# *Efficient Market Hypothesis in South Africa: Evidence from Linear and Nonlinear Unit Root Tests*

Andrew Phiri
*North West University, South Africa*
*andrewp@cti.ac.za*

This study investigates the weak form efficient market hypothesis (EMH) for five generalized stock indices in the Johannesburg Stock Exchange (JSE) using weekly data collected from 31st January 2000 to 16th December 2014. In particular, we test for weak form market efficiency using a battery of linear and nonlinear unit root testing procedures comprising of the classical augmented Dickey-Fuller (ADF) tests, the two-regime threshold autoregressive (TAR) unit root tests described in Enders and Granger (1998) as well as the three-regime unit root tests described in Bec, Salem, and Carrasco (2004). Based on our empirical analysis, we are able to demonstrate that whilst the linear unit root tests advocate for unit roots within the time series, the nonlinear unit root tests suggest that most stock indices are threshold stationary processes. These results bridge two opposing contentions obtained from previous studies by concluding that under a linear framework the JSE stock indices offer support in favour of weak form market efficiency whereas when nonlinearity is accounted for, a majority of the indices violate the weak form EMH.

*Key Words:* Efficient Market Hypothesis (EMH), Johannesburg Stock Exchange (JSE), South Africa, Threshold Autoregressive (TAR) model, unit roots
*JEL Classification:* C22, C51, G14

## Introduction

The ability of a stock market to perform its role efficiently is highly contingent to the extent on which it can be deemed efficient. The hypothesis demonstrating the efficiency of capital markets is grounded upon the realization that competitive behaviour existing among profit-seeking participants will ensure that asset prices continuously adjust to reflect all price-influential information (Jawadi, Bruneau, and Sghaier 2009). Deriving from this logic, an important attribute of efficient capital markets is that the prices of the securities must reflect all available information and any new information should be rapidly absorbed into the prices (Nisar and Hanif 2012). The resulting efficient market hypothesis (EMH) suggests that stock prices fully reflect all available information in the market and no investor is able to earn excess return based on some secretly held private, public or historic information. In this sense, an efficient capital market makes it impossible for investors to forecast future price variations since the anticipated events are already integrated in the present stock price (Jawadi, Bruneau, and Sghaier 2009). Pragmatically, the EMH can be segregated into three forms depending upon the information set to which stock prices adjust. For instance, under the weak form EMH, prices reflect all past security market information; hence, information on past prices and trading volumes cannot be used for profit. Within a semi-strong form efficient market, stock prices fully reflect all publically available information and are concerned with both the speed and accuracy of the market's reaction to information as it becomes available. Under the strong form efficiency, prices are expected to reflect both public and private information and this hypothesis is concerned with the disclosure efficiency of the information market than the pricing efficiency of the securities market.

Plethoras of empirical studies have been conducted to test the efficiency of stock markets for both industrialized and emerging market economies. A vast majority of these studies opt to test the weak-form EMH by assimilating this hypothesis to the random walk of stock returns. While the findings of these studies generally support the weak-form efficiency for developed and mature stock exchanges, the empirical evidence for South Africa and other emerging economies remains inconclusive (Bonga-Bonga and Mukande 2010). One credible reason for the observed variation of empirical results obtained from previous studies is that they do not take into consideration possible nonlinear behaviour in the JSE stock indices. As conveniently noted by Lim (2011), the assumption of linearity may be trivializing the entire issue since this assumption implicitly implies that the level of market efficiency remains unchanged throughout the estimation period. Sources of asymmetric behaviour in stock markets are well documented in the literature and are inclusive of the presence of transition costs and market frictions; interaction of heterogeneous agents and diversity in agents beliefs (Hasanov and Omay 2007). Thus given the possibility of both linear and nonlinear structures being associated with underlying data generating processes, we formally test the stationary properties of the time series by applying a battery of unit root tests comprising of a combination of linear and nonlinear testing procedures to investigate the market efficiency hypothesis within the Johannesburg Stock Exchange (JSE). In particular, we consider three unit root tests namely: the augment Dickey-Fuller (ADF) unit root tests, Enders and Granger (1998) nonlinear unit root tests as well as Bec, Salem, and Carrasco (2004) nonlinear unit root tests. We apply these unit root tests to five indices on the JSE: the all share index, the JSE top 40 companies index, the industrials index, the financial index, the mining index and the gold index.

Having outlaid the background to the study, we present the remainder of our study as follows. The following section presents a brief review of previous literature in the South African context. Section three of the paper outlines the empirical framework used in the study whereas section four presents the data as well as the empirical results obtained from the study. We then conclude our study in section five by drawing out academic as well as policy implications associated with our study.

## Literature Review

Following the pioneering studies of Osborne (1962) and Fama (1965), weak-form efficiency in capital markets has been widely accepted as being a determining factor in supporting the evidence of efficient stock markets across the empirical literature. Since then, a plethora of authors have contributed to the expanding literature by running a variety of formal tests to confirm the existence of weak-form efficiency in various stock markets worldwide. However, the literature tends to present conflicting evidence pertaining to the subject matter, with such conflict evidence appearing to be more pronounced for developing or emerging economies with South Africa bearing no exception to this rule. In an extensive review of previous studies conducted on the JSE, Mlambo and Biekpe (2007) conclude that different methodologies applied to various time periods in the literature could account for the observed conflicting evidence in the literature. This insinuation becomes evident when considering the studies of Smith, Jefferis, and Ryoo (2002), Magnusson and Wydick (2002) and Jefferis and Smith (2005), who have all found the JSE to be weak-form efficient using the runs test and random walk tests. Conversely, Appiah-Kusi and Menyah (2003) found that the JSE is not weak form efficient during periods prior to 1995 while the stock indices revert to weak-form efficiency subsequent to the year 2000. Interestingly enough, such inconclusiveness is not only restricted to South African case studies and can be also identified for a host of other emerging economies as has been documented for

India (Gupta and Basu 2007), for Sri Lanka (Wickremasinghe 2005), for Jamaica (Robinson 2005), for South Asian economies (Nisar and Hanif 2012), for Latin American economies (Worthington and Higgs 2003) as well as for other African economies (Ntim et al. 2011).

In addition, even more recently, there has been growing empirical support in notion of a nonlinear data generating process (DGP) for various stock prices or indices worldwide. One of the earliest works on the subject matter was presented by Li and Lam (1995) who used a threshold autoregressive conditional heteroscedastic (TARCH) to establish that the model structure of Hong Kong stock returns data tends to fluctuate over a horizon of time periods. Another study worth taking note of is that presented in Shively (2003), who finds evidence of stock prices in international markets being consistent with a regime-reverting random walk process containing a deterministic trend. Other forms of nonlinear time series analysis which have also emerged in the literature include the Markov Switching (MS) models (Schaller and van Norden 1997), Neural Networks (NN) models (Albano, La Rocca, and Perna 2013); smooth transition regression (STR) models (Bonga-Bonga 2012) and statistical models incorporating the use of chaotic nonlinearity (Abyyankar, Copeland, and Wong 1997; Kohers, Pandey, and Kohers 1997; Pandey, Kohers, and Kohers 1998). Yet despite these empirical advancements made in the literature, it should be noted that a majority of the empirical evidence obtained from the use of nonlinear econometric models have managed to produce but a weak consensus concerning the nature of various stock indices worldwide.

There also exists a separate class of empirical studies, which lean towards the use of nonlinear unit root testing procedures, and this strand of empirical literature appears to have attained more success in establishing weak-form EMH for various stock markets. A popular citation among these works are the studies of Narayan (2005; 2006) who applies the unit root testing procedure of Caner and Hansen (2001) to US stock prices and finds that the data evolves as a nonlinear time series characterized by a unit root process. Notably, this finding is highly consistent with the weak-form EMH. Similarly, Munir and Mansur (2009) apply similar unit root tests to those used by Narayan (2006) and establish a unit root process in the behaviour of the Malaysian stock exchange market. Furthermore, Lee, Tsong, and Lee (2014) apply smooth transition regression (STR) heterogeneous panel unit root tests to OECD, G6, Asian and other European economies and establish that a majority of the countries under observation conform to the weak-form EMH; whereas Hasanov and Omay (2007) employ the STR unit root test of Kapetonois, Shin, and Snell (2003) to establish weak-form market efficiency for Bulgarian, Czech, Hungarian and Slovakian stock markets. Although still in its infants stages of implementation, Oskooe (2011) used nonlinear Fourier unit root tests for the Iran stock market and was able to validate the weak-form EMH in this particular stock market. Without discarding the positive developments presented in the literature thus far, the empirical literature, never-the-less, remain devoid of bridging the aforementioned two strands of empirical works examining asymmetric behaviour in the stock market prices. Undertaking such a task could prove to bridge the empirical hiatus existing between univariate nonlinear modelling of stock prices, on one hand, and nonlinear unit root tests, on the other hand.

## Econometric Methodology

Given that the phenomenon of random walks is associated with EMH, one way to test the weak-form EMH is to examine whether a historical sequence of stock prices are independent of one another or whether they contain a unit root. For analytical purposes, we begin by subjecting a univariate time series of stock indices, pt, to the following ADF auxiliary test regression:

$$\Delta p_t = \mu_t + \beta_t + \varphi p_{t-1} + \sum_{i=1}^{p} \alpha_i \Delta p_{t-1} + \varepsilon_t, \tag{1}$$

where $\mu_t$ is a drift term, $t$ is time and $\varepsilon_t$ is an independent and identically distributed white noise disturbance term. The DF statistic, DF$\varphi_\mu$, is then used to test the null hypothesis of a unit root (i.e. H0: $\varphi = 0$) against the alternative of a stationary process (i.e. H1: $\varphi < 0$). The test statistic rejects the null hypothesis of a unit root when the statistic is of a lower absolute value compared with critical values tabulated in MacKinnon (1996). If the null hypothesis of a unit root cannot be rejected, then one can assume that the observed time series is non-stationary such that deviations from its mean trend are infinitely persistent. Conversely, when the null hypothesis of a unit root is rejected then it follows that the time series is considered to be stationary or integrated of order I(0). However, the ADF unit root test has been heavily criticized from three main perspectives. Firstly, it is widely believed that the ADF test does not consider the case of heteroskedasticity and non-normality frequently revealed in raw data of economic time series variables. Secondly, the ADF test is considered to be formulated on a misspecified econometric model devoid of a moving-average (MA) component. Lastly, the ADF tests are unable to discriminate between a unit root process and a near unit root process with a high degree of autocorrelation and are also sensitive to structural breaks or other nonlinearities existing within time series data. Therefore, seeing that stock return times series in emerging economies such as South Africa, are generally characterized by some stylized facts such as flat tails, excess kurtosis, skewness and volatility clustering; possible periods of nonlinearity may be the result of market adjustment as it is highly likely that financial asset prices are affected by events of a political, social and economic nature (Lim 2011). Hence, the appeal of nonlinear unit root testing procedures in evaluating the weak-form EMH for South African stock returns becomes apparent.

Methodologically, Enders and Granger (1998) as well as by Caner and Hansen (2001), have eloquently demonstrated how conventional linear unit root tests such as the Dickey-Fuller tests have got considerably low power in testing for unit roots when the underlying data generating process is found to be nonlinear. Hence, when evidence of asymmetries in a univariate time series emerges, then corresponding asymmetric unit root tests must be implemented to determine the stochastic properties of the time series. In introducing asymmetric adjustment in the unit root testing procedure, we apply the asymmetric unit root tests of Enders and Granger (1998) and Bec, Salem, and Carrasco (2004) to evaluate the integration properties for both two-regime and three-regime processes, respectively. Notably, both of the aforementioned unit root tests are both generalizations of the Dicker-Fuller unit root testing procedure implemented under Hansen's (2000) TAR framework. Take for instance, the unit root test of Enders and Granger (1998) which is derived from the following Dickey Fuller auxiliary unit root testing regression:

$$p_t = \varphi p_{t-1} + \xi_t, \tag{2}$$

where $\xi_t$ is a white noise error term. As a means of accommodating asymmetric behaviour within the unit root test regression Enders and Granger suggest the re-formulation of equation (3) in terms of their first differences. The resulting nonlinear auxiliary unit root testing regression is specified as:

$$\Delta p_t = I_t \psi_1 \xi_t + (1 - I_t) \psi_2 \xi_t, \tag{3}$$

where $I_t$is a zero-one Heaviside indicator function which governs the regime switching behaviour of the error term $\xi_t$. In our paper, we will consider four different functions for the Heaviside function. Under the first function, we specify the indicator function as TAR process with a zero-threshold value:

$$I_{.t} = \begin{cases} 1, & \text{if } \xi_{t-1} \geq 0 \\ 0, & \text{if } \xi_{t-1} < 0 \end{cases}. \tag{4}$$

Under the second specification we, specify a C-TAR process with consistently estimated or a non-zero threshold estimate:

$$I_{.t} = \begin{cases} 1, & \text{if } \xi_{t-1} \geq \gamma \\ 0, & \text{if } \xi_{t-1} < \gamma \end{cases}. \tag{5}$$

The third method of partitioning the threshold regimes is to specify the Heaviside indicator function based on the differences in the error terms. The resulting momentum threshold autoregressive (MTAR) model with a zero threshold value assumes the following indicator function:

$$I_{.t} = \begin{cases} 1, & \text{if } \Delta\xi_{t-1} \geq 0 \\ 0, & \text{if } \Delta\xi_{t-1} < 0 \end{cases}. \tag{6}$$

whereas the forth method of partitioning the threshold models is to specify them as a MTAR model with a consistently estimated or non-zero threshold value (i.e. C-MTAR) and this is represented by the following indicator function:

$$I_{.t} = \begin{cases} 1, & \text{if } \Delta\xi_{t-1} \geq \gamma \\ 0, & \text{if } \Delta\xi_{t-1} < \gamma \end{cases}. \tag{7}$$

Based on regressions (2–6), three empirical issues need to be addressed. Firstly, the threshold value (i.e. $\gamma$) for the C-TAR and C-MTAR regressions need to be estimated since they are not specified a prior. Therefore, we follow Hansen (2000) by ordering the threshold value in ascending order such that $\gamma_0 < \gamma_1 < \cdots < \gamma_T$, where $T$ is the number of observations after tranculating the upper and lower 15 percent observations. Thereafter, we perform a grid search and estimate the true threshold value as the threshold value, which minimizes the residual sum of squares (RSS). Secondly, we need to test for asymmetric effects among the time series. To this end, Enders and Dibooglu (2001) propose the use of a modified $F$-statistic, $\varphi_\mu$, to test the null hypothesis of linear process, that is, a test that the model regime coefficients, $\psi_1$ and $\psi_2$, are equal (i.e. $\psi_1 = \psi_2$) against the alternative nonlinear hypothesis in which the regime coefficients differ (i.e. $\psi_1 \neq \psi_2$). Lastly, we test for unit roots in the observed time series. Following Enders and Silkos (2001) we use of a modified $F$-statistic, NDF$\varphi_\mu$, to test the null hypothesis of a unit root, which is essentially a test of the model regime coefficients being simultaneously equal to zero (i.e. $\psi_1 = \psi_2 = 0$) against the alternative of a stationary two-regime TAR process in which the model coefficients differ and are both not equal to zero (i.e. $\psi_1 \neq \psi_2 \neq 0$). In the aforementioned tests of asymmetries and unit root behaviour, the null hypotheses can be rejected if the $F$-statistic is lower in absolute value in comparison with the critical values as tabulated in Enders and Granger (1998).

Yet there remains the possibility that the time series may evolve as a three-regime mean reverting process as opposed to a two-regime process. Henceforth, as a means of circumventing this issue, we follow in pursuit of Bec, Salem, and Carrasco (2004) by implementing unit root testing procedures based upon the following three-regime threshold autoregressive (TAR) auxiliary function:

$$\Delta p_t = \begin{cases} \mu_1 + \sigma_1 \Delta p_{t-1} + \delta_1 p_{t-1} \text{ if } -\infty < p_{t-1} \leq \tau_1 \\ \mu_2 + \sigma_2 \Delta p_{t-1} + \delta_2 p_{t-1} \text{ if } \tau_1 < p_{t-1} \leq \tau_2 \\ \mu_3 + \sigma_3 \Delta p_{t-1} + \delta_3 p_{t-1} \text{ if } \tau_2 < p_{t-1} \leq \infty \end{cases}, \quad (8)$$

where $\sigma_i$ are the regression coefficients and the threshold, $\tau$, is defined such that $\tau_2 = -\tau_1 = \tau$. Restrictions of $\sigma_i \leq 1$ are imposed on the regression coefficients to ensure that nonstationarity can only be detected in the corridor regime of the three-regime process. The unit root testing procedure is based upon the statistical significance of the regression parameters, $\sigma_i$. Under the null hypothesis, a unit root process (i.e. H0: $\sigma_1 = \sigma_2 = \sigma_3$; $\delta_1 = \delta_2 = \delta 3 = 0$) is tested against the alternative of a stationary three-regime TAR process (i.e. H1: $|\sigma_1| < 1$, $|\sigma_2| < 0$, $|\sigma_3| \leq 0$).

However, prior to the testing of these hypotheses there must exist a singular threshold estimate value of $\hat{\tau}$, which is to be plugged into the unit root test regression. Bec, Salem, and Carrasco (2004) suggest that the threshold value can be selected a prior by the statistician in testing for the unit root hypothesis. Thereafter, the asymptotic distributions of

TABLE 1 Descriptive Statistics of JSE Share Indices

| | *ALSI* | *Top40* | *Ind* | *Fin* | *Min* | *Gold* |
|---|---|---|---|---|---|---|
| Mean | 20877.94 | 18919.31 | 19510.73 | 16729.89 | 23295.43 | 2174.5 |
| Median | 20875.63 | 18976.45 | 20642.36 | 17002.6 | 24597.7 | 2364.78 |
| Maximum | 43132.75 | 38683.17 | 42443.24 | 31566 | 48258.56 | 3360.39 |
| Minimum | 7243.08 | 6780.72 | 5496.68 | 7397.84 | 5681.71 | 685.29 |
| Std. dev. | 818.77 | 720.14 | 10558.83 | 6779.16 | 858.44 | 653.25 |
| Skewness | 0.23 | 0.21 | 0.22 | 0.29 | 0.06 | −0.74 |
| Kurtosis | −1.28 | −1.30 | −1.12 | −1.01 | −1.28 | −0.45 |
| JB | 127.39 | 128.339 | 118.03 | 112.86 | 126.04 | 96.89 |
| Probability | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

these unit root tests are derived from Supremum based tests on the Wald, Lagrange Multiplier and Likelihood Ratio statistics. From the these unit root connotations, a time series can only be rendered as being a stationary three-regime TAR process if the above test statistics are of smaller value in comparison to their computed critical values.

## Data and Empirical Analysis

### DATA DESCRIPTION

All data used in our study consists of daily closing indices of the all share index (*ALSI*); the JSE top 40 companies index (*top*40); the industrials index (*ind*), the financial index (*fin*), the mining index (*min*) and the gold index (*gold*) and has been collected from the McGregor statistical database. Our collected data covers a weekly sample period from 31st January 2000 to 16th September 2014. From our summary statistics of the time series data, as reported in table 1, we conclude that the data under observation are normally distributed. We base these conclusions since the Jarque-Bera (JB) statistic exceeds the critical $p$-values for all significance levels.

Furthermore, we detect skewness and kurtosis in the data, which may be caused from a pattern of volatility in financial markets, were periods of volatility are followed by periods of relative stability. A plausible explanation for these patterns may be underlying nonlinear trends in the data generating process (DGP) of the observed time series. The time series plot of the stock indices used in our study, as shown in figure 1, verifies this assumption of non-normality and non-linearity in the data.

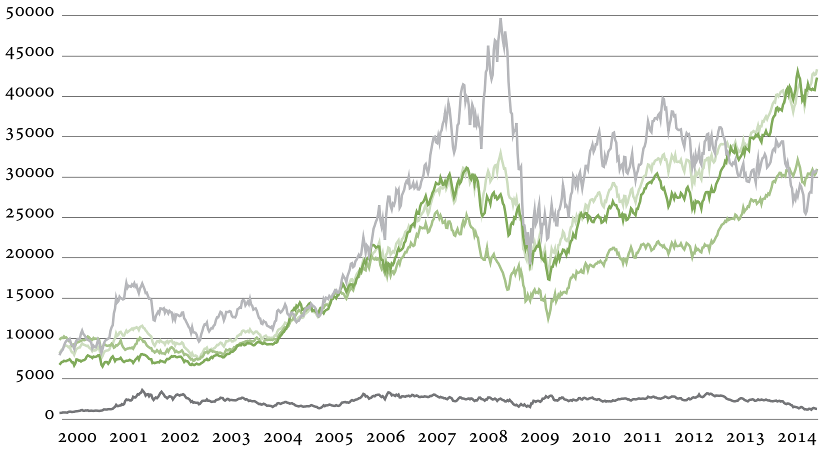


FIGURE 1 Time Series Plots of JSE Share Indices (light green – *ALSI,* green – *fin,* dark green – *ind,* light gray – *min,* dark gray – *gold*)

## EMPIRICAL RESULTS

We begin our empirical analysis by investigating the integration properties of the JSE stock price indices using the linear ADF unit root tests. In particular, we perform the ADF under three empirical settings, namely: (1) with a constant or drift, (2) with a trend, and (3) with neither a constant nor a trend. On deciding on the optimal lag for the time series under the ADF unit root test, we account for a maximum of eight lags and thereafter select the optimal lag length based upon the lag, which minimizes the residual variance of the Akaike information criterion (AIC) and the Bayesian information criterion (BIC). The results of the linear ADF unit root tests are reported in table 2.

Starting with the model including no trend and no intercept, we observe that the all share index, the financial index, the industrial index and the JSE top 40 companies index manage to successfully reject the null hypothesis of a unit root in favour of a stationary process at significance levels of at least 5 percent. The remaining stock price indices, namely; the gold index and the mining index; all fail to reject the null hypothesis of a unit root and only retain their stationarity in their first differences at all levels of significance. Given the overall ambiguity associated with the results obtained from the ADF unit root test with no trend and no intercept, we discard these results and proclaim that the model is misspecified for South African data. On the other end of the spectrum, when a trend or a constant are included within the unit root test regression, we find

TABLE 2 ADF Unit Root Test Results

| Variable | Test statistics | | |
|---|---|---|---|
| | *None* | *Drift* | *Trend* |
| *ALSI* | −2.62*** | 1.51 (−5.72)*** | −1.95 (−5.77)*** |
| *Top40* | −2.41** | −4.15 (−5.63)*** | −2.06 (−5.66)*** |
| *Ind* | −2.90*** | −1.77 (−7.90)*** | −2.15 (−7.96)*** |
| *Fin* | −2.26** | −1.85 (−8.27)*** | −1.75 (−8.37)*** |
| *Gold* | 0.63 (−8.15)*** | −1.91 (−8.12)*** | −2.93 (−8.24)*** |
| *Min* | −0.95 (−5.46)*** | −0.90 (−5.47)*** | −2.99 (−5.49)*** |

NOTES ***, **, and * denote the 1%, 5% and 10% significance levels respectively. The test statistics for the first difference of the time series are reported in parentheses. The lag length for the time series under the ADF test is selected through the minimization of the AIC and BIC.

that all the time series fail to reject the null hypothesis of a unit root and only favour stationarity of the time series in their first differences. Therefore, in generalizing these results, we conclude that each of the time series is integrated of order I(1) when subjected to linear ADF unit root tests. And yet caution is taken in interpreting the obtained results, since the ADF unit root tests are notoriously known for being sensitive to possible structural breaks, which may be manifested in the form nonlinearities in the time series. Bearing this in mind, we thus proceed to apply nonlinear unit root testing procedures of Enders and Granger (1998) to the JSE stick price indices and report the results in table 3.

In screening through our obtained results, we are able to pinpoint a couple of intriguing observations. We firstly note that all observed time series reject the null hypothesis of linearity at all levels of significance for all model specifications. This result is worth highlighting since, as previously mentioned, the linear ADF unit root tests have difficulty in distinguishing between pure unit root processes and nonlinearity in the data. However, in turning to the results of the unit root tests performed for the time series, our results becomes less conclusive. In particular, we find that for the TAR model specification with a zero threshold, we can reject the unit root hypothesis in favour of threshold stationarity for half of the stock indices (i.e. the all share index, the mining index and the JSE top 40 companies index). For the TAR specification with a consistently estimated threshold (i.e. C-TAR model) the unit root hypothesis is rejected for two-thirds of the stock indices (i.e.; the all share index, the JSE top 40 companies index; the mining index and the gold index). Meanwhile, un-

TABLE 3 Enders and Granger (1998) Root Test Results

| Variable/test type | | TAR | C-TAR | MTAR | C-MTAR |
|---|---|---|---|---|---|
| *ALSI* | (1) | 33.33*** | 37.03*** | 32.58*** | 0.00*** |
| | (2) | 3.03* | 8.35* | 1.95 | 3.14* |
| *Top40* | (1) | 33.17*** | 36.06*** | 31.36*** | 33.87*** |
| | (2) | 4.33* | 8.52*** | 1.70 | 5.34* |
| *Ind* | (1) | 31.85*** | 32.09*** | 31.84*** | 33.81*** |
| | (2) | 0.04 | 0.38 | 0.02 | 2.84* |
| *Fin* | (1) | 35.35*** | 35.86*** | 37.18*** | 41.47*** |
| | (2) | 0.22 | 0.92 | 2.76* | 8.72* |
| *Gold* | (1) | 32.18*** | 33.89*** | 31.60*** | 32.55*** |
| | (2) | 0.82 | 3.28* | 0.03 | 1.35 |
| *Min* | (1) | 28.78*** | 31.67*** | 25.7*** | 27.86*** |
| | (2) | 4.66* | 9.04** | 0.02 | 3.26* |

NOTES Test type: (1) linearity test, (2) unit root test. ***, **, and * denote the 1%, 5% and 10% significance levels respectively. The test statistics for the first difference of the time series are reported in parentheses. The lag length for the time series under the ADF test is selected through the minimization of the AIC and BIC.

der the MTAR model with a zero threshold, only the financial index manages to reject the unit root hypothesis whereas under the MTAR model with a consistently estimated threshold (i.e. C-MTAR model) all observed time series reject the unit root hypothesis with the exception of the gold index. Generally these results present a reversal of those previously obtained for the linear ADF tests previously performed, in the sense that under the Enders and Granger (1998) nonlinear unit root tests, only half of the estimated regressions conform to the weak form EMH for the JSE indices. We do not considered these obtained results as being conclusive since, as pointed out by Narayan and Smyth (2007), a loss of power in unit root tests may occur when ignoring two-or more breaks in unit root testing procedures that only account for one threshold point. Henceforth, we are encouraged to further conduct nonlinear unit root tests under the context of a three-regime TAR model as described in Bec, Salem, and Carrasco (2004).

Given that the implementation of Bec, Salem, and Carrasco (2004) nonlinear unit root testing procedure requires the identification of a predetermined threshold value; we began our empirical procedure by firstly performing our grid search across the possible values of the threshold

TABLE 4 Threshold Regression Estimates and Tests of Linearity

| Variable | ALSI | *Top40* | *Ind* | *Fin* | *Min* | *Gold* |
|---|---|---|---|---|---|---|
| $\tau$ | 25784 | 26028 | 22582 | 14534 | 23948 | 2481 |
| LR($\tau$) | 25.01 (0.00)*** | 32.87 (0.00)*** | 38.75 (0.00)*** | 33.74 (0.00)*** | 26.64 (0.00)*** | 25.78 (0.00)*** |
| c($\tau$) | 18.42 | 29.39 | 24.79 | 23.45 | 17.16 | 13.94 |

NOTES ***, **, and * denote the 1%, 5% and 10% significance levels respectively. The test statistics for the first difference of the time series are reported in parentheses.

variable i.e. $\psi = [\underline{\tau}, \overline{\tau}]$. In the spirit of Hansen (2000), we restrict our grid search to values of $\tau$ to specific quantiles by eliminating the smallest and largest 15 percent of the observational data. The remaining values consist of the potential values of $\tau$ which can be search over for the true estimate $\hat{\tau}$. Our estimates from the TAR model, as reported in table 2, depict threshold values of price indexes of 25784 for the all share index, 26028 for top 40 companies, and 22582 for industrials, 41534 for financials, 23948 for mining and 2481 for gold. Interestingly enough, each of these estimated break points for all estimated indexes points to two separate periods, the first being between the months of January and May 2007, whereas the second period corresponds to that of between August and November 2009. Coincidentally, we find that we can attribute these periods to the significant supply shocks caused by the financial crisis of 2007–2008 caused by the closing down of major banks in the USA, which affected a majority of financial sectors worldwide.

Subsequent to the estimation of the optimal threshold values for each of the time series, we proceed to perform the LR tests for the threshold estimates and derive the associated bootstrap $p$-values using Hansen (2000) bootstrap procedure. In particular, we estimate the TAR regression given at the optimal threshold value, $\hat{\tau}$, at lag length ($p$) and extract the regression residuals to be used as an empirical distribution for the bootstrapping procedure i.e. $\varepsilon^{*} = \varepsilon_1{}^{*}, \varepsilon_2{}^{*}, \ldots, \varepsilon_n{}^{*}$. We then draw a sample from the empirical distribution in order to create a bootstrap sample, which used to calculate the LR statistic of the estimated TAR model under the null and alternative hypothesis, respectively. By replicating this procedure 1000 times and calculating the percentage in which the simulated statistic exceeds the actual we are able to provide the bootstrap estimate of the asymptotic $p$-values under the null hypothesis of linearity. Furthermore, we form asymptotic confidence intervals for based upon non-rejection

TABLE 5 Bec, Salem, and Carrasco (2004) Unit Root Test

| Variable | | $W_T(\tau)$ | $LM_T(\tau)$ | $LR_T(\tau)$ |
|---|---|---|---|---|
| ALSI | | 9.12 | 8.63 | 8.87 |
| *Top*40 | | 8.55 | 8.12 | 8.33 |
| *Ind* | | 11.12 | 10.41 | 10.76 |
| *Fin* | | 6.58 | 6.32 | 6.45 |
| *Gold* | | 19.75** | 17.60* | 18.64** |
| *Min* | | 16.64* | 15.86 | 15.84** |
| Critical values | 10% | 16.181 | 15.87 | 15.77 |
| | 5% | 18.4 | 17.63 | 17.89 |
| | 1% | 23.01 | 21.75 | 22.23 |

NOTES ***, **, and * denote the 1%, 5% and 10% significance levels respectively. *P*-values are reported in parentheses.

region of confidence level of the LR statistic. The estimated LR test statistics and their asymptotic confidence intervals, as reported in table 5, confirm that the null hypothesis of linearity can be rejected for all indices at a one percent significance level. In other words, the linear AR model can be strongly rejected in favour of a nonlinear TAR model thus permitting us to proceed with implementation of Bec, Salem, and Carrasco (2004) nonlinear unit root testing procedures. The results of the aforementioned unit root tests are reported in table 5.

As a first step towards examining the stationary properties of the time series variables, we compute the threshold unit root test statistics (i.e. $W_T(\tau)$, $LM_T(\tau)$ and $LR_T(\tau)$) together with the associated bootstrap critical $p$-values values at significance values of 1 percent, 5 percent and 10 percent using 1000 bootstrap replications. Our estimation results show that a majority of the JSE stock indices significantly reject the unit root hypothesis in favour of a stationary nonlinear process. In particular, 4 price indices (i.e. all share index; the JSE top 40 companies index; the industrials index and the financial index) reject the unit root hypothesis whereas the remaining two indices (i.e. the mining index and the gold index) reject the threshold stationary hypothesis. Even though not completely definitive, the obtained results present an element of clarity to the issue of nonlinearities and unit roots existing within the observed time series. The results particularly prove that most stock indices in the JSE evolve as both nonlinear and non-stationary processes thus violating the weak form hypothesis.

## Conclusions

The presented paper sought to investigate the efficient market hypothesis for five generalized stock price indices under the JSE (i.e. all share index, top 40 companies, industrial sector, financial sector, mining sector and gold stock prices) using weekly data collected between the period of 31st January 2000 and 16th December 2014. To this end, we carried out conventional linear ADF unit root tests as well as the nonlinear unit root testing procedures as proposed by Enders and Granger (1998) and Bec, Salem, and Carrasco (2004). The overall empirical results obtained in our study bridge two opposing contentions obtained from previous studies by suggesting that when linear unit root tests are employed then the time series are unable to reject the unit root hypothesis, thus offering support for the weak-form EMH. Conversely, when nonlinearities are accounted for in the unit root testing procedures, the empirical evidence appears to offer more support for threshold stationarity thus failing to support the weak-form EMH for the JSE stock prices. With special reference to the results obtained from Bec, Salem, and Carrasco (2004) nonlinear unit root test results, we particularly observe that the stock indices associated with the primary sectors (i.e. mining sector and gold prices) evolve as unit root processes whereas the indices associated with secondary sectors (i.e. all share index, top 40, financial sector, industrial sector) evolve as nonlinear yet stationary processes. In other words, our empirical analysis demonstrates on how the primary sector stock indices are more indicative of being weak-form market efficient whereas secondary sector indices prove to reject the EMH.

Seeing that the efficiency of stock markets are directly linked to the decision-making of investors as well as to the enhancement of the role of stock market development process, the empirical results obtained in our study bear important implications for both individual and institutional investors as well as for South African regulatory policymakers. In particular, our findings of weak-form market efficiency associated with the stock indices of the primary sector implies that investors in the primary sector of the JSE trade like noise traders, who purely speculate and treat the market like a burgeoning casinos. Therefore the primary sector of the JSE can provide as an efficient outlet for potential investors who would have previously considered directing their investments towards more developed stock markets. On the other end of the spectrum, the rejection of the weak-form EMH for the stock indices in the secondary sector of the JSE primarily implies that stock price movements could be exploited using technical analysis. As discussed in Magnusson and Wydick (2002), such market inefficiency may be caused by some sort of consensus between traders in condition of their prices on the trading patterns of other traders or in the previous day's trading volume as a measure of market consensus. Nonetheless, our empirical analysis place strong emphasis on the significance of institutional and regulatory mechanisms in monitoring the market activities within the primary sector of the JSE in order to minimize possible abnormal profitable arbitrage opportunities within the stock market.

Notwithstanding some of the useful inferences derived from our study, we do not discard the fact that our current empirical analysis does present its own shortcomings. For instance, the unit root testing procedures are only able to account for weak-form market efficiency in the stock market data without direct evaluating semi-strong form as well as strong form stock market efficiency. It is very possible that emerging African economies such as South Africa will be able to pass tests for semi-strong form efficiency, which dictates that public information cannot be utilized to earn supra-abnormal returns. Hence at this juncture, it would be pre-mature to completely reject the possibility of semi-strong form EMH based on the rejection of the weak-form EMH as has been established for most stock indices in our current study. Moreover, it is unlikely that South Africa would be subject to strong-form efficiency since private information exploited by insiders is highly likely to yield abnormal returns on the stock market. Therefore, a convenient guideline for future research would be to focus on investigating the validity of semi-strong form market efficiency for stock prices within the JSE.

## References

Abyyankar, A., L. Copeland, and W. Wong. 1997. 'Uncovering the Nonlinear Structure in Real-Time Stock Indices: The S&P 500, the DAX, the Nikkei 225 and the FTSE-100.' *Journal of Business and Economic Statistics* 15:1–14.

Albano G., M. La Rocca, and C. Perna. 2013. 'Testing the Weak-Form Market Efficiency: Empirical Evidence from the Italian Stock Exchange.' *Neural Nets Surroundings: Smart Innovation, Systems and Technologies* 19:227–36.

Appiah-Kusi J., and K. Menyah. 2003. 'Return Predictability in African Stock Markets.' *Review of Financial Economics* 12:247–70.

Bec, F., M. Salem, and M. Carrasco. 2004. 'Tests for Unit Roots versus

Threshold Specification with an Application to the Purchasing Power Parity Relationship.' *Journal of Business and Economic Studies* 22 (4): 382–95.

Bonga-Bonga, L. 2012. 'The Evolving Efficiency of the South African Stock Exchange.' *International Business and Economics Research Journal* 11 (9): 997–1002.

Bonga-Bonga, L., and M. Makakabule. 2010. 'Modelling Stock Returns in the South African Stock Exchange.' *European Journal of Economics, Finance and Administrative Sciences* 19:168–77.

Caner, W., and B. Hansen. 2001. 'Threshold Autoregression with a Unit Root.' *Econometrica* 69 (6): 1555–96.

Enders, W., and S. Dibooglu. 2001. 'Long-Run Purchasing Power Parity with Asymmetric Adjustment.' *Southern Economic Journal* 68 (2): 433–45.

Enders, W., and C. Granger. 1998. 'Unit Root Tests and Asymmetric Adjustment with an Example Using the Term Structure of Interest Rates.' *Journal of Business and Economic Statistics* 16 (3): 304–11.

Enders, W., and P. Silkos. 2001. 'Cointegration and Threshold Adjustment.' *Journal of Business and Economic Statistics* 19 (2): 166–76.

Fama, E. 1965. 'The Behaviour of Stock Markets.' *Journal of Business* 38:34–105.

Gupta, R., and P. Basu. 2007. 'Weak for Efficiency in India.' *International Business and Economics Research Journal* 6:57–64.

Hansen, B. 2000. 'Sample Splitting and Threshold Estimation.' *Econometrica* 68 (3): 575–603.

Hasanov, M., and T. Omay. 2007. 'Are the Transition Stock Markets Efficient? Evidence from Nonlienar Unit Root Tests.' *Central Bank Review* 2:1–12.

Jawadi, F., K. Bruneau, and N. Sghaier. 2009. 'Nonlinear Cointegration Relations between Non-Life Insurance Premiums and Financial Markets.' *The Journal of Risk and Insurance* 76 (3): 753–83.

Jefferis, K., and G. Smith. 2005. 'The Changing Efficiency of the African Stock Markets.' *South African Journal of Economics* 73 (1): 54–67.

Kapetanois, G., Y. Shin and A. Snell. 2003. 'Testing for a Unit Root in the Nonlinear Star Framework.' *Journal of Econometrics* 112:359–79.

Kohers, T., V. Pandey and G. Kohers. 1997. 'Using Nonlinear Dynamics to Test for Market Efficiency amoung the Major US Stock Exchanges.' *Quarterly Review of Economics and Finance* 37:523–45.

Lee, C., C. Tsong and C. Lee. 2014. 'Testing for the Efficient Market Hypothesis in Stock Prices: International Evidence from Nonlinear Heterogeneous Panels.' *Macroeconomic Dynamics* 18 (4): 943–58.

Li, W., and K. Lam. 1995. 'Modelling Asymmetry in Stock Returns by a

Threshold Autoregressive Conditional Heteroscedastic Model.' *Journal of the Royal Statistical Society* Series D 44 (3): 331–41.

Lim, K. 2011. 'The Evolution of the Stock Market Efficiency over Time: A Survey of the Empirical Literature.' *Journal of Economic Surveys* 25 (1): 16–108.

MacKinnon, J. 1996. 'Numerical Distribution Functions for Unit Roots and Cointegration Tests.' *Journal of Applied Econometrics* 11:601–18.

Magnusson, M., and B. Wydick. 2002. 'How Efficient Are Africa's Emerging Stock Markets?' *Journal of Development Studies* 38:141–56.

Mlambo, C., and N. Biekpe. 2007. 'The Efficient Market Hypothesis: Evidence from Ten African Stock Markets.' MPRA Paper 25968, Munich Personal REPEC Archive, Munich.

Munir, Q., and K. Mansur. 2009. 'Is Malaysian Stock Market Efficient? Evidence from Threshold Unit Root Tests.' *Economics Bulletin* 29 (2): 1359–70.

Narayan, P. 2005. 'Are the Australian and New Zealand Stock Prices Nonlinear with a Unit Root?' *Applied Economics* 37:2161–6.

Narayan, P. 2006. 'The Behaviour of US Stock Prices: Evidence from a Threshold Autoregressive Model.' *Mathematics and Computers in Simulation* 71:103–8.

Narayan, P., and R. Smyth. 2007. 'Mean Reversion versus Random Walk in G7 Stock Prices: Evidence from Multiple Trend Break Unit Root Tests.' *Journal of International Financial Markets Institutions and Money* 17:152–66.

Nisar, S., and M. Hanif. 2012. 'Testing Weak-Form of Efficient Market Hypothesis: Empirical Evidence from South-Asia.' *World Applied Sciences Journal* 17 (4): 414–27.

Ntim, C., K. Opong, J. Danbolt, and F. Dewotor. 2011. 'Testing the Weak-Form Efficiency in African Stock Markets.' *Managerial Finance* 37 (3): 195–218.

Osborne, M. 1962. 'Periodic Structure in the Brownian Motion in the Stock Prices.' *Operational Research* 10:345–79.

Oskooe, S. 2011. 'Stock Market Efficiency from Nonlinear Unit Root Test.' Paper presented at the World Congress on Engineering, London, 6–8 July.

Pandey, V., T. Kohers, and G. Kohers. 1998. 'Deterministic Nonlinearity in the Stock Returns of Major European Markets and the United States.' *Financial Review* 33:45–63.

Robinson, J. 2005. 'Stock Price Behaviour in Emerging Markets: Tests for Weak Form Market Efficiency on the Jamaican Stock Exchange.' *Social and Economic Studies* 54 (2): 51–69.

Schaller, H., and van S. Norden. 1997. 'Regime Switching in Stock Market Returns.' *Applied Financial Economics* 7:177–91.

Shively, P. 2003. 'The Nonlinear Dynamics of Stock Prices.' *The Quarterly Review of Economics and Finance* 43:505–17.

Smith, G., K. Jefferis, and H. Ryoo. 2002. 'African Stock Markets: Multiple Variance Ratio Tests of Random Walks.' *Applied Financial Economics Journal* 12:475–84.

Wickremasinghe, G. 2005. 'Efficiency of Foreign Exchange Markets: A Developing Country Perspective.' *Asian Academy of Management Journal* 10 (1): 1–17.

Worthington, A., and H. Higgs. 2003. 'Tests of Random Walks and Market Efficiency in Latin American Stock Markets: An Empirical Note.' Discussion Paper 157, Queensland University of Technology, Brisbane.