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**Article**

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# Validity of Weak-Form Market Efficiency in Central and Eastern European Countries (CEECs): Evidence from Linear and Nonlinear Unit Root Tests

Mehmet Levent Erdas<sup>1</sup>

**Abstract:** This paper aims to focus weekly stock market prices from the CEECs (Lithuania, Hungary, Romania, Croatia, Slovenia, Poland, Bulgaria, the Slovak Republic, Latvia, Estonia, and the Czech Republic) markets for evidence of weak-form market efficiency. This is complemented by the use of comprehensive unit root tests to test for abnormal return behaviour in these stock markets. For this purpose, Harvey et al. (2008) linearity test was applied in order to determine the characteristics of the series. The results indicate that the series with linear characteristics are Slovenia, Bulgaria, the Slovak Republic, Estonia, and the Czech Republic and those with non-linear characteristics are Lithuania, Hungary, Romania, Croatia, Poland, and Latvia. Then, in order to examine the weak-form market efficiency, DF-GLS (1996), Phillips-Perron (1988) and Lee-Strazicich (2003) unit root tests are applied to linear series and Kapetanios et al. (2003) and Kruse (2011) tests were applied to nonlinear series. The linear and non-linear unit root tests evidence that all the selected stock markets in CEECs have a unit root, in other words, are non-stationary. In the period analyzed, the results suggest that the weak-form efficient market hypothesis holds in the CEECs. Accordingly, the results indicate support for the validity of the random walks hypothesis in all the selected stock markets in CEECs. It means that investors should not be able to earn abnormal returns by carrying out the same analysis and analysing historical prices in CEECs. The finding of weak-form market efficiency has notable implications from the point of capital allocation, stock price predictability, and the influence of shocks to stock prices.

**Keywords:** Central and Eastern European Countries, Linear and Nonlinear Unit Root Tests, Weak-Form Market Efficiency, Random Walk Hypothesis.

**JEL Classification:** G14, G15, C22

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## Introduction

In recent decades, the importance of the stock market's role in economic development has been realized by many governments, financial institutions, and investors. Stock markets are the most significant lead indicator of any economy especially emerging and developing markets (Nisar and Hanif, 2012: 414). The investors who are planning to invest in the capital markets try to make their decisions primarily on the factors affecting the previous price movements and transaction volumes on the equities and prices of the equities and then on price forecasting. As economies progress, more capitals and investments are needed to meet economic growth; and if the efficient market hypothesis (EMH) is valid in the stock market, it is possible to provide an opportunity as a durable tool in the mobilization and allocation of savings among competing uses which are substantial to the growth of any countries (Manasseh et al., 2016: 1474). Hence, the issue of measuring market efficiency is important for security analysts, investors for investment decision and policymakers (Khan and Khan, 2016: 14).

The EMH is still a major issue in the finance literature and the concept of EMH is sound. EMH is substantially associated with the logic of the RWH. The equity prices; which are formed through the purchase and sale transaction and other public information; both act as a guide for the investors to make more accurate decisions on their investments, and enable a better allocation of the funds between the companies; and thus they also enable to provide a higher economic growth rate (Yartey and Adjasi, 2007: 4). Accordingly, the concept of efficient market and RWH are two crucial subjects in terms of explanation of the security price movements and behaviors of the investors within the economy and finance literature (Atakan, 2008: 99).

Current or potential investors who are considering investment in the securities exchanges calculate the expected values of the equity prices while making decisions on their investments. If the equity price is lower than the expected value, they decide to purchase it; and if it is higher than the expected value, they decide to sell it. If the market is efficient, the expected price and the current price will be the same since the price of the equities contains all information (Gemicci and Polat, 2018: 139). If the EMH is valid for the relevant stock market, it is reflected in the information immediately, so it is not possible to predict the price from the previous data by the investors, so technical analysis for this phenomenon does not work for investors (Gilani et al., 2015: 28).

The idea on that the price movements are formed randomly in the markets and their distribution is incidental, and therefore they cannot be estimated in advance is first suggested by Paul Samuelson (1965) and Fama (1965) with the name "efficient market hypothesis" to the contemporary literature in finance, and outlined as the idea that prices of financial assets fully reflect all available information. Both of them stated that the EMH presumes that stock return arranges immediately for any new data (Kofarbai and Zubairu, 2016: 261). Fama (1970), who brought the concept of efficient markets in the literature, described it as a market where numerous rational profit maximization compete in actively, the future market value of each equity is tried to be estimated and all of the important current information can be obtained by all of the market participants almost cost-free (Chuvakhin, 2001: 3). The EMH seeks answers for the question of whether the information types such as historical prices, internal information and other documentation and information can be used to provide returns above average. The EMH

depends on the speed and direction of the prices against new information. Within the efficient market, if the new information on the values of the equities arises due to the competition between the investors, the whole effect of this information will reflect on the market prices immediately (Fama, 1970). As a result of the new information, it will not be possible for the investors to provide supernormal returns when the prices of the securities applied to the new information accurately and expeditiously (Karan, 2004: 271; Nisar and Hanif, 2012: 414). The prices formed in an efficient market reflect on the information causing the formation of the historical prices. The investors make their decisions on purchasing and selling by following the historical prices (Sarikamis, 2000: 144; Atan et al., 2009: 35). Consequently, the EMH can be approached as containing two claims: (1) stock returns are random in an efficient market; (2) market participants cannot gain abnormal profit in such a market.

There are a couple of ways that help to determine whether the efficient market is efficient. One of those ways is to test the RWH (Yucel, 2016: 109). The RWH is one of the tests utilized to determine whether stock prices follow a random movement or not (Ananzeh, 2016: 173). The main aim to test the RWH is whether the information such as the historical price and transaction values, other public information and internal information can be used to provide supernormal returns (Kiyilar, 1997: 2). It is stated with the RWH that the successive price changes are independent based on the prices which reflect all of the obtainable information completely and they also have the same distribution (Ananzeh, 2014: 119; Kiyilar, 1998: 95). It is also said with the RWH that the equity prices move independently from the historical prices; in other words, the historical price movements do not affect the estimation of future prices (Narayan and Smyth, 2004: 707). Besides, if a price movement of equity has a structure with mean reversion or it follows a stationarity process; it means that the shocks on the equity prices will be temporary, the prices will return into their trends. From the viewpoints of the investors, this means that it is possible to estimate the future price movements to provide abnormal returns by following the behaviors of the equities (Gozbasi, 2014: 8).

It can be concluded that the weak-form of EMH is valid in cases where the prices are conformed with the RWH (Atakan, 2008: 99). According to the hypothesis, there is a relation between the prices of the securities and information, and they are always formed according to the new information declared. The markets are classified according to the type of new information reflected by the prices (Fama, 1970: 383). Fama (1970) classified the tests regarding the EMH based on three levels of markets: weak-form, semi-strong form and the strong form of market efficiency. Accordingly; the situation where all information related to the historical securities is reflected in the prices forms the weak efficient market, the situation where all public information is reflected in the prices of the securities forms the semi-strong efficient market, and the situation where not only public information but also in-company information are reflected in the prices of the securities forms the strong efficient market (Fama, 1991: 1576). This research focused only on the weak-form market efficiency of the selected stock markets of CEECs.

There are two assumptions to be implemented for the weak efficiency. The first of them is the non-stationarity of the series and independent and homogeneous distribution of the residuals from the random model. It is necessary by testing the weak-form of the hypothesis where the changes in the prices of the securities are completely random. The

changes in the prices should conform to the RWH here. Therefore, testing the weak-form of EMH will transform into testing RWH. It is suggested with the weak EMH that the previous returns of the current prices of the securities reflect the data such as other information on the securities and transaction value. If the weak-form of the effective market is valid for a market, the changes in the prices of the securities are formed completely random. Therefore, it will not be possible to try to estimate the future price of the securities by using their historical price series. Accordingly, it is possible to say that the utilization of the technical analysis will not provide extra earnings if the market is efficient in the weak-form (Novickyte and Degutis, 2014: 8-9). In sum; the weak efficient markets are the markets where any kind of information on the future prices cannot be provided through the historical prices; and therefore, the investors who make short-term forward purchase and sale through buy and hold strategy cannot provide super-normal returns compared to the ordinary investors by using information such as historical prices and transaction volume.

The performance of the stock markets is considered as a very important indicator to evaluate the performance of the economy. Accordingly, equity markets and stock markets play an important role in every economy. The existence of RWH in the stock market has significant implications for issuers of equity and portfolio investors. As Worthington and Higgs (2006) indicated in their study, the existence of the EMH in the equity markets supports the direction of the direct foreign investments to the country, market inclusion and increases in the saving rates. Hence, RWH and EMH have been broadly tested financial and economic fields with diverse results from both developed and developing capital markets. Accordingly, the purpose of this study is to reveal whether the investors make investments in the real values of the equities with the decisions they made in exchanges of the countries in the CEECs by testing the validity of the weak-form of the EMH in those exchanges. The countries in the analysis are in the group of developing and underdeveloped countries. Considering the literature and theoretical studies, these countries are likely to be efficient in weak-form. In line with this expectation, the major focus of this paper is to investigate the weak-form of the EMH in the market indices of CEECs from January 2010 to December 2018. This paper contributes to the empirical literature on the validity of weak-form market efficiency for CEECs by using both new econometric techniques and comprehensive unit root analysis.

The remainder of this paper is organized as follows: The next section comprises of literature review on the validity of the weak-form efficiency. Afterward, the research methodology is presented. Then, the data and experimental results are reported and discussed. The last section includes the attempts of the paper with important issues on policy implications and future studies.

### **Literature review**

As Conkar et al. (2018) indicated in their study; since an efficient market plays an important role in the development of the economy and also of the financial sector through the formation of the source allocation capital and distribution of the channels of the assets, researching the market efficiency is crucial for academicians, implementers and policymakers (Sakarya et al., 2018: 102). Therefore, there are a lot of researches on the validity of the EMH for different countries in the literature. In the tests for the weak-

form of the EMH, different testing methods such as autocorrelation coefficients, stationarity tests, normal distribution analysis, run tests, and unit root tests were used. The majority of these methods are based on the unit root analysis in the literature. Therefore, these studies tested the weak-form of the efficient market hypothesis. Within the tests for the weak-form of the EMH, one can distinguish the tests for controlling the RWH. Although the statistical and econometric tests used in the researches are different, researching the validity of the weak-form of the EMH of the financial series, which is the subject of this study is also the common ground of almost all studies.

In this section, the most recognized studies on the weak-form market efficiency in the developed and developing markets are presented. The researchers are done in different countries, the results, the statistical and econometric methods are presented in Table 1 in summary.

**Table 1. Selected studies on the weak-form market efficiency for stock markets**

Studies/Year	Stock Markets/Data	Methodologies	Results
Lo and MacKinlay (1988)	ABD; New York and AMEX Stock Exchange (1962-1985)	Variance Estimators	New York and AMEX stock prices fails to exhibit RWH
Li and Lam (1995)	Hong Kong; Hang Seng Stock (1970-1991)	Threshold Autoregressive Conditional Heteroscedastic	Hang Seng stock is efficient. Stock prices follow RWH
Al-Loughani and Chappell (1997)	FTSE 30 Share Index (1938-1989)	BDS Test	FTSE 30 Share Index didn't hold weak-form of efficiency
Chan et al. (1997)	18 International Markets (1961-1992)	PP Unit Root Test And Cointegration Test	All the countries are efficient.
Choudhry (1997)	Argentina, Brazil, Colombia, Chili México, Venezuela (Jan 1989 - Dec 1993)	The ADF Unit Root Test	All countries consistent with the null hypothesis of weak-form efficiency.
Kawakatsu and Morey (1999)	16 Developing Countries (Jan 1976-Dec 1997)	DF-GLS And The KPSS Unit Root Tests	The stock markets are weak-form inefficient
Abraham et al. (2002)	Kuwait, Bahrain, Saudi Arabia (Oct 1992 - Dec 1998)	The Variance Ratio	Saudi Arabia and Bahrain are efficient in weak-form, and follow RWH
Buguk and Brorsen (2003)	Borsa Istanbul (1992-1999)	ADF Unit Root Test, GPH Test Variance Ratio Test	The Borsa Istanbul is efficient in the weak-form, the stock prices follow RWH
Chaudhuri and Wu (2003)	Seventeen Emerging Markets (Jan 1985 - Apr 2002)	Seemingly Unrelated Regression Tests	Stock prices of all these markets are consistent with the weak-form of EMH
Smith and Ryoo (2003)	Greece, Turkey, Hungary, Portugal and Poland (Apr 1991 - Aug 1998)	The Multivariate Ratio Test	Turkey is efficient in the weak-form and exhibits price behaviour that resemble to RWH
Narayan and Smyth (2004)	South Korea (1981-2003)	ADF, Zivot and Andrews, LP Unit Root Tests	There existed weak-form of efficiency and it exhibits characteristics of RWH

Worthington and Higgs (2004)	20 European States (Aug 1995 - May 2013)	The Correlation Test, The Run Test, The Unit Root Test and The Multivariate Tests	Hungary, Germany, Ireland Portugal, Sweden and the UK are efficient in the weak-form
Narayan (2005)	Australian and New Zealand (Unknown Dates)	Unit Root Tests And Unrestricted Two-Regime Threshold Autoregressive Model	Both countries are nonlinear processes and consistent with the weak-form of EMH.
Narayan (2006)	ABD; New York Stock Exchange (1964-2003)	Unrestricted Two-Regime Threshold Autoregressive	The paper that supports the efficiency in weak-form for New York Stock Exchange
Celik and Tas (2007)	Developing Countries (1998-2007)	Linear Unit Root Test	Accept weak-form efficiency and RWH for many countries
Hasanov and Omay (2007)	Bulgarian, Czech, Hungarian, Slovakian Stock Markets (1991-2005)	The STR Unit Root Test of Kapetanios et al. (2003)	The weak-form of efficiency is validity in these countries and these countries follow RWH
Hooi and Smyth (2007)	Eight Asian Countries (Jan 1998 - June 2005)	Panel Unit Root Test With One or Two Structural Breaks	Eight Asian countries are not weak-form-efficient and these markets were unable to follow RWH
Narayan and Smyth (2007)	G-7 Stock Prices (1960-2003)	Unit Root Tests With One And Two Structural Breaks	Stock prices of all these markets are consistent the RWH
Narayan and Prasad (2007)	The Stock Exchange Markets of 17 Countries (Jan 1988 - Mar 2003)	LLC, The SURADF And The MADF Tests	The paper that supports there existed weak-form of efficiency for all countries
Lean and Smyth (2007)	8 Asian Countries (Jan 1988 - June 2005)	Two Break LM Panel Unit Root Test	The paper supported the efficiency on these Asian countries
Mollah (2007)	Botswana Stock Exchange (1989-2005)	K-S Normality, Auto-Correlation And Run Tests Auto Regressive ARIMA Model	Botswana Stock Exchange is not informationally efficient and did not follow weak-form of efficiency
Ozdemir (2008)	Borsa Istanbul (1990-2005)	ADF And LP Unit Root Tests, Runs Test, Variance Ratio Test	The paper that supports the efficiency in weak-form for Borsa Istanbul
Narayan (2008)	The Stock Markets of the G-7 Countries (Jan 1975 - Apr 2003)	Two Break Panel LM Unit Root Test	The paper that supports the efficiency in weak-form for Australia and New Zealand
Pele and Voineagu (2008)	Romanian Capital Market (9/19/1997-1/09/2007)	Unit Root Test, The Partial Autocorrelation	Weak-form and RWH are valid for Romanian Capital Market
Munir and Mansur (2009)	Kuala Lumpur Stock Exchange Composite Index (1980-2008)	Unrestricted Two-Regime Threshold Autoregressive	The stock markets are weak-form efficient and they found to be moving randomly
Gourishankar et al. (2009)	Bombay and National Stock Exchanges (1997-2009)	Non-Parametric test, Runs test and BDS Test	The stock markets are weak-form efficient and it found to be moving randomly

Liu (2010)	China Stock Market (2001-2008)	Parametric and Non-Parametric Tests	China Stock Market was unable to follow weak-form of efficiency and RWH
Irfan et al. (2010)	Karachi Stock Exchange (Jan 1999 - Aug 2009)	Unit Root Test, Autocorrelation Tests and ARIMA Mode	The market is not efficient in weak-form
Zaubia and Nahlehb (2010)	Mena Countries; Morocco, Tunisia, Egypt Jordan Turkey (Jan 2004 - Dec 2006)	ADF and PP Unit Root Tests	Stock prices of all these countries are consistent with the weak-form and RWH
Borges (2010)	UK, France, Germany Greece Portugal and Spain (Jan 1993 - Dec 2007)	Correlation Test, The Run Test, The ADF Test and The Lomackinley Multivariate Ratio Test	Germany and Spain are efficient in weak-form, and follow RWH
Lee et al. (2010)	32 Developed and 26 Developing Countries (Jan 1999 - May 2007)	Multiple Structural Breaks	The paper reject the null hypothesis of weak-form efficiency, these economies did not follow RWH
Alexeev and Tapon (2011)	Toronto Stock Exchange (Aug 1980 - Aug 2010)	ARMA, EGARCH and Bootstrap Methodology	Weak-form of efficiency and RWH are valid for Toronto Stock Exchange
Mishra (2011)	Emerging and Developed World Capital Markets (Jan 2007 - Dec 2010)	Unit Root Test and GARCH	These economies didn't hold weak-form of efficiency and were not following the RWH
Haque et al. (2011)	Pakistani Stock Market (2000-2010)	Traditional Unit Root Tests, Ljung-Box, Q-Statistic of Autocorrelations, Runs Test	The paper rejected the RWH and weak-form of efficiency
Kim et al. (2011)	Dow Jones Industrial Average Index (Jan 1900 - June 2009)	Automatic Variance Ratio, Automatic Portmanteau, Generalized Spectral Tests	They accept the existence of weak-form of efficiency
Bashir et al. (2011)	Pakistani Stock Exchange (June 1997 - Apr 2009)	ADF And PP Unit Root Tests, Johansen Co-Integration, VAR	The paper refuted the null hypothesis of weak-form EMH
Mehmood et al. (2012)	Karachi Stock Exchange (Jan 2001 - Nov 2011)	ADF And PP Unit Root Tests And Johansen Co-Integration	The paper accepts existence of weak-form of efficiency and RWH for the Karachi Stock Exchange
Ezepue and Omar (2012)	Nigerian Stock Market (2000-2010)	Parametric and Non-Parametric Tests	Not weak-form efficient and Do not follow the RWH
Zeren and Konuk (2013)	Developing Countries; Argentina, Brazil, China, Indonesia, India, Philippines Mexico, Malaysia, Turkey and Russia (1988-2012)	ADF and KSS Unit Root Tests	Accept weak-form for India, Argentina Indonesia, Mexico, Russia and Turkey; Reject for Brazil China, Philippines and Malaysia
Gozbası et	Borsa Istanbul	Nonlinear Unit Root	Borsa Istanbul is efficient in the



al. (2014)	(1 July 2002 - 7 July 2012)	Tests	weak-form and the stock prices follow RWH
Gumus and Zeren (2014)	G -20 Countries (Various Start Dates)	Harvey Linearity, The Fourier ADF and The Fourier KSS Unit Root Tests	Weak-form and RWH for the markets of the nine countries
Gozbasi (2014)	Borsa Istanbul (Jan 2004 - Mar 2014)	Harvey Linearity Kapetonois et al. (2003), Kruse (2011) Tests	Borsa Istanbul is efficient in the weak-form and the stock prices follow RWH
Lee et al. (2014)	OECD, G-6, Asian and Other European Economies (Unknown Dates)	Smooth Transition Regression, Heterogeneous Panel Unit Root Tests	Accept RWH for majority of the countries
Dragoṭă and Ţilică (2014)	Post-Communist East European Countries (Jan 2008 - Dec 2010)	Unit Root Tests, Runs Test, Variance Ratio Test, Filter Rules Test and The January Effect	The weak-form and RWH cannot be rejected for some assets
Ryaly et al. (2014)	Asian Stock Markets; India, South Korea, Singapore, Japan, Hong Kong (July 1997 - Nov 2013)	Unit Root Test, Serial Correlation Test, The Runs Test	Weak-form of EMH and RWH are valid for all the Asian stock markets
Alom and Raquib (2014)	Dhaka Stock Exchange (1998-2012)	Autocorrelation Function Tests	The stock market didn't hold weak-form of efficiency and was not following the RWH
Ananzeh (2014)	Amman Stock Market (Jan 2000 - Dec 2013)	ADF And PP Unit Root Tests, Runs and Autocorrelation Tests	Amman Stock Market stock market is inefficient at the weak-form
Hepsag and Akcalı (2015)	G-7 And E-7 Countries (Various Start Dates)	Asymmetric Nonlinear Unit Root Test	Weak-form and RWH are valid for France, Italy, Japan, the USA, Brazil, China, India, Indonesia, Mexico and Turkey, Canada, Germany, the UK, Russia
Gilani et al. (2015)	Islamabad Stock Exchange (Jan 2013 - Dec 2013)	Run Test and ADF Test	The stock market is weak-form inefficient and it found to be moving non-randomly.
Phiri (2015)	Five Generalized Stock Indices in the Johannesburg Stock Exchange (Jan 2000 - Dec 2014)	Linear And Nonlinear Unit Root Tests	The linear model suggests that JSE is efficient in the weak-form; the nonlinear model suggests that majority of the stock indices didn't hold weak-form of efficiency.
Said and Harper (2015)	Russian Stock Market (2003-2012)	Autocorrelation and Box-Ljung Test	The market is not efficient in weak-form
Malhotra et al. (2015)	10 Selected Stock Exchanges in Asia-Pacific Market (1997-2012)	Autocorrelation and Run Test	There existed weak-form of efficiency for monthly returns but fail to exhibit RWH in daily and weekly returns

Nwachukwu and Shitta (2015)	24 Emerging and Nine Industrial Stock Market Exchanges (Jan 2000 - Dec 2010)	Parametric and Non-Parametric Techniques and January Effects	Stock market exchanges are efficient in the weak-form, the stock prices follow RWH
Yang et al. (2015)	MIST Stock Markets; Mexico, India, South Korea Turkey (Apr 2004 - Apr 2012)	Sequential Panel Selection Method, Fourier KSS, Fourier Panel KSS	Stock markets of all these markets are consistent with the weak-form of efficient market
Hussain et al. (2016)	Chittagong Stock Exchange (2006-2016)	Run Test Autocorrelation Test Coefficient Test, Ljung-Box Statistics	The paper refuted the null hypothesis of weak-form efficiency.
Anlas and Toraman (2016)	Turkish Stock Market (1988-2011)	Multiple Structural Breaks	Turkish Stock Market follows RWH
Khan and Khan (2016)	Karachi Stock Exchange (1991-2015)	Unit Root Tests, The Run Test and Autocorrelation Test	Unit root tests reveal that the KSE is efficient in the weak-form, the run and autocorrelation tests reveal that there is no validity of weak-form efficiency of KSE
Malcioglu and Aydin (2016)	Istanbul Stock Exchange (3.7.2000-22.9.2015)	Harvey Linearity Test	There is no existence of weak-form efficiency of ISE
Rahman et al. (2016)	Chittagong Stock Exchange (2006-2015)	Parametric/Non-Parametric Methods	There is no existence of weak-form efficiency of Chittagong Stock Exchange
Yucel (2016)	Borsa Istanbul (2000-2015)	Unit Root Tests	All indexes in Borsa Istanbul follow the weak-form of EMH and consistent with the RWH
Pervez et al. (2018)	Dhaka Stock Exchange (June 2004 - Mar 2018)	K-S Test with Lilliefors Coefficient, Run Test, Autocorrelation Test, Unit Root Tests and Variance Ratio Test	Dhaka Stock Exchange is weak-form inefficient and it found to be moving non-randomly
Tokić et al. (2018)	Developing Eastern European Countries; Croatia, Serbia, Slovenia, Slovakia (Jan 2006 - Dec 2016)	Serial Correlation Test, Runs Test, Unit Root Tests, Variance Ratio Test and January Effect	Croatia, Slovenia, Slovakia confirm the validity of weak-form of EMH
Gemici and Polat (2018)	MIST Countries; Mexico, Indonesia, South Korea Turkey (Jan 1988 - July 2017)	Furuoka Unit Root Test	These markets are not efficient in weak-form

Source: Author's compilation.

In literature, EMH is examined by parametric and non-parametric tests such as variance ratio test, run test, autocorrelation test, linear, and nonlinear unit root test. The above-mentioned results suggest that the weak-form of EMH and RWH are confirmed by many studies in the literature; however, they are not supported by a few studies. In light

of the above-mentioned literature, it is evident that the mixed results are reached by various studies. In other words, the research background cannot reveal a common idea for the weak-form of efficiency in developed and developing countries. While the consensus says that stock prices in developed markets exhibit an RWH, there are no obvious outcomes regarding stock prices in developing markets. To this end, both traditional and modern econometric techniques are employed for measuring the weak-form of efficiency for developing countries in this study.

**Methodology**

One of the common methods preferred to research the validity of the weak-form of the EMH is unit root tests. The unit root tests are the tests performed to research the stationarity of the time-series (Tari, 2014: 382). Using the unit root tests suitable for the structure of the equity market series will be important in terms of the reliability of the results.

It is important to research whether the series are linear before researching whether the exchange series of the relevant countries are stationarity for the accurate interpretation of the results. When the studies are reviewed, it can be observed that lots of linearity tests were developed in lots of literature. Harvey and Leybourne (2007) and Harvey et al. (2008) are frequently used in the literature. In this study, the test method developed by Harvey et al. (2008) was used to test the linearity of the series, since; this test has a better performance in terms of statistical power and size properties than the one introduced by Harvey and Leybourne (2007).

In their study, Harvey et al. (2008) suggested the following test statistics which can be calculated by using the following two test statistics which enable us to test the linearity when the stationarity features of the time-series are unknown. In the approach suggested by Harvey et al. (2008), the following weighted statistics were developed to test the stationarity under the null hypothesis and nonstationary under the alternative hypothesis (Gozbası, 2014). Harvey et al. (2008) test statistic is calculated with the following equations. First of all, Harvey et al. (2008) suggest a weighted average of  $W_0$  and  $W_1$  statistics:

$$W_\lambda = \{1 - \lambda\}W_0 + \lambda W_1 \tag{1}$$

where,  $\lambda$  is a function that converges in probability to zero when  $y_t$  is I(0) and to one when  $y_t$  is I(1).  $W_\lambda$  is asymptotically distributed as  $\chi^2_2$ . While  $W_0$ , which involves null and alternative hypotheses respectively for linearity and non-linearity if the series is considered as I(0), is a standard Wald test;  $W_1$ , which involves null and null hypotheses respectively for linearity and non-linearity if the series is considered as I(1) is also a standard Wald test (Vasconcelos and Junior, 2016: 117). The  $\lambda$  parameter in the formula indicated the weight and calculated with the following formula (Harvey et al. 2008; Harvey and Leybourne, 2007):

$$\lambda(U, S) = \exp\left(-g \left(\frac{U}{S}\right)^2\right) \tag{2}$$

where,  $g$  represents a finite positive constant, Harvey et al. (2008) stated in their study that the value should be calculated as  $U, S$ .  $U$  is the statistical standard unit root test of Dickey-Fuller and  $S$  is the statistic of the stationarity non-parametric test of Harris et al. (2003). If the series does not contain a unit root,  $(U/S)^2$  diverges, resulting in  $\lambda$  gets

closer to zero, and if the series contains a unit root,  $(U/S)^2$  converges to zero resulting in  $\lambda$  gets closer to 1 (Harvey et al., 2008). The statistics of the Harvey test and  $W_0$  statistics which test the basic hypothesis where the series is stationarity are calculated with the addition of the restricted and unrestricted residual sum of squares of the following model. To compute the statistic  $W_1$  initially in equation (1), the coefficients are selected as they will stabilize  $v_t$  based on the nonlinear first degree AR(1) model for the stationarity time-series  $y_t$ .

$$y_t = \mu + v_t$$

$$\Delta v_t = \theta_\Delta v_{t-1} + \delta f(\Delta v_{t-1}, \varphi) \Delta v_{t-1} + \varepsilon_t \tag{3}$$

where,  $\theta$ ,  $\delta$  and the function  $f(\cdot, \varphi)$  are chosen such that  $v_t$  is assumed to be globally stationary. In order to get the  $W_0$  test statistics in the equation (1), the edited version of the nonlinear first degree autoregressive model with the Taylor expansion under  $\varphi=0$  assumption in the stationarity time-series is presented in the following equation (4) again through the equation (3).

$$\Delta v_t = \gamma_1 \Delta v_{t-1} + \gamma_2 (\Delta v_{t-1})^2 + \gamma_3 (\Delta v_{t-1})^3 + \varepsilon_t \tag{4}$$

Considering the equation (4), it is possible to present the null hypothesis for linearity and the alternative hypothesis for non-linearity respectively as follows:

$$H_{0,0}: \gamma_2 = \gamma_3 = 0$$

$$H_{1,0}: \gamma_2 \neq 0, \text{ or/and } \gamma_3 \neq 0$$

In order to test the hypothesis, it is possible to write the data creation process presented in equation (5) in observed  $y_t$  as follows:

$$y_t = \beta_0 + \beta_1 y_{t-1} + \beta_2 y_{t-2}^2 + \beta_3 y_{t-3}^3 + \sum_{j=1}^p \beta_4 \Delta y_{t-j} + \varepsilon_t$$

$$\Delta y_t = \lambda_1 \Delta y_{t-1} + \lambda_2 (\Delta y_{t-1})^2 + \lambda_3 (\Delta y_{t-1})^3 + \sum_{j=1}^p \lambda_4 \Delta y_{t-j} + \varepsilon_t \tag{5}$$

Where  $\Delta$  and  $p$  represent the difference operator and the number of delays, respectively. In the model, linearity null hypothesis ( $H_{0,0}: \beta_2 = \beta_3 = 0$ ) is tested against the nonlinearity alternative hypothesis by a Wald statistic ( $H_{1,0}: \beta_2 \neq 0$  and/or  $\beta_3 \neq 0$ ). Here, the statistic of the standard Wald test is:

$$W_0 = T \left( \frac{RSS_0^r}{RSS_0^u} - 1 \right) \tag{6}$$

The  $RSS_0^r$  value within the formula indicates the total residual sum of squares of the regression model obtained by applying the restriction under the basic hypothesis, and  $RSS_0^u$  indicates the sum of the squared residuals in OLS and it is obtained from the  $RSS$  unrestricted model.  $T$  is the number of observations. The  $W_0$  test statistics conform with the chi-squared distribution  $\chi^2$ . In accordance with the  $W_1$  statistics, which is compatible with the linearity test if the examined series are considered as  $I(1)$ ,  $y_t$ , which is the first difference of the series, are nonlinear. Thus, we assume the following nonlinear process AR(1) for a series  $I(1)$ :

$$y_t = \mu + v_t$$

$$\Delta v_t = \delta_1 \Delta v_{t-1} + \delta_2 f(\Delta v_{t-1}, \varphi) \Delta v_{t-1} + \varepsilon_t \tag{7}$$

It is necessary to rewrite this data creation process through the Taylor expansion second time with the equation (7) in order to test the basic hypothesis ( $\delta_2=\delta_3=0$ ) on linearity.

$$\Delta v_t = \gamma_1 \Delta v_{t-1} + \gamma_2 (\Delta v_{t-1})^2 + \gamma_3 (\Delta v_{t-1})^3 + \varepsilon_t \tag{8}$$

The null hypothesis of linearity and the alternative of nonlinearity are expressed respectively as:

$$H_{0,0}: \gamma_2 = \gamma_3 = 0$$

$$H_{1,0}: \gamma_2 \neq 0, \text{ or/and } \gamma_3 \neq 0$$

Like the previous case of analysis I(0), equation (8) can be rewritten as:

$$y_t = \zeta_0 + \zeta_1 y_{t-1} + \zeta_2 y_{t-2}^2 + \zeta_3 y_{t-3}^3 + \sum_{j=1}^p \zeta_4 \Delta y_{t-j} + \varepsilon_t \tag{9}$$

In this case,  $H_{0,1}$  and  $H_{1,1}$  are as presented above, this is because  $y_t = v_t$  are the null and alternative hypotheses. Accordingly, the Wald statistics by equation (10) can be presented as follows:

$$W_0 = T \left( \frac{RSS_0^r}{RSS_0^u} - 1 \right) \tag{10}$$

where,  $W_0$  follows an asymptotic  $\chi^2$ .

In the cases where the time-series do not have the features of linearity, the nonlinear unit root tests are implemented in order to determine the features of the unit roots. Within this scope, the nonlinear exponential smooth transition autoregressive (ESTAR) models are used commonly in order to model the behaviors of the financial time-series (Gozbasi, 2014: 13). The tests developed by Kapetanios et al. (2003) (hereafter KSS) and Kruse (2011) are used frequently for the nonlinear series within the literature. The nonlinear ESTAR unit root tests suggested KSS (2003) and Kruse (2011) were used in this study. KSS (2003) introduced a test based on the ESTAR model to study the stationarity of the nonlinear time-series. This test is important since it reveals the stationarity globally in case the unit root tests which are based on the linear time-series technique reject the stationarity (Bozkurt and Okumus, 2016: 31).

In the unit root test developed by KSS (2003), the time-series are assumed to follow an autoregressive process in the first stage of the exponential smooth transition and the existence of the unit root which is a null hypothesis is tested against the nonlinear ESTAR stationarity hypothesis which is the alternative one. When the ADF, Perron and Zivot-Andrews tests reject the existence of the unit roots, the mentioned test sometimes brings results on stationarity. This prevents the unnecessary difference and thereby any information loss and also provide an insight for the investors (Ilalan, 2018: 660).

The model used as a base for the KSS unit root test is expressed as follows (Kapetanios et al., 2003: 361-362):

$$y_t = \beta y_{t-1} + \gamma y_{t-1} \Theta(\theta; y_{t-d}) + \varepsilon_t \tag{11}$$

In the model,  $\varepsilon_t \sim iid(0, \sigma^2)$  and  $\beta$  and  $\gamma$  indicate the unknown parameters. Additionally,  $y_t$  represents the zero-mean stochastic process. Following the STAR model literature, the transmission function on the exponential form is presented as follows.

$$\Theta(\theta; y_{t-d}) = 1 - \exp(-\theta y_{t-d}^2) \tag{12}$$

Here, it is presumed that  $\theta \geq 0$  and if  $d \geq 1$  it is a lag parameter. In the KSS (2003) test, the exponential STAR (ESTAR) model can be presented as follows by using the appropriate parameters. It can be expressed with the equation above (Kapetanios et al., 2003: 361-362):

$$\Delta y_t = \phi y_{t-1} + \gamma y_{t-1} [1 - \exp(-\theta y_{t-d}^2)] + \varepsilon_t \tag{13}$$

Here, the raw data can be the data which is acquired from the average or trend-free according to the data production process of the macroeconomic variable discussed.  $\varepsilon_t$  is an error term that has a normal distribution and is a zero mean and constant variance. The null hypothesis of this test process is  $H_0: \theta=0$  and the alternative hypothesis of it is  $H_1: \theta>0$ . Here, if  $\phi = \beta - 1$  and  $\theta$  is positive in the equation, the mean reversion speed can be determined effectively. In the KSS (2003) test, the ESTAR stationarity process in the alternative hypothesis is studied in consideration of the basic hypothesis which indicates the unit root process.

The nonlinear unit root test of Kruse (2011), which is known as tau test in the literature, is an advanced version of the KSS (2003) test. Whereas the KSS (2003) test assumes  $c$  as zero; in the study of Kruse (2011), the emphasis was put on the real-world examples that it is necessary to consider the possibility of non-zero location parameter is imminent (Anoruo and Murthy, 2014: 3). The time-series model which allows the non-null location parameter in the exponential transformation function in the Kruse (2011) test can be presented as below:

$$\Delta y_t = \phi y_{t-1} (1 - \exp\{-\gamma(y_{t-1} - c)\}) + \varepsilon_t \tag{14}$$

As we employed in the KSS (2003) test, Kruse (2011) applies a first-order Taylor expansion to the transition function,  $G(y_{t-1}; \gamma, c) = (1 - \exp\{-\gamma(y_{t-1} - c)\})$ , around  $\gamma=0$  and proceeds with the regression test and it is possible to get a first order Taylor approximation of equation (115) (Kapetanios et al., 2003: 361-362):

$$\Delta y_t = \delta_1 y_{t-1}^3 + \delta_2 y_{t-1}^2 + \sum_{j=1}^p \varphi_j \Delta y_{t-j} + \varepsilon_t \tag{15}$$

From the model (15), the null and alternative hypotheses can be redescribed as follows. In equation (15), the null hypothesis of a unit root is  $H_0: \beta_1 = \beta_2 = 0$  and the alternative hypothesis of a globally stationary ESTAR process is  $H_1: \beta_1 < 0, \beta_2 \neq 0$ . Note that in  $H_1$  the  $\beta_2$  has two-sidedness due to the fact that the location parameter,  $c$ , may assume real values (Vasconcelos and Junior, 2016: 120).

In Kruse (2011) the strictly stationary ESTAR process is researched within the alternative hypothesis in consideration of the basic hypothesis, which indicates the unit root process. The  $\tau$  statistics suggested by Kruse (2011) is as follows:

$$\tau = t_{\beta_{\varnothing_2}}^2 + 1(\hat{\beta} < 0)t_{\beta_1=0}^2 \tag{16}$$

Based on this, Kruse (2011) proposes a  $\tau$  test by utilizing the null hypothesis of unit root test it against the ( $H_0: \delta_1 = \delta_2 = 0$ ) globally stationary ESTAR process ( $H_1: \delta_1 < 0, \delta_2 \neq 0$ ). The critical values for this test statistics are presented both KSS et al. (2003) and Kruse (2011). Here, Kruse indicates that *tau* test carry outs quietly decent in terms of size and power (Anoruo and Murthy, 2014: 3). After the estimation of both models; the statistical value of the parameter in question is compared with the critical table value, and if the null-hypothesis is rejected, the series is decided to be stationarity.

## Data and empirical results

Most of the empirical studies on testing the weak-form of EMH and RWH focus on the developed stock markets in different parts of the world. To this end, in this study, the return values obtained from the weekly closing values of the indexes which have the highest values and transaction volumes in the exchanges of CEECs. The paper about the RWH of the share prices of the companies listed at CEECs consists of the previous data of them from January 2010 to December 2018, which contains 469 observations, and all the series required for this paper were extracted from *investing.com* and *bloomberg.com* databases. All series were transformed into natural logarithms before the analysis to eliminate the scale effect between series. Weekly data is used for 11 countries that are selected among the CEECs depending on the data restrictions. These countries are as follows: Lithuania, Hungary, Romania, Croatia, Slovenia, Poland, Bulgaria, Slovak Republic, Latvia, Estonia, and the Czech Republic. In the study, the linearity of the time-series was primarily tested and according to the results, the nonlinear unit root tests were applied. The test of Harvey et al. (2008) is applied for the linearity, and the DF-GLS and Phillip-Perron unit root tests are performed for the linear unit root test while the nonlinear ESTAR unit root tests introduced by KSS (2003) and Kruse (2011) are applied for the nonlinear unit root test.

The indexes, data periods, and the number of observations of the exchanges of the countries were presented in Table 2.

**Table 2. Description of stock markets**

Countries	Stock Markets	Period Covered	Observation
Lithuania	Vilnius SE General	1/3/2010-12/23/2018	469
Hungary	Budapest SE (BUX)	1/3/2010-12/23/2018	469
Romania	BET (BETI)	1/3/2010-12/23/2018	469
Croatia	CROBEX (CRBEX)	1/3/2010-12/23/2018	469
Slovenia	Blue-Chip (SBITOP)	1/3/2010-12/23/2018	469
Poland	WIG (WIG)	1/3/2010-12/23/2018	469
Bulgaria	BSE SOFIX (SOFIX)	1/3/2010-12/23/2018	469
Slovak Rep.	SAX (SAX)	1/3/2010-12/23/2018	469
Latvia	Riga General (OMXRGI)	1/3/2010-12/23/2018	469
Estonia	Tallinn SE General (OMXTGI)	1/3/2010-12/23/2018	469
Czech Rep.	PX (PX)	1/3/2010-12/23/2018	469

*Source: All data are extracted from the investing.com and bloomberg.com.*

Before analyzing the weak-form EMH of the exchanges of the CEECs, descriptive statistics of the used series are investigated. Table 3 of the descriptive statistics gives us the means, the median, the maximum, the minimum, the standard deviation, the skewness and the kurtosis of each series from January 2010 to December 2018.

**Table 3. Descriptive statistics of the stock markets**

Stock Markets	Mean	Median	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis	Jar-Ber
Lithuania	467.2071	454.3700	722.0300	266.1500	118.3957	0.524709	2.303456	31.001*
Hungary	24,352.38	22,074.46	40,785.87	14,940.77	7,356.734	0.896421	2.379592	70.334*
Romania	6,446.223	6,472.800	8,920.490	4,216.590	1,246.481	0.114587	1.910167	24.236*
Croatia	1,858.505	1,823.230	2,333.760	1,588.180	159.2231	1.132974	3.696933	109.82*
Slovenia	740.6398	754.9000	1,010.810	501.2700	105.7958	0.091709	2.535467	4.8743*
Poland	49,868.00	49,077.61	66,897.08	36,549.47	7,125.422	0.305093	2.314766	16.451*
Bulgaria	481.7463	454.2500	725.4800	288.2000	117.1011	0.317197	2.074534	24.601*
Slovak Rep.	253.3370	231.1900	359.7900	179.4700	53.85915	0.369644	1.529321	52.947*
Latvia	563.6238	439.1400	1,071.770	309.0700	231.6594	1.060111	2.598240	91.001*
Estonia	861.0675	826.4100	1,316.270	422.0400	226.1586	0.432605	2.111856	30.043*
Czech Rep.	1,108.825	997.9000	1,295.400	811.2600	103.8452	0.598206	2.774426	28.966*

Source: Own computation (E-views).

Notes: \*  $p < 0.01$ . \* denotes that the series are not normally distributed.

As seen in Table 3, the mean values of volatilities of the stock market of CEECs are 467.207, 24,352.38, 6,446.223, 1,858.505, 740.6398, 49,868.00, 481.7463, 253.3370, 563.6238, 861.0675, 1,108.825, respectively. It can also be observed that the highest value of the stock markets is Poland and the lowest value of them is the Slovak Republic. Also, the standard deviations of volatilities of the stock market of CEECs are found as 118.3957, 7,356.734, 1,246.481, 159.2231, 105.7958, 7,125.422, 117.1011, 53.85915, 231.6594, 226.1586, 103.8452, respectively. It can also be observed that the highest standard deviation of the stock markets is Hungary and the lowest standard deviation of them is Slovak Republic. For a standard normal distribution, skewness should be zero and kurtosis should be at three. It is seen that the stock market series are skewed to the right. It can be observed that the frequency distributions of the above-mentioned series are non-normal distributed based on skewness and kurtosis. The Jarque-Bera statistics also confirm the same.

Figure 1 provides the plots of stock indices over time in changes for the eleven countries. See Appendix 1. Figure 1 reflects the evolution of stock markets of CEECs between the years of January 2010 and August 2018. As seen in Figure 1, the stock price of Lithuania, Hungary, Romania, Poland, Bulgaria, Slovak Republic, Latvia, and Estonia has an increasing trend and has been frequently uptrend by years but the price or return of Croatia, Slovenia, and the Czech Republic is more balanced, and increases and decreases in Croatia, Slovenia, and Czech Republic series are felt most heavily during 2010-2018. In general, it can be observed that the line of all series has monotonically displayed increasing or decreasing trends between 2010 and 2018.

After the descriptive statistics related to the series were determined, it is the turn of the determination of the validity of the weak-form EMH for the exchanges of the CEECs. If the equity market is stationarity; in other words, it does not contain any unit root; the effects of the shocks will be temporary, and this will mean the EMH is valid. On the contrary; if the equity market is not stationarity; in other words, it does contain unit roots; the effects of the shocks will be permanent, and this will mean the EMH is valid in the weak-form. For this purpose, in order to research on the existence of the weak-



form EMH in the exchanges of the CEECs; among the linear unit root tests, the DF-GLS and Phillips-Perron; among the multiple structural break unit root tests, the Lee-Strazicich (2003); and among the nonlinear unit root tests, the unit root tests KSS (2003) and Kruse (2011) were applied. The linearity test of Harvey et al. (2008) was used to determine whether the structure of the series is linear. The *Eviews 10.0* software was used for the DF-GLS and Phillips-Perron unit root tests which do not consider the breaks; the *Gauss 10.0* software was used for the multiple break unit root tests of Lee-Strazicich (2003) and the Harvey et al. (2008) test to analyze the linearity of the tests; and *R for Windows* program was used for the nonlinear unit root tests of KSS (2003) and Kruse (2011).

The weakness of the tests which analyze the stationarity of the series in the literature is the assumption that the series to be analyzed should not contain unit roots; in other words, they should be stationary. This assumption causes serious problems with the usability of the test. The most important problem is that the linearity test which will be applied to the non-stationarity series can produce misleading results. Especially the factors such as transaction costs for the economic and financial time-series, short selling transactions, price gaps on the purchase and sale of the equities and corporational restrictive practices can cause nonlinearity (McMillan, 2005; Kim et al., 2008). Therefore, before analyzing the series econometrically, analysing the structures of the variables of the economic and financial time-series with the processes and tests suitable for their structures is important for the interpretability of the results. Accordingly, whether the features of the series have linear structures were analyzed primarily in this study. The ESTAR-type test method of Harvey et al. (2008) which tests the linearity and also applied commonly in the literature was used in the study.

Harvey et al. (2008) test is called  $W_\lambda$  and is distributed as a  $\chi^2_2$ . We display the results of applying the  $W_\lambda$  test in Table 4. As mentioned earlier, since the stationarity assumption which is one of the strong sides of the Harvey et al. (2008) test was smoothed, another stationarity test was not applied to the series. The results of the stocks market are characterized by Harvey et al. (2008) linearity test.

**Table 4. Harvey et al. (2008) linearity test results**

Stock Markets	$W_\lambda$	Results
Lithuania	10.309***	Nonlinear
Hungary	13.011***	Nonlinear
Romania	17.833***	Nonlinear
Croatia	10.744***	Nonlinear
Slovenia	0.754	Linear
Poland	8.270**	Nonlinear
Bulgaria	4.395	Linear
Slovak Republic	2.909	Linear
Latvia	29.332***	Nonlinear
Estonia	3.354	Linear
Czech Republic	4.240	Linear

Source: Own computation (*R for Windows*).

Notes: The  $W_\lambda$  statistic follows the  $\chi^2_2$  distribution and the relevant critical values are 9.21 (%1), 5.99 (%5) and 4.60 (%10). The estimation and tests were conducted using a program code written in GAUSS that was produced by Harvey et al. (2008). \*\*\* and \*\* denote the rejection of the null of linearity at the %1 and 5% significance level, respectively.

As a result of the study, the series whose linearity was analyzed were determined to be linear and nonlinear structure. The basic hypothesis of the Harvey linearity test indicated that the series is linear, and the alternative hypothesis of it indicated that the series is nonlinear. In table 4, the hypothesis of linearity is, hence, rejected in 6 cases of 11 CEECs. In Table 4, it can be observed that the basic hypothesis is rejected on the 0.01 and 0.05 significance levels of the series of the selected exchange indexes of Lithuania, Hungary, Romania, Croatia, Poland, and Latvia. In this case; it was concluded that the structures of the exchange series of Slovenia, Bulgaria, Slovak Republic, Estonia, and the Czech Republic are linear in contrast with the structures of the exchange series of Lithuania, Hungary, Romania, Croatia, Poland, and Latvia are nonlinear. After determining the linearity structure of the exchanges, it was the turn of the unit root tests to test the validity of the weak-form of the EMH. The validity of the weak-form of the EMH for the exchanges of the countries with the linearity feature was analyzed with the linear unit root tests of DF-GLS and Phillip-Perron; and two structural breaks unit root test of Lee-Strazicich (2003). Firstly, the DF-GLS and Phillip-Perron unit root tests were applied and the results of them are presented in Table 5.

**Table 5. Linear unit root test results**

Stock Markets	DF-GLS unit root test (Intercept and Trend Model)	
	Level	1st difference
Slovenia	-0.795175	-21.98332***
Bulgaria	-1.334746	-11.37111***
Slovak Republic	-1.021779	-4.016579***
Estonia	-1.366531	-3.864496***
Czech Republic	-2.299399	-5.014476***
Stock Markets	Phillips-Perron unit root test (Intercept and Trend Model)	
	Level	1st difference
Slovenia	-2.583464	-22.00643***
Bulgaria	-2.151323	-19.81364***
Slovak Republic	-1.881629	-28.94991***
Estonia	-2.652761	-21.38647***
Czech Republic	-2.492108	-21.74376***

Source: Own computation. (E-views).

Notes: This table presents results for unit root tests with an intercept and a trend. \*\*\* denotes the rejection of the null of a unit root at the %1 significance level at first difference. The unit root test for the DF-GLS were obtained by applying the Schwarz information criteria. For the spectral estimation method Bartlett Kernel was determined and for the Newey-West method Bandwidth options were used. Schwarz information criteria were selected for automatic lag selection. DF-GLS test critical values: -3.48 (%1), -2.89 (%5), and -2.57 (%10). Phillips-Perron test critical values: 3.977787 (%1), -3.419453 (%5), and -3.132320 (%10).

The unit root tests of DF-GLS and Phillip-Perron were applied to the series firstly to test the efficiency of the series of the exchanges of the CEECs in the weak-form. The results of the double-unit root tests are presented in Table 5. The results of the unit root tests

presented in Table 5 were reached by extracting the levels and differences respectively. The common result of both tests indicated that when the level values of the series are analyzed with intercepts and trends, the equity exchanges are non-stationarity, in other words, they contain unit roots. It was determined that all series became stationarity in the significance level of %1 in the DF-GLS unit root tests in their 1st difference. In other words, while the DF-GLS unit root test cannot reject the hypothesis which says the series is non-stationarity in the level in the 1% significance level; it rejects the null hypothesis which says the series is non-stationarity when the first difference of each series is tested for a unit root. It was determined that all series became stationarity or did not contain any unit roots in the significance level of 1% in the Phillip-Perron unit root tests in their first difference. In other words, while Phillip-Perron unit root test cannot reject the hypothesis which says the series are non-stationarity in the level in the 1% significance level; it rejects the null hypothesis which says the series are non-stationarity when the first difference of each series is tested for a unit root. Additionally, it can be observed in Table 5 that the test statistics in the Phillip-Perron test became stronger by getting higher. The results of both DF-GLS and Phillip-Perron unit root tests indicated that all series are integrated into the first difference. Thus, it was concluded that the weak-form of the EMH is valid for the exchanges in the five three countries, namely, Slovenia, Bulgaria, Slovak Republic, Estonia, and the Czech Republic, in other words, those countries have a unit root and follow an RWH. This is suggesting that past values cannot be used to predict the current value. Therefore, it is possible to say that the participants who make investments in those markets cannot provide super-normal returns with those investments.

Although the application of the linear unit root tests is really easy, they cannot obtain the structural breaks and nonlinear trends. As a result, it is suggested that the data is non-stationarity and the series are stabilized with the subtraction method. However, as Brooks (2014) indicated, this operation causes an information-loss on the long-term relations between the variables (Ilalan, 2018: 660). Additionally, it is known through the previous studies that the linear unit root tests have a low level of strength. For this purpose, the new generation unit root tests were applied for the nonlinear trends with breaks for the exchanges of those countries where the weak-form of the EMH is valid.

As the second group of unit root tests, the unit root tests with structural breaks were used in the study. In Table 6, the results of the two structural breaks unit root test of Lee-Strazicich (2003) are presented.

The results of the two structural breaks unit root test of Lee-Strazicich (2003) can be observed in Table 6. The results indicated that the exchange series of the countries are higher than the critical table values in the study of Lee-Strazicich (2003) for the A and C models, therefore they are non-stationarity at the level in the significance level of %1, in other words, they do not contain unit roots. It was observed that all series became stationarity after their first difference. Thus, it was concluded that the weak-form of the EMH is valid for the exchanges in the five three countries, namely, Slovenia, Bulgaria, the Slovak Republic, Estonia, and the Czech Republic, in other words, those countries have a unit root and follow an RWH. This is consistent with the weak-form of the EMH suggesting that past movements in stock prices cannot be used to predict their future movements. Accordingly, these results and structural breaks are determined as internal

and were confirmed by Lee-Strazicich (2003) unit root test. This result implies that the CEECs stock markets are not easily predictable. Consequently, both the traditional and LM structural break unit root tests confirmed the RWH for five countries with a linear structure. It can be implied that investors should not rely heavily on historical prices in an attempt to time the stock markets in these countries.

**Table 6. Unit root test with two structural breaks results**

Stock Markets	Lee and Strazicich (2003) LM Test											
	Model A			Breakpoints (TB <sub>1</sub> -TB <sub>2</sub> )			Model C			Breakpoints (TB <sub>1</sub> -TB <sub>2</sub> )		
Slovenia	-1.371			7/31/2011-3/23/2014			-3.915			8/26/2012-8/23/2015		
Bulgaria	-1.666			12/11/2011-6/08/2014			-2.329			8/07/2011-2/10/2013		
Slovak Rep.	-1.600			1/18/2015-2/22/2015			-4.237			1/06/2013-10/18/2015		
Estonia	-1.957			7/31/2011-2/16/2014			-2.938			4/17/2011-2/12/2012		
Czech Rep.	-3.467			7/17/2011-8/28/2011			-4.575			7/17/2011-8/06/2017		
Critical values for the LM unit root test statistic based on Model C												
$\lambda_2$	0.4			0.6			0.8					
$\lambda_1$	%1	%5	%10	%1	%5	%10	%1	%5	%10	%1	%5	%10
0.2	-6.16	-5.59	-5.27	-6.41	-5.74	-5.32	-6.33	-5.71	-5.33			
0.4	-	-	-	-6.45	-5.67	-5.31	-6.42	-5.65	-5.32			
0.6	-	-	-	-	-	-	-6.32	-5.73	-5.32			

Source: Own computation (Gauss).

Notes: Lee and Strazicich (2003) indicate the LM-type two break unit root test. TB<sub>1</sub> and TB<sub>2</sub> are the break dates. The Model A and C denote the breaks on the intercept and the breaks on the intercept and trend, respectively. Critical values for the LM test based on Model A at 10%, 5% and 1% significant levels are -3.504, -3.842 and -4.545 respectively. Critical values for the other coefficients follow the standard normal distribution.  $\lambda_j$  denotes the location of breaks.

KSS (2003) and Kruse (2011) unit root tests among the nonlinear unit root tests were applied in order to determine whether the EMH is valid in the weak-form for the equity markets of Lithuania, Hungary, Romania, Croatia, Poland, and Latvia which were determined through the test of Harvey et al. (2008). The results of the KSS (2003) and Kruse (2011) test results are presented in Table 7.

Kapetanios et al. (2003) and Kruse (2011) where the null of a linear unit root process is tested against the alternative of a globally stationary nonlinear ESTAR model. The estimated results of the KSS (2003) and Kruse (2011) nonlinear unit root test for Lithuania, Hungary, Romania, Croatia, Poland, and Latvia are presented in Table 7. Table 7 indicates the null hypothesis of unit root could not be rejected for raw, demeaned and detrended series, indicated from the value of  $t_{NL}$  which is greater than  $t_{NL}$  critical value for all significance level. In line with the results from the KSS test, the Kruse (2011) test also cannot reject the null hypothesis of unit root giving the value of  $\tau$  test, which is less than their critical value. Both tests suggest that Lithuania, Hungary, Romania, Croatia, Poland, and Latvia have a unit root, and the stock market for these countries is non-stationary. Empirical evidence suggests that the weekly stock prices for the selected stock markets of these countries are efficient in weak-form and exhibit RWH. Accord-

ingly, it is impossible to say that making predictions through the historical price movements and providing abnormal returns for the investors who think to make investments in the exchanges of those countries. Thus, this result confirms the efficiency of the exchanges of those countries in its weak-form. As a result, these findings evidenced that abnormal returns do not occur in these countries.

**Table 7. Results of the ESTAR-type unit root tests**

Stock Markets	KSS ( $t_{NL}$ )			$\tau$ ( $t$ )		
	Raw	Demean	Detrend	Raw	Demean	Detrend
Lithuania	1.944913	-1.980725	-2.058675	6.114072	8.176642	5.012147
Hungary	1.011081	-0.444442	-2.608448	1.039024	5.266097	7.042262
Romania	0.581756	-2.217067	-2.878157	2.349545	4.904826	8.710675
Croatia	-0.672917	-2.016415	-2.352110	6.947133	5.466154	7.956265
Poland	0.700364	-2.189545	-2.979273	3.266712	5.815160	9.366575
Latvia						
<i>Critical Values</i>						
%1	-2.82	-3.48	-3.93	13.15	13.75	17.10
%5	-2.22	-2.93	-3.40	9.53	10.17	12.82
%10	-1.92	-2.66	-3.13	7.85	8.60	11.10

Source: Own computation (R for Windows).

Notes: KSS( $t_{NL}$ ): KSS (2003).  $\tau$ : Kruse (2011). The critical values for the two statistics are obtained from KSS (2003) and Kruse (2011). The optimum lag length is selected according to Akaike Information Criteria (AIC).

## Conclusions and recommendations

While the companies with the funding needs turn towards exchanges of securities in order to supply long-term funds they need, the investors also turn towards exchanges to provide more returns. Therefore, the exchanges have an active role in the inclusion of the capital of the country. Besides, the steps of the companies contributing the most to the national income of the countries for sustainability have a crucial role in the establishment of the economic stabilization. It is exactly this point where the exchanges in the heart of the finance sector enable new investments by providing pecuniary resources for the companies and enables the companies to receive shares from the profit earned by giving the investor's partnership rights. Those features of the exchanges contribute to the companies, to the investors, and also to the national economy.

Investors apply trading strategies and technical analysis for investment decisions; hence, measuring the efficiency of the stock market is important for both investors and policy-makers. Being efficient in the weak-form means for a market that the prices or returns in this market are incidental, in other words, the random walk model is valid for determining the price movements in this market. Accordingly, the weak-form EMH is for testing the RWH. Hence, the issue of EMH is important for analysts, investor's investment decisions, and regulators of the stock market to improve the flow of information.

The EMH is one of the widely discussed subjects, and therefore, it attracts a lot of attention in the field of modern finance. There is no complete agreement on the efficiency of the equity markets in the literature, and the subject holds its currency in both international and national literature. From this point of view, testing the validity of the weak-form of the EMH of the exchanges of the selected countries with the new econometric techniques considered as necessary for the study. The main contribution of this paper is to focus on the issue of nonlinearities in the selected stock market series and the existence of a nonlinear unit root in the series. The objective of this paper is to examine empirically the validity of weak-form market efficiency and RWH in the context of unit root test based on linear and nonlinear techniques of the stock market with the highest value of CEECs. As mentioned before, there are numerous tests in the literature that study whether the economic and financial series are linear or nonlinear. The linearity test of Harvey et al. (2008) has a specific advantage when compared with the others. For this purpose, first of all, the linearity test applied revealed that the selected index returns of Lithuania, Hungary, Romania, Croatia, Poland, and Latvia have nonlinear structure, and indicated that it is necessary to apply nonlinear unit root test to analyze the unit root features of the series in question. After determining the linearity features of those series, the KSS (2003) and Kruse (2011) nonlinear unit root test was applied for the nonlinear series. On the other hand; the selected index returns of Slovenia, Bulgaria, the Slovak Republic, Estonia, and the Czech Republic have a linear structure. The stationarity of the linear series was analyzed with the DF-GLS and Phillip-Perron among the traditional unit root tests, and with the Lee-Strazicich (2003) unit root test with two structural breaks. It was determined with the results of the DF-GLS and Phillip-Perron unit root tests that the selected index returns of Slovenia, Bulgaria, Slovak Republic, Estonia, and Czech Republic contain unit roots, in other words, they are non-stationarity. As a result, the traditional unit root tests supported the weak-form of EMH and RWH for these countries. Also, these results were confirmed supported by Lee-Strazicich (2003) unit root test. According to those results, it was concluded that the markets of the relevant countries are efficient in the weak-form, and the RWH is valid for them. Accordingly, it is impossible to receive successful results from the technical analysis method which is used frequently by the experts and based on the previous price movements in the selected exchange indexes of those countries. Hence one should not be able to make a profit from using something that everybody else knows in the stock markets of the CEECs. It was determined with the results of the nonlinear ESTAR unit root tests applied for the series of Lithuania, Hungary, Romania, Croatia, Poland, and Latvia that the selected index returns of those countries contain unit roots, in other words, they are non-stationary. According to those results, the selected index returns of those countries are observed as effective in the weak-form; therefore, the RWH is valid for those indexes. Thus, the prediction of the future price of all of these markets will be impossible through technical analysis and analyzing the historical prices, investors in these markets cannot provide abnormal returns by carrying out the same analysis. Hence one should not be able to make a profit from using something that everybody else knows in the stock markets of the CEECs. These results are supported by most of the existing studies in the literature. Our findings are consistent with Smith and Ryoo (2003), Hasanov and Omay (2007) Pele and Voineagu (2008), Dragotă and Țilică (2014), Tokić et al. (2018).

This paper examines the weak-form efficiency of the stock markets in CEECs with a specific focus on the weak-form market efficiency. Accordingly, the contribution of this

paper lies mainly in the application of the selected methodology to CEECs markets for evidence of weak-form market efficiency. Government policymakers and CEECs' stock market participants place a special emphasis on the RWH in the stock market. The existence of the weak-form of EMH in the stock market can allure foreign portfolio investment; promote the domestic savings, and developing the pricing and availability of capital. Therefore, stock markets in CEECs are affected by investor's investment decisions and regulators and such kinds of policies should be implemented. However, it depends on the validity of the semi-strong and strong forms of EMH in the stock markets whether the investors can create profitable investment opportunities through other macroeconomic variables and international macroeconomic factors. Therefore, new researches analyzing whether the semi-strong and strong forms of EMH for the stock markets of the Central and Eastern European Countries are required. Accordingly, it is further suggested that future studies should employ alternative methodologies such as the event study in testing the semi-strong form of efficiency and compare the findings thereof with those in the current study. Further research can be employed with more sophisticated methods of analyzing the weak-form of efficiency. Earning abnormal returns may be investigated by running back testing of technical analysis strategies. The validity of the semi-strong and strong forms of the EMH for those markets can be studied. In our analysis, the weak-form of the EMH was tested on the exchange indexes with the highest value of the CEECs. From this point of view, policy suggestions can be made by comparing the market efficiency between the highest and the lowest exchange indexes by testing the weak-form of the EMH for the exchange indexes with the lowest values of those countries; It can be said that carrying out comparative studies can be useful if the financial data of different countries can be accessed. Furthermore, since the majority of the economic and financial time-series contain unit roots, using the linearity analysis for future studies on linearity will increase the reliability.

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## Appendix 1

**Figure 1. Evolution of stock markets from 01/2010 to 12/2018.**

