early 2000s, the period of analysis in this case extends to 2012, and therefore includes the most recent developments in the evolution of the Zambian foreign-exchange market.

Data

The study utilises daily nominal USD/ZMK exchange rates from 1 August 2003 to 31 December 2012 primarily sourced from I-Net Bridge. The Bank of Zambia economics department data are used to supplement omissions in I-Net data from 1 August 2003 to 31 December 2005. This period was chosen because it corresponds with the period when the Bank of Zambia introduced the Interbank-based framework of exchange rate in Zambia, that is, July 2003. Prior to this, foreign-exchange trading was done through an auction system. This means that the true reflection of the nominal exchange rate came into effect around this time. By allowing the forces of supply and demand to determine the foreign-exchange trading, the sample period shows a true reflection of the market value of the exchange rate. The data comprise daily closing foreign-exchange rates. Daily data are used because of being readily available, and the huge data set required to ensure better results is only possible with daily data. Historically, the USD/ZMK exchange rates exhibit huge daily swings, and the use of daily data ensures that this trend is captured in the analysis. The exchange-rate percentage returns (exchange-rate returns henceforth) are calculated in the usual format by taking the first differences of the natural logarithm of the exchange rates as follows:

$$Y_t = (\log P_t - \log P_{t-1})*100 \tag{2}$$

Where Y_t is the daily exchange-rate return, $\log P_t$ is the natural logarithm of the present day's exchange rate, and $\log P_{t-1}$ is the natural logarithm of the previous day's exchange rate.

Descriptive statistics

Table 1 gives the arithmetic mean, standard deviation, kurtosis and skewness of the nominal USD/ZMK daily exchange rate (nominal exchange rate henceforth), where the USD/ZMK exchange rate is the number of local currency units (ZMK) equivalent to one USD. The exchange rate of the Zambian kwacha ranges from 2935 to 5720 per one US dollar, with an average exchange rate of 4417 kwachas per dollar. Table 2 illustrates basic statistics for the daily returns of the USD/ZMK exchange rate. The daily return ranges from -16.81 to 8.29 per cent, with the mean and median of 0.0038 and 0.0000 per cent respectively. If a data series is exactly normally distributed, values of skewness and excess kurtosis are zero. Skewness measures the spread of returns around the mean. Negative skewness implies that the actual returns are likely to deviate further downwards from the mean returns, while positive skewness implies that actual mean returns are likely to deviate further upwards from the mean returns. A normal distribution has a skewness value of zero. Kurtosis measures the peakedness of a distribution compared to a normal distribution. The values of skewness and kurtosis in Tables 1 and 2 show that the distribution of the nominal USD/ZMK exchange rate and exchange-rate returns are negatively skewed and more peaked relative to a normal distribution. The negative skewness of the USD/ZMK exchange-rate returns indicates a tendency for the ZMK to depreciate against the USD (Vats & Kamaiah 2011). The Jarque-Bera test confirms that the daily nominal exchange rates and exchange-rate returns are not normally distributed at the one per cent level.

Table 1: Descriptive statistics for nominal USD/ZMK daily exchange rates

Nominal USD/ZMK	
Mean	4417.4640
Median	4556.1000
Maximum	5720.0000
Minimum	2935.0000
Standard deviation	586.6141
Skewness	-0.5044
Kurtosis	2.5613
Number of observations	2457
Jarque-Bera	123.9037*

* significant at one per cent level

Table 2: Descriptive statistics for the daily returns of USD/ZMK exchange rates

USD/ZMK exchange- rate returns	
Mean	0.003769
Standard deviation	1.092886
Minimum	-16.807380
Maximum	8.285791
Median	0.000000
Skewness	-1.528090
Kurtosis	33.928180
Number of observations	2457
Jarque-Bera	123.9037*

* significant at one per cent level

Note: Daily return at day *t* (Y_t) is computed as $Y_t = \log P_t - \log P_{t-1}$, where P_t is the USD/ZMK exchange rate on day *t*.

Methodology

The study utilises the variance ratio methodology developed by Lo and MacKinlay (1988) and Wright (2000)'s ranks and signs non-parametric VR tests and draws on the work by Vats and Kamaiah (2011) and Ajayi and Karemera (1996). We also make use of the well-known Augmented Dickey-Fuller unit root test and the Ljung-Box Q-statistic (1978) to test the autocorrelations in the series. To enable us to define clearly the methodology to be used in this paper, it is important to note the two implications of the RWH. The first implication is that the variance of a sample of a time series is proportional to the sampling interval. This indicates that the variance of a time-series return is linear in observation intervals, meaning increments are not correlated. The second implication is that expected future exchange-rate increments are unpredictable. This implies that the successive values of a time series are not correlated, and hence the time series does not have a unit root. This paper focuses on testing the first implication. This is because, apart from some important departures from the random walk that a unit root test cannot detect, the autocorrelation aspect may yield interesting implications for alternative models of exchange rates. However, a unit root test is carried out for the purposes of comparison.

Unit root test

We apply the well-known unit root test, namely the Augmented Dickey Fuller (ADF) test. This test is used to examine unit roots in a time series. We apply this test on exchange rates as well as on exchange-rate returns and expect the log of exchange rates to be integrated of order one, I(1) and the returns series to be integrated of order zero, I(0). The null hypothesis is that the series is non-stationary (unit root). We apply the following two regression models of the ADF test, namely models 1 and 2.

$$\text{Model 1: } \Delta y_t = c_0 + \delta_{t-1} \sum_{i=1}^{p} \Delta y_{t-1} + \mu_t \tag{3}$$

$$\text{Model 2: } \Delta y_t = c_0 + c_1 t + \delta y_{t-1} + \beta \sum_{i=1}^{p} \Delta y_{t-1} + \mu_t \tag{4}$$

Model 1 (intercept) includes a constant term c_0, while Model 2 (trend and intercept) includes a constant term c_0 and a trend term c_1; p is the number of lagged variable terms, and μ_t is white noise. We apply both models to our data in this study.

Ljung-Box Q-statistic Test

We make use of the Ljung-Box Q-statistic (1978) for comparison with our VR test. This is a derived version of Box-Pierce Q-statistic (1970). While the Box-Pierce Q test is a joint test of the hypothesis that the first k autocorrelation coefficients are zero and establishes that the data are independent and identically distributed (iid), the Ljung-Box Q-statistic is used to test the joint hypothesis that all the autocorrelation coefficients up to a defined lag (m) are simultaneously equal to zero (Ajayi & Karemera 1996). In other words, it tests for high-order serial correlation in the residuals. We apply this test to the nominal daily exchange-rate data. It is defined as:

$$Q = n(n+2)\sum_{k=1}^{m}\left(\frac{\rho_k^2}{n-k}\right) \tag{5}$$

Where n is the number of observations, m is the number of lags, and ρ_k is the autocorrelation coefficient at lag k. Q follows the chi-square distribution with m degrees of freedom. Ajayi and Karemera (1996) provide a comparison with the VR by implementing the Box-Pierce Q tests. Liu and He (1991) find that the basic difference between the Box-Pierce Q test and the VR ratio test is that the Box-Pierce Q test adds up the squares of the autocorrelations, while the VR ratio test adds up weighted autocorrelations. It follows, therefore, that given certain characteristics of the exchange-rate data series, the Box-Pierce Q test may not reject the null hypothesis, while the variance ratio does. Ajayi and Karemera (1996) indicate that it is also possible that the Box-Pierce Q test may be more powerful than the variance ratio test under restrictive conditions. The comparison therefore helps to make our results more robust.

Lo-MacKinlay variance ratio test

According to Vats and Kamaiah (2011), if a time series of returns follows a random walk, then in a finite sample the increments in the variance are linear in the observation interval; that is, the variance of returns should be proportional to the sample interval. In other words, the test implies that the increments in a random-walk series are linear in the sample interval. Specifically, the variance estimated from the q-period returns should be q times as large as the variance estimated from one-period returns (Vats & Kamaiah 2011). Thus, the variance of yearly returns should be 12 times the variance of monthly returns.

To test for the random walk in the exchange-rate series, we follow the procedure used by Lo and MacKinlay (1988) in testing the random walk process, where they used stock-market returns. This involves the use of specification tests based on variance estimates. In particular, the method exploits the fact that the variance of the increments in a random walk is linear in the sampling interval. In developing the variance ratio test, we follow Ajayi and Karemera (1996), in which, if a time series, such as spot exchange rates, $S_0, S_1, S_2, \ldots S_n, \ldots S_N$ at equally spaced intervals, follows a random walk, then the variance of n^{th} differences ($n > 1$) will be n times the variance of the first difference. That is, if S_t, is a true random walk, then:

$$VAR(S_t - S_{t-n}) = n(VAR(S_t - S_{t-1}) \quad , \tag{6}$$

where VAR is the variance operator. Lo and MacKinlay (1988) examine the RWH by testing the null-hypothesis that the variance ratio is given by:

$$VR\ (n) = \frac{1}{n}\frac{VARS(S_t - S_{t-n})}{VARS(S_t - S_{t-1})} = 1 \tag{7}$$

According to Ajayi and Karemera (1996), this hypothesis is tested under both homoscedastic and heteroscedastic specifications of the variances. If the variance ratio is less than one, it indicates the presence of negative serial correlation, which is consistent with a mean-reverting behaviour in the series. A variance ratio greater than one indicates the presence of positive serial correlation. Lo and MacKinlay (1988) derive an asymptotic standard normal test statistic, Z(n), which provides the statistical significance of the variance ratio, as well as an alternative statistic, Z*(n), which is robust to heteroscedasticity and non-normal disturbances,

$$Z(n) = \frac{VR\ (n) - 1}{[\phi(n)]^{1/2}}, \tag{8}$$

which follows a standard normal distribution where ϕ is the homoscedasticity variance ratio and

$$Z(n) = \frac{VR\ (n) - 1}{[\phi^*(n)]^{1/2}}, \tag{9}$$

which follows a standard normal distribution where ϕ^* is the heteroscedasticity variance ratio. We discuss the empirical results in the next section.

Wright's ranks- and signs-variance ratio

When applying a battery of VR tests to exchange rates or equities to test for random walk or weak-form efficiency, many researchers have applied Wright's (2000) ranks- and signs-variance ratio to complement the Lo-MacKinlay test. The ranks and signs VR tests are found to give better estimates when the sample size is smaller and tend to be more powerful than the conventional variance ratio tests in the presence of serial correlation. The tests based on ranks are exact under the iid assumption, whereas the tests based on signs are exact even under conditional heteroscedasticity

(Vats & Kamaiah 2011). Gradojević et al. (2010) further state that the ranks and signs test is relatively simple, as it avoids distortions in the absence of the need to conform to any asymptotic approximations. The statistics defining Wright's ranks and signs are derived as follows: given that Y_t is a time series of exchange rate returns with a sample size of T, then we have:

$$Y_t = X_t - X_{t-1} \tag{10}$$

Assuming that $r(Y_t)$ is a rank of Y_t among $T_1, T_2......T_r$, then $r(Y_t)$ is the number from 1 to T and given by:

$$r_{1t} = \frac{r(Y_t) - \frac{T+1}{2}}{\sqrt{\frac{(T-1)(T+1)}{12}}} \tag{11}$$

$$r_{2t} = \Phi^{-1}\left(\frac{r(Y_t)}{T+1}\right), \tag{12}$$

where Φ is the standard normal cumulative distribution function and Φ^{-1} is the inverse of the standard normal cumulative distribution function. The series r_{1t} is a simple linear transformation of the ranks, standardised to have a sample mean of 0 and a sample variance of 1, whilst r_{2t} has a sample mean of 0 and a sample variance approximately equal to 1. The essence of Wright's tests can be seen here in that he substitutes r_{1t} and r_{2t} for the return $Y_t = X_t - X_{t-1}$ in the definition of Lo-MacKinlay's test statistic. We can now define the rank-based variance ratio test statistics *R1* and *R2* as:

$$R_1 = \left(\frac{\frac{1}{Tk}\sum_{t=k}^{T}(r_{1t} + r_{1t-1}....r_{1t-k+1})^2}{\frac{1}{T}\sum_{t=1}^{T} r_{1t}^2} - 1\right)\left(\frac{2(2k-1)(k-1)}{3kT}\right)^{-1/2} \tag{13}$$

$$R_2 = \left(\frac{\frac{1}{Tk}\sum_{t=k}^{T}(r_{2t} + r_{2t-1} \ldots r_{2t-k+1})^2}{\frac{1}{T}\sum_{t=1}^{T} r_{2t}^2} - 1 \right) \left(\frac{2(2k-1)(k-1)}{3kT} \right)^{-1/2} \tag{14}$$

Having defined the ranks, we now turn to the signs. Given a series Y_t, let $u(Y_t, q) = 1(Y_t > q) = 0.5$. It then follows that $u(Y_t, 0) = 0.5$ if Y_t is positive, and -0.5 otherwise. Wright (2000) further states that letting $s_t = 2u(Y_t, 0) = 2u(\varepsilon_t, 0)$, then s_t is an independently and identically distributed series with a mean of 0 and variance of 1. Wright states that the S_2 test is expected to have a lower power and as such is not considered in this paper. The sign-based variance ratio test statistic *S1* is defined as:

$$S_1 = \left(\frac{\frac{1}{Tk}\sum_{t=k}^{T}(s_t + s_{t-1} \ldots s_{t-k+1})^2}{\frac{1}{T}\sum_{t=1}^{T} s_t^2} - 1 \right) \left(\frac{2(2k-1)(k-1)}{3kT} \right)^{-1/2} \tag{15}$$

The main motivation behind the application of the ranks and signs methodology is to complement the results in the Lo-MacKinlay test.

Discussion of empirical findings

ADF unit root results

We present the results of the Augmented Dickey Fuller test in Table 3. The upper panel (a) shows the results for the actual daily nominal exchange rate, while the lower panel (b) contains the results for the exchange-rate returns defined as:

$$Y_t = (\log P_t - \log P_{t-1}) * 100, \tag{16}$$

Where $\log P_t$ is the natural logarithm of the present day's exchange rate, and $\log P_{t-1}$ is the natural logarithm of the previous day's exchange rate.

Table 3(a): Results of unit root test for nominal daily exchange rate

Augmented Dickey Fuller test			
		Intercept	Trend and intercept
Nominal daily USD/ZMK		−1.8583	−2.4162
		(0.3524)	(0.3709)
Critical values:	1%	−3.43	−3.96
	5%	−2.86	−3.41
	10%	−2.57	−3.13

Table 3(b): Results of unit root test for daily exchange rate returns

Augmented Dickey Fuller test			
		Intercept	Trend and intercept
Returns USD/ZMK		−49.6968	−49.6919
		(0.0001)	(0.0000)
Critical values:	1%	−3.43	−3.96
	5%	−2.86	−3.41
	10%	−2.57	−3.13

Note: The lag length of the ADF test is chosen based on the Akaike Information Criterion (AIC) and the Schwarz Information Criterion (SIC) method of setting the maximum number of lags at 26. The ADF statistic is shown in the main row, while the MacKinnon approximate p-value for Z(t) is given in parentheses below the main row.

The lag length of the ADF test is chosen based on the Akaike Information Criterion and the Schwarz Information Criterion method of setting the maximum number of lags at 26. We run the tests on the RWH for both intercept and trend and intercept models. As expected, the daily nominal exchange rates are non-stationary; that is, they are integrated of order one. If a series shows a random walk, then its first difference is expected to be stationary. ADF unit root tests have supported stationarity in exchange-rate returns for both intercept, and trend and intercept models at the one per cent significance level. Figures 1 and 2 show the graphs of the daily actual nominal exchange rates and the exchange-rate returns plotted over time respectively. The results shown in Figures 1 and 2 are consistent with our prior expectations.

The nominal exchange rate is non-stationary, while the exchange-rate returns are stationary.

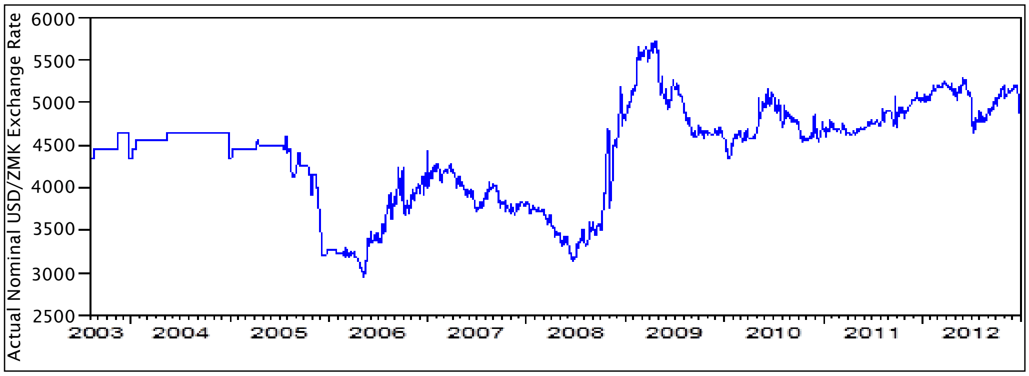

Figure 1: Nominal daily USD/ZMK exchange rate from 1 August 2003 to 31 December 2012 indicating a non-stationary series

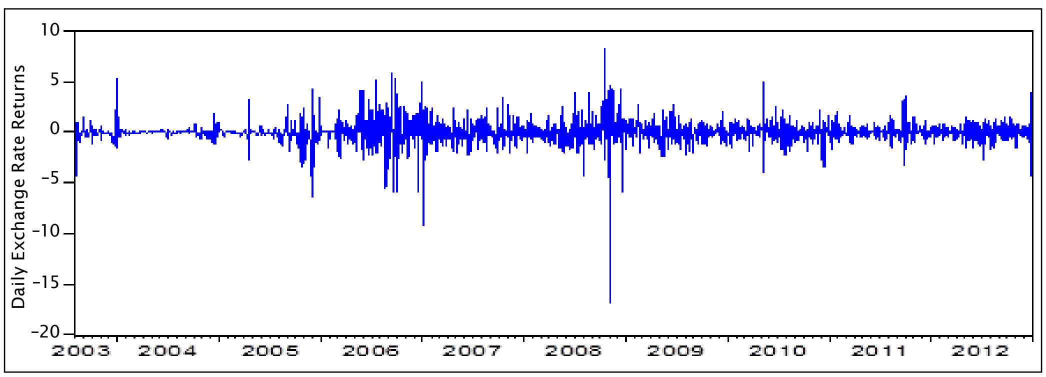

Figure 2: USD/ZMK exchange-rate returns from 1 August 2003 to 31 December 2012 indicating a stationary series

Table 4 shows the results of the Lo-MacKinlay VR test. The usual variance ratio VR(n) and Z(n), where n represents multiples of each sampling frequency, is calculated for each data set for the cases n = 2, 4, 8 and 16. The heteroscedasticity-consistent variance ratio VR*(n) tests are also performed by calculating the Z*(n) for each of the cases n = 2, 4, 8 and 16.

The variance ratios are reported in the main rows, while the Z and Z* statistics are, respectively, given in parentheses and square brackets below the main row entries. The variance ratio estimates in Table 4 are less than unity for all the n periods. A key

Table 4: Variance ratios VR(n) and variance ratio test statistics Z(n) and Z*(n) (daily exchange-rate returns)

Period	2	4	8	16
Variance ratios	0.490840	0.259106	0.129083	0.061725
Z(n)	(25.23296)*	(19.62621)*	(14.59106)*	(10.56388)*
Z*(n)	[7.612995]*	[6.790282]*	[6.059578]*	[5.153585]*

* significant at one per cent level

Note: One-sided homoscedasticity test statistics, Z(n), and heteroscedasticity consistent test statistics, Z*(n), are, respectively, given in parentheses and square brackets below the variance ratios.

observation is that the ratios decrease with an increase in n. The RWH is rejected in terms of the hypothesis of homoscedasticity in all four sampling intervals. This can be seen from Table 4. To clarify, the Z statistics associated with intervals q = 2, 4, 8, 16 are 25.23296, 19.62621, 14.59106 and 10.56388, respectively, with a p-value of zero per cent. The four Z values indicate that the variance ratios are significantly different from one at the one-per cent level. The RWH is therefore rejected for the USD/ZMK exchange-rate returns for all four intervals under examination. In the study of the Serbian foreign exchange market, Gradojević, Djaković and Andjelić (2010) state similar results in which they reject the random-walk model on sampling intervals n = 2, 4 and 8, but fail to reject it at the sampling interval of n = 16. The results here are consistent with Gradojević et al. (2010).

Like many other data series, time series data are susceptible to problems of heteroscedasticity. In view of this therefore, the rejection of the RWH under the maintained hypothesis of homoscedasticity may be due to the presence of heteroscedasticity or serial correlation in the data series. We carry out a comparison of the Z(n) statistic with the Z*(n) statistic, which is robust to heteroscedasticity. If the rejection of the RWH is robust to heteroscedasticity, we can then conclude that the rejection is caused by serial correlation in the data series. The evidence from the Z*(n) statistic, which is robust to heteroscedasticity, indicates that the RWH is actually robust to heteroscedasticity in all four intervals. The Z*(n) statistics robust to heteroscedasticity for the four intervals are, as given in Table 4, 7.612995, 6.790282, 6.059578 and 5.153585 respectively. At the one per cent level, in all the four sampling intervals, we reject the null of the RWH. This indicates that for all the intervals, RWH is rejected because of autocorrelation of the daily increments in the exchange-rate series.

As noted previously, the ratios under heteroscedastic-consistent estimates also decrease with an increase in sample intervals. Owing to the high volatility of the USD/ZMK exchange rate, more credence should be given to the heteroscedasticity robust estimates (Gradojević et al. 2010). The rejection of the RWH seems to support evidence on the ground. The Zambian foreign-exchange market has recently evidenced an emphasis on technical analysis. Both local and international banks have put staff on technical-analysis training to learn the tools needed to use past and current information to profit from exchange-rate movements. The rejection of RWH seems to support this trend. The Zambian kwacha, like many other commodity-driven currencies, rarely follows the random-walk process. The exchange rate is, to a large extent, determined by foreign-currency flows and as such one expects the exchange rate to follow a non-random walk pattern. The Zambian currency trading market is dominated by the large multinational banks. These banks keep foreign-currency accounts for multinationals and development organisations, the major foreign-exchange participants. Most foreign-currency flows therefore end up in just a few banks. The result is that trading is concentrated in these select few banks, which are able to influence market rates mainly due to the relationships between them, or as a result of loan agreements (World Bank 2005). These agreements result from the banks' extension of loans to multinationals in which they agree to transact foreign exchange between themselves. In most cases, these agreements are entered into at head-office level. This simply means that banks tie their loan facilities to foreign-exchange business, a huge source of non-funded income resulting in the crowding out of other banks. This promotes inefficiency in the market. The results support the rejection of RWH for all the sampling periods $n = 2, 4, 8$ and 16. However, we proceed to perform another VR test to compare with these results.

Wright's ranks and signs tests results

The results for Wright's ranks and signs tests are given in Table 5. The ranks (*R1* and *R2*) and signs (*S1*) provide strong support for the rejection of RWH for all the sampling intervals. This reinforces the strong evidence against the RWH found by applying the Lo-MacKinlay test. Owing to the weaker testing power of *S2*, we have omitted it from the analysis in this study.

Table 5: Wright's non-parametric ranks and signs variance ratios and test statistics

Number of lags K				
	k=2	k=4	k=8	k=16
R1	0.580246*	0.384208*	0.271011*	0.207384*
	(20.802180)	(16.312270)	(12.213250)	(8.923930)
R2	0.533964*	0.318748	0.197070	0.133437*
	(23.095820)	(18.046290)	(13.452020)	(9.756490)
S1	0.723941*	0.624186*	0.597720*	0.613803*
	(13.680930)	(9.955280)	(6.739672)	(4.348128)

* significant at one per cent level

Note: The variance ratios are reported in the main rows. One-sided test statistics are given in parentheses below the row entries.

Ljung-Box Q-statistic results

If a series follows a random walk, then the first difference of that series must exhibit stationarity. The ADF tests have shown that the USD/ZMK exchange-rate returns are indeed stationary.

One of the conditions needed for a series to show a random-walk process is that the increments in the series must be serially uncorrelated. However, the results shown in Table 6 do not support this. We run the test up to 36 lags. The test statistic for the Box-Pierce Q test for 36 lags is reported to be 79 916 with a p-value of 0.0000. Here we report up to the 15th lag due to space constraints. The null hypothesis of no serial correlation is rejected at the one per cent level. We can therefore conclude that the series is serially correlated, which provides support against the RWH in the sample, further confirming the VR test results.

The overall results from the variance ratio tests provide evidence against the RWH in the Zambian exchange-rate market. This is consistent with other studies for the emerging markets and developing economies. Ajayi and Karemera (1996) used daily rates to examine RWH using the variance ratio tests on the currencies of eight economies of the Pacific Basin. The results are inconsistent with the random-walk process. For an economy in transition, Gradojević et al. (2010) reject RWH in the euro-Serbian dinar exchange-rate market using Lo and MacKinlay's (1988) variance ratio test and Wright's (2000) non-parametric ranks and signs tests. It is also worth pointing out that, unlike in Ajayi and Karemera (1996), the results in this study are consistent with those of Gradojević et al. (2010) in that the VR tests provide strong support against the RWH for all the sampling periods.

The Box-Pierce statistics in this study are consistent with Ajayi and Karemera (1996), as the homoscedasticity-consistent variant provides support against RWH. All the variance ratio estimates in this sample are observed to be less than unity, indicating the tendency of the kwacha to depreciate against the dollar. This is inconsistent with Chen (2009), who finds positive serial correlation. However, the results of this study show evidence of negative serial correlation, which has been linked to exchange-rate depreciation and unofficial intervention in the exchange rate (Huizinga, 1987). This is consistent with the official policy pronouncements by monetary authorities in Zambia. The Zambian kwacha is freely traded, and the Bank of Zambia rarely intervenes in the exchange-rate market. The rejection of the RWH brings out some interesting implications. Monetary authorities can implement policies aimed at intervening in the exchange rate to address the imbalances that result from the non-efficient market. For traders, the rejection of the RWM presents opportunities for higher-than-average market return on the exchange rate through technical and fundamental analysis if transaction costs are trivial.

Conclusion

The objective of this study is to investigate the validity of the random-walk hypothesis in the Zambian foreign-exchange market with respect to the USD/ZMK exchange rate. This study uses the conventional Lo-MacKinlay variance ratio and Wright's (2000) ranks and signs non-parametric variance ratio tests to examine the behaviour of the daily USD/ZMK exchange-rate market. Based on the results of the test statistics, the RWH is rejected and this provides support for the violation of the weak-form market-efficiency hypothesis. Both the Lo-MacKinlay test and Wright's (2000) methodology provide support against the RWH at all sampling intervals; Wright's (2000) methodology is more powerful as it provides strong evidence against the RWH at all the samplings intervals.

According to Ajayi and Karemera (1996), evidence against RWH provides support for the classical monetary models of exchange rates, which hold Purchasing Power Parity as the long-run equilibrium model. From 2010 onwards, the Zambian foreign-exchange market has received considerable interest from technical analysts. Traders from a number of banks have undergone technical-analysis training to acquire the skills needed to benefit from reading foreign-exchange trade volumes and price movements. The usefulness of this has remained debatable, but evidence from this study lends support to technical analysis.

Table 6: Autocorrelation coefficients (AC) and Standard Box-Pierce Q-statistics (daily exchange rates)

Lag (L)	USD/ZMK (AC)
1	0.996
2	0.993
3	0.990
4	0.986
5	0.983
6	0.981
7	0.978
8	0.975
9	0.972
10	0.969
11	0.967
12	0.964
13	0.962
14	0.959
15	0.956
Box-Pierce Q (15)	35 215*

* significantly different from zero at one per cent level.

The relatively less-developed foreign-exchange market in Zambia lends support against the RWH as it is prone to huge swings and spikes exacerbated by the lack of foreign-exchange controls. This study utilises daily closing USD/ZMK spot exchange rates. For future studies, daily, weekly and monthly nominal rates for the euro, the South African rand and the British pound against the Zambian kwacha can be used with a battery of VR tests to examine the RWH. Owing to the high dependence of the Zambian economy on copper as a major foreign-exchange earner, studies linking the RWM to commodity prices are also worth undertaking to understand this topic further.

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