Predictable or Random?-A Test of the Weak-Form Efficient Market Hypothesis on the Ghana Stock Exchange

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Abstract The study examines the predictability of index returns on the Ghana stock market within the framework of the weak-form efficient market hypothesis using historical daily, weekly, monthly, and quarterly returns for a period of 28 years (1990-2017). The descriptive statistics reveal huge disparity between the mean and standard deviation, a phenomenon that suggests that the stock market is highly risky. In the same vein, the return series were also found to be positively skewed with leptokurtic kurtosis. The Jarque-Bera statistics showed a non-normality of return distribution. The random walk hypothesis (RWH) was tested using four robust statistical tests, namely the Ljung-Box autocorrelation test, unit root tests, the runs test, and variance ratio tests (such as Wright’s rank and sign and Lo-MacKinlay). The empirical results showed that all four tests rejected the random walk hypothesis required by the weak-form efficient market hypothesis in all four return series. This provides empirical basis to infer that the GSE is inefficient at weak-form. The rejection of the RWH on a daily, weekly, monthly, and quarterly basis is possibly an indication that the weak-form inefficient characteristic of the GSE is not sensitive to return frequency.

Keywords: weak-form efficiency, random walk, Ghana, Ghana stock market, index returns

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1. Introduction

The Efficient Market Hypothesis (EMH) has assumed a significant role in financial theory, evidenced by the multitude of research aiming to test its suitability, validity, and the insights it presents [1]. The huge inquest into the EMH could also be a consequence of the significance of the stock market in economic progression. As noted by [2], the growing importance of the global stock market ecosystem has opened new research frontiers in financial development literature since the stock market has become one of the most popular investment outlets. According to [3], more liquid markets can create long-term investments through the crucial function of financial intermediation. Nonetheless, the ability of the stock market to present itself as an effective financial intermediary and assure investors of fair returns is contingent on efficiency.

Reference [4] describes an efficient market as one in which the price of a share already contains all there is to know about it. He explains further that for a market to be efficient, successive price changes in individual securities must be independent or must exhibit what he termed a “random walk pattern.” Specifically, share prices and returns adjust rapidly at the arrival of new information, meaning they fully reflect all available data and should therefore follow a random walk process. Intuitively, market efficiency prevents arbitraging and accumulating abnormal profits (profits that exceed the market premium). A simple strategy of buying and holding is as good as any more complicated technical and mechanical procedure for timing purchase and sales [5]. Granted that prices fully reflect available information and anticipated risk, the only way an investor can possibly maximize higher returns is by purchasing riskier investments. These insights largely motivated the empirical interest and inquest into the efficiency of stock markets that lasted over a decade and consisted of a vast amount of research conducted using myriad statistical approaches. These studies have mainly centered on developed markets, leaving a pronounced research lacuna in emerging (and particularly, developing) economies.

The Ghana Stock Exchange (GSE) has recently seen an unprecedented growth in market capitalization, volume traded, and value. Similarly, the composite index returns has also witnessed significant improvement over the years, a phenomenon that could plausibly be explained by investor confidence in the bourse. Notwithstanding these developments, there is a palpable dearth of empirical attempts at ascertaining the level of market efficiency, a concept that requires examination. Reference [6] laments that this research lacuna may have contributed to the
inability of African markets to attract huge equity investments similar to those obtained by Asian and American economies.

This study aims to fill this research lacuna by examining the weak-form efficiency of the GSE within the framework of the random walk proposition. The study considers the daily, weekly, monthly, and quarterly index returns of all firms listed on the market since its inception. This provides empirical evidence that is representative of a part of the market, but rather the entire market. 

The assumption is that the GSE is efficient across the four index returns (daily, weekly, monthly, and quarterly). This study is at variance with existing studies in a myriad of ways. First, this study combines robust parametric and non-parametric methods to test the validity of the EMH on the four named return series. Second, by using recent data, this study captures contemporary developments that may have bearing on market efficiency.

The rest of this study is structured in three sections. The ensuing section presents the literature review and is followed by the methodology in the third section. The fourth section presents the empirical results and findings.

2. Review of Literature

The efficient market hypothesis was propounded by Fama in 1970 and popularized in his famous review paper entitled “Efficient Capital Markets: A Review of Theory and Empirical Work.” He submits that “a market in which prices always `fully reflect' available information is called efficient.”

The intuition of the EMH is that at any given time, a security price fully incorporates all available information. Specifically, stock prices adjust instantaneously to new information to ensure that the prevailing price reflects it. Recognizing the different forms of information (private and public), the EMH categorizes exhibiting strong, semi-strong, and weak-form efficiency. Strong-form efficiency encapsulates both private and publicly available information. The semi-strong form focuses only on public information, whereas weak-form efficiency espouses that future prices are random in nature and cannot be predicted, but permits short-run excess. All three forms of market efficiency refute the possibility of long-run excess returns to investors. The exacting requirement that prices “fully” reflect all available information implies that investors cannot capitalize on readily available information for profit maximization and underpins the criticism of the EMH given that investors are widely perceived as rational and risk averse within the efficient capital market view.

The main idea underpinning the random walk theory or the weak-form efficient market proposition is that current or future return changes are independent of the sequence of historical returns. Specifically, successive returns are serially independent. Empirical financial literature presents a wealth of evidence for and against the efficient market theory. In relative terms, however, much of the research agrees that market is reasonably efficient at weak-form, particularly in developed economies. In the context of developing economies, the findings are mixed and appear to be time-and data frequency-sensitive.

Reference [8] assessed the random walk proposition on the Nigerian Stock Exchange (NSE) within the Generalized Autoregressive Conditional Heteroscedasticity (GARCH) framework. He concluded that the NSE returns were weak-form efficient for the period of 1984 to 2006 and that the market was generally efficient at weak-form. However, he found evidence of volatility clustering, indicating inefficiency in selected specific periods including the period of internationalization of the Nigerian capital market in 1995 and from 2000 to 2006. Reference [9] also assessed the random walk proposition on the NSE, with an initial premise that daily and weekly return series (2005-2009) would follow a random walk. He concluded that the Nigerian stock market was inefficient in the weak form.

Reference [10] used autocorrelation and the Phillips-Perron (P-P) and Augmented Dickey-Fuller (ADF) unit root tests to assess the efficiency of the Botswana stock market using 738 weekly closing prices. He found the market to be efficient at weak and semi-strong forms. In a cross-country empirical study involving South Africa, Egypt, Ghana, and Mauritius, Reference [6] used both parametric and nonparametric tests (such as the Kolmogrov-Smirnov (KS) goodness of fit test, the runs test, the autocorrelation test, and the variance ratio test) to assess the efficiency of their stock markets. They found that while the South African market followed a random walk (meaning it was efficient at weak-form), the markets of Egypt, Ghana, and Mauritius were weak-form inefficient. [11] conducted a study using the variance ratio test to assess the efficiency of eight markets in the Middle East and North Africa (MENA). Their findings failed to reject the random walk proposition, thus indicating that the selected MENA markets were efficient at weak-form. However, [12] conducted similar research on the MENA markets and reported contradictory results.

More specifically regarding Ghana, one of the initial studies by [13] reported that the market generally followed an up-and-down pattern in sync with good and bad news, respectively. He inferred that the up-and-down phenomenon was at variance with the EMH. [14] also examined the efficiency of the GSE for the period spanning November 1990 to December 2005. They used the Lo-MacKinlay (LOMAC) and the Wright variance ratio tests and reported mixed findings. The LOMAC test rejected the random walk theory, but the Wright test results were inconclusive. They concluded that the GSE was weak-form inefficient based on the LOMAC results. Using daily stock returns that spanned from 2006 to 2011, [15] sought to find if automation improved efficiency on the GSE through the unit root test, variance ratio test, and the GARCH framework (1,1). They found significant evidence of weak-form inefficiency before and after automation.

3. Methodology

3.1. Data and Empirical Tests

Historical GSE daily, weekly, monthly, and quarterly returns for a period of 28 years (1990-2017) were used for analysis. The study used four different robust and supplementary empirical tests namely Auto-correlation test, Unit root test, Runs test and Variance ration test to
assess the random walk proposition on the GSE. The rationale behind using these four tests described were:

- Weak-form efficiency requires the absence of correlation of return trends over time, hence the need for an autocorrelation test such as the Ljung-Box test;
- Weak-form efficiency requires that the return series are stationary, thus emphasizing the need for unit root tests;
- Under conditions of infrequent trading (like in some emerging markets), EMH could not be tested by looking at autocorrelation, making the runs test of randomness an alternative necessity; and
- EMH proposes that stock returns follow a random or stochastic. [17] explain that the autocorrelation coefficient is a natural time series extension of the random walk, thus the need for either the conventional Lo and MacKinlay test, the more robust Wright test, or both.

3.1.1. Auto Correlation Test

This study applied the Ljung and Box autocorrelation test to establish whether GSE returns exhibited serial dependence. The Ljung-Box Q-statistics assume a null hypothesis (H₀) that all autocorrelations equal zero. Specifically, the absence of correlation in successive returns is an indication of randomness or stochastic series [16]. Thus, a significant Q-statistic rejects the null hypothesis and indicates that there is predictability in future returns or the series is inefficient in weak-form (not random). The advantage of this approach over the chi-square (χ²) distribution is its finite sample correction ability and that it yields a superior fit. The mathematical depiction of the Ljung-Box autocorrelation test is as shown in equation (1):

\[ Q_{\text{Ljung-Box}} = n(n+2) \sum_{t=1}^{K} \frac{\phi^2(t)}{n-t}, \]

where \( \phi^2(t) \) was the estimated autocorrelation coefficient, \( t \) was a given lag and \( n \) was the sample size. If an autocorrelation test is used with the assumption that different values at lags are not correlated, then they cannot be used for prediction and the series is considered to be random or stochastic. [17] explain that the autocorrelation coefficient is a natural time series extension of the correlation coefficient between two random variables.

3.1.2. Unit Root Test

Given that random walk requires the presence of a unit root (non-stationary) in the series, this study applied two unit root test procedures namely the Augmented Dickey-Fuller (1979) and the Phillips-Perron (1988) unit root tests. The ADF test assumes that \( x \) series follow an Autoregression AR(\( p \)) process with the null hypothesis that \( \beta=0 \) versus the alternative of \( \beta<0 \). The ADF model applied in this study was:

\[ \Delta \ln(P_{it}) = \alpha_0 + \alpha_1 t + \gamma \ln(P_{it-1}) + \sum_{i=1}^{k} \delta_i \ln(P_{it-i}) + \epsilon_{it}, \]

where \( \ln(P_{it}) \) was the variable being tested for unit roots, and \( \epsilon_{it} \) was the random error term which was normally distributed with a mean of zero and constant variance. The nonparametric Phillips-Perron test was used as an augmented test to overcome the problem of serial correlation in the error term and to correct for finite sample effects. The fitted P-P test in this study was given as:

\[ \Delta \ln(P_{it}) = \alpha_0 + \gamma \ln(P_{it-1}) + \epsilon_{it}. \]

The operational hypothesis was \( H_0: \rho=1 \) against \( H_1: \rho<1 \).

The presence of unit root in a series is an indication of random walk, and that as a result it leads to weak-form efficiency. Otherwise, rejection of unit root at the level (1 (0)) implies that successive returns contain deterministic trends and are dependent of each other.

3.1.3. Runs Test

The runs test is a nonparametric statistical approach in which a hypothesis of serial independence is tested to measure the independence of consecutive occurrences of runs. It does not require any specific probability distribution given its non-parametric nature, and both positive and negative runs are used in the test statistics count. The anticipated number of runs, \( m \), with respect to observed runs, \( R \), was given as:

\[ m = \frac{N(N+1)-\sum_{i=1}^{3} p_i^2}{N}. \]

When both \( (m) \) and \( (R) \) were assumed to be greater than 30, \( m \) corresponded to approximately a normal distribution with a standard error (σ\( m \)) of runs as specified below:

\[ \sigma_m = \frac{1}{\sqrt{2N(1-N^2)}}. \]

where \( N \) represented the total number of returns in the sample, and \( n \) was a count of changes of runs, with \( i=1 \) for positive changes, \( i=2 \) for negative changes, and \( i=3 \) for no changes. Following the standard normal Z-statistic (\( Z=(R-m)/\sigma m \)), the consistency of the actual number of runs was investigated with respect to the hypothesis of independence. The null hypothesis of randomness is rejected if Z-value exceeded or equaled ±1.96 at 95% level of significance. A positive/negative Z-value indicated a negative/positive serial correlation in the return series, respectively [18]. The need for the runs test in this study was informed by its superiority over the autocorrelation test since it does not depend on assuming a finite variance of the return distribution.

3.1.4. Variance Ratio Test

The variance ratio (VR) approach has gained resounding popularity in recent years (see, Cochrane, 1988; Lo and MacKinlay, 1988). The VR methodology entails testing the random walk hypothesis (RWH) against stationary alternatives by exploiting the fact that the variance of random walk increments is linear in all
sampling intervals. Specifically, the k-period differences \( (y_t - y_{t-k}) \) or sample variance of k-period return of the time series \( y_t \), is k times the sample variance of one-period return (or the first difference) denoted by \( y_t - y_{t-1} \). Thus, the VR at lag k is defined as the ratio between \( \left( \sqrt[k]{k} \right)^{th} \) of the k-period return (or the k-th difference) to the variance of the one-period return (or the first difference). As such, the variance computed at each individual lag interval k \((K = 2,3,...,N)\) for a random walk process should equal unity. Specifically, when returns are uncorrelated over time, then \( \text{Var}(y_t) = \text{Var}(y_{t-1}) = \sqrt[k]{k} \). Hence, the VR test could be perceived as a specification of \( H_0: \rho_1 = ... = \rho_K = 0 \), which implies that returns are not serially correlated. This study used the variance ratio test developed by [19] to assess the possibility of random movement (random walk hypothesis) of returns on the time series.

The standardized ranks were thus depicted as:

\[
M_1(k) = \frac{\text{VR}(x; k) - 1}{\Phi(k)^{1/2}},
\]

where the asymptotic variance, \( \Phi(k) \), was defined as:

\[
\Phi(k) = \frac{2(2k-1)(k-1)}{3kT}.
\]

However, the null asymptotic distribution is not applicable under conditional heteroscedasticity. Thus, the study adopted the robust test statistic \( M_2(k) \) proposed by Lo and MacKinlay:

\[
M_2(k) = \frac{\text{VR}(x; k) - 1}{\Phi^*(k)^{1/2}},
\]

where:

\[
\Phi^*(k) = \sum_{j=1}^{k-1} \left[ \frac{2(k-j)}{k} \right]^2 \delta(j),
\]

and

\[
\delta(j) = \frac{T}{(T-\mu)^2} = \frac{\sum_{t=1}^{T} (x_t - \mu)^2}{(T-\mu)^2}.
\]

The choice of the Lo and MacKinlay test is particularly powerful when k is large and robust against numerous forms of heteroscedasticity and non-normality of the stochastic term. The test specification included use of unbiased variances, heteroscedastic robust standard errors, and data demeaning with drift allowed. The study also estimated the nonparametric Wright variance ratio tests (using ranks and signs) on the ground that the Lo-MacKinlay asymptotic tests, whose sampling distribution is approximated based on its limiting distribution, are biased and right-skewed in finite samples. Particularly, [20] argues that the variance-ratio tests used in Lo and MacKinlay tests do not hold if the data are either positively or negatively correlated. Consequently, the series (returns) in the Lo and MacKinlay VR statistic were substituted with two linear transformations and the resultant test statistics under which the tests were conducted were given as:

\[
R_1(k) = \left[ \left( \frac{(Tk)^{-1} \sum_{t=1}^{T} (y_t + r_{t-1} + \cdots + r_{t-k})^2}{T^{-1}N^2} \right) - 1 \right]^{1/2}.
\]

and

\[
R_2(k) = \left[ \left( \frac{(Tk)^{-1} \sum_{t=1}^{T} (r_{t+k} + r_{t-k} + \cdots + r_{t+k})^2}{T^{-1}N^2} \right) - 1 \right]^{1/2}.
\]

The standardized ranks were thus depicted as:

\[
r_{1t} = \frac{r(y_t) - 0.5(T+1)}{\sqrt{(T-1)(T+1)}},
\]

and

\[
r_{2t} = \Phi^{-1} \left( \frac{r(y_t)}{T+1} \right).
\]

Similarly, the tests based on the signs of first difference returns were given by:

\[
S_t(k) = \left[ \left( \frac{(Tk)^{-1} \sum_{t=1}^{T} (x_t + x_{t-1} + \cdots + x_{t-k})^2}{T^{-1}N^2} \right) - 1 \right]^{1/2}.
\]

where \( s_t \) assumed a zero drift value whose unconditional mean was zero and \( s_t \) took an iid sequence and had variance equal to unity. The study did not estimate the Wright’s \( s_t \) test since his Monte Carlo simulations indicate that its size and power properties are inferior to the \( s_t \).
The study also estimated the multiple VR test where the VR of all observation intervals was assumed to be simultaneously equal to 1. Reference [21] indicates that the single variance ratio may not be completely adequate for testing the random walk hypothesis, as it is useful for testing only the individual variance ratios for a specific interval. The joint null and alternative hypotheses were given as:

\[ H_0 : V(k_i) = 1, \quad i = 1, \ldots, m, \]

\[ H_1 : V(k_i) \neq 1, \quad i = 1, \ldots, m. \]

The joint test statistic for the homoscedastic assumption associated with the Lo and Mackinlay test was given as:

\[ MV_1 = \sqrt{T} \max_{1 \leq i < m} \left| M_1(y; k_i) \right|. \]  \hspace{1cm} (16)

The statistic followed the studentized distribution with \( m \) (number of variance ratio) and \( T \) (sample size). Similarly, the ranks-based and signs-based multiple variance ratio test statistics were defined as:

\[ CD_{R1} = \max_{1 \leq i < m} \left| R_1(k_i) \right|. \]  \hspace{1cm} (17)

\[ CD_{R2} = \max_{1 \leq i < m} \left| R_2(k_i) \right|. \]  \hspace{1cm} (18)

and

\[ CD_{S1} = \max_{1 \leq i < m} \left| S_1(k_i) \right|. \]  \hspace{1cm} (19)

### 4. Empirical Results and Findings

#### 4.1. Descriptive Statistics

The descriptive statistics of returns on the GSE indices are presented in Table 1. The skewness of the return series was positive for the four indices (daily, weekly, monthly, and quarterly returns). This implied that the asymmetric tail of returns on the GSE extended more towards positive values, which indicated a significant probability of large gains and a small probability of losses. The kurtosis parameter also showed significant positive excess kurtosis, implying leptokurtic (fat-tailed) distribution. The skewness and the leptokurtic returns were an indication of non-normality distribution of the returns on the GSE. The non-normal distribution of the four sets of return series was further affirmed by the significance of the Jarque-Bera statistics.

| Index Returns | Daily | Weekly | Monthly | Quarterly |
|---------------|-------|--------|---------|-----------|
| Mean          | 29.06775 | 28.99263 | 29.05750 | 29.05750 |
| Median        | 17.79115 | 17.87295 | 17.80057 | 17.99344 |
| Maximum       | 163.3454 | 163.3276 | 163.2805 | 162.8822 |
| Minimum       | -54.65351 | -54.68208 | -54.55608 | -53.93594 |
| Std. Dev.     | 25.27072 | 25.23537 | 25.30307 | 25.36089 |
| Skewness      | 0.835412 | 0.837968 | 0.835703 | 0.836033 |
| Kurtosis      | 3.099037 | 3.098693 | 3.090330 | 3.089641 |
| Jarque-Bera   | 852.1773 (0.000000) | 171.3762 (0.000000) | 39.22461 (0.000000) | 13.08458 (0.001441) |
| (Prob*)       | Observations | 7305 | 1461 | 336 | 112 |

#### 4.2. Autocorrelation Test

The results of autocorrelation (AC) and partial autocorrelation (PAC) tests for daily, weekly, monthly, and quarterly index returns are presented in Table 2 and Table 3. Negative correlations suggested that sequential returns were inversely correlated, showing that stock returns were possibly drifting towards mean values rather than drifting away. Positive correlations suggested that sequential returns were possibly sustained, indicating that return changes might carry momentum. The correlation coefficients and the Ljung-Box Q statistic are shown for 36 lags. The results showed strong signs of autocorrelation in the return series as the coefficient of all lags were significantly different from zero. Thus, the null hypothesis of random walk (RW) was rejected and the four return data series were concluded to exhibit no weak-form market efficiency, a further affirmation of the predictability of returns on the GSE.

The significance of the Q-statistic across the lags indicates that the efficiency in the weak-form in the four return series did not improve over time.

#### 4.3. Unit Root Assessment

The results of the ADF and the non-parametric Phillip-Perron (P-P) tests for daily, weekly, monthly, and quarterly index returns are shown in Table 4. The results showed that the respective p-values of the four sets of data series in the two tests were less than 0.05 at 5% significance level. This implied that the data sets were stationary and thus the null hypothesis of unit root was rejected in both tests. Given that weak-form market efficiency required randomness in the returns, the series must exhibit non-stationarity.

#### 4.4. Results of Runs Test

The runs test assumed that runs did not follow any systematic pattern of occurrence or there was no predictable pattern of run occurrence. Table 5 presents the results of the runs test for daily, weekly, monthly, and quarterly GSE index returns. The Z-statistics associated with the four return series were all negative and significant, indicating that the real numbers of runs were less than the expected numbers (see Table 5). In the same vein, the magnitude of the Z-values was less than the critical values (< 1.95) at 5%, affirming the absence of randomness in the returns. This refuted the fundamental assumption of the test that runs did not follow a systematic pattern.

#### 4.5. Variance Ratio Results

The variance ratio test in this study was conducted under the null hypothesis that stock returns followed an RW, the variance ratios were expected to be equal to one. Individual and joint variance ratio tests were conducted for multiples of 2, 4, 8, 16, and 32 days. The individual VR results in this study were reported under two different assumptions namely homoscedasticity and heteroscedasticity. The LOMAC results (Table 6) under the null hypothesis that stock returns follow a RW showed that the variance ratios were substantially greater than 1, indicating the
absence of mean reversion in the four return series (daily, weekly, monthly, and quarterly) under both the homoscedastic and heteroscedastic assumptions. This implies that the random walk hypothesis is rejected and that the return indexes are not weak-form efficient. This means that the GSE returns follow a systematic pattern and could be predicted with historical return values.

The ranks and signs variance ratio test results for the four GSE index returns are reported in Table 7. The table indicates the estimates of the variance ratio and their corresponding test statistics $R_1(k)$, $R_2(k)$, and $S_1(k)$ for lags $k = 2, 4, 8, 16, 32$. The ranks and signs test results for daily, weekly, and monthly returns were consistent with the LOMAC test results. The results indicated that the RWH was rejected at all lags for the daily, weekly, and monthly return series. However, the Wright VR test for the quarterly return series presented mixed results. The null hypothesis of random walk was rejected at lag $k = 2, 4, 8$ for $R_1(k)$, $R_2(k)$, and $S_1(k)$. However, the RWH was not rejected for lag $k = 16$ and 32, implying that the return series were weak-form efficient at those levels. These mixed results in the quarterly returns is consistent with the adaptive market hypothesis, which states that some violations may occur in some time periods and not in others. However, the Chow-Denning joint test rejected the null hypothesis under the modified LOMAC (CD (M)) and modified Wright (CD_{R1}, CD_{R2}, and CD_{S1}) VR tests.

Reference [19] explain that the single variance ratio may not be completely adequate for testing the random walk hypothesis. The joint variance ratio test in this study was thus aimed to serve as a final robustness assessment of random walk on the index returns on the GSE. The results of the joint variance ratio Lo and Mackinlay-based, ranks-based, and signs-based tests are reported in Table 8. Similar to the individual VR tests, the null of randomness is upheld if the joint probability was greater than 0.5 (i.e., if the Z-statistic lay between $\pm$ 1.96 at the 5% confidence level). Results in Table 8 show that the joint test rejected the RWH at the 1% level of significance for the four augmenting VR tests. This provides robust affirmation that the return series did not follow random walk or $VR \neq 1$. Specifically, the return series were inefficient at weak-form. This provided the empirical basis to infer that informed investors stood the chance of exploiting arbitrage across the four return series.

![Table 2. AC and PAC for daily and weekly index returns](image-url)
| K | Monthly AC | Monthly PAC | Q-Stat | Prob | Quarterly AC | Quarterly PAC | Q-Stat | Prob |
|---|------------|-------------|--------|------|--------------|---------------|--------|------|
| 1 | 0.975      | 0.975       | 322.23*** | 0.000 | 0.888        | 0.888         | 90.760*** | 0.000 |
| 2 | 0.937      | -0.267      | 620.95*** | 0.000 | 0.686        | -0.486        | 145.45*** | 0.000 |
| 3 | 0.888      | -0.201      | 890.02*** | 0.000 | 0.434        | -0.250        | 167.50*** | 0.000 |
| 4 | 0.829      | -0.157      | 1125.1*** | 0.000 | 0.174        | -0.111        | 171.08*** | 0.000 |
| 5 | 0.761      | -0.126      | 1324.0*** | 0.000 | -0.017       | 0.226         | 171.11*** | 0.000 |
| 6 | 0.686      | -0.101      | 1486.0*** | 0.000 | -0.165       | -0.201        | 174.40*** | 0.000 |
| 7 | 0.605      | -0.081      | 1612.5*** | 0.000 | -0.268       | -0.118        | 183.15*** | 0.000 |
| 8 | 0.521      | -0.064      | 1706.3*** | 0.000 | -0.327       | -0.050        | 196.27*** | 0.000 |
| 9 | 0.433      | -0.049      | 1771.6*** | 0.000 | -0.356       | 0.021         | 212.01*** | 0.000 |
| 10| 0.345      | -0.036      | 1813.1*** | 0.000 | -0.353       | -0.055        | 227.63*** | 0.000 |
| 11| 0.258      | -0.024      | 1836.4*** | 0.000 | -0.324       | -0.039        | 240.89*** | 0.000 |
| 12| 0.173      | -0.012      | 1846.9*** | 0.000 | -0.275       | -0.016        | 250.53*** | 0.000 |
| 13| 0.105      | 0.311       | 1850.8*** | 0.000 | -0.205       | 0.042         | 255.96*** | 0.000 |
| 14| 0.041      | -0.089      | 1851.4*** | 0.000 | -0.127       | -0.012        | 258.05*** | 0.000 |
| 15| -0.018     | -0.077      | 1851.5*** | 0.000 | -0.046       | 0.000         | 258.33*** | 0.000 |
| 16| -0.072     | -0.066      | 1853.4*** | 0.000 | 0.031        | 0.007         | 258.45*** | 0.000 |
| 17| -0.122     | -0.056      | 1858.6*** | 0.000 | 0.088        | -0.025        | 259.49*** | 0.000 |
| 18| -0.166     | -0.047      | 1868.5*** | 0.000 | 0.127        | 0.001         | 261.68*** | 0.000 |
| 19| -0.205     | -0.039      | 1883.6*** | 0.000 | 0.144        | -0.009        | 264.54*** | 0.000 |
| 20| -0.240     | -0.031      | 1904.2*** | 0.000 | 0.139        | -0.022        | 267.21*** | 0.000 |
| 21| -0.269     | -0.023      | 1930.2*** | 0.000 | 0.103        | -0.132        | 268.68*** | 0.000 |
| 22| -0.293     | -0.016      | 1961.3*** | 0.000 | 0.053        | 0.030         | 269.08*** | 0.000 |
| 23| -0.312     | -0.010      | 1996.7*** | 0.000 | -0.002       | 0.004         | 269.08*** | 0.000 |
| 24| -0.327     | -0.004      | 2035.6*** | 0.000 | -0.055       | -0.019        | 269.52*** | 0.000 |
| 25| -0.341     | 0.043       | 2078.1*** | 0.000 | -0.081       | 0.034         | 270.48*** | 0.000 |
| 26| -0.350     | -0.019      | 2123.1*** | 0.000 | -0.099       | -0.076        | 271.93*** | 0.000 |
| 27| -0.356     | -0.020      | 2169.7*** | 0.000 | -0.114       | -0.073        | 273.87*** | 0.000 |
| 28| -0.359     | -0.019      | 2217.1*** | 0.000 | -0.129       | -0.073        | 276.41*** | 0.000 |
| 29| -0.357     | -0.017      | 2264.4*** | 0.000 | -0.173       | -0.187        | 281.03*** | 0.000 |
| 30| -0.353     | -0.015      | 2310.6*** | 0.000 | -0.214       | 0.020         | 288.13*** | 0.000 |
| 31| -0.346     | -0.013      | 2355.1*** | 0.000 | -0.236       | 0.028         | 296.91*** | 0.000 |
| 32| -0.336     | -0.010      | 2397.2*** | 0.000 | -0.227       | 0.045         | 303.13*** | 0.000 |
| 33| -0.323     | -0.008      | 2436.4*** | 0.000 | -0.137       | 0.267         | 308.18*** | 0.000 |
| 34| -0.309     | -0.005      | 2472.3*** | 0.000 | -0.008       | 0.009         | 308.19*** | 0.000 |
| 35| -0.292     | -0.002      | 2504.6*** | 0.000 | 0.146        | 0.062         | 311.71*** | 0.000 |
| 36| -0.274     | -0.000      | 2533.0*** | 0.000 | 0.305        | 0.104         | 327.33*** | 0.000 |

Note: K: Number of lags, AC: Autocorrelation, PAC: Partial Autocorrelation, Q-Stat: Ljung-Box Q-Statistics, ***: significant at 1%.

### Table 4. Unit root test results

| Series (returns) | Augmented Dickey-Fuller test (level series) | Phillips-Perron test (level series) |
|------------------|--------------------------------------------|------------------------------------|
|                  | Test statistic                              | Adj. test statistic                |
| Daily            | -82.94245                                   | -87.97205                          |
| Weekly           | -12.5067                                   | -40.24146                          |
| Monthly          | -2.525661                                   | -2.736345                          |
| Quarterly        | -2.152155                                   | -2.285058                          |

ADF Test critical values:
- 1% level: -2.566552
- 5% level: -1.941041
- 10% level: -1.616553

P-P Test critical values:
- 1% level: -2.565279
- 5% level: -1.940868
- 10% level: -1.616671

*MacKinnon (1996) one-sided p-values.
### Table 5. Runs test for GSE returns

| Runs parameters | Daily returns | Weekly returns | Monthly returns | Quarterly returns |
|-----------------|---------------|----------------|-----------------|------------------|
| Mean            | -49.756       | -45.998        | -44.617         | -41.560          |
| No. of non-missing Obs | 7304        | 1460           | 335             | 111              |
| No. below mean   | 2431          | 872            | 198             | 66               |
| No. above mean   | 1645          | 588            | 137             | 45               |
| No. of Runs      | 14            | 14             | 14              | 14               |
| Expected Runs (E(R)) | 1002.233    | 703.378        | 162.946         | 54.514           |
| Sdev(R)         | 32.456        | 18.375         | 8.834           | 5.054            |
| Z-value         | -45.432       | -37.517        | -16.861         | -8.015           |
| P-value (2-tailed) | 0.000       | 0.000          | 0.000           | 0.000            |
| Conclusion      | Non-randomness| Non-randomness | Non-randomness  | Non-randomness   |

### Table 6. Results of LOMAC individual VR tests

#### M1 (homoscedastic assumption)  
#### M2 (heteroscedastic assumption)

| Period | Var. Ratio | z-Statistic | Prob* | Var. Ratio | z-Statistic | Prob* |
|--------|------------|-------------|-------|------------|-------------|-------|
| Daily returns |
| 2      | 1.029925   | 2.557473    | 0.0105| 1.029925   | 8.677088    | 0.0000|
| 4      | 1.089607   | 4.093451    | 0.0000| 1.089607   | 13.91675    | 0.0000|
| 8      | 1.208295   | 6.018031    | 0.0000| 1.208295   | 20.55463    | 0.0000|
| 16     | 1.442883   | 8.599015    | 0.0000| 1.442883   | 29.64894    | 0.0000|
| 32     | 1.900325   | 12.06283    | 0.0000| 1.900325   | 42.38913    | 0.0000|

| Weekly |
|--------|---------|-----------|-------|---------|-----------|-------|
| 2      | 1.132399| 5.058962  | 0.0000| 1.132553| 8.315855  | 0.0000|
| 4      | 1.392607| 8.018644  | 0.0000| 1.393694| 13.33504  | 0.0000|
| 8      | 1.893728| 11.54457  | 0.0000| 1.899092| 19.70294  | 0.0000|
| 16     | 2.811906| 15.72865  | 0.0000| 2.834677| 28.29470  | 0.0000|
| 32     | 4.267041| 19.57044  | 0.0000| 4.352650| 39.00231  | 0.0000|

| Monthly returns |
|-----------------|---------|-----------|-------|---------|-----------|-------|
| 2               | 1.375493| 6.872653  | 0.0000| 1.378764| 7.186956  | 0.0000|
| 4               | 2.056844| 10.33949  | 0.0000| 2.073566| 11.3298   | 0.0000|
| 8               | 3.102619| 13.01005  | 0.0000| 3.168466| 15.87566  | 0.0000|
| 16              | 3.637992| 10.96920  | 0.0000| 3.820716| 14.43669  | 0.0000|
| 32              | 2.337363| 3.838220  | 0.0001| 2.625688| 5.182933  | 0.0000|

| Quarterly |
|-----------|---------|-----------|-------|---------|-----------|-------|
| 2         | 1.523752| 5.518071  | 0.0000| 1.523752| 5.512235  | 0.0000|
| 4         | 2.127862| 6.351603  | 0.0000| 2.127862| 7.04153   | 0.0000|
| 8         | 1.769585| 2.741031  | 0.0061| 1.769585| 2.953928  | 0.0031|
| 16        | 0.627380| 0.891881  | 0.3725| 0.627380| 0.960979  | 0.3366|
| 32        | 0.447385| 0.912754  | 0.3614| 0.447385| 0.981801  | 0.3262|

### Table 7. Wright VR test results

#### Daily returns

| $Q$  | $R_1$  | $R_2$  | $R_3$  | $R_4$  | $R_5$  | $R_6$  |
|------|--------|--------|--------|--------|--------|--------|
| Var. Ratio | z-Statistic | Prob* | Var. Ratio | z-Statistic | Prob* | Var. Ratio | z-Statistic | Prob* |
| K    |        |        |        |        |        |        |
| 2    | 1.994152| 84.96364|0.0000  | 1.978068| 83.58907|0.0000  | 1.993702| 84.92520|0.0000 |
| 4    | 3.980400| 136.1510|0.0000  | 3.929974| 133.8475|0.0000  | 3.972618| 135.7955|0.0000 |
| 8    | 7.943886| 200.6222|0.0000  | 7.816610| 196.9449|0.0000  | 7.896495| 199.2530|0.0000 |
| 16   | 15.82858| 287.9115|0.0000  | 15.51806| 281.8826|0.0000  | 15.60843| 283.6372|0.0000 |
| 32   | 31.38091| 407.0527|0.0000  | 30.60536| 396.6617|0.0000  | 30.40905| 395.1033|0.0000 |

#### Weekly returns

| $R_1$  | $R_2$  | $S_1$  |
|--------|--------|--------|
| Var. Ratio | z-Statistic | Prob* |
| K    |        |        |        |
| 2    | 1.970790| 37.0938|0.0000  |
| 4    | 3.897412| 59.1769|0.0000  |
| 8    | 7.673673| 86.2059|0.0000  |
| 16   | 14.80054| 119.7086|0.0000  |
| 32   | 26.65676| 153.6908|0.0000  |
either overvalued or undervalued. That a substantial proportion of stocks on the GSE were quarterly) in this study was an indication that the market the four return series (daily, weekly, monthly, and including those of [22], who concluded that the GSE was inefficient at weak-form. The inefficiency observed across weak-form. These results corroborated earlier studies proposition, implying that the market was inefficient at empirical conclusions (reported in Table 9) unanimously efficient market hypothesis, also popularly known as the Ghana Stock Exchange within the presumption of the EMH is the Chow-Denning joint test associated with the Lo and Mackinlay homoscedasticity version of the VR test, CD( is the rank-score test, and CD1, represent the sign-based test.

| Series (returns) | CD(Mv1) | CD1 | CD2 | CD3 |
|------------------|---------|-----|-----|-----|
| Daily            | 12.06283*** (0.0000) | 287.91515*** (0.0000) | 281.8826*** (0.0000) | 283.6372*** (0.0000) |
| Weekly           | 19.57044*** (0.0000) | 153.6908*** (0.0000) | 144.0933*** (0.0000) | 141.4123*** (0.0000) |
| Monthly          | 13.01005*** (0.0000) | 32.07010*** (0.0000) | 29.52719*** (0.0000) | 30.23585*** (0.0000) |
| Quarterly        | 6.351603*** (0.0000) | 8.623067*** (0.0000) | 7.948361*** (0.0000) | 8.371214*** (0.0000) |

Note: *** denote rejection of the null hypothesis of random walk at 1%, 5% and 10%, respectively. Bootstrapped p-values are in parentheses. CD(Mv1) is the Chow-Denning joint test associated with the Lo and Mackinlay homoscedasticity version of the VR test, CD1 is associated with the Wright rank test, CD2 denotes the rank-score test, and CD3, represent the sign-based test.

5. Conclusion

The study assessed the predictability of returns on the Ghana Stock Exchange within the presumption of the efficient market hypothesis, also popularly known as the random walk theory. The four different but augmenting empirical conclusions (reported in Table 9) unanimously disavowed the weak-form efficient market (random walk) proposition, implying that the market was inefficient at weak-form. These results corroborated earlier studies including those of [22], who concluded that the GSE was inefficient at weak-form. The inefficiency observed across the four return series (daily, weekly, monthly, and quarterly) in this study was an indication that the market was generally inefficient. This provided the basis to infer that a substantial proportion of stocks on the GSE were either overvalued or undervalued.

The founding prerequisite of the EMH is that returns must follow a random walk or future vicissitude in returns, and for all practical purposes should be unpredictable. Thus, the plausible empirical conclusion from the results is that returns on the GSE are predictable (follow a logical pattern) or there is a possibility for some investors to generate abnormally high returns beyond equilibrium through trading strategies that are based on historical returns. Though an inefficient market is an indication of profitable arbitraging trading predicated on market predictability the consequential investor attraction is not entirely desirable. An inefficient market also creates a congenial framework for insider trading, and it is prone to over-inflated prices and speculation. However, this study is unable to answer the question of whether exploitation may be profitable given that inefficiency also drives up transaction cost. It is thus imperative for investors to be aware that big gains are as likely as big losses in inefficient markets.

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