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GDP per Capita for West-Balkan Countries: Evidence from Linear and Nonlinear Unit Root Tests

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Abstract: The purpose of the paper is to investigate whether the economic trends of the Western Balkans are characterized by stationarity, long-term stability or permanent structural disruptions. Furthermore, the purpose of the work is to analyze institutional impacts on development and identify sustainable development pathways, as well as to assess economic resilience after crises. For this purpose, we examine the stationarity of GDP per capita (adjusted for purchasing power parity-PPP) during the period 1990-2023. To achieve this goal, we apply both linear and nonlinear unit root tests, after first evaluating the series in linear and nonlinear terms. The results of the linear tests showed that the GDP per capita series at the variable levels have a unit root. Linear tests with structural breaks find evidence of stationarity in the levels of the variables in some of the Western Balkan countries. When nonlinear unit root tests are used (with and without structural breaks) we find stationarity in some of the countries we examine.

Keywords: GDP per capita; West-Balkan countries; Linear and Nonlinear Unit Root Tests; Fourier unit root tests.

JEL classification: C12; C22; O40.

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1. INTRODUCTION

Modeling real GDP per capita has attracted the interest of researchers since the work of Nelson and Plosser (1982). In the macroeconomic literature, both Neo-Keynesian and Monetarist economists believe that business cycles are transitory phenomena and that output returns to its natural rate in the long run. Nelson and Plosser (1982) argue that a unit root in real output is inconsistent with the idea that business cycles are a transitory phenomenon. Furthermore, they note that shocks to real output create permanent effects in the system. This means that shocks to real output that have permanent effects (global financial, climate, pandemic and war) will have uncontrolled effects on the economy.

If real output contains a unit root, the structural reform that a government might pursue will be of limited value, because the impact of that reform in the long run will be offset by other shocks. Conversely, if real output is stagnant, only a large shock will have permanent effects on the country's growth trajectory. Therefore, it is important to assess the validity of the unit root hypothesis in real output. Stationarity of real GDP per capita in an economy suggests that business cycles have stable fluctuations around a defining trend. Since real GDP per capita is an important macroeconomic variable for economic policy analysis, it is essential to statistically determine whether real GDP per capita is stationary or contains a unit root. Furthermore, choosing the right control is important for drawing conclusions such as forecasting and making decisions for planning and formulating economic policy.

The empirical literature has concluded that real GDP, at the level form of the series, is non-stationary, using either univariate unit root tests or unit root tests on panel data. The key characteristic of all these tests is that they assume a symmetric adjustment process. In contrast, Enders and Granger (1998) test the null hypothesis of a unit root against the alternative of stationarity with asymmetric adjustment. They demonstrate that movements toward the long-run equilibrium relationship are better modeled as an asymmetric process. Therefore, they show that standard linear unit root tests have lower power in the presence of misspecified dynamics. Moreover, Enders and Granger (1998) relax the assumption of linearity in standard unit root tests by developing tests capable of distinguishing between linear non-stationary processes and nonlinear stationary processes. That is, the null hypothesis tested is that of a unit root, against the alternative of a nonlinear stationary process. Based on these assumptions, the literature identifies two sources of nonlinearity: Regime-dependent nonlinearity, meaning nonlinearity in the speed of mean reversion depending on the regime; and time-dependent nonlinearity, where structural breaks occur-that is, nonlinearity in the deterministic components.

The power of standard unit root tests depends on the specification of the alternative hypothesis. Structural breaks and nonlinear data in standard unit root tests cause erroneous results, resulting in a reduction in the statistical power of these standard tests. Perron (1989) first notes that stationary processes with structural breaks are very often mistakenly interpreted as unit root processes.

Recent empirical literature allows for nonlinear dynamics for unit root testing procedures. Kapetanios *et al.* (2003) argue that standard unit root tests suffer from a strong problem when applied to Data Generating Process (DGP) data. Kapetanios *et al.* (2003), Kruse (2009), and Sollis (2009) apply regime-dependent, nonlinear unit root tests. The above tests differ in the speed of adjustment towards equilibrium. Kapetanios *et al.* (2003), and Kruse (2009), use the exponential smooth transition autoregressive model (ESTAR), while Sollis (2009) uses the asymmetric exponential smooth transition autoregressive model

(AESTAR). Christopoulos and Leon-Ledesma (2010) apply tests that incorporate two structural breaks and nonlinearity simultaneously.

The main problem encountered in studies based on unit root tests is the selection of the correct test. Different tests that are chosen produce different results. Therefore, the primary goal is to first select a unit root test that is appropriate for the data structure in order to avoid any results with deviations. To achieve this, we develop the Harvey *et al.* (2008) linearity test which is used to investigate whether the series is linear or not. The reason why the Harvey *et al.* (2008) test is used is that the variables are not affected by the levels of stationarity. That is, the variables under investigation can be either zero-order integrals I(0), or first-order integrals I(1).

The countries of the Western Balkans have close ties with the EU and their goal is to ensure stable, prosperous and well-functioning democratic societies for a path towards the EU. Reforms are essential for their European path, but the most important and vital thing is the improvement of political and economic governance, the rule of law, media freedom and conditions for civil society. The EU also provides political and economic support to the countries of the region to strengthen good neighbourly relations and build shared prosperity through regional integration. In addition to its strong political support for the Western Balkans, the EU supports regional cooperation organizations to stimulate economic development, improve connectivity and strengthen security across the region (European Bank for Reconstruction and Development, 2024).

The standard of living in the Western Balkans lags far behind that of the EU. All six Western Balkan countries have a per capita gross domestic product (GDP) (adjusted for purchasing power parity (PPP)) that is less than half the EU average. The underlying problem is low productivity due to lack of investment, weak institutions, unfavorable demographics and a difficult business environment. The GDP gap between the Western Balkans and the EU has narrowed over the last two decades, but the pace of convergence has slowed since the global financial crisis of 2008-2009. The key question is: what can be done to speed up the rate of convergence? (European Bank for Reconstruction and Development, 2024).

The aim of the paper is to provide direct evidence for the stationarity of real GDP per capita using unit root methods with linear and nonlinear dynamics. There are several important differences between this work and previous ones that tested the properties of stationarity in per capita GDP. First, the paper uses the Harvey *et al.* (2008) test to investigate whether the series of GDP per capita for the Western Balkan countries is linear or not. Second, it uses linear tests as well as tests with a structural break. Third, it detects the stationarity of GDP per capita with a nonlinear ESTAR model around a nonlinear symmetric equilibrium with the tests of Kapetanios *et al.* (2003), and Kruse (2009). Fourth, it analyzes the test of Sollis (2009) that examines the asymmetric adjustment of countries' GDP per capita with a nonlinear ESTAR model depending on the direction of deviation. Fifth, with the Fourier ADF test of Enders and Lee (2012a), it examines the stationarity of GDP per capita with nonlinear structural breaks through cyclical changes without specifying time points.

The rest of this paper is organized as follow: Section 2 presents the literature review. Data and methodology are provided in Section 3 and Section 4 respectively. Section 5 reports the empirical results and discussion. Finally, Section 6 presents conclusions and policy implications.

2. LITERATURE REVIEW

In the context of time series analysis, and following the influential study "Trend and Random Walk in Macroeconomic Time Series" by Nelson and Plosser (1982), GDP per capita is often examined for the presence of a unit root, which indicates that the series is non-stationary. In this way, the stationarity of real per capita GDP has been analyzed, aiming to determine whether the effects of shocks are temporary or permanent. Moreover, it has been observed that the findings of studies on the stationarity of per capita GDP vary depending on the country, the time period covered, and the econometric methods applied. In this regard, this section of the literature review focuses on studies that investigate the stationarity of per capita GDP.

Table no. 1 presents a literature review of some empirical works that analyze the stationary property of GDP per capita. The grouping of the papers was done according to linear and nonlinear unit root tests with and without structural breaks as well as unit root tests on panel data.

Table1 no. 1 – Literature Summary on Stationarity of GDP

Studies	Countries	Time Period	Method	Results
Studies that used traditional unit root and structural breaks tests				
Narayan (2007)	G7 Countries	1870-2001	Lee and Strazicich (2003)	Italy and Germany Stationary
Chang *et al.* (2009)	24 OECD countries	1970-2006	Carrion-i-Silvestre *et al.* (2009)	Stationary for 22 Countries
Narayan and Narayan (2010)	79 developing countries	1970-2005	Zivot and Andrews (1992) unit root test with one structural break & Lumsdaine and Papell (1997) unit root test with two structural breaks.	Stationary for 40 Countries
Chapsa *et al.* (2015)	14 EU countries	1950-2010	Zivot and Andrews (1992) unit root test with one structural break	Stationary for 6 Countries
Stanisic *et al.* (2018)	Western Balkan (WB) and the Central and Eastern European	1993-2015	Augmented Dickey-Fuller (ADF) test and Zivot-Andrews (ZA)	Stationary Slovenia Latvia, Bosnia, Herzegovina (ADF) Bulgaria, Hungary, Lithuania (Z-A)
Dritsaki and Dritsaki (2021)	Bulgaria, Croatia, Greece, Romania, Slovenia	1990-2020.	Zivot and Andrews (1992) unit root test with one structural break	Unit Root
Studies that used unit root tests on panel data				
Ozturk and Kalyoncu (2007)	27 OECD countries	1950-2004.	Im *et al.* (2003) test to panel data	Unit Root
Genç *et al.* (2011)	The Gulf Cooperation Council (GCC) Countries	1950-2004	Levin *et al.* (2002), Im *et al.* (2003), Hadri (2000), Maddala and Wu (1999)	Unit Root

Studies	**Countries**	**Time Period**	**Method**	**Results**
Furuoka (2011)	9 Asian Countries	1970-2007	Pesaran (2007), Choi (2001), Panel Unit Root	Unit Root
Oskooe and Akbari (2015)	27 OPEC Countries	2000-2012	Im *et al.* (2003) Panel unit root test	Unit Root
Zeren and İşlek (2019)	D8 countries	1960-2014	BCIPS Lee *et al.* (2016) Fourier functions	Stationary
Hacıimamoğlu (2021)	G-7 countries	1970-2019	BCIPS Lee *et al.* (2016)	Stationary
Radulović and Kostic (2024)	5 Western Balkan countries (Serbia, Albania, Bosnia and Herzegovina, Montenegro, and North Macedonia)	1998-2020	(CIPS) panel unit root test.	Stationary
Studies that used nonlinear unit root tests				
Cuestas and Garratt (2011)	Selection of countries	1960-2008	Nonlinear (ESTAR) KSS (2003)	Stationary
Su and Chang (2011)	7 Eastern European countries	1969-2009	Enders and Lee (2012a, 2012b) Fourier Unit Root Test	Stationary Bulgaria, Latvia, and Romania
Shen *et al.* (2013)	9 Central-Eastern European Countries	1969-2009	Panel KSS with Fourier Unit Root Test	Unit Root for 6 Countries
Solarin and Anoruo (2015)	52 African Countries	1960-2011	KSS (2003) Non-Linear Unit Root Test	Stationary for 23 Countries
Omay *et al.* (2017)	USA	1875:1-2015:2	Fractional Frequency Flexible Fourier Form (FFFFF) Dickey-Fuller (Omay, 2015)	trend-stationary
Zeren and İşlek (2019)	D8 countries	1960-2014	Lee *et al.* (2016) and using Fourier functions.	Stationary
Canarella *et al.* (2020)	U.K.	1270-2016 1700-2016.	Omay *et al.* (2018)	Nonlinear stationary asymmetric process
Alancıoğlu (2025)	Turkey	1960-2022	RALS-LM και RALS-ADF, Fourier KPSS, Fourier ADF, and Fourier GLS (Meng *et al.*, 2017)	Stationary

GDP per capita is usually tested for stationarity to determine whether economic shocks have temporary or permanent effects. Traditional unit root tests, such as Augmented Dickey-Fuller (ADF), Phillips-Perron (PP), and Kwiatkowski-Phillips-Schmidt-Shin (KPSS), often find that real GDP per capita series contain a unit root (non-stationary), suggesting that shocks have long-run effects. In many papers and for many countries, GDP per capita is found to be non-stationary, meaning it follows a random path rather than returning to a trend. This suggests that shocks to the economy can have permanent effects on the path of growth.

The papers that test GDP per capita for unit roots assume either that there are no structural breaks, or that there is a structural break. These papers support the unit root or stationarity hypothesis. With multiple structural breaks, the empirical results point against the unit root or in others the results are mixed. Therefore, traditional tests may lack power and sometimes may fail to distinguish between a true unit root and a stationary series with structural break, leading to conflicting results depending on the data set and the test method. The choice of control and the presence of structural changes in the data (such as financial crises or wars) significantly affect whether unit roots are found.

Studies using panel techniques (LLC, IPS, Hadri) suggest that GDP per capita is non-stationary. Unit root tests in panels exploit both cross-sectional and longitudinal information. Panel unit root tests, or nonlinear tests, are often applied to GDP per capita to determine whether it is stationary or contains a unit root. These tests enhance statistical power over individual time series tests, often revealing that real GDP per capita is mean-reverting (stationary) or trend-stationary for many countries. Studies often show that while each country's GDP data may appear non-stationary, panel-level analysis often shows that real GDP per capita is stationary.

Nonlinear unit root tests, such as those of KSS, Kruse, and Sollis, or approaches based on Fourier functions, are more powerful than traditional linear tests for analyzing real GDP per capita. Nonlinear tests often reveal that apparently nonstationary data actually follow a nonlinear, mean-reverting (stationary) process. While linear tests often fail to reject the unit root hypothesis for GDP per capita (implying that shocks have permanent effects), nonlinear tests often reject it, suggesting that economies adjust to shocks in a nonlinear manner. Nonlinear controls often take into account state-dependent behavior (e.g., different rates of adaptation during recessions versus booms) using methods such as the Exponential Smooth Transition (ESTAR) model.

Research work with structural changes and nonlinear trends suggests that the use of Fourier approximations can take into account complex, nonlinear determinant trends that could otherwise be misinterpreted as a unit root. Studies have found evidence of nonlinear stagnation in real GDP per capita of OECD countries, Europe, and some African countries, in contrast to findings of non-stationarity from linear tests.

The empirical results of the work in the above table are unclear and the issue of the stationarity property of per capita GDP is still not clear, so further research is required on the issue we are examining.

3. DATA

For the analysis of the paper, we use annual data for the period 1990-2023 for the six Western Balkan countries. The GDP per capita variable is given based on purchasing power parity (PPP) in US dollars at constant 2021 prices and is taken from the World Development Indicators databases from the World Bank. The gap of missing observations, for some countries, has been filled using a simple average or trend fitting.

Figure no. 1 presents the graphs of GDP per capita of the Western Balkan countries from1990 to 2023.

From Figure no. 1 we observe that the GDP per capita of all countries shows an increasing trend except for the year 2020 when all countries show a decrease in GDP with Montenegro showing the largest. Like Europe and the rest of the world, the Western Balkans went through a recession in 2020 due to the Covid-19 pandemic. The Covid-19 crisis brought containment measures, business closures, and a decline in household income and consumption. The decline in employment was greatest in Montenegro (75%), while in the remaining countries the decline was 50% (World Bank, 2020). The summary statistics of West Balkan countries are provided in Table no. 2.

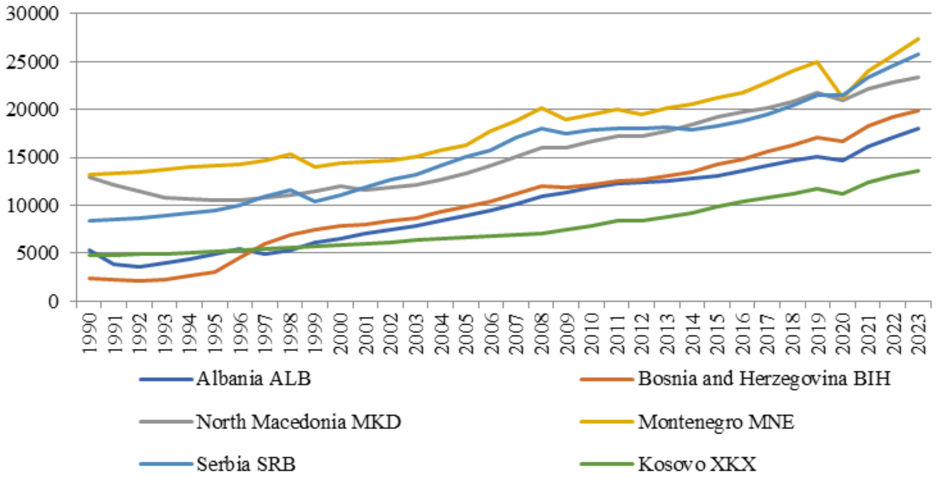

Figure no. 1 – Evolution of the GDP per capita, PPP (constant 2021 international $)

Table no. 2 – Descriptive statistics of the GDP per capita PPP (constant 2021 international $)

Country	Mean	Max.	Min.	Std.Div	Skew.	Kurt.	J-B
Albania	9,820.8	17,975.8	3,603.4	4,282.5	0.136	1.780	2.212 (0.330)
Bosnia and Herzegovina	10,379.5	19,829.2	2,148.3	5,273.2	-0.048	2.025	1.358 (0.506)
North Macedonia	15,445.6	23,323.9	10,491.6	4,212.5	0.415	1.753	3.179 (0.204)
Montenegro	18,216.8	2,7342	13,145.4	4,148.1	0.482	2.060	2.568 (0.276)
Serbia	15,466.2	25,718.4	8,345.3	5,010.1	0.187	2.003	1.607 (0.447)
Kosovo	7,780.4	13,642.6	4,736.7	2,650.3	0.713	2.279	3.623 (0.163)

Note: Std. dev denotes standard deviation and J-B denotes the Jarque-Bera test normality.

Descriptive statistics of GDP per capita in the Western Balkan countries highlight significant variations in the level of economic well-being in the region. The highest average level is recorded in Montenegro at $18,216.8, indicating that this country is the best performing country in the group. On the contrary, Kosovo has the lowest GDP per capita with $7,780.4, reflecting the most limited productive potential and the lowest level of development compared to other countries.

The largest variation in GDP per capita is observed in Bosnia and Herzegovina, which has a standard deviation of $5,273.2. This suggests that its economic activity is characterized by more pronounced fluctuations over time, possibly due to political, institutional, and productive instabilities. In contrast, Kosovo presents the smallest standard deviation of 2,650.3, indicating a more stable but lower level of economic performance.

Regarding distribution characteristics, the asymmetry is positive in all countries except Bosnia and Herzegovina, which indicates that high values of GDP per capita have a greater impact on shaping the distribution than low ones. In most countries, therefore, periods of relatively higher economic growth “pull” the average value upwards. Bosnia and Herzegovina, with negative asymmetry, appears to have a distribution that is more burdened by lower growth rates.

The kurtosis is less than 3 in all countries, which indicates a flat distribution, i.e. a distribution with more “spread out” values than the normal one. This finding, combined with the asymmetry, confirms that the evolution of GDP per capita is not characterized by extreme values but follows a relatively smooth dynamic.

Finally, the Jarque-Bera test demonstrates that the normality assumption is not rejected for any of the Western Balkan countries. This result strengthens the statistical reliability of subsequent tests, given that many methods are subject to assumptions related to the normality of the underlying distributions.

Overall, the findings depict a region with strong economic heterogeneity, differing levels of development, and variations in the stability of GDP per capita over time. These elements are crucial for interpreting the results of unit root tests and formulating economic convergence strategies.

4. METHODOLOGY

As we have mentioned, the purpose of our work is to examine the stationarity of the per capita GDP of the Western Balkan countries in the period 1990-2023. To this end, we apply various linear and nonlinear unit root techniques in order to check the order of integration of real GDP per capita in the countries we study. The unit root tests to be applied in the work require examining the series for linearity and their structural breaks. Specifically, before applying individual unit root tests, we begin by testing the null hypothesis of linearity against a nonlinear alternative. Also, to investigate whether the series we examine remain stable over time or exhibit abrupt structural breaks, we apply the structural breaks test. Therefore, linearity and structural breaks are among the basic diagnostic checks that a researcher should investigate before performing data analysis (Dritsaki and Dritsaki, 2025).

To test the linearity of the series, we use the Harvey *et al.* (2008) test, which is currently one of the most popular. The Harvey *et al.* (2008) test can be applied to either I(0) or I(1) processes. Also, when the order of integration is unknown, Harvey *et al.* (2008) suggest constructing a weighted average Wald test statistic. Furthermore, the test is not affected strongly by structural breaks.

For linear unit root tests, we use the Phillips and Perron (1988) test mainly for the way it deals with serial correlation and heteroscedasticity in the errors. Also, in linear unit root tests we use the test of Eliott *et al.* (1996), who propose a modified Dickey-Fuller test using the generalized least squares (GLS) method who argue that their test has greater power than that of Dickey-Fuller when we do not know the mean and trend in the series (Enders, 1995).

Because ignoring structural breaks (financial crises, policy changes, wars) in per capita GDP data leads to the incorrect acceptance of the null hypothesis of the unit root, we used in our work the tests of Zivot and Andrews (1992), and Perron and Vogelsang (1992). Both tests provide more evidence of stationarity, showing that shocks are often temporary. The Zivot and Andrews test allows for an endogenous break that can be at the intercept, the trend, or both. The test is repeated for all possible time points and the one that gives the most negative t-statistic is selected. The null hypothesis states that the series has a unit root with no structural break. The alternative shows that the series is stationary with a structural break. The Perron and Vogelsang test allows for a break that can be an Additive Outlier (abrupt break) or an Innovation Outlier (gradual break). The null hypothesis states that the series has a unit root with a structural break. The alternative shows that the series is stationary with a structural break.

Nonlinear unit root tests determine whether a time series is stationary, allowing for nonlinear, flexible adjustments toward equilibrium rather than assuming a linear process. For nonlinear unit root tests, we use the tests of Kapetanios *et al.* (2003), Kruse (2009), Sollis (2009), as well as the Enders and Lee Fourier Unit Root Test (Enders and Lee, 2012a). The KSS test controls a nonlinear ESTAR-type adjustment, i.e. near zero it behaves like a random walk, and far from zero it exhibits strong regression. The null hypothesis states that the series has a unit root (linear random walk) and the alternative nonlinear stationary process ESTAR. The Kruse test is an extension of KSS that allows for a non-zero threshold. The assumptions are the same as for KSS. The Sollis test tests for asymmetric adaptation, i.e. different behavior on rise/fall. The test is based on the AESTAR model. The null hypothesis states that the series has a unit root and the alternative states that the series has asymmetric nonlinear stationarity. The Enders and Lee Fourier Unit Root test is based on Fourier series. The Fourier terms approximate smooth, unknown structural breaks, without defining breaks. The null hypothesis states that the series has a unit root while the alternative is that it is stationary with smooth breaks (Dritsaki and Dritsaki, 2025).

4.1. Linear and nonlinear time series test

Linear and nonlinear tests of time series determine whether the data follows a linear process or a complex, non-stationary, or chaotic structure. Basic methods include testing surrogate data to test a linear relationship under the null hypothesis. Linear time series assume a fixed structure. The residuals of these models should be independent and distributed in the same way (white noise). If the residuals in a fitted linear model still show autocorrelation in their squares, this is a strong indication of nonlinear dependencies. Nonlinear time series are characterized by asymmetric cycles, time-varying variation (variability), or changes that cannot be captured by simple linear regressions.

One of the fundamental properties that researchers look for in time series data is stationarity. The presence of stationarity in a time series is the cornerstone for applying econometric techniques to data analysis. It is therefore important to investigate, before testing the stationarity of the series, whether the series are linear or nonlinear (Dritsaki *et al.*, 2024). Linear models have the advantage of being simple and intuitive. However, they have some limitations such as:

- They cannot allow for strong asymmetries in the data (Enders and Granger, 1998).
- They are not suitable for data characterized by sudden and irregular jumps (Guris *et al.*, 2017).
- They are not suitable for series that are not time reversible (Bisaglia and Gerolimetto, 2014).

The linearity tests developed by Harvey and Leybourne (2007) and Harvey *et al.* (2008) were used to test the time series under consideration. The Harvey *et al.* (2008) test can be applied to either I(0) or I(1) processes. Furthermore, when the order of integration is unknown, Harvey *et al.* (2008) suggest constructing a weighted average Wald test statistic which can be written as follows:

$$W_{\lambda} = (1-\lambda)W_0 + \lambda W_1 \quad (1)$$

where W_0 and W_1 denote the Wald tests when the variable is I(0) and I(1), respectively. Both tests follow the standard X^2 distribution. The parameter λ in the above formula indicates the weight and is calculated by the following formula according to Harvey *et al.* (2008); Harvey and Leybourne (2007).

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

where g represents a finite positive constant. U is the Dickey-Fuller unit root test statistic and S is the nonparametric stationarity test statistic of Harris *et al.* (2003). If the series being tested for linearity is stationary, the ratio $\left(\frac{U}{S}\right)^2$ will diverge, causing λ to converge to zero. On the contrary, if the series contains a unit root, the ratio $\left(\frac{U}{S}\right)^2$ will converge to zero, resulting in λ converging to one (Harvey *et al.*, 2008).

Harvey *et al.* (2008) examine the linearity of a series starting from a nonlinear first-order autoregressive model AR(1) for a time series y_t stationary in the levels (integrated zero-order I(0), with $t=1, \ldots, T$ where T is the sample size. The series y_t is estimated as:

$$y_t = \mu + u_t \tag{2}$$

$$u_t = \rho u_{t-1} + \delta f(u_{t-1}, \vartheta) u_{t-1} + \varepsilon_t \tag{3}$$

where ρ, δ are used in the function $f(.\vartheta)$ and are chosen so that u_t is stationary. In the above function ε_t is a white noise process with mean zero iid. The function $f(.\vartheta)$ is assumed to allow a Taylor series expansion with $\vartheta = 0$ so that model (3) is approximated to the second order by Guris *et al.* (2017).

$$u_t = \delta_1 u_{t-1} + \delta_2 u_{t-2}^2 + \delta_3 u_{t-3}^3 + \varepsilon_t \tag{4}$$

According to function (4) the null hypothesis and the alternative can be formulated as follows:

$$H_{0,I(0)} : \delta_2 = \delta_3 = 0 \quad \text{(linearity)}$$

and the alternative

$$H_{1,I(0)} : \delta_2 \neq 0, \; and \; / or \;\; \delta_3 \neq 0 \quad \text{(nonlinearity)}$$

where $H_{1,I(0)}$ indicates a hypothesis under the assumption of y_t being I(0). Under these conditions, the following happens:

$$y_t = \beta_0 + \beta_1 y_{t-1} + \beta_2 y_{t-2}^2 + \beta_3 y_{t-3}^3 + e_t \quad (5)$$

According to function (5) the null hypothesis and the alternative can be formulated as follows:

$$H_{0,I(0)} : \beta_2 = \beta_3 = 0 \text{ (linearity)}$$

and the alternative

$$H_{1,I(0)} : \beta_2 \neq 0, \ \ and \ /or \ \ \beta_3 \neq 0 \text{ (nonlinearity)}$$

The standard Wald statistic for testing these limitations is given by the following formula:

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

where T is the number of observations, RSS_0^u denotes the residual sum of squares from the unrestricted OLS regression in (5) and RSS_0^r is a restricted ordinary least square(OLS) regression imposing $\beta_2 = \beta_3 = 0$ in (5). It W_0 follows the asymptotic $X^2(2)$ distribution under the null $H_{0,I(0)}$.

Harvey *et al.* (2008) also examine the linearity of a series starting from a nonlinear first-order autoregressive model AR(1) for a time series y_t stationary in first differences (first-order integrated I(1).

$$y_t = \mu + u_t \quad (7)$$

$$\Delta u_t = \phi \Delta u_{t-1} + \lambda f(\Delta u_{t-1}, \vartheta)\Delta u_{t-1} + \varepsilon_t \quad (8)$$

where ϕ, λ are used in the function $f(.\vartheta)$ and are chosen so that Δu_t is stationary. In the above function ε_t is a white noise process with mean zero iid . The function $f(.\vartheta)$ is assumed to allow a Taylor series expansion with $\vartheta = 0$ so that the model (8) is approximated to the second order by:

$$\Delta u_t = \lambda_1 \Delta u_{t-1} + \lambda_2 (\Delta u_{t-1})^2 + \lambda_3 (\Delta u_{t-1})^3 + \varepsilon_t \quad (9)$$

According to the above, the null hypothesis and the alternative can be formulated as follows:

$$H_{0,I(0)} : \lambda_2 = \lambda_3 = 0 \text{ (linearity)}$$

and the alternative

$$H_{1,I(1)} : \lambda_2 \neq 0, \;\; and \;\; / or \;\; \lambda_3 \neq 0 \quad \text{(nonlinearity)}$$

where $H_{1,I(1)}$ indicates a hypothesis under the assumption of y_t being I(1). Under these conditions with $\Delta y_t = \Delta u_t$ η y_t becomes:

$$\Delta y_t = \lambda_1 \Delta y_{t-1} + \lambda_2 (\Delta y_{t-1})^2 + \lambda_3 (\Delta y_{t-1})^3 + \varepsilon_t \tag{10}$$

Therefore, according to function (10) the null hypothesis and the alternative can be formulated as follows:

$$H_{0,I(1)} : \lambda_2 = \lambda_3 = 0 \quad \text{(linearity)}$$

and the alternative

$$H_{1,I(1)} : \lambda_2 \neq 0, \;\; or \;\; \lambda_3 \neq 0 \quad \text{(nonlinearity)}$$

The corresponding Wald statistic based on function (10) to control these restrictions is given by the following formula:

$$W_1 = T\left(\frac{RSS_0^r}{RSS_0^u} - 1 \right) \tag{11}$$

where T is the number of observations, RSS_0^u denotes the residual sum of squares from the unrestricted OLS regression in (10) and RSS_0^r is a restricted OLS regression imposing $\lambda_2 = \lambda_3 = 0$ in (10). The W_1 follows the asymptotic $X^2(2)$ distribution under the null $H_{0,I(1)}$.

4.2. Unit root linear test

The methodology for testing a linear unit root assumes that the series moves towards equilibrium, despite the fact that the deviation process is linear and the adjustment rate is constant. If these conditions hold, linear unit root tests are valuable tools for determining whether economic time series follow a consistent pattern or not. To test for a linear unit root, we use the Phillips and Perron (1988), the Eliott *et al.* (1996) test, as well as unit root tests with a single structural break, specifically those of Zivot and Andrews (1992) and Perron and Vogelsang (1992).

4.2.1. Phillips-Perron test

Phillips and Perron (1988) proposed a methodology to test the existence of stationarity in a time series in which the well-known hypotheses about the disruptive term, such as the autocorrelation hypothesis, are not met. Phillips and Perron (1988) proposed a nonparametric test for estimating the model coefficients, that is, they make a correction to the t-statistic. This test differs from the augmented Dickey and Fuller (1979, 1981) test mainly in how it examines autocorrelation and heteroscedasticity in the errors. The Phillips-Perron regression test is the following:

$$\Delta y_t = \beta' D_t + \pi y_{t-1} + u_t \tag{12}$$

where u_t is the term is integral of order zero I(0) and may be heteroscedastic.

4.2.2. Eliot, Rothenberg and Stock test

Eliott *et al.* (1996), proposed a test modifying the Dickey and Fuller (1979, 1981) test using the generalized least squares (GLS) method. Eliott *et al.* (1996), claim that the DF-GLS test has significantly improved power when we do not know the mean and trend in the series – see p. 813 from Eliott *et al.* (1996).

The DF-GLS test proposed by Eliott *et al.* (1996), is based on the following regression without the determinant variables:

$$\Delta Y_t^d = \delta_2 Y_{t-1}^d + \beta_1 \Delta Y_{t-1}^d + \beta_2 \Delta Y_{t-2}^d + \ldots + \beta_p \Delta Y_{t-p}^d + u_t \tag{13}$$

where Y_t^d is the time series (detrended) free from trends.

4.3. Unit root tests with one structural break

One of the hypotheses we make in linear unit root testing is that time series evolve smoothly over time. However, there are some cases where time series exhibit abrupt changes in their course due to various events. In this case the well-known unit root tests are not reliable. In this paper we present two tests with a structural change due to the small number of observations that deal with the nonlinearity due to structural breaks.

4.3.1. Zivot-Andrews test

Zivot and Andrews (1992) following the form of Perron (1989), models and considering that the structural point (TB) is an endogenous phenomenon, propose three models for unit root tests, which are the following:

A. Model with Intercept

$$y_t = \hat{\mu}^A + \hat{\vartheta}^A DU_t(\hat{\lambda}) + \hat{\beta}^A t + \hat{\alpha}^A y_{t-1} + \sum_{j=1}^{k} \hat{\gamma}_j^A \Delta y_{t-j} + \hat{e}_t \tag{14}$$

B. Model with Trend

$$y_t = \hat{\mu}^B + \hat{\beta}^B t + \hat{\rho}^B DT_t^*(\hat{\lambda}) + \hat{\alpha}^B y_{t-1} + \sum_{j=1}^{k} \hat{\gamma}_j^B \Delta y_{t-j} + \hat{e}_t \tag{15}$$

C. Model with Both Intercept and Trend

$$y_t = \hat{\mu}^C + \hat{\vartheta}^C DU_t(\hat{\lambda}) + \hat{\beta}^C t + \hat{\rho}^C DT_t^*(\hat{\lambda}) + \hat{\alpha}^C y_{t-1} + \sum_{j=1}^{k} \hat{\gamma}_j^C \Delta y_{t-j} + \hat{e}_t \quad (16)$$

where DU_t is a dummy variable for the mean shift and appears in every possible change, whereas DT_t^* is the corresponding variable for mean shift and trend.

$$DU_t(\lambda) = \begin{cases} 1, & \alpha\nu \ \ t > T\lambda \\ 0 & otherwise \end{cases} \quad \text{and} \quad DT_t^*(\lambda) = \begin{cases} t - T\lambda, & \alpha\nu \ \ t > T\lambda \\ 0 & otherwise \end{cases}$$

The above models are based on Perron (1989) models, as a data-dependent algorithm is used as a proxy for Perron to determine the structural points.

4.3.2. Perron and Vogelsang test

Perron and Vogelsang (1992), proposed a class of statistical tests that allows for two different forms of structural changes. The Additive Outlier model (AOM) and the Innovative Outlier model (IOM). The forms of these models are given below:

The Innovative Outlier model (IOM):

$$y_t = \mu + \delta DU_t + \vartheta D(T_b)_t + \alpha y_{t-1} + \sum_{i=1}^{k} \gamma_i \Delta y_{t-i} + e_t \quad (17)$$

The Additive Outlier model (AOM) which is performed in two stages, is formulated as follows:

$$y_t = \mu + \delta DU_t + \hat{y}_t \qquad \text{(first stage)} \quad (18)$$

$$\hat{y}_t = \sum_{i=0}^{k} w_i D(T_b)_{t-i} + \alpha \hat{y}_{t-1} + \sum_{i=1}^{k} \gamma_i \Delta \hat{y}_{t-i} + e_t \quad \text{(second stage)} \quad (19)$$

where $\hat{y}_t$ in equation (19) represents the time series data free from trends.

Perron and Vogelsang (1992) argue that the tests in the above models are made with the minimum value of the t-statistic in the sum of the autoregressive coefficients over all possible structural points of the appropriate autoregression.

4.4. Nonlinear unit root test

A nonlinear form that can be used to control for the nonlinear unit root is the nonlinear exponential smooth transition autoregressive process (ESTAR) model. The ESTAR model is suitable for cases where deviations from equilibrium decrease smoothly as we move away from the equilibrium point. The univariate model of the first-order nonlinear exponential smoothing transitional autoregressive process (ESTAR) has the following form:

$$y_t = \beta y_{t-1} + \gamma y_{t-1}\left[1 - \exp\left\{-\vartheta(s_t - c)^2\right\}\right] + e_t \tag{20}$$

where y_t is the series under analysis β is the linear coefficient and γ is the degree of nonlinearity c is the center of the regime, usually taken to be 0 for weighted series, $\vartheta \geq 0$ is the slope parameter and provides the speed of transition to the mean inversion, is the transition variable and $e_t \to iid(0, \sigma^2)$. Therefore, we can assume that model (20) is a mean zero stochastic process. Furthermore, in model (20) a joint hypothesis is considered where one parameter is one-sided, while the others are two-sided under the alternative is considered and we propose a modified Wald test for a unit root against an alternative nonlinear ESTAR procedure (Hu and Chen, 2016).

4.3.1. Kapetanios, Shin, Snell (KSS) Unit Root Test

Kapetanios *et al.* (2003) developed a procedure for detecting the presence of non-stationarity, against nonlinear but globally stationary exponential smooth transition autoregressive ESTAR processes. For this purpose, they use the following ESTAR model.

$$\Delta y_t = \gamma y_{t-1}\left[1 - \exp\left\{-\vartheta y_{t-1}^2\right\}\right] + e_t \tag{21}$$

Furthermore, Kapetanios *et al.* (2003) used the first-order Taylor series in model (21) to obtain the following auxiliary regression:

$$\Delta y_t = \rho y_{t-1}^3 + \sum_{i=1}^{k} \lambda_i \Delta y_{t-i} + e_t \tag{22}$$

The two hypotheses of equation (22) are written as follows:
$H_0 : \rho = 0$ (the series follows a unit root process).
$H_1 : \rho < 0$ (the series follows a nonlinear stationary process of the form ESTAR).

The above hypotheses are tested by statistics $t_{NL} = \dfrac{\hat{\rho}}{s.e.(\hat{\rho})}$, where $\hat{\rho}$ is its estimate from the auxiliary regression (22).

Under the null hypothesis the statistic has the following asymptotic distribution (see Kapetanios *et al.* (2003).

$$t_{NL} \Rightarrow \frac{\left\{\frac{1}{4}W(1)^4 - \frac{3}{2}\int_0^1 W(r)^2 dr\right\}}{\sqrt{\int W(r)^6 dr}}$$

όπου $W(r)$ is the standard Brownian motion defined on $r \in [0;1]$.

Here, Kapetanios *et al.* (2003) assume that y_t is a mean zero stochastic process. When the process has nonzero mean and/or linear time trend, Kapetanios *et al.* (2003) suggest demean or detrend the data.

4.3.2. Kruse Unit Root Test

Kruse (2009) extends the unit root test of Kapetanios *et al.* (2003) by allowing for the exponential smooth transition autoregressive (ESTAR) model:

$$y_t = \beta y_{t-1} + \gamma y_{t-1}\left[1 - \exp\left\{-\vartheta (s_t - c)^2\right\}\right] + e_t \tag{23}$$

the parameter $c \neq 0$ as non-zero. Based on this, using the Taylor approximation, the above function is transformed into the following form:

$$\Delta y_t = \delta_1 y_{t-1}^3 + \delta_2 y_{t-1}^2 + \sum_{j=1}^{p} \varphi_j \Delta y_{t-j} + e_t \tag{24}$$

Kruse (2009) test examines the nonlinear stationary exponential smooth transition autoregressive (ESTAR) against the null hypothesis of a unit root.

The two hypotheses of equation (24) are written as follows:

$H_0 : \delta_1 = \delta_2 = 0$ (the series follows a unit root process)

$H_1 : \delta_1 < 0, \delta_2 \neq 0$ (the series follows a nonlinear stationary process of the form ESTAR).

For the above hypothesis testing, Kruse (2009) proposed the Abadir and Distaso (2007) test, which is a modified Wald statistic and is formulated as follows:

$$\tau = t^2_{\delta_2^{\perp}=0} + 1\left(\hat{\delta}_1 < 0\right) t^2_{\delta_1=0}$$

Kruse (2009) shows that the statistic follows the asymptotic distribution which is free from nuisance parameters.

$$\tau \Rightarrow A\left(W(r)\right) + B\left(W(r)\right)$$

where A and B are functions of Brownian motion $W(r)$ – see Kruse (2009).

4.3.3. Sollis Unit Root Test

The tests developed by Kapetanios *et al.* (2003) and Kruse (2009) are based on the assumption that mean reversion is symmetrical at every point. This assumption implies that negative and positive deviations have the same effect. Sollis (2009), extended this assumption and developed a new test that allows for both symmetric and asymmetric nonlinear adjustments. In other words, it permits differentiation in the impact of negative and positive shocks on the series. In this test, the speed of mean reversion depends on the sign of the shock, not just its magnitude (Cuestas and Ramlogan-Dobson, 2013). The asymmetric exponential smoothing transitional autoregressive model (AESTAR) developed by Sollis (2009) is formulated as follows:

$$\Delta y_t = \left[1-\exp\left(-\theta_1 y_{t-1}^2\right)\right]\left[1+\exp\left(-\theta_2 y_{t-1}\right)\right]^{-1} p_1 + \left\{1-\left[1+\exp\left(-\theta_2 y_{t-1}\right)\right]^{-1} p_2\right\} y_{t-1} + \sum_{i=1}^{k} k_i \Delta y_{t-i} + e_t \tag{25}$$

where $\theta_1 \geq 0$ and $\theta_2 \geq 0$.

The model (25) with Taylor approximations can be formulated as follows:

$$\Delta y_t = \alpha\left(p_2^* - p_1^*\right)\theta_1\theta_2 y_{t-1}^4 + p_2^*\theta_1 y_{t-1}^3 + \varepsilon_t \tag{26}$$

where p_1^* and p_2^* is a linear function of p_1 and p_2. If $\alpha = 1/4$ then the above function can be written as:

$$\Delta y_t = \varphi_1 y_{t-1}^4 + \varphi_2 y_{t-1}^3 + \varepsilon_t \tag{27}$$

where $\varphi_1 = p_2^*\theta_1$ and $\varphi_1 = \alpha\left(p_2^* - p_1^*\right)\theta_1\theta_2$

Function (27) can be written as:

$$\Delta y_t = \varphi_1 y_{t-1}^4 + \varphi_2 y_{t-1}^3 + \sum_{i=1}^{k} k_i \Delta y_{t-i} + \varepsilon_t \tag{28}$$

The null hypothesis of equation (28) is written as follows:

$H_0 : \varphi_1 = \varphi_2 = 0$ (unit root or non-stationarity)

Note: While the above hypothesis H_0 indicates the non-stationarity of the series, the alternative hypothesis represents the symmetric or asymmetric stationarity ESTAR. In case of rejection of the null hypothesis, to decide whether the series exhibits symmetric or asymmetric stationarity ESTAR, we make the following hypotheses:

$H_0 : \varphi_2 = 0$ (symmetric stationarity ESTAR)

$H_1 : \varphi_2 \neq 0$ (asymmetric stationarity ESTAR)

The above hypotheses are tested with the F statistic and the critical values are listed on Table no. 1 of the article by Sollis (2009).

4.3.4. Enders and Lee Fourier Unit Root Test (Fourier ADF unit root test)

The Fourier ADF test belongs to the linear class of unit root tests with the incorporation of nonlinear determinants. That is, the Fourier terms are nonlinear in time but the model remains linear in the parameters. Enders and Lee (2012a) propose a unit root test with the Fourier function following the Dickey Fuller unit root test where the deterministic term is a time- dependent function denoted by $\alpha(t)$:

$$y_t = \alpha(t) + \rho y_{t-1} + \gamma t + \varepsilon_t \tag{29}$$

where $\alpha(t)$ is a determinant of t, and ε_t is a stationary disturbance with variance σ_ε^2. The null hypothesis for the unit root test is $\rho = 1$.

In the case where the form of the determinant is not known, Enders and Lee (2012a) proposed the Fourier approach for unknown determinants, which is defined as follows:

$$\alpha(t) = \alpha_0 + \sum_{k=1}^{n} \alpha_k \sin\left(\frac{2\pi kt}{T}\right) + \sum_{k=1}^{n} \beta_k \cos\left(\frac{2\pi kt}{T}\right) \quad for \quad n \le \frac{T}{2} \tag{30}$$

where n represents the number of frequencies, k represents the optimal frequency, t is the trend, and T is the number of observations. It should be mentioned here that if the coefficients of the trigonometric terms are not statistically significant that is, $\alpha_k = \beta_k = 0$ then the function (30) is linear, so the unit root test is done with the traditional tests. In order to use the above functional form, a large value of n should not be used in the regression (30). Furthermore, the use of many component frequencies uses degrees of freedom which may lead to over-fitting. Therefore, instead of setting its specific form according to Enders and Lee (2012b) we should select the appropriate frequencies to be included in the regression (30). Suppose we use only one frequency k to examine the following regression: (Enders and Lee, 2012a).

$$\Delta y_t = \rho y_{t-1} + c_1 + c_2 t + c_3 \sin\left(\frac{2\pi kt}{T}\right) + c_4 \cos\left(\frac{2\pi kt}{T}\right) + e_t \tag{31}$$

In the above equation, t represents the trend, T represents the number of observations, $\sin\left(\frac{2\pi kt}{T}\right)$ and $\cos\left(\frac{2\pi kt}{T}\right)$ represent the trigonometric terms of the Fourier function.

To estimate the above regression, we create a three-step procedure:

In the first step, all models are estimated for 1<k <5 and the model with the smallest residual squares (SSR) is selected as the appropriate model. If the residuals exhibit serial correlation, we increase the regression (31) with lags of the variable. Secondly, we test the linearity or not of the most appropriate model by testing the coefficients c_3 and c_4. If the coefficients, that is $c_3 = c_4 = 0$, are not statistically significant, then the function (31) is linear, so the unit root test is performed using traditional tests. The hypothesis of linearity or not is examined by testing the F test. If the coefficients $c_3 \ne c_4 \ne 0$ i.e. are statistically significant then the Fourier function is significant and can be used to test for the unit root with the Fourier ADF unit root test (FADF). The critical values for the above hypothesis are presented at the bottom of Table 1a of Enders and Lee (2012a).

In the third step, the FADF test statistics are calculated using the best-fit model and the unit root hypothesis is tested against the critical values. The critical values depend only on the frequency k and the sample size T – Table no. 1a of Enders and Lee (2012a). The unit root test is performed using the significance of the coefficient ρ of y_{t-1}. If the calculated statistic is less than the critical value of Enders and Lee (2012a), the null hypothesis of the unit root is rejected, so we say that the series is stationary.

5. EMPIRICAL RESULTS AND DISCUSSION

5.1. Linear and nonlinear tests

In theoretical and empirical econometric studies, the investigation of linearity is one of the crucial issues. Classical tests of linearity are based on the assumption that the variables are zero I(0) or first-order I(1) integrated. In empirical studies, this issue is particularly problematic. Harvey *et al.* (2008), proposed a new linearity test that can be applied whether the variables are I(0) or I(1). In their paper they propose a Wald test when the order of integration is unknown which is a weighted Wald mean and tests the null hypothesis of linearity when the variable is known to have a unit root and when it is known to be stationary (Cuestas *et al.*, 2012). Given the importance of this issue in theoretical and empirical econometrics, the linear or nonlinear structure of each time series must be investigated. The table below presents the results of the Harvey *et al.* (2008) test regarding the linearity (or nonlinearity) of per capita GDP.

The results of Harvey *et al.* (2008) linearity test for GDP per capita in the Western Balkan countries highlight significant differences in the dynamics of economic growth among the countries in the region. Specifically, it is found that the countries of Bosnia and Herzegovina, North Macedonia, and Serbia follow a linear economic path, while on the contrary the countries of Albania, Montenegro, and Kosovo display nonlinear dynamics.

Table no. 3 – Harvey *et al.* (2008) linearity test results

Country	Wλ	Result
Albania	25.043***	Nonlinear
Bosnia and Herzegovina	0.903	linear
North Macedonia	5.086	linear
Montenegro	13.597***	Nonlinear
Serbia	3.596	linear
Kosovo	20.889***	Nonlinear

Notes: The Wλ statistic follows the $\chi^2(2)$ distribution and the relevant critical values are 9.21 (%1), 5.99 (%5) and 4.60 (%10). *** and ** denote the rejection of the null of linearity at the %1 and 5% significance level, respectively.
Source: author's calculations

Countries that exhibit linearity seem to be characterized by a stable and smooth evolution of GDP per capita over time. This suggests that the economic growth process in these economies may be driven by relatively stable, time-consistent trends without strong regimes of change, abrupt changes or non-linear structural relationships. Linear behavior is compatible with more mature or stabilized economic processes, possibly due to more stable institutions, lower volatility in the productive base, or limited exposure to severe economic shocks.

In contrast, the countries Albania, Montenegro, and Kosovo exhibit nonlinearity, which suggests that their GDP per capita is affected by nonlinear phenomena, such as periodic structural changes, regimes with different growth rates, external shocks, or changes in economic policy. The existence of nonlinearity is compatible with economies in transition, with frequent adjustments of their production structure and higher uncertainty. Also, such dynamics are often associated with economies that seek convergence but with an uneven, wavy or interrupted growth path.

The differentiation between linear and nonlinear countries reinforces the position that the Western Balkans do not constitute a homogeneous economic unit but instead exhibit significant differences in terms of their stability and pattern of economic growth. Understanding these differences is crucial for choosing the appropriate methodology for subsequent unit root tests. For linear countries, classical linear tests are more appropriate, while for nonlinear countries, nonlinear or regime-oriented tests oriented to the data structure are required.

Overall, the results indicate that countries with nonlinear behavior are likely to be in a more unstable or transitional economic trajectory while those with linearity exhibit more stable and predictable developments in GDP per capita. The findings constitute an important basis for the correct interpretation of subsequent unit root tests and for drawing conclusions regarding the long-term sustainability and convergence of the region's economies.

5.2. Unit root linear test

The validity of the GDP per capita of countries with the linearity characteristic was analyzed with the linear unit root tests of Phillips and Perron (1988), and Eliott *et al.* (1996) as well as with tests with a structural change, such as the tests of Zivot and Andrews (1992) and Perron and Vogelsang (1992). Table no. 4 gives the results of linear unit root tests at the series levels.

Table no. 4 – Linear unit root test results

Country	Level			
	Phillips-Perron		DF-GLS	
	Intercept	Intercept and Trend	Intercept	Intercept and Trend
Bosnia and Herzegovina	0.654[1]	-2.344[2]	2.015(0)	-1.913(0)
North Macedonia	1.493[3]	-4.763[1]*	-1.918(8)	-1.821(0)
Serbia	1.333[2]	-1.561[3]	2.258(0)	-1.361(0)

Note: 1. *, **, *** for significance levels 1, 5 and 10 respectively.
2. The numbers in brackets refer to the bandwidth of the autocorrelation for the Phillips-Perron (PP) test equations based on the Newey and West (1994) estimator using the Bartlett kernel (correcting for heteroscedasticity and autocorrelation of the residuals).
3. To reject the unit root hypothesis we use the tables of MacKinnon (1996).
4. The numbers in parentheses represent the number of time lags of the dependent variable used for white noise errors (autocorrelation correction).
5. The number of time lags for the ADF equation was selected using the Modified Akaike (MAIC).
6. To reject the unit root hypothesis, we use the tables of MacKinnon (1996), when the equation has only a constant, and the tables of Eliott *et al.* (1996),when the equation presents a constant and a trend.

The results of the above table show that the Phillips and Perron (1988) linear test showed that only North Macedonia exhibits stationarity and only in the model that includes a constant and a trend. This finding suggests that the country's GDP per capita may follow a long-term downward or upward trajectory around a defining linear path, without exhibiting permanent stochastic deviations.

In contrast, the Eliott *et al.* (1996) test, which is generally considered more robust in small samples, does not reject the null hypothesis of a unit root for any of the countries Bosnia and Herzegovina, North Macedonia, and Serbia. This suggests that the growth process in these countries likely follows a stochastic path and the long-term deviations are not temporary.

This result, combined with the linearity test of Harvey *et al.* (2008), reinforces the view that while North Macedonia exhibits linear dynamics, its stationarity is not strongly confirmed under all linear tests.

5.3. Unit root tests with one structural break

Common unit root tests (Dickey and Fuller, 1979, 1981; Phillips and Perron, 1988) have low power to reject the null hypothesis and are affected by the presence of structural break. In particular, Enders (1995) argues that if the Dickey Fuller test rejects the null hypothesis of a unit root, there is no need to continue. Furthermore, Perron (1989) noted that if the data series is subject to structural changes, traditional linear tests are not robust and do not reject the null hypothesis of a unit root.

Linear controls with an endogenous structural breaks provide a more realistic picture for economies such as those of the Western Balkans, which have undergone significant transformations in the last 25 years (transition economies, political changes, 2008 global crisis, 2020 pandemic, etc.).

The results of the above table show that only North Macedonia exhibits stationarity (model with constant) with endogenously localized structural break in 2006. This year coincides with a period of stabilization and intensification of relations with the EU, as well as with the country's pre-accession institutional adjustments. The existence of such a change reinforces the view that North Macedonia's growth curve underwent a significant turning point that likely affected the level (or even the trend) of GDP per capita.

Table no. 5 – Unit root test with structural breaks results

Country	Zivot-Andrews Level					
	Intercept	**Break**	**Trend**	**Break**	**Intercept and Trend**	**Break**
Bosnia and Herzegovina			-3.302	1998		
North Macedonia	-4.702**	2006	-3.976	2018	-3.819	2018
Serbia	-1.677	2011	-2.069	2018	-2.609	2014

Note: *, **, *** for significance levels 1, 5 and 10 respectively.

The results of the Perron and Vogelsang (1992) test provide clear indications that per capita GDP for the two Western Balkan countries, North Macedonia and Serbia, is stationary when possible structural breaks in the time course of the series are taken into account.

More specifically, in the Innovation model with constant and trend, North Macedonia exhibits stationarity with a localized structural break in 2016, while Serbia exhibits similar behavior with a turning point in 2020. These findings suggest that significant economic events or reform interventions in the respective periods likely influenced the course of GDP per capita, creating one-off or gradual changes in the long-term trend.

Table no. 6 – Unit root test with structural breaks results

Country	Perron and Vogelsang Level							
	Innovation				Additive			
	Intercept	Break	Intercept and Trend	Break	Intercept	Break	Intercept and Trend	Break
Bosnia and Herzegovina	-0.871	1995	-3.283	1995	-1.570	2021	-3.413	2020
North Macedonia	-1.377	2021	-5.369*	2016	-2.651	2012	-3.868	2006
Serbia	-0.341	2017	-7.266*	2020	-0.812	2015	-5.833*	2000

Note: *, **, *** for significance levels 1, 5 and 10 respectively.

Furthermore, for Serbia, the Additive model with constant and trend also detects stationarity with a structural break identified in 2000, a year associated with the profound political and economic changes following the end of the conflict period and the beginning of gradual normalization and economic restructuring. The fact that Serbia exhibits stationarity in two different approaches to the Perron and Vogelsang (1992) test with different points of change reinforces the hypothesis that its economic course was shaped by multiple and temporally differentiated structural breaks.

Overall, the results of the Perron and Vogelsang (1992) test emphasize that, unlike linear unit root tests, the incorporation of structural breaks allows the emergence of stationarity in series that would otherwise be characterized as non-stationary. This suggests that the dynamics of GDP per capita in these countries are not smooth and linear, but are influenced by significant historical and political economic events that alter the trajectory of long-term economic growth.

5.4. Nonlinear unit root test

The nonlinear unit root tests developed by Kapetanios *et al.* (2003) and Kruse (2009) examine the implications of a specific type of nonlinear dynamics. In addition, they provide an alternative framework for testing the null hypothesis of a unit root process against the alternative of a stationary nonlinear exponential smooth transition autoregressive (ESTAR) process. The estimated results of the KSS, Kruse, and Sollis tests from the nonlinear unit root analysis for Albania, Montenegro, and Kosovo are presented on Table no. 7.

Table no. 7 – Nonlinear unit root tests results

	KSS(t_{NL})		Kruse(τ)		Sollis(F)		
	k	Stat	k	Stat	k	$H_0 : \varphi_1 = \varphi_2 = 0$	$H_0 : \varphi_2 = 0$
Albania	0	-4.276*	0	11.501**	1	5.654**	4.089
Montenegro	0	-2.016	0	2.793	1	3.675	2.379
Kosovo	0	-5.621*	1	18.026*	1	18.219*	16.305*

Notes: The symbols *, ** and *** mean rejection of the null hypothesis of unit root at the 1%, 5% and 10% respectively. KSS: −3.48, −2.93, −2.66; Kruse: 13.75, 10.17, 8.6; Sollis: 6.883, 4.954, 4.157.

The results of the nonlinear unit root tests on Table no. 7 show that the economic series of GDP per capita for the three Western Balkan countries Albania, Montenegro, and Kosovo exhibit dynamics that cannot be satisfactorily described by linear models. The existence of nonlinearity, as also identified by the Harvey test, is verified and reinforced by the three nonlinear tests (KSS, Kruse, and Sollis) which capture different forms of nonlinear self-regression.

The KSS test (Kapetanios *et al.*, 2003) which checks for symmetric ESTAR-type nonlinearity shows that:

- Albania and Kosovo exhibit stationarity.
- Montenegro does not show statistically significant evidence of a return to long-run equilibrium.

These findings suggest that for Albania and Kosovo, GDP per capita follows a nonlinear adjustment mechanism where deviations from the long-term path are corrected when they become large enough, which is characteristic of economic variables that react slowly to small changes but more strongly to large ones.

The Kruse test, which controls for more flexible forms of nonlinearity through quadratic and cubic terms, confirms stationarity for Albania and Kosovo and at the same time captures a more complex form of nonlinear adjustment than the KSS. The convergence of the KSS-Kruse results for these two countries strengthens the credibility of the finding of nonlinear stationarity. In contrast, Montenegro shows no signs of stationarity in this test either, suggesting that it may be following either a higher-order nonlinear process or a truly non-stationary path.

The Sollis test distinguishes between symmetric and asymmetric nonlinear adjustment. The results show that:

- Albania and Kosovo exhibit stationarity in the symmetric version of the test.
- However, Albania does not exhibit stationarity in the asymmetric version of Sollis.

The non-stationarity in the asymmetric form suggests that the adjustment process of GDP per capita in Albania is symmetric. That is, positive or negative deviations from the long-term trend are handled by the economy in a similar way, without a stronger or slower adjustment in one direction or the other. In Kosovo, on the other hand, the results are consistent in both Sollis test approaches, suggesting a pure form of symmetric nonlinear stationarity. Montenegro, once again, does not show evidence of stationarity in either the symmetric or the asymmetric version.

Overall, the results show that:

- Albania and Kosovo: The existence of nonlinear stationarity is recognized in all nonlinear tests (with minor exceptions regarding symmetry). This suggests that their economies, despite experiencing fluctuations, maintain a long-term path to which they return, but the adjustment process is not linear.
- Montenegro: It shows no sign of stationarity in any of the nonlinear tests, which is consistent with the high volatility and structural instability that characterizes its economic system. The absence of stagnation suggests that GDP per capita may follow a prolonged non-stationary path, likely influenced by external factors (tourism, fiscal imbalances, small economic size).

The above tests have made an invaluable contribution to unit root testing by taking nonlinearity into account. Although these tests consider the asymmetric speed of mean reversion (as in the Sollis (2009) test), they do not address nonlinearity in the deterministic components. However, according to Becker *et al.* (2004); Becker *et al.* (2006), in nonlinear unit root tests, the form of the structural breaks is assumed to be known, which in reality is not feasible-neither the form of the breaks nor the exact break dates are usually known. From this perspective, the Fourier approach offers a valuable solution to the question of how structural breaks should be modelled.

In their study, Enders and Lee (2012b) showed that one or more structural breaks can be captured using low-frequency Fourier functions. It is not necessary to know the number or location of the breaks when applying the test. The appropriate frequency value in the Fourier function must be estimated in equation (31).

The following table presents the results of the FADF (Fourier Augmented Dickey-Fuller) unit root test.

Table no. 8 – Fourier ADF unit root test results

Countries	$\hat{k}$	Min SSR	$F(\hat{k})$	k^*	FADF
Albania	1	3570139	9.314^b	1	−4.6519**
Montenegro	1	2928702	7.936^c	1	−1.7250
Kosovo	1	2159487	13.97^a	2	−7.1869*

Notes: 1. All unit root tests include an intercept and trend,
2. a, b, and c show that the trigonometric terms are statistically significant at the 1%, 5%, and 10% significance levels, respectively.
3. k* indicates the optimal frequency.
4. *,**Indicates that the series is stationary at the 1% and 5% significance level.
5. The critical values for the $F(\hat{k})$ statistics are 12.21, 9.14 and 7.78 for 100 observations and the 1%, 5% and 10% significance levels, respectively (Enders and Lee, 2012a).
6. The critical values for the FADF statistics are -4.95, -4.35 and -4.05 for 100 observations and the 1%, 5% and 10% significance levels, respectively (Enders and Lee, 2012a).

The statistical significance of the Fourier terms on Table no. 8 across all countries Albania, Montenegro, Kosovo shows that:

1. The GDP per capita series do not follow a linear path.
2. There are smooth but non-linear structural breaks in the long-term trend, which cannot be detected by traditional linear tests or tests with abrupt structural breaks (such as Z-A, PV).

This means that the economies of these countries are characterized by gradual, cyclical or periodic changes, possibly due to:

- Recurrent economic cycles.
- Gradual reforms.
- Alignment with the EU.
- Structural breaks in production and employment.

Finding statistical significance verifies that the nonlinearity identified by Harvey and the nonlinearity tests (KSS, Kruse, Sollis) is substantial and present in the model and not a chance finding.

The results of the FADF (Fourier ADF) test show that Albania and Kosovo exhibit stationarity, while Montenegro exhibits a unit root.

In detail for each country we can report the following:

Albania

The existence of stationarity when smooth structural breaks are allowed for suggests that GDP per capita follows a non-linear but stable long-term path, which is not fully captured by linear or abrupt tests. The agreement of the FADF results, with KSS and Kruse, reinforces the conclusion that Albania exhibits nonlinear stationarity.

Kosovo

Similar to Albania, Kosovo exhibits stationarity, confirming that GDP per capita returns to long-run equilibrium, but in a non-linear and cyclical manner, due to the significant influence of Fourier terms. The consistency with KSS, Kruse and Sollis makes the finding stable and robust.

Montenegro

The failure to reject the unit root even when smooth changes are allowed means that Montenegro's GDP per capita does not return to long-run equilibrium, even when the method is highly flexible and captures gradual economic changes. This reinforces the findings of the other tests (linear and nonlinear) which showed a consistent absence of stationarity in Montenegro.

Possible reasons:

- High dependence on tourism.
- Strong volatility in the balance of payments.
- Small and vulnerable economy.
- Delayed structural adjustments.

6. CONCLUSIONS AND POLICY IMPLICATIONS

This paper examines the dynamics of GDP per capita in the Western Balkan countries, utilizing a wide range of linear, nonlinear and structural unit root tests, in order to investigate whether their economic trajectories are characterized by stationarity, long-term stabilization or permanent disturbances. The results demonstrate significant heterogeneity across countries, but also some common patterns that reflect their economic structure and degree of integration into European markets.

The linear PP and DF-GLS tests generally failed to detect stationarity in most countries, with the exception of North Macedonia for which the PP test in the constant-trend combination shows a stabilizing process. This suggests that for most economies in the sample, economic shocks have a long-term and permanent effect on income.

However, when endogenous structural cuts (Zivot-Andrews) are introduced, the results change. North Macedonia shows stationarity with a cut in 2006, which is associated with significant economic reforms. Even more encouraging are the results of Perron-Vogelsang, where North Macedonia and Serbia show stationarity in the Innovation and Additive models, with intercepts in 2016, 2020 and 2000. This means that much of the non-stationarity in linear tests was due to the failure to incorporate important economic events, such as crises, reforms, and entry into new European frameworks.

The importance of these results is crucial because they show that the disruptions in the economies of these countries are not necessarily permanent when taking into account major economic events, such as the global financial crisis, the debt crisis in Europe, and reform periods in the face of European adjustment.

Nonlinear tests (KSS, Kruse, and Sollis) provide a complementary picture. The countries of Albania and Kosovo show clear signs of nonlinear stationarity, confirming nonlinear recovery mechanisms, which are common in emerging economies where growth phases and recessions do not follow a linear path. In the Sollis test, Albania shows stationarity but without asymmetry, while Kosovo shows a clear return to a symmetric trend.

The Enders-Lee test shows a statistically significant presence of trigonometric terms in all countries, so the fluctuations of GDP per capita follow cyclical or periodic nonlinear forms. The FADF test shows stationarity in Albania and Kosovo, but a unit root in Montenegro.

The overall picture from the nonlinear controls shows that the economies of Albania and Kosovo have nonlinear recovery mechanisms, while Montenegro shows greater vulnerability to permanent shocks.

Overall, the results of the checks reveal three groups of countries:

A. Countries with stabilization trends (Albania, Kosovo, North Macedonia, Serbia).

These economies show a return to a long-term trend, either linear or non-linear. Policy should focus on strengthening infrastructure, institutional reforms, and diversification of production.

B. Countries with permanent shock effects (Montenegro).

GDP is permanently affected by external shocks due to high dependence on tourism. The policy priority is to diversify the economy, strengthen fiscal reserves and develop sustainable sectors.

C. Countries with a mixed picture (Bosnia and Herzegovina).

No stationarity has been observed and the disruptions appear to have lasting effects. Institutional, administrative and financial reforms are needed.

In conclusion, we can say that the Western Balkan countries are not moving along a single development trajectory. The different dynamics that emerged indicate that the process of convergence with the EU requires individualized policies per country, aiming to enhance stability, resilience and productivity.

Policy Proposals

For the countries Albania, Kosovo, North Macedonia, Serbia.

- Strengthening infrastructure and productivity.
- Improving institutions, transparency and administrative capacity.
- Promoting export orientation.
- Investments in education, digital economy and innovation.
- Supporting export orientation and diversification of the production base

For Montenegro

- Reducing over-reliance on tourism.
- Developing sustainable sectors (energy, logistics, agri-food).
- Strong fiscal discipline and building reserves.
- Deepening financial supervision.

For Bosnia and Herzegovina

- Improving institutional functioning and governance.
- Political stabilization and strengthening investment confidence.
- Improving competitiveness and exports.
- Regional economic integration.

GDP per capita in the Western Balkan countries does not follow a uniform path. Most economies show signs of gradual convergence and a return to the long-term trend, especially when non-linearities and structural breaks are taken into account. However, some economies remain vulnerable to permanent shocks. The prospect of economic convergence with the EU requires targeted differentiated and institutionally stable policies adapted to the findings of empirical tests.

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