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Unit root modeling for trending stock market series

Afees A. Salisu [a,b,*], Umar B. Ndako [c], Tirimisiyu F. Oloko [b], Lateef O. Akanni [d]

[a] *Department of Economics, Federal University of Agriculture, Abeokuta, Nigeria*
[b] *Center for Econometric and Allied Research (CEAR), University of Ibadan, Nigeria*
[c] *Monetary Policy Department, Central Bank of Nigeria, Abuja, Nigeria*
[d] *Department of Economics, University of Lagos, Lagos, Nigeria*

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Abstract

In this paper, we examine how the unit root for stock market series should be modeled. We employ the Narayan and Liu (2015) trend GARCH-based unit root and its variants in order to more carefully capture the inherent statistical behavior of the series. We utilize daily, weekly and monthly data covering nineteen countries across the regions of America, Asia and Europe. We find that the nature of data frequency matters for unit root testing when dealing with stock market data. Our evidence also suggests that stock market data is better modeled in the presence of structural breaks, conditional heteroscedasticity and time trend.

JEL classification: C12; C58; F30; G15

Keywords: Trend; Structural break; Conditional heteroscedasticity; Unit root; Stock market

1. Introduction

The analysis of integration properties of economic series is not new in the literature. Several attempts have been made to characterize the statistical properties of most of the series we engage in empirical analysis. This concept is considered crucial both from statistical and policy perspectives. First, most time series models and techniques require pre-testing the underlying series for unit root. For instance, modeling and forecasting with univariate models such as the Autoregressive Moving Average (ARMA) process relies on stationarity of the series under examination and therefore pre-testing such series with unit root becomes inevitable. Secondly, the impact of shocks can as well be assessed based on the outcome of unit root testing. If a series exhibits unit root, shocks to such series will have permanent effects. However, if it is stationary, then the impact of shocks will be transient. Thirdly, the response of series to shocks has implications for the effectiveness of any policy adjustments. For instance, if a series contains a unit root, policies designed to alter the natural path of the series will be effective because such policies will push the series away from its long-run trend path in the absence of such policies (See also Smyth, 2013; Lean & Smyth, 2013).

Evidently, different economic series have been considered in the literature on unit root testing. Prominent among these series are the real exchange rates [see for example, in the last decade or so, Narayan & Narayan, 2007 (covering Italy); Cushman & Michael, 2011 (OECD Countries); Matsuki & Sugimoto, 2013 (Asia); and El Montasser, Fry, & Apergis, 2016 (US-China)]; Purchasing Power Parity [see Darné & Hoarau, 2008 (focusing on Australia); Hung & Weng, 2011 (Central Asia); Su, Liu, Zhu, & Lee, 2012 (OPEC Countries); Wu & Lin, 2011 (European Union); Liu, Zhang & Chang, 2012 (Transition economies); Yilanci, 2012 (Central and Eastern Europe); Cuestas & Regis, 2013 (OECD

* Corresponding author.
E-mail addresses: salisuaa@funaab.edu.ng, aa.salisu@cear.org.ng (A.A. Salisu).
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Countries); Bahmani-Oskooee, Chang, & Lee, 2016 (Africa); and Zerihun & Breitenbach, 2016 (South African Development Community)]; and Real interest rate parity hypothesis [see Güney & Hasanov, 2014 (Post-Soviet Countries); Fu, Li, & Ma, 2015 (Asia); and Güney, Telatar, & Hasanov, 2015 (Transition economies]. Other variables include Energy consumption [see Lean & Smyth, 2014 (Malaysia); Mishra & Smyth, 2014 (US); Shahbaz, Khraief, Mahalik, & Zaman, 2014; Ozturk & Aslan, 2015 (OECD Countries) and Zhu & Guo, 2016]; Inflation rate [see Basher & Westerlund, 2008; Romero-Ávila & Usabiaga, 2009 (OECD Countries); Huang, Lin, & Yeh, 2010 (US); Narayan & Popp, 2011 (G7 Countries); and Yıldırım, Özdemir, & Doğan, 2013 (OECD Countries)]; Income [see Jewell, Lee, Tieslau, & Strazicich, 2003 (OECD Countries); Smyth & Inder, 2004 (China); Beechey & Österholm, 2008 (US); Dawson & Strazicich, 2010 (OECD and Non-OECD Countries); and Solarin & Anoruo, 2015 (Africa)]; and Stock indices [see Tabak, 2007 (Brazil); Narayan, 2008 (G7 Countries); Hasanov, 2009; Gozbasi, Kucukkaplan, & Nazlioglu, 2014 (Turkey); and Tiwari & Kyophilavong, 2014 (BRICS)]. A few others that have received very little attention include CO2 emissions [see Lee, Chang, & Chen, 2008 (OECD countries); Tiwari, Kyophilavong, & Albulescu, 2016 (Sub-Saharan Africa)]; Health expenditure [see Jewell et al., 2003 (OECD Countries); Payne, Anderson, Lee, & Cho, 2015 (OECD Countries]; House prices [see Yang & Wang, 2012 (Sweden); Lean & Smyth, 2014 (Malaysia); Chang, Wu, & Gupta, 2015 (South Africa)]; and Unemployment [Lee, Hu, Li, & Tsong, 2013 (OECD Countries); Bakas & Papapetrou, 2014 (Greece)].

This growing literature on unit root testing has offered different dimensions for verifying the underlying statistical properties of time series. Although, the application of the Augmented Dickey Fuller [ADF]-type unit root tests has remained prominent in the literature regardless of the data frequency; however, when dealing with high frequency series such as daily, weekly and monthly data types, the white noise error assumed in the ADF-type may not be appropriate. There are increasing evidences suggesting that high frequency series such as oil price, stock price, inflation, exchange rate, commodity prices, among others, tend to exhibit conditional heteroscedasticity in addition to their random walk behavior. This observation was first conceptualized and analytically documented by Kim and Schmidt (1993) and thereafter examined by Ling and Li (1998), Seo (1999), Ling, Li, and McAleer (2003) and Cook (2008). Classified as Generalized Autoregressive Conditional Heteroscedasticity [GARCH]-based unit root tests, the tests allow for a GARCH process in the test regression unlike the white noise error assumed in the ADF-type unit root tests. Cook (2008), following Kim and Schmidt (1993) and Haldrup (1994), notes that when error in the ADF-type test regression follows a GARCH process and is ignored, the test is subject to typically moderate size distortion.

Notwithstanding, the earlier versions of the GARCH-based unit root test of Kim and Schmidt (1993) and others are not without their shortcomings. These versions do not account for structural breaks which seem to be a prominent feature of high frequency series. Thus, using these tests in the presence of significant structural breaks may render the statistical inference invalid. In a recent paper by Narayan and Liu [NL thereafter] (2011), the GARCH-based unit root was extended to include two exogenous structural breaks and thereafter, Narayan, Liu, and Westerlund [NLW] (2016) modified the latter to allow for two endogenously determined structural breaks based on the procedure of Narayan and Popp (2010). These tests with structural breaks are found to have better size and power properties than those without structural breaks.

An extension of the NL (2011) and NLW (2016) was also proposed by NL (2015) wherein a time trend was suggested in the test regression. For robustness, the performance of the trend GARCH-based unit root test was compared with others including the NL (2011) and NLW (2016) tests and they find that the trend based test outperforms other GARCH-based tests regardless of whether the break dates are chosen exogenously or endogenously. They conclude that as long as a time trend is included, the manner in which structural breaks is chosen does not make the test unstable. In other words, whether the breaks are selected exogenously or endogenously, in so far a time trend is included in the test regression, the outcome is stable and correctly sized.

It is important to emphasize here that there are several ADF-type unit root tests including the NP (2010) test that also account for both structural breaks and time trend in the test regressions; however, they do not allow for conditional heteroscedasticity.

Motivated by these attractions, we subject the NL (2015) test to empirical scrutiny using the global stock markets covering both the developed and emerging financial markets. The choice of global stock markets [particularly the selected financial markets] is deliberate for a number of reasons. First, there are substantial evidences suggesting that the global stock markets are highly volatile [i.e. they exhibit conditional heteroscedasticity] and have as well witnessed several structural shifts in response to shocks [see Diebold & Yilmaz, 2009]. Our preliminary analyses [see Section 3.0 of our paper] are clear indications of the inherent conditional heteroscedasticity and structural breaks in global stock markets. Secondly, as presented under descriptive statistics, all the series are trending and in fact the trend coefficients for the selected series are all statistically significant. These underlying statistical features of the global stock markets seem to agree with the trend GARCH-based unit root test. Therefore, we further verify whether accounting for these features when subjecting the stock market indices to unit root testing will enhance the rate of rejections. In addition, understanding the stationarity of stock market indices has implications for policy and forecasting. For instance, if a stock market series is non-stationary, the unit root may be transmitted to other macroeconomic variables. Thus, if there is a shock to stock market, it may spill over to other financial markets such as the bond market, foreign exchange market, money market and commodity market, given its connection with these markets. Also, if a stock series exhibits stationarity, the future values of the series

Table 1
Data identification and coverage.

Country	Stock market index	Daily data		Weekly data		Monthly data	
		Start date	End date	Start date	End date	Start date	End date
Australia	ASX	7/12/1989	21/12/2015	22/09/1989	23/12/2015	31/10/1988	30/12/2015
Argentina	MERVAL	19/10/1989	18/12/2015	22/09/1989	23/12/2015	31/10/1988	30/12/2015
Brazil	IBOVESPA	21/12/1989	18/12/2015	22/12/1989	23/12/2015	29/12/1989	30/12/2015
Chile	IPSA	6/2/1989	18/12/2015	22/09/1989	23/12/2015	31/01/1989	30/12/2015
France	CAC 40	8/12/1989	21/12/2015	4/3/1988	23/12/2015	31/10/1988	30/12/2015
Germany	DAX	8/12/1989	21/12/2015	22/09/1989	23/12/2015	31/10/1988	30/12/2015
Hong Kong	HANG SENG	7/12/1989	21/12/2015	22/09/1989	23/12/2015	31/10/1988	30/12/2015
Indonesia	JCI INDEX	15/04/1988	21/12/2015	22/09/1989	23/12/2015	31/10/1988	30/12/2015
Japan	NIKKEI 225	11/12/1989	21/12/2015	22/09/1989	23/12/2015	31/10/1988	30/12/2015
Malaysia	FBMKLCI	16/01/1990	21/12/2015	22/09/1989	23/12/2015	31/10/1988	30/12/2015
Mexico	MEXBOL	19/01/1994	18/12/2015	21/01/1994	23/12/2015	31/01/1994	30/12/2015
Philippines	PCOMP	14/03/1989	21/12/2015	22/09/1989	23/12/2015	31/10/1988	29/12/2015
Singapore	STI	31/08/1999	21/12/2015	3/9/1999	23/12/2015	31/08/1999	30/12/2015
South Korea	KOSPI	25/09/1989	21/12/2015	24/09/1989	23/12/2015	31/10/1988	30/12/2015
Taiwan	TWSE	23/01/1989	21/12/2015	23/09/1989	23/12/2015	31/10/1988	30/12/2015
Thailand	SET	22/02/1989	21/12/2015	22/09/1989	23/12/2015	31/10/1988	30/12/2015
Turkey	BIST 100	21/08/1989	21/12/2015	22/09/1989	23/12/2015	31/10/1988	30/12/2015
UK	FTSE 100	7/12/1989	21/12/2015	27/11/1987	23/12/2015	31/10/1988	30/12/2015
US	S&P 500	7/12/1989	18/12/2015	4/12/1987	23/12/2015	31/10/1988	30/12/2015

Source: Data stream and global financial data.

can easily be generated from its past values since the series is stable over time with constant mean and variance.

Another important issue that is just emerging in the unit root literature is the need to subject the test to different data frequencies. Recently, NL (2015) and Salisu and Adeleke (2016) find that data frequency does matter for unit root testing. In other words, unit root testing has been empirically validated to be sensitive to data frequency. Consequently, we also utilize three different data frequencies namely daily, weekly and monthly data frequencies for all the selected stock markets. In addition, we conduct robustness checks by allowing for different lag combinations of the GARCH terms namely GARCH (1,2), GARCH (2,1) and GARCH(2,2) and their results are evaluated against the GARCH (1,1). Thus, we are able to determine whether the performance of the trend GARCH-based unit root test is not sensitive to data frequency and the GARCH structure.

Finally, in addition to the NL (2015) test, we also consider earlier versions of the GARCH-based unit root tests such as the Cook (2008) and the NLW (2016) tests in order to more carefully verify whether accounting for time trend and structural breaks matters for the series. With these considerations, we are able to robustly ascertain the behavior of stock market data and how their unit root test should be modeled.

Foreshadowing our results, we find that stock market data is better modeled in the presence of structural breaks, conditional heteroscedasticity and time trend. Our evidence also suggests that the nature of data frequency matters for unit root testing when dealing with stock market data. These results are non-existent in the literature as far as unit root testing of stock market data is concerned.

We structure the rest of the paper as follows. The next section explains the framework for the test. Section 3 presents data issues and preliminary analyses. The results of the unit root tests including robustness checks are presented in Section 4 while Section 5 concludes the paper.

2. The framework for GARCH-Based unit root tests

As earlier noted, a more generalized GARCH-based unit root test is the one proposed by NL (2015). The Cook (2008) and the NLW (2016) are special cases of the NL (2015). Let us begin with the NL (2015). The latter considers a test regression that includes two endogenous breaks and a time trend as given below (see NL, 2015, pg. 396):

$$y_t = \alpha_0 + \alpha_1 t + \delta y_{t-1} + \sum_{i=1}^{k} D_i B_{it} + \varepsilon_t; \quad i = 1, \ldots, k \tag{1}$$

where y_t denotes the series under consideration; t is a time trend; $B_{it} = 1$ if $t \geq T_{B_i}$ and $B_{it} = 0$ otherwise. The parameter α_0 represents the intercept, α_1 is the time trend coefficient, δ is the autocorrelation coefficient and D_i is the break dummy coefficient. The underlying null hypothesis for the test is that there is unit root; that is, $H_0 : \delta = 1$. However, for the purpose of empirical application, an alternative specification as given below is used as the test regression:

$$\Delta y_t = \alpha_0 + \alpha_1 t + \rho y_{t-1} + \sum_{i=1}^{k} D_i B_{it} + \varepsilon_t; \quad i = 1, \ldots, k \tag{2}$$

Where $\rho = (\delta - 1)$ and Δ, as usual, is the first difference operator. In equation (2), the null hypothesis of unit root given as $H_0 : \rho = 0$ is tested against the alternative hypothesis of stationarity denoted as $H_1 : \rho < 0$.

The NLW (2016) is obtained by restricting $\alpha_1 = 0$ in equation (2). Therefore, the test regression for NLW (2016) can be written as:

Table 2a
Descriptive statistics for daily stock data.

Country	Mean	Max	Min	S.D.	Skew	Kurt	J.B	ADF	PP	ARCH	Trend
Argentina	1808.58	14173.87	15.89	2476.22	2.76	10.55	23509.3	0.13 [6]	0.27 (12)	182.31***	0.93***
Australia	3509.65	6853.6	1204.52	1397.3	0.22	1.93	367.73	−2.57 [0]	−2.57 (0)	169.16***	0.67***
Brazil	26624.72	73516.81	0.01	23579.73	0.46	1.65	709.86	−2.19 [0]	−1.96 (10)	199.94***	11.63***
Chile	1903.23	5040.97	54.12	1436.77	0.60	1.96	706.22	−1.94 [3]	−1.94 (9)	149.18***	0.69***
France	3579.62	6922.33	1441.17	1288.22	0.21	2.20	223.85	−2.03 [0]	−1.83 (26)	109.00***	0.40***
Germany	4974.64	12374.73	1322.68	2525.27	0.45	2.59	271.58	−2.18 [0]	−2.10 (17)	123.72***	1.15***
Hong Kong	14350.65	31638.22	2736.55	6510.49	0.12	2.05	258.18	−3.47**[0]	−3.42**(7)	163.29***	3.17***
Indonesia	1507.49	5523.29	94.35	1560.65	1.19	2.93	1592.34	−1.33 [7]	−1.43 (5)	117.95***	0.68***
Japan	15577.11	38915.87	7054.98	5318.97	1.00	4.91	2045.86	−3.51** [2]	−87.25	77.93***	−1.82***
Malaysia	1030.95	1892.65	262.7	400.23	0.56	2.22	496.64	−1.99 [1]	−1.94 (13)	52.75***	0.17***
Mexico	18890.67	46357.24	1447.52	15106.25	0.44	1.58	631.81	−2.65 [1]	−2.43 (38)	105.63***	9.10***
Philippines	2756.58	8127.48	516.21	1783.43	1.32	3.89	2127.43	−1.07 [3]	−1.01 (12)	88.95***	0.68***
Singapore	2502.81	3831.19	1170.85	668.49	−0.20	1.71	311	−2.19 [0]	−2.28 (10)	83.36***	0.45***
South Korea	1112.42	2228.96	280	534.74	0.61	1.90	781.72	−2.67 [1]	−2.60 (1)	140.51***	0.22***
Taiwan	6788.62	12495.34	2560.47	1759.96	0.08	2.35	131.19	−3.14* [1]	−2.98 (5)	143.36***	0.33***
Thailand	825.94	1753.73	207.31	377.29	0.43	2.10	419.68	−1.67 [1]	−1.56 (15)	39.31***	0.06***
Turkey	26326.48	93178.87	7.71	27907.76	0.73	2.11	802.49	−2.76 [0]	−2.79 (3)	70.29***	13.67***
UK	4849	7103.98	1990.3	1405.64	−0.42	1.92	513.05	−2.13 [3]	−2.28 (17)	132.41***	0.58***
US	1066.58	2130.82	295.46	460.84	0.13	2.45	103.10	−1.83 [2]	−1.74 (21)	144.80***	0.21***

Note: The ADF is carried out with time trend and the optimal lag length is selected automatically using the Schwarz Information Criterion (SIC). The maximum lag length specified is 8 and optimal lag length obtained for each series is enclosed in square brackets []. The PP test is estimated with time trend and the Bartlett Kernel Spectral estimation and the Newey−West automatic bandwidth selection option was used. The optimal bandwidth is enclosed in brackets (). The null hypothesis of unit root is tested against alternative of absence of unit root. The critical values for the ADF and PP tests are −3.9595, −3.4105 and −3.1370 respectively for 1%, 5% and 10% respectively. The Autoregressive Conditional Heteroscedasticity test (abbreviated as ARCH) which follows the Engle (1982) Lagrangian Multiplier (LM) procedure is included in the table to test for the null hypothesis that there is 'no ARCH' effect. The chi-squared $n*R^2$ statistic is reported for the ARCH-LM test. The maximum lag length chosen for the test is 10 for the daily and weekly series, while maximum of 5 lags is chosen for monthly series as a result of its smaller number of observations. Trend in the table represents the coefficient of trend term. ***, ** and * are level of significance at 1%, 5% and 10% respectively.

Source: Computed by the authors.

$$\Delta y_t = \alpha_0 + \rho y_{t-1} + \sum_{i=1}^{k} D_i B_{it} + \varepsilon_t; \quad i = 1, \ldots, k \tag{3}$$

In other words, the main distinction between the NL (2015) and NLW (2016) is the inclusion of a time trend in the former. Similarly, to derive the Cook (2008) GARCH-based unit root test from equation (2), the parameters for both the trend term and structural breaks are restricted to zero and the resulting equation is given below:

$$\Delta y_t = \alpha_0 + \rho y_{t-1} + \varepsilon_t; \tag{4}$$

One major difference between the standard unit root tests and the GARCH-based unit root lies in the way the error term is treated. In the case of the latter, as the term implies, rather than assuming a white noise error term, the ε_t is assumed to follow a GARCH process. This may be valid for series that are available at a high frequency such as financial series which tend to exhibit random walk as well as conditional heteroscedasticity. Bollerslev (2001) succinctly highlights some of the inherent features of financial series and why it is important to account for these features when modeling and forecasting the series.

For computational simplicity, the ε_t follows the first-order generalized autoregressive conditional heteroscedasticity model, denoted as GARCH (1,1) as shown below:

$$\varepsilon_t = \eta_t h_t^{1/2}; \tag{5a}$$

$$h_t = \phi + \alpha \varepsilon_{t-1}^2 + \beta h_{t-1} \tag{5b}$$

Where $\varepsilon_t \sim \text{NID}(0,1)$; $\phi > 0$; $\alpha \geq 0$; and $\beta \geq 0$. Since we are using endogenously determined structural breaks as the break dates are unknown, the T_{B_i} has to be estimated and the resulting estimates are used for the unit root testing. In this paper, we follow the Bai and Perron [BP] (2003) multiple structural break test to determine the break dates.[1] We favor the use of BP test in determining the breaks as it allows for a maximum of five structural breaks in time series (see also, NL, 2015). It also involves a sequential application of $\sup F_T(l+1|l)$ test which is assumed to work best in selecting the number of breaks. The BP (2003) test provides the following procedure to estimate the number of breaks in a time series data.

i. Consider a model and estimate with a small number of breaks or without breaks.
ii. Then, perform parameter constancy tests for each of the sub-samples (those obtained by cutting off at the estimated breaks), adding a break to a sub-sample associated with a rejection with the test $\sup F_T(l+1|l)$.

[1] In any case, as noted by NL (2015), the manner in which structural breaks is chosen does not make the test unstable as long as there is a time trend in the test regression.

Table 2b
Descriptive statistics for weekly stock data.

Country	Mean	Max	Min	S.D.	Skew	Kurt	J-B	ADF	PP	ARCH	Trend
Argentina	1832.01	14173.87	17	2513.87	2.72	10.3	4725.5	0.80 [7]	1.02 (22)	60.10***	4.49***
Australia	3495.88	6760.1	1241.56	1403.19	0.23	1.92	78.42	−2.47 [0]	−2.51 (6)	13.67***	3.23***
Brazil	26648.6	72766.93	0.01	23609.65	0.45	1.65	150.19	−2.01 [0]	−2.07 (6)	30.10***	55.13***
Chile	1949.18	5006.59	56.95	1427.32	0.58	1.92	144.84	−1.89 [0]	−1.90 (5)	20.79***	3.36***
France	3441.83	6813.66	1016.71	1347.41	0.24	2.14	59.09	−2.04 [0]	−1.98 (7)	11.68***	2.11***
Germany	4940.37	12374.73	1334.89	2543.74	0.46	2.57	59.88	−2.23 [0]	−2.20 (1)	17.41***	5.57***
Hong Kong	14278.09	30468.34	2667.99	6576.3	0.11	2.04	55.21	−3.26* [0]	−3.61** (9)	19.40***	15.07***
Indonesia	1579.93	5514.79	225.32	1573.38	1.12	2.75	287.98	−1.55 [1]	−1.66 (9)	16.67***	3.44***
Japan	15748.83	38915.87	7173.1	5616.16	1.16	5.25	594.33	−2.57 [0]	−2.70 (8)	22.18***	−9.08***
Malaysia	1025.21	1885.72	302.91	402.57	0.56	2.21	107.97	−1.80 [0]	−2.16 (15)	13.12***	0.80***
Mexico	18873.17	46231.44	1519.52	15139.56	0.44	1.58	131.92	−2.38 [1]	−2.46 (4)	26.07***	43.77***
Philippines	2811.94	8127.48	516.21	1800.31	1.28	3.75	406.1	−0.92 [0]	−1.05 (5)	10.95***	3.35***
Singapore	2505.47	3814.38	1184.96	669.18	−0.21	1.71	65.11	−2.18 [0]	−2.39 (6)	9.68***	2.14***
South Korea	1137.1	2197.82	301.23	541.5	0.53	1.78	150.35	−2.70 [0]	−2.69 (6)	20.64***	1.15***
Taiwan	6774.61	12495.34	2655.85	1735.23	0.06	2.34	25.64	−4.20*** [3]	−4.41*** (15)	32.96***	2.06***
Thailand	833.94	1682.85	207.31	379.3	0.39	2.07	84.26	−1.39 [0]	−1.60 (12)	23.22***	0.25***
Turkey	26490.34	91924.84	12.06	27954.62	0.72	2.09	164.15	−2.75 [0]	−2.75 (11)	24.21***	66.38***
UK	4642.39	7089.77	1582.8	1549.79	−0.36	1.81	117.88	−2.31 [1]	−2.22 (22)	13.41***	3.04***
US	1012.34	2126.64	223.92	487.99	0.16	2.28	37.62	−1.71 [1]	−1.75 (17)	18.10***	1.02***

Note: The ADF is carried out with time trend and the optimal lag length is selected automatically using the Schwarz Information Criterion (SIC). The maximum lag length specified is 8 and optimal lag length obtained for each series is enclosed in square brackets []. The PP test is estimated with time trend and the Bartlett Kernel Spectral estimation and the Newey−West automatic bandwidth selection option was used. The optimal bandwidth is enclosed in brackets (). The null hypothesis of unit root is tested against alternative of absence of unit root. The critical values for the ADF and PP tests are −3.9595, −3.4105 and −3.1370 respectively for 1%, 5% and 10% respectively. The Autoregressive Conditional Heteroscedasticity test (abbreviated as ARCH) which follows the Engle (1982) Lagrangian Multiplier (LM) procedure is included in the table to test for the null hypothesis that there is 'no ARCH' effect. The chi-squared $n*R^2$ statistic is reported for the ARCH-LM test. The maximum lag length chosen for the test is 10 for the daily and weekly series, while maximum of 5 lags is chosen for monthly series as a result of its smaller number of observations. Trend in the table represents the coefficient of trend term. ***, ** and * are level of significance at 1%, 5% and 10% respectively.

Source: Computed by the authors.

iii. Repeat this process and increase l sequentially until the test $\sup F_T(l+1|l)$ fails to reject the null hypothesis of no additional structural changes.

The estimated endogenous structural breaks obtained through the BP (2003) process are then incorporated in the relevant test regressions for the unit root tests.[2]

3. Data and preliminary analyses

We utilize daily, weekly and monthly data of stock prices from data collected from Bloomberg terminal for nineteen (19) countries cutting across seven (7) developed economies (Australia, France, Germany, Hong Kong, Japan, United Kingdom and United States) and twelve (12) emerging economies (Argentina, Brazil, Chile, Indonesia, Malaysia, Mexico, Philippines, Singapore, South Korea, Taiwan, Thailand and Turkey). Our choice of countries is motivated by Diebold and Yilmaz (2009) paper which considered the selected countries as a good representation of the global stock exchange market. Because they are classified as developed and emerging markets, they are more likely to respond to shocks than the less developed ones due to their level of financial integration in the global space. The same premise was used to motivate the choice of countries in Salisu and Adeleke (2016) paper wherein the integration properties of sovereign bond yield data were analyzed.

Table 1 presents the start date and end dates for the stock prices covering the selected countries over the three data frequencies. This period envelopes numerous financial market occurrences including the East Asian crises (July, 1997 to January, 1998), capital outflows from emerging economies (May to June, 2006), dollar crisis (March, 2005), global financial market crisis (2007−2008) and other structural breaks such as the US terror attack (September, 2011).

Descriptive statistics of the series are provided in Tables 2a, 2b and 2c. These statistics which include mean, minimum, maximum and standard deviation values of the stock market series for each country across the different data frequencies reflect virtually similar values. Similar results are also observed for the skewness and kurtosis. By implication, the descriptive statistics are not expected to be distinctly different with regard to the choice of data frequencies. The values of the Skewness and Kurtosis statistics across all countries show that they are mostly positively skewed and platykurtic, except in the case of Argentina which is leptokurtic. This may imply that the distribution of the series across all frequencies is non-normal. The Jarque-Bera (JB) test which is a formal test for the normal distribution of the series is further carried out and reported in the tables for all data frequencies. The JB result

[2] This procedure of testing for unit root using the GARCH-based approach is consistent with Salisu and Adeleke (2016).

Table 2c
Descriptive statistics for monthly stock data.

	Mean	Max	Min	S.D.	Skew	Kurt	J-B	ADF	PP	ARCH	Trend
Argentina	1781.77	12972.14	0.17	2520.8	2.73	10.33	1140.09	0.74 [7]	0.79 (58)	32.44***	18.81***
Australia	3437.13	6779.1	1279.82	1431.18	0.26	1.9	20.17	−2.34 [0]	−2.85 (7)	8.46***	13.91***
Brazil	26641.54	72592.5	0.01	23635.59	0.45	1.64	34.67	−2.07 [1]	−1.97 (2)	7.59***	238.74***
Chile	1906.03	4956.96	54.44	1446.08	0.59	1.94	34.06	−2.04 [1]	−1.99 (3)	10.88***	14.39***
France	3501.08	6625.42	1478.2	1325.8	0.24	2.12	13.73	−1.75 [0]	−2.07 (7)	3.83***	8.89***
Germany	4832.94	11966.17	1275.99	2602.16	0.48	2.52	15.69	−2.02 [0]	−2.20 (4)	3.81***	24.14***
Hong Kong	13903.69	31352.58	2273.91	6821.61	0.11	2.05	12.97	−3.46** [0]	−3.72** (2)	5.23***	65.96***
Indonesia	1540.22	5518.68	136.16	1570.89	1.16	2.84	73.43	−1.49 [1]	−1.50 (4)	5.41***	14.18***
Japan	16328.47	38915.87	7568.42	6313.22	1.18	4.55	108.72	−1.70 [0]	−1.79 (7)	10.60***	−45.22***
Malaysia	1005.46	1882.71	302.91	413.28	0.55	2.23	24.25	−2.56 [2]	−2.23 (3)	3.36***	3.52***
Mexico	18841	45628.09	1537.4	15206.66	0.44	1.58	30.7	−2.26 [0]	−2.43 (8)	5.99***	189.55***
Philippines	2751.93	7940.49	548.29	1808.75	1.29	3.78	98.95	−0.96 [0]	−1.20 (4)	1.60*	14.31***
Singapore	2504.28	3763.57	1235.25	672.04	−0.21	1.72	14.82	−2.29 [0]	−2.75 (6)	3.83***	9.26***
South Korea	1130	2192.36	297.88	539.99	0.58	1.85	36.58	−2.27 [0]	−2.32 (1)	7.00***	4.67***
Taiwan	6815.03	12054.35	2705.01	1756.12	0.08	2.34	6.31	−3.59** [1]	−3.73** (5)	8.09***	7.39***
Thailand	821.08	1682.85	214.53	379.4	0.44	2.11	21.55	−1.63 [0]	−1.76 (5)	4.43***	1.20***
Turkey	25466.1	88945.82	3.74	27924.26	0.78	2.16	42.29	−2.63 [0]	−2.65 (3)	9.34***	272.57***
UK	4735.03	6984.43	1792.4	1484.92	−0.38	1.84	26.19	−2.10 [0]	−2.15 (6)	2.69***	12.76***
US	1037.4	2107.39	273.7	477.85	0.15	2.34	7.16	−1.56 [0]	−1.81 (8)	2.58***	4.44***

Note: The ADF is carried out with time trend and the optimal lag length is selected automatically using the Schwarz Information Criterion (SIC). The maximum lag length specified is 8 and optimal lag length obtained for each series is enclosed in square brackets []. The PP test is estimated with time trend and the Bartlett Kernel Spectral estimation and the Newey−West automatic bandwidth selection option was used. The optimal bandwidth is enclosed in brackets (). The null hypothesis of unit root is tested against alternative of absence of unit root. The critical values for the ADF and PP tests are −3.9595, −3.4105 and −3.1370 respectively for 1%, 5% and 10% respectively. The Autoregressive Conditional Heteroscedasticity test (abbreviated as ARCH) which follows the Engle (1982) Lagrangian Multiplier (LM) procedure is included in the table to test for the null hypothesis that there is 'no ARCH' effect. The chi-squared $n*R^2$ statistic is reported for the ARCH-LM test. The maximum lag length chosen for the test is 10 for the daily and weekly series, while maximum of 5 lags is chosen for monthly series as a result of its smaller number of observations. Trend in the table represents the coefficient of trend term. ***, ** and * are level of significance at 1%, 5% and 10% respectively.

Source: Computed by the authors

Table 3
Bai and Perron (2003) multiple structural breaks for global stock markets.

Country	Daily			Weekly			Monthly		
	T_1	T_2	NSB	T_1	T_2	NSB	T_1	T_2	NSB
Argentina	29/10/2014 (185.70)	05/02/2014 (90.26)	5	05/12/2014 (85.77)	23/10/2014 (61.79)	5	31/07/2014 (61.15)	30/01/2015 (57.94)	5
Australia	22/01/2008 (64.31)	28/02/2008 (56.77)	5	07/12/2007 (50.43)	03/10/2008 (25.75)	5	29/08/2008 (20.90)	30/05/2008 (18.82)	4
Brazil	02/03/1993 ($5.03*10^6$)	21/10/2008 (76.70)	5	17/04/1992 ($2.57*10^5$)	19/09/2008 (51.95)	5	30/06/1993 (1630.71)	30/09/2008 (27.92)	4
Chile	10/10/2008 (110.19)	22/10/2008 (59.01)	5	03/10/2008 (57.85)	22/07/2011 (22.02)	5	30/04/2009 (15.62)	31/10/2007 (13.86)	3
France	24/01/2008 (51.85)	11/09/2008 (24.49)	5	28/01/2000 (49.80)	03/10/2008 (24.60)	4	29/10/1999 (8.11)	30.04/2003 (8.11)	1
Germany	24/08/2015 (33.86)	13/08/2015 (30.75)	5	16/01/2009 (40.24)	07/08/2015 (20.72)	5	29/07/2011 (12.03)	31/12/2014 (8.87)	1
Hong Kong	22/01/2008 (79.29)	06/02/2008 (46.32)	5	02/11/2007 (24.93)	03/10/2008 (23.12)	5	29/08/2008 (13.58)	31/12/2007 (13.23)	4
Indonesia	27/09/2011 (75.00)	09/09/2013 (59.01))	5	14/06/2013 (32.30)	13/09/2013 (30.56)	5	31/10/2008 (18.30)	30/05/2008 (15.34)	4
Japan	06/04/1990 (68.39)	01/10/1990 (29.89)	5	20/07/1990 (33.79)	17/08/1990 (21.99)	5	30/03/1990 (25.88)	31/05/1990 (14.39)	3
Malaysia	13/01/1994 (76.32)	12/02/1998 (43.31)	5	25/07/1997 (19.49)	14/11/1997 (18.66)	5	31/01/1994 (12.88)	31/03/1998 (12.05)	2
Mexico	01/10/2008 (45.41)	13/11/2008 (32.74)	5	10/10/2008 (37.83)	29/07/2011 (15.92)	5	30/05/2008 (20.88)	28/02/2007 (13.05)	2
Philippines	19/06/2013 (78.42)	16/08/2013 (52.41)	5	27/03/2009 (19.03)	14/06/2013 (17.55)	5	30/11/1994 (10.74)	31/05/2013 (9.93)	1
Singapore	22/08/2007 (28.16)	07/10/2011 (34.49)	5	17/08/2007 (28.59)	20/02/2009 (11.22)	4	31/12/2007 (14.18)	30/06/2008 (9.43)	2
South Korea	29/10/2008 (53.75)	07/10/2011 (34.49)	5	26/10/2008 (37.68)	31/07/2011 (26.14)	3	31/05/2008 (12.36)	30/04/2007 (10.55)	2
Taiwan	15/05/1990 (33.20)	02/06/1990 (27.27)	5	17/03/1990 (50.38)	26/05/1990 (21.53)	5	30/12/1989 (19.95)	28/02/1990 (11.85)	3
Thailand	20/08/1990 (103.77)	11/01/1994 (51.12)	5	17/08/1990 (45.35)	14/09/1990 (19.94)	4	29/10/1993 (23.72)	31/05/1996 (10.81)	3
Turkey	19/06/2013 (147.65)	26/06/2013 (32.74)	5	20/02/2009 (27.47)	24/05/2013 (26.99)	5	31/03/2009 (14.08)	29/04/2011 (13.35)	4
UK	24/01/2008 (62.35)	12/09/2008 (28.11)	5	13/02/2009 (66.40)	29/07/2011 (15.26)	3	30/10/2000 (11.58)	29/08/2008 (8.94)	1
US	26/09/2008 (54.12)	03/10/2008 (43.41)	5	02/06/2000 (35.85)	16/01/2009 (18.92)	5	29/09/2000 (1289)	29/08/2008 (8.90)	2

Note: NSB denotes number of significant structural breaks. The $\sup F_T(l+1|l)$ test statistics for the breaks are reported in parentheses. The critical values for $\sup F_T(l+1|l)$ at 10% level of significance as obtained from the Bai and Perron (2003) paper are 7.04, 8.51, 9.41, 10.04 and 10.58, respectively, for $l = 1, 2, 3, 4, 5$. The T_1 and T_2 denote the two largest breaks. Nonetheless, virtually all the values for T_1 and T_2 are significant.

Table 4
Results of NL (2015) Trend GARCH (1,1)-based unit root tests.

Country	Daily series	Weekly series	Monthly series
Argentina	−0.23	−1.32	−0.40
Australia	**−2.59***	−3.21	−2.54
Brazil	4.30	0.05	−0.18
Chile	0.17	−0.50	−2.38
France	**−2.67***	−2.62	−0.82
Germany	−2.07	−2.17	**−4.59*****
Hong Kong	−1.43	−1.50	−1.561
Indonesia	−2.40	−0.78	−2.26
Japan	−1.24	−2.43	−2.89
Malaysia	−2.53	**−3.65****	**−3.94****
Mexico	−1.29	−1.46	−1.34
Philippines	1.23	−1.57	−2.90
Singapore	−1.33	−2.50	−2.28
South Korea	−1.05	−2.40	−2.65
Taiwan	**−2.67***	**−3.39***	**−3.87***
Thailand	−0.54	−1.83	−2.72
Turkey	4.89	−0.27	4.48
UK	**−2.91****	**−3.50***	**−4.67****
US	**−2.65***	−1.84	−2.22
No. of rejections	**5**	**3**	**4**

Note: The critical values for daily frequency at the 1%, 5% and 10% levels are −3.34, −2.87 and −2.54 respectively; for weekly data, they are −4.11, −3.61and −3.37 respectively and for monthly data, the critical values are computed as −4.47, −3.89 and −3.51 respectively for 1%, 5% and 10%. ***, ** and * denote statistical significance at 1%, 5% and 10% levels respectively. The bold in the table denotes countries with stationary stock series. Since our observations are quite close to those used in NL (2015), we find the average of the computed critical values for 10% level of statistical significance as reported in Table 6 of the paper for each data frequency of the selected six energy series and the resulting averages are used as critical values here.

rejects the null of normality for all the data frequencies. Hence, confirming that the series are non-normal.

The next two test results reported in the descriptive statistics tables, ADF and PP (Philip-Perron), test for the presence or otherwise of unit root in the series. The results obtained reveal that nearly all the series considered are non-stationary for all data frequencies except for Japan which is stationary for daily data series only, and Taiwan (except PP test for daily series) and Hong Kong which are stationary and consistent across all data frequencies.

The ARCH-LM test is conducted to evaluate the heteroscedasticity property of the series. The null hypothesis of absence of ARCH effect is rejected for all series irrespective of the data frequencies. This indicates that the series under examination also exhibit conditional heteroscedasticity in addition to their non-stationary behavior. This further strengthens the need to allow for a GARCH process in the test regression of for unit root contrary to the white noise error often assumed for most series when modeling.

The next statistical test carried out evaluates the presence of significant trend term in the series. To execute this, each of the series is regressed on a constant and time trend. The obtained coefficients are reported as Trend in Tables 2a, 2b and 2c. The significance of the coefficient implies that the inclusion of the trend term in the unit root test regression is necessary; otherwise, the trend term in the unit root is redundant. The estimated results reveal that all the coefficients are statistically significant at 1% level for all data frequencies and most of them are positive. Thus, the inclusion of the trend term is

Table 5
Results of Cook (2008) and NLW (2016) Unit Root tests.

Country	Daily series		Weekly series		Monthly series	
	Cook (2008)	NLW (2016)	Cook (2008)	NLW (2016)	Cook (2008)	NLW (2016)
Argentina	1.826	1.912	−0.488	−0.392	0.940	0.747
Australia	2.281	2.418	0.345	0.797	0.561	1.323
Brazil	4.86	4.916	0.481	7.635	6.605	12.059
Chile	4.949	4.297	1.824	2.022	0.567	1.350
France	0.938	0.772	−0.856	−2.196	−0.123	−0.976
Germany	2.424	2.471	1.389	0.544	0.877	−0.903
Hong Kong	0.182	0.282	−0.488	−0.029	−0.356	0.118
Indonesia	3.322	2.275	0.809	0.947	−0.208	−1.151
Japan	−1.883	−1.648	−2.592	−2.771	−1.576	−2.582
Malaysia	−0.108	0.202	−0.745	−0.694	−1.224	−1.248
Mexico	2.168	1.727	1.507	1.291	1.109	1.149
Philippines	3.054	2.465	0.772	−1.461	0.071	0.861
Singapore	−0.508	−0.263	−0.762	−1.235	−1.477	−0.647
South Korea	0.983	0.141	−0.569	−1.497	−1.061	−2.195
Taiwan	−0.561	−0.852	−1.505	−1.349	−2.709	−3.032
Thailand	1.844	1.959	−0.875	−0.939	−1.476	−2.669
Turkey	4.946	5.376	1.777	−1.159	0.232	−0.567
UK	0.316	−0.009	−0.986	−1.097	−1.783	−1.507
US	1.817	0.726	1.254	0.173	1.091	0.063
No. of rejections	None	None	None	None	None	None

Note: ***, **, * indicate 10%, 5% and 1% levels of significance. As previously noted, the Cook test is also a GARCH-based unit root test, however, it does not account for structural breaks and time trend. The NLW (2016) test is also a GARCH-based unit root test which allows for structural breaks and heteroscedasticity but does not model time trend. The critical values used for the Cook (2008) test were obtained from Table 1 of the research article although the critical values were only rendered at the 5% level. As the estimated GARCH parameter combinations over around (0.05, 0.90), we selected the appropriate critical value which is −2.861.

Table 6
Robustness check for NL (2015) test.

Country	Daily series			Weekly series			Monthly series		
	GARCH (1, 2)	GARCH (2,1)	GARCH (2,2)	GARCH (1, 2)	GARCH (2,1)	GARCH (2,2)	GARCH (1, 2)	GARCH (2,1)	GARCH (2,2)
Argentina	−0.23	−0.23	−0.28	−1.03	−1.14	−1.16	−0.38	156.35	−0.50
Australia	−2.44	**−2.68***	**−9.96***	−3.13	−2.91	−2.89	−2.28	−2.38	−1.85
Brazil	5.27	6.03	3.00	6.88	1.46	8.27	2.28	2.04	1.12
Chile	−0.13	0.01	−1.34	−0.49	−0.35	−0.59	−2.28	−2.32	**−57.21*****
France	**−2.67***	**−2.61***	**−2.81***	−2.84	−2.66	−2.71	−0.90	−0.90	−0.90
Germany	−2.32	−2.09	−2.15	−2.01	−2.02	−1.97	**−4.60*****	**−4.36****	**−4.03****
Hong Kong	−1.41	−1.51	−1.40	−1.47	−1.59	−1.49	−0.96	−1.33	−1.10
Indonesia	−0.60	−2.05	−0.19	−0.02	−0.26	0.12	−1.74	−1.34	−1.20
Japan	−1.22	−1.22	−1.18	−1.98	−2.11	−2.08	−2.60	−2.59	−2.67
Malaysia	**−2.78***	**−2.59***	**−2.69***	**−3.91****	**−3.73****	**−3.69****	**−3.86***	**−3.72***	**−4.32****
Mexico	−1.21	−1.27	−1.84	−1.24	−1.22	−2.95	−1.33	−1.37	**−244.51*****
Philippines	1.39	1.49	15.65	−1.39	−1.60	−1.59	−0.27	−0.62	−0.27
Singapore	−1.40	−1.40	−1.50	−2.31	−2.34	−2.33	**−76.35*****	−2.49	−2.58
South Korea	−1.09	−1.07	−1.11	−2.30	−2.40	−2.21	−2.60	−2.56	−2.70
Taiwan	**−2.86***	**−2.91****	**−2.67***	−3.03	−2.94	**−4.41***	**−9.12*****	**−4.12****	**−4.45****
Thailand	−0.61	−0.56	−0.74	−1.62	−1.57	−1.64	−2.65	−2.61	−2.74
Turkey	5.18	14.44	0.91	−2.78	0.28	0.37	−0.49	**−4.53*****	−1.82
UK	**−2.93****	**−2.98****	**−2.82***	−3.19	−3.24	−3.19	**−4.75*****	**−4.69*****	**−4.77*****
US	**−2.76***	**−2.63***	**−2.75***	−1.59	−1.56	−1.52	−2.35	−2.16	−2.29
No. of rejections	**5**	**6**	**6**	**1**	**1**	**2**	**5**	**5**	**6**

Note: The critical values for daily frequency at the 1%, 5% and 10% levels are −3.34, −2.87 and −2.54 respectively; for weekly data, they are −4.11, −3.61and −3.37 respectively and for monthly data, the critical values are computed as −4.47, −3.89 and −3.51 respectively for 1%, 5% and 10%. ***, ** and * denote statistical significance at 1%, 5% and 10% levels respectively. The bold in the table denotes countries with stationary stock series.

necessary in the test regression for the GARCH-based unit root.

We further evaluate the behavior of the trends by accounting for possible structural breaks in the series. In other words, are the trend coefficients from the original trend regression not sensitive to structural breaks? To achieve this, we employ the BP (2003), which is an endogenous structural break test, to determine the break points for the stock market series. The result of the BP (2003) test is reported in Table 3. With the exception of few stock markets involving monthly data that has one (1) structural break (France, Germany, Philippines and UK), virtually all the series across all the data frequencies have at least three (3) structural breaks. The results of the extended trend regression are reported as Trend 1 in Tables 2a, 2b & 2c. The results reveal that all the trend term coefficients maintained their statistical significance and sign even after the inclusion of structural breaks. Therefore, the behavior of the trend term is robust to structural breaks.

In sum, similar to the attributes of the bond yield series examined by Salisu and Adeleke (2016), the stock price series examined in this study are characterized by non-normality, trend, non-stationarity and heteroscedasticity. In the next section, we examine whether the non-stationarity of some series is due to the presence of statistical features inherent in the series in question which are ignored in the standard unit root tests like ADF and PP. In essence, we further evaluate empirically whether the trend-GARCH-based unit root framework will be more appropriate when testing the stock market series for unit root.

4. Unit root test results

The significance of trend term inclusion in unit root regressions is demonstrated using three GARCH-based tests. These tests are Cook (2008), NL (2015) and NLW (2016). As previously noted, the Cook (2008) test does not account for time trend and structural breaks while the NLW (2016) test only captures structural breaks. On the other hand, the NL (2015) test accommodates both structural breaks and time trend. For the NL (2015) and NLW (2016), we utilize two structural breaks, as identified through the BP (2003) tests (see Table 3 for BP test results) which are incorporated as regressors in the two tests. The motivation for this approach hinges on the simulations of NL (2015) indicating that regardless of the approach used in selecting the break dates, endogenous or exogenous, the size properties are close to nominal 5% level. This approach is also consistent with the work of Salisu and Adeleke (2016) wherein the BP (2003) was used to determine the break points included in the unit root test regressions for sovereign bond yield series.

The results for these tests are presented in Tables 4 and 5. Table 4 reports the NL (2015) tests while the results for Cook (2008) and NLW (2016) are both presented in Table 5. Our findings reveal that unit root test for stock market series is sensitive to data frequency particularly when dealing with high frequency data such as those considered in this paper. This result is consistent with the findings of NL (2015) for energy series and Salisu and Adeleke (2016) for sovereign bond series.

Based on the NL (2015) results, we are able to reject the null hypotheses of unit root for five (5) countries using the daily frequency while three (3) and four (4) rejections are recorded respectively for the weekly and monthly frequencies. Taiwan and UK have rejections across all the data frequencies. Australia, France and US are rejected alongside the other two countries in the daily frequency, while Malaysia is rejected in both weekly and monthly data frequencies. Germany is the fourth country with stationary series in the monthly frequency. Countries with non-stationary stock prices across all the data frequencies are Argentina, Brazil, Chile, Hong Kong, Indonesia, Japan, Mexico, Philippines, Singapore, South Korea, Thailand and Turkey.

The NL (2015) result is compared with Cook (2008) and NLW (2016) results. The result of the NL (2015) outperforms both Cook (2008) and NLW (2016). It was observed that none of the series exhibits unit root across all the data frequencies under Cook (2008) and NLW (2016) tests. These findings support and strengthen the argument that accounting for time trend jointly with structural breaks and conditional heteroscedasticity is important, especially when dealing with stock market series.

The underlying default GARCH model used to compute the NL (2015) results presented in Table 4 is the GARCH (1, 1) model. To examine robustness and consistency, the NL (2015) test is subjected to different lag combinations of the symmetric GARCH model which are GARCH (1,2), GARCH (2, 1) and GARCH (2, 2). The obtained results for each of the three (3) symmetric combinations reveal almost similar result with the initial GARCH (1, 1) model. Therefore, we can conclude that the NL (2015) test exhibits robustness to the lag combinations of the GARCH model. By implication, the NL (2015) appears to be strongly insensitive to the lag order of the symmetric GARCH model, as also found by Salisu and Adeleke (2016).

5. Conclusion

This study further extends the application of the trend-GARCH based unit root test to global stock prices data covering nineteen countries drawn from America, Asia and Europe. Three data frequencies − daily, weekly and monthly − ranging across different start and end periods are utilized. To verify the claims of NL (2015) that this test outperforms other GARCH-based tests, our analysis was extended to include Cook (2008) test that does not account for both structural breaks and trend, and NLW (2016) test that accounts for only structural breaks without trend. The ADF and PP tests were also carried out for all the series across all frequencies. Our results revealed that the unit root test for stock market series is better modeled in the presence of structural breaks, time trend and conditional heteroscedasticity. Summarily, it may be necessary to carry out preliminary tests for structural breaks, time trend and conditional heteroscedasticity when modelling with stock price series.

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