Are Stock Prices in the U.S. both Nonlinear and Nonstationary? Evidence from Threshold Autoregressive Model Tests

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Abstract

This paper empirically tests, using the daily closing values of the Dow Jones Industrial Average (DJIA) data from February 5, 1971 through July 1, 2011 whether stock prices in the United States are both nonlinear and nonstationary by applying the unrestricted two-regime Threshold Autoregressive unit root tests (TAR) proposed by Caner and Hansen (2001). Unlike the traditional linear unit root tests, the TAR model simultaneously tests for the presence of nonlinearity and nonstationarity in the data generating processes. The implications of the outcomes of the unit root tests for structural analysis and econometric forecasting can hardly be exaggerated. The findings of the paper indicate that DJIA stock price time-series is nonlinear and nonstationary in two regimes. Stock prices exhibiting randomness suggest that the data generating process is nonstationary and thus makes it extremely difficult to accurately forecast stock price changes. The evidence of the presence of a unit root in stock prices also implies that the weak-form efficient market hypothesis is valid for the U.S. stock market.

I. Introduction

In recent years, investigating the time series properties of stock prices and stock returns in order to statistically test the validity of the random-walk hypothesis (or weak-form market efficiency) in various markets has become one of the active research areas in financial econometrics. Besides testing the applicability of the random-walk hypothesis, several other considerations are driving the direction of the research in this area. It is well understood that for an effective and efficient financial econometric structural analysis, financial modeling and forecasting the future course of financial variables, one needs to examine whether the time series incorporated in the estimation is stationary in levels. An economic variable is said to be stationary if its mean and variance are time independent. In an economy, if the time series on stock prices is empirically found to be nonstationary in levels, one of the inferences that an analyst can make is that the series does not mean-revert, and therefore financial forecasting based on past prices is futile. A nonstationary stock price series also implies that the stock market is potentially unpredictable.

Econometric studies of stock markets are undertaken for both developed and developing economies. Testing of the random-walk hypothesis for the U.S. stock market is interesting because of its well-developed stock market, characterized by the availability of rapid dissemination of financial and economic information, a lack of too many regulations, and the free market nature of the economic system. There have been numerous statistical investigations on stock market efficiency that test the validity of the random-walk hypothesis for stock markets in the U.S., using various stock indices [Fama (1970), Lo & McKinley (1988), Fama & French (1988), Kim et al. (1991), Richardson (1993), Narayan (2006), Murthy et al. (2011)]. These research studies use different methodologies and data periods, and their findings are mixed. A majority of these studies employ unit root testing methodology to determine whether the random walk hypothesis is valid in the U.S. stock market. Many apply a linear unit root test such as the Augmented Dickey-Fuller (ADF) test and/or some of its improved and modified variations.

Two econometric issues that have emerged recently in testing the stochastic nature of stock prices are whether stock price time series have any nonlinearities and simultaneously they are a unit root processes. Recently, it has been shown in the econometric literature that the linear unit root tests have low statistical power, and the tests also suffer from severe size distortions if indeed the data generating process is nonlinear. For instance, Enders and Granger (1998) demonstrate that the widely used traditional unit root tests (i.e. ADF tests) exhibit low statistical power when the dynamics of the data generating process are incorrectly specified [Pippenger & Goering (1993), Peel & Taylor (2002) and Kapetanios et al. (2003)]. There are many reasons to expect nonlinearity of stock prices because of the presence of transaction costs, bid-ask price spreads, market frictions and regulations, etc. [Balke & Fomby (1997)]. Balke and Fomby (1997) show that in the presence of transaction costs (or adjustment costs) and other market frictions in the system, the correcting mechanism towards the long-run equilibrium does not take place instantaneously, symmetrically and in a linear fashion. In financial markets, one often notices heterogeneous agents' beliefs in present-value asset pricing, herd behavior, liquidity constraints, restrictions imposed on short-selling, and price bubbles leading to asymmetric adjustments and nonlinearities.

Kapetanios et al. (2003) have shown that sometimes in the presence of transaction costs, the size of the deviation from the equilibrium determines the rate of correction to the long-run equilibrium, and the functional form of the data generating process. For instance in the stock market, if a dealer perceives that the profits from trading are less than transaction costs, he or she has no incentive to trade. Therefore, mean reversion may not take place in that regime, or it may be very weak, resulting in stock prices exhibiting a random-walk behavior. The rate of mean reversion may vary in different regimes of the data generating process of a financial variable. On the contrary, in other regimes benefits may outweigh transaction costs leading to a mean reverting process. Therefore, a nonlinear approach to studying the efficiency of a stock market is more realistic than the widely used linear approach.

There are a small number of studies that consider the possible existence of nonlinearities in stock markets, the notable ones being Shively (2003), Chen et al., (2005), Narayan (2006), Qian et al., (2008), Munir & Mansur (2009), Hasanov (2009) and Gobasi et al., (2014). Of these studies, Shively (2003) and Narayan (2006) use the threshold approach to study nonlinearities in U.S. stock markets. Narayan (2006) employs the Caner-Hansen TAR model to investigate the time-series properties of the NYSE composite index. Alternatively, Shively (2003) uses the S&P 500 stock price data for the period 1 January 1970 through 29 December 2000. Narayan (2006) considers the monthly data on NYSE composite index for the period June 1964 through April 2003. Shively (2003) and Narayan (2006) find evidence indicating nonlinear behavior of U.S. stock prices. Narayan's (2006) findings support the random-walk hypothesis. The present paper extends the literature by using a much larger data sample (10,194 daily observations) on DJIA. To the authors' knowledge, this is the first empirical attempt to employ the Caner-Hansen TAR model on the DJIA time-series with such a long time span and number of observations.

As discussed above, studies in behavioral finance suggest that there is an asymmetric adjustment in different stock market regimes because traders react differently in a rising market versus a falling market [Schleifer (2000)]. Furthermore, many time-series econometricians have alluded to the significance of the unit root tests that incorporate structural breaks [Perron (1989), Zivot &

Andrews (1992) and Lee & Strazicich (2003)]. One may expect occurrences of structural breaks in financial markets due to financial liberalization, financial regulation, major economic events, rapid developments in information technology and faster communication. A nonlinear approach to unit root testing takes into consideration the possible occurrence of structural breaks, determined endogenously, in the data generating process without making any assumptions regarding the number of breaks. Moreover, the approach undertaken in this paper controls for the presence of frequent outliers in the data sample. Therefore, in light of the theoretical reasons mentioned above, a comprehensive unit root procedure testing the efficiency hypothesis, explores the possibility of any threshold effects in stock prices and consequently in stock returns.

II. Model Specification and Data

Using the notations and the model framework suggested by Caner-Hansen (2001), we specify a two-regime threshold autoregressive unit root model as follows:

$$\Delta y_t = \theta_t x_{t-1} I_{(Zt-1,,\prec\lambda)} + \theta_2 x_{t-1} I_{(Zt-1\geq\lambda)} + \varepsilon_t \qquad (1)$$

where y_t denotes the relevant data generating process (the relevant stock price index), with x_{t-1} = (y_{t-1}, I, Δy_{t-1}, ..., Δy_{t-k})' , t = 1, 2…,T and the threshold variable, $z_t = y_t - y_{t-m}$ for some $m \geq 1$. Here, the threshold variable z_t indicates stock returns and the notation m represents the delay order parameter. The delay order indicates the time the market takes to respond to a deviation from equilibrium. The term $\boldsymbol{\varepsilon_t}$ represents a normally distributed error term, with a mean of zero and constant variance. We use an indicator function, ***I***, which equals 1 if the expression within the parentheses in (1) is true, and 0 otherwise. The variable k is the autoregressive order in (1). The variable Z_t represents the return on stocks at the time horizon of m lags. The unknown threshold parameter λ, to be estimated from the data, is the level of the $\mathbf{y_t}$ variable that triggers a possible change in the regime or nonlinearity in (1). The threshold parameter λ assumes values within the interval $\lambda \varepsilon \Lambda = [\lambda_1, \lambda_2]$, where λ_1 and λ_2 are selected according to the probability that $\rho\ (z_t \geq \lambda_1) = \pi_1 > 0$, and $\rho\ (z_t \leq \lambda_2) = \pi_2 < 1$. The components of the vectors in (1), θ_1 and θ_2 are given by the expressions:

$$\theta_1 = \begin{pmatrix} \rho_1 \\ \beta_1 \\ \sigma_1 \end{pmatrix} \qquad \text{and} \qquad \theta_2 = \begin{pmatrix} \rho_2 \\ \beta_2 \\ \sigma_2 \end{pmatrix}$$

where $\rho_1$and ρ_2 represent the slope coefficient on y_{t-1}, β_1 and β_2 are scalar intercepts, while σ_1 and σ_2 are the slope coefficients on the lagged difference exogenous variables including deterministic terms (Δy_{t-1} .., Δy_{t-k}).

Model 1 is calibrated by using the least squares method. The vector estimates on various coefficients will be used to test for the presence of both nonlinearity or a threshold effect and a unit root in the two regimes. Specifically, the null hypothesis of H_0: $\theta_1 = \theta_2$ is examined with a Wald test. We use the Wald statistic, $W_T = W_T$ (Est. λ) = $\text{Sup}_{\lambda \varepsilon \Lambda} W_{T(\lambda)}$. If the observed W_T is greater than the critical or the bootstrap W_T value, then we reject the null hypothesis of linearity and conclude that there is a threshold effect or nonlinearity in the data generating process. In order to ascertain statistically for the presence of a unit root in the time-series on Log (DJIA) in both regimes (a complete unit root), using the Wald statistic $R_{2T,}$ we test the null-hypothesis that H_0: $\rho_1 = \rho_2 = 0$, against the alternative hypothesis that H_1: $\rho_1 \neq 0$ or $\rho_2 \neq 0$. Here, $R_{2T} = t_1^2 + t_2^2$, where $t_1^2 + t_2^2$ are the squared t-ratios for the estimates of ρ_1 and ρ_2, respectively. Caner and Hansen (2001) contend that the two-sided Wald statistic may suffer from less power and therefore, they recommend the one-sided version R_{1T}.

To test whether the time-series on Log (DJIA) has a partial unit root or regime dependent unit root, we perform the one-sided version of the R_{2T}, called the R_{1T}. The one-sided test is constructed as $R1T = t_1^2 I(\rho 1 < 0) + t_2^2 I(\rho 2 < 0)$. In the partial unit root test, the null is maintained as H_0: $\rho_1 = \rho_2 = 0$ and H_1: $\rho_1 < 0$ and $\rho_2 = 0$ or $\rho_2 = 0$ and $\rho_2 < 0$. Though these R_{2T} and R_{1T} tests have sufficient power against the null hypothesis of unit root, they fail to discriminate between the stationarity and a partial unit root case. Therefore, we also conduct the individual t-tests, t_1 and t_2.

The data sample used consists of daily stock price observations on DJIA from 5 February 1971 to 31 July 2011 (10,194 observations). Data are collected from Yahoo Finance's website. This sample is unique in the sense the sample period covers a large span and is devoid of any major wars. Additionally, to the authors' knowledge no studies on the market efficiency covering this long period exist in the literature. Moreover, including such a long span of time renders statistical testing both efficient and meaningful because most of the unit root tests are asymptotic tests.

III. Empirical Findings

Table 1 reports the summary statistics on DJIA daily stock series over the period 1971 through 2011, both in levels and logarithms. During this period, we notice a considerable amount of dispersion, as indicated by the vast range between the minimum and maximum values. The market also exhibits a high level of volatility as shown by the observed standard deviation of DJIA during the period. The results of the Jarque-Bera test results for normality show that we reject the null hypothesis of normality at the 1% level of statistical significance.

Table 1 Summary statistics

	DJIA	Log(DJIA)
Mean	4877.507	8.013
Median	2917.530	7.978
Maximum	14164.530	9.558
Minimum	577.600	6.359
Std. Dev.	4228.139	1.037
Skewness	0.5700	0.0352
Kurtosis	1.6885	1.3935
Jarque-Bera	1282.628	1098.328
Probability	0.000	0.000

In Table 2, the results of the traditional linear unit root tests are reported for the log-level time series, Log(DJIA). Here, it is worth noting that while the ADF, MZ_a and MZ_t tests maintain the null hypothesis of the presence of a unit root in the data generating process, the KPSS test states that the null hypothesis is stationarity. As the observed ADF, MZ_a and MZ_t test statistics are less than the critical values at the 5% level, we fail to reject the null of non-stationarity. The observed test statistics, for the first-differenced variable of Δ Log (DJIA), not reported here for space consideration, exceed the critical values at the 1%, 5% and 10% levels. Therefore, from the information provided in Table 2, we statistically discern that the Log (DJIA) is nonstationary and thus, is integrated of the order 1.

Table 2 Linear unit root test results with a constant and a trend

Time Series	ADF	MZ_a	MZ_t	KPSS
Log(DJIA)	-2.167 (2)	-4.044	-1.42	1.231*

*Bandwidth=79. The lags for the ADF tests were determined by the SBC. The null hypothesis of the KPSS unit root test is stationarity (i.e. convergence). For the MZa and MZt tests, the 5% critical values are -17.30 and -2.91. For the ADF test, 5% and 1% critical values are respectively, -3.410 and -3.959.

The results of the Caner-Hansen Threshold Autoregressive Model (TAR) to statistically determine whether there is any threshold effect in the Log (DJIA) time series are presented in Table 3. The joint null hypothesis to be tested here is that $\theta_1 = \theta_2$, which maintains that there is no threshold effect. The appropriate test statistic for the joint null hypothesis is the Wald statistic, W_T. As it is well known that the critical values for the non-standard asymptotic null distribution of W_T cannot be computed, we have to use the boot-strap approach with 2000 replications suggested by Caner-Hansen (2001) to generate the critical values. The observed W_T test statistic that we select here depends on the optimal delay parameter, m. The optimal delay parameter is determined on the basis of either the lowest residual variances from the OLS estimation of the null linear and TAR model, or the largest observed W_T.

Table 3 also reports Wald test results for various delay orders ranging from 2 to 5. Thus, we observe that the optimal m that is associated with the largest W_T of 68.8 is 3. This observed W_T value is greater than the critical values at the 1%, 5% and 10% level, and it has a bootstrapped p-value of zero, indicating that we can reject the joint null hypothesis that there is no threshold effect.

For the chosen m = 3, the observed W statistics is 68.8 with bootstrap 10%, 5% and 1% critical values of 23.2, 25.4 and 29.6, respectively. The bootstrap p-value is 0.0004. Thus, the test results overwhelmingly point out that vectors θ_1 and θ_2 are not statistically identical, a threshold exists and therefore, the Log (DJIA) time series is a nonlinear data generating process during the sample period studied. This finding is different from those of many previous studies testing the stochastic behavior of the U.S. stock market time series, with the exception of Narayan (2006), although our study is based on the daily data consisting of a much larger data period.

Table 3 Results of the Caner-Hansen for a threshold effect

m	2	3	4	5
Observed Wald Statistic	43.7*	68.8*	35.9*	47.4*
$W_{10\%}$	19.3	19.3	18.8	18.7
$W_{5\%}$	21.6	21.2	21.2	21.3
$W_{1\%}$	26.6	26.7	21.3	26.0
p-value*	0.001	0.000	0.002	0.000
ADF = -0.331				

Optimal delay parameter m =3. *Significant at the bootstrapped p-values and also at the 1% critical values.

In table 4, we report the Least Squares estimates of the unconstrained TAR model for the optimal delay parameter of 3. We notice that the estimated threshold parameter is 0.024. The TAR model is divided into two regimes of the Z_{t-1} variable depending on the value of the threshold parameter. In the first regime, $Z_{t-1} < 0.024$. This takes place when the stock prices have fallen, remained the same or increased by less than 0.024 over a three-day period. This regime consists of 85% of the sample observations. On the contrary, when the threshold parameter Z_{t-1} is above the threshold level of 0.024, the second regime occurs. In the second regime, stock prices have risen by more than 0.24 over a three day period. The second regime accounts for about 15% of the sample observations. Also, we observe that in Regime 1, the main driver of the TAR model is ΔY_{t-1}, in Regime 2, ΔY_{t-1}, ΔY_{t-2}, ΔY_{t}-3 and ΔY_{t-4} drive the threshold model.

Table 4 Least squares estimates from unconstrained TAR model

	$Z_{t-1} < \lambda$		$Z_{t-1} > \lambda$	
Regressors	Coefficient	S.E.	Coefficient	S.E.
Yt-1	0.000	0.000	-0.000	0.000
Intercept	0 .001	0.000	-0.001	0.002
ΔY_{t-1}	0.071*	0.014	-0.059*	0.014
ΔY_{t}-2	-0.016	0.014	-0.068*	0.014
ΔY_{t}-3	- 0.006	0.014	0.055	0.015*
ΔY_{t-4}	0.007	0.012	-0.058*	0.017
ΔY_{t-5}	-0.021	-0.021	-0.008	0.017
Threshold Estimate =λ= 0. 024; Regime 1(85%); Regime 2 (15%)				

S.E. denote the standard errors. * Significant at the 1% level.

In order to further find out if the Log (DJIA) nonlinear time series is also simultaneously a nonstationary process, we use the threshold unit root tests of R_{1T} and R_{2T}. Here, R_{1T} is expressed as $R_{1T} = t_1^2 I_{(\rho 1<0)} + t_2^2 I_{(\rho 2<0)}$. The results are reported in Table 5. The R_{1T} statistics are not significant, as determined by both the conventional levels of statistical significance and the boot strap p-values, for all values of m. We also find that for the optimal m-value, the one-sided Wald R_{1T} unit root test fails to reject the null of a unit root at various levels of statistical significance. In addition, the bootstrapped p-value for this test statistics is 0.985. When we examine the R_{2T} threshold unit root test results, we find very similar results. Again, the R_{2T} statistics are not at all significant. For the optimal delay parameter m=3, the observed R_{2T} is 0.867, which is less than the 1% and 5% boot strap critical values. Furthermore, we note that the observed R_{2T} has a p-value of 0.916, indicating that we fail to reject the null hypothesis of the presence of a unit root in the Log (DJIA) series.

Table 5: One and two-sided Wald tests for the threshold unit roots

	R_{1T}					R_{2T}				
m	R_{1T}	$W_{10\%}$	$W_{5\%}$	$W_{1\%}$	P-value*	R_{2T}	$W_{10\%}$	$W_{5\%}$	$W_{1\%}$	P-value*
2	2.23	9.26	11.4	15.6	0.723	2.34	9.75	11.9	16.2	0 .744
3	0.66	9.34	11.4	16.5	0.911	0.87	9.70	11.9	17.3	0.916
4	0.62	9.37	11.6	15.9	0.919	1.02	9.66	11.8	16.4	0.994
5	0.43	9.42	11.3	16.0	0.942	0.442	9.85	11.5	164	1.00

*Bootstrapped p-Values. Selected optimal m =3

Caner-Hansen point out that the one-sided Wald R_{1T} and R_{2T} threshold unit root tests are not statistically able to discriminate between the complete or full unit root and the partial unit roots in two regimes. Therefore in Table 6, we report the results of the individual t-test results, t_1 and t_2 statistics. For the optimal value of the delay parameter, the observed t_1 and t_2 values respectively are 0.813 and –0.453. These statistics are below the bootstrap critical values at the 10%, 5% and 1% levels indicating that we fail to reject the null hypothesis of the presence of a unit root in the data generating process, Log (DJIA). The bootstrap p-values are 0.584 and 0.945, respectively. Thus, the statistical evidence on the partial unit root tests reported in Table 6 clearly shows that the series on Log (DJIA) is nonstationary which indicates a random walk in both the regimes.

Table 6: Threshold partial unit root tests in the two regimes

	t_1				t_2			
m	t_1	$t_{5\%}$	$t_{1\%}$	P-value	t_2	$t_{5\%}$	$t_{1\%}$	P-value
2	-0.330	2.91	3.60	0.873	1.49	2.89	3.55	0.706
3	0.813	2.90	3.59	0.599	-0.453	2.90	3.75	0.896
4	0.788	2.94	3.62	0.909	-0.630	2.91	3.62	0.915
5	0.655	2.90	3.56	0.642	-0.114	2.94	3.62	0.841

Selected optimal m=3.

IV. Conclusions

This paper has empirically tested, using the daily closing values of the Dow Jones Industrial Average stock price data from 5 February 1971 through 1 July 2011, whether stock prices in the U.S. are both nonlinear and nonstationary by applying the unrestricted two-regime Threshold Autoregressive unit root tests (TAR) proposed by Caner and Hansen (2001). Unlike the traditional linear unit root tests, the unrestricted two-regime Caner-Hansen TAR model simultaneously tests for the presence of both nonlinearity and nonstationarity in the data generating processes. The implications of the outcomes of the unit root tests for structural analysis and econometric forecasting can hardly be exaggerated. The findings of the paper show that the stock price time series is a nonlinear data generating process and is nonstationary (unit root) in both regimes. The presence of nonlinearity or a threshold effect in the Log(DJIA) series indicates that in the US stock market, transaction costs, frictions, heterogeneous beliefs of agents and structural breaks are present. Stock prices that are nonstationary are consistent with the efficient market hypothesis. We also believe that this paper extends the literature on the efficiency market hypothesis of stock markets, and presents a comprehensive unit root analysis by testing simultaneously two important properties of nonlinearity and nonstationarity.

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