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# Revisiting Purchasing Power Parity in OECD Countries: New Evidence from Nonlinear Unit Root Test with Structural Breaks

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## OECD Ülkelerinde Satın Alma Gücü Paritesinin İncelenmesi: Doğrusal Olmayan Yapısal Kırılmalı Birim Kök Testinden Yeni Kanıtlar

### Abstract

This study aims to investigate the purchasing power parity (PPP) hypothesis for 38 OECD member countries over the period 1994:M1-2021:M9 by performing Hepsag's (2021) unit root test. It fills the gap in the literature since it is one of the first studies conducted performing a unit root test that considers structural change and nonlinearity for all OECD countries. The study, in which conventional unit root tests such as the ADF, KPSS, and the Fourier KPSS, which allow merely structural change, yield conflicting results regarding the validity of the PPP hypothesis, determines that the PPP hypothesis is valid for countries with stationary real effective exchange rates at the level such as Finland, France, Germany, Greece, Hungary, Iceland, Italy, Japan, Korea, Lithuania, Luxembourg, Mexico, Norway, Slovakia, Slovenia, Spain, Switzerland, Turkey, and the USA according to Hepsag's (2021) unit root test results.

**Keywords** : Real Effective Exchange Rates, OECD, Purchasing Power Parity, Nonlinearities, Structural Break, Unit Root.

**JEL Classification Codes** : C22, F30, F41.

### Öz

Bu çalışma, 1994:M1-2021:M9 döneminde 38 OECD üyesi ülke için satın alma gücü paritesi (SAGP) hipotezini Hepsağ (2021) birim kök testi ile incelemeyi amaçlamaktadır. OECD ülkelerinin tamamı için hem yapısal değişimi hem de doğrusal olmamayı dikkate alan birim kök testi ile yapılan ilk çalışmalardan biri olması nedeniyle literatürdeki boşluğu doldurmaktadır. Çalışmada ADF, KPSS gibi geleneksel ve Fourier KPSS gibi sadece yapısal değişime izin veren birim kök testleri SAGP hipotezinin geçerliliğine ilişkin çelişkili sonuçlar vermiştir. Hepsağ (2021) test sonuçlarına göre reel efektif döviz kurlarının seviyede durağan tespit edildiği Finlandiya, Fransa, Almanya, Yunanistan, Macaristan, İzlanda, İtalya, Japonya, Kore, Litvanya, Lüksemburg, Meksika, Norveç, Slovakya, Slovenya, İspanya, İsviçre, Türkiye ve ABD'de SAGP hipotezinin geçerli olduğu belirlenmiştir.

**Anahtar Sözcükler** : Reel Efektif Döviz Kurları, OECD, Satın Alma Gücü Paritesi, Doğrusal Olmama, Yapısal Değişim, Birim Kök.

## 1. Introduction

The purchasing power parity (PPP) hypothesis is one of the most prominent and influential economic notions, assessing the equilibrium values of currencies and forming the basis of various open economy models. In its simplest terms, PPP asserts that the determination of the exchange rate between two currencies in any period relies upon the quotient between price levels in the two countries and those price levels are equated as a common currency at that exchange rate which leads to the same purchasing power of a unit of one currency in both economies. The PPP hypothesis is first introduced as an empirical tool by Cassel (1918) as "it represents the true equilibrium of the exchanges". Cassel (1918) argues that the actual exchange rate cannot have considerable deviations from its purchasing power parity in the case of comprehensive and free trade between two countries. During its early stages, the concept has been questioned by several researchers (Keynes, 1923; Taussig, 1927; Haberler, 1945), and most objections concentrated on the process of exchange rate determination and the prevalence of monetary disturbances (Katseli-Papaefstratiou, 1979). However, the hypothesis has survived and is still one of the most controversial economic issues[1].

Investigating the validity of PPP requires the inclusion of domestic and foreign prices and exchange rates. The price of one currency in terms of another is known as the nominal exchange rate, and the real exchange rate is then an adjustment of the nominal exchange rate by relative prices (Sarno & Taylor, 2002; MacDonald, 2007). The real exchange rate is also helpful in testing PPP in a context that allows nonstationarity. In principle, if the real exchange rate is nonstationary (contains a unit root), the variable will deviate from its long-run equilibrium due to the permanent effects of relevant disturbances. However, if the real exchange rate does not contain a unit root (is stationary), the disturbances will tend to end, and the equilibrium will be reached in the long-run (Cuestas & Regis, 2013). The deviation of the real exchange rate in the short and long-run is one of the highly-debated topics in exchange rate economics (Dornbusch & Krugman, 1976; Rogoff, 1996). Rogoff (1996) denotes the real exchange rate's high short-term volatility and the slow mean reversion speed[2]. According to Rogoff (1996), in the short-run, prices behave relatively inflexibly to the changes in the nominal exchange rate, so there is a common thought that PPP cannot explain short-term exchange rate movements (Frenkel, 1981). Although monetary disturbances have a temporary impact on the real exchange rate as a result of the adjustment of commodity prices over time and the diffusion of real exchange rate variations, some studies (Roll, 1979; Stockman, 1980; Adler & Lehmann, 1983; Darby, 1983; Junge, 1985) believe that the deviations in the real exchange rate are of a permanent nature which makes it unable to return to any initial state. This argument also contends that real exchange rate behaviour is primarily influenced by real demand and supply disturbances. These disturbances change frequently due to the high short-term fluctuations of the exchange rate

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[1] *See MacDonald & Taylor, 1992; Sarno & Taylor, 2002; and Christopoulos & Leon-Ledesma, 2010 for a detailed information on the theoretical and empirical aspects of real exchange rate and purchasing power parity.*

[2] *This idea is known as the PPP puzzle in literature. See Rogoff, 1996; Cheung & Lai, 2000; and Taylor, 2003.*

(Junge, 1985), and thus PPP cannot be a long-run relationship. However, some studies (Huizinga, 1987; Grilli & Kaminsky, 1991) indicate that the random walk behaviour of a real exchange rate is rejected over extended periods. This real exchange rate behaviour is only a feature post World War II due to the transitory fluctuations. So, in a typical period, PPP is expected to hold in the long run. However, the empirical studies have inconclusive findings on long-run equilibrium, and the controversy on PPP is still valid.

An exchange rate would deviate in the short run from its equilibrium due to several reasons; actual and expected inflation, trade barriers, taxation, exchange market interventions, shifts in international capital movements and productivity bias which implies productivity differentials in tradable goods sectors rather than in non-tradable goods sectors (Balassa, 1964; Samuelson, 1964; Baillie & McMahon, 1989; Diebold et al., 1991; Taylor, 2002; Taylor, 2003; Bahmani-Oskooee & Nasir, 2005; Rusydi & Islam, 2007). However, the linear adjustment of the real exchange rate in the long-run is also problematic. Madsen and Yang (1998) pointed out that real exchange rate adjustments follow an asymmetric adjustment process. According to Chang et al. (2012b), the linear relationship of the real exchange rate is inconvenient if prices are sticky downward but not in the opposite direction. Taylor (2003) also believes that the nonlinear adjustment of the real exchange rate can be a primary source to resolve the PPP puzzle, and there are several potential sources of nonlinearity. Transport costs, tariffs and nontariff barriers are some of the primary potential sources which cause a distinction between similar goods in different markets and culminate nonlinearities in goods arbitrage. Heckscher (1916) was the first to state that the adjustment may exhibit a nonlinear nature due to the transaction costs in international arbitrage. For instance, let's assume that the prices of two identical goods in a common currency differ because the validity of PPP is not fulfilled in two other countries. In this case, arbitrage would not occur unless the expected profit rate exceeds the freight cost between the two countries (Taylor & Taylor, 2004). Several studies are concentrating on transaction costs in international goods trade (Beninga & Protopapadakis, 1988; Williams & Wright, 1991; Dumas, 1992; Sercu et al., 1995; O'Connell, 1998).

Given the above background, the primary goal of this paper is to determine if PPP holds in all OECD (Organization for Economic Cooperation and Development) member countries over a given period. This study contributes to the extant literature in the following aspects. First, to the best of our knowledge, this is the first study which investigates the validity of PPP with a recently developed methodology of Hepsag (2021) that accounts for both nonlinearity and structural breaks in the real exchange rate by performing a nonlinear exponential smooth transition autoregressive unit root test (ESTAR). Second, this study is one of the limited numbers of studies that consider both nonlinearity and structural breaks simultaneously for the OECD case and one of the very few studies that investigate the mentioned methodology in all OECD member countries. The organisation of the paper is structured as follows. The next section includes a comprehensive review of the literature. The third section introduces the model and the methodology and presents the model's findings. The final section concludes the paper and emphasises the study's preliminary results.

## 2. Literature Review

The empirical literature on PPP is exceptionally vast. The collapse of the short-run PPP has caused a direction to test whether PPP holds in the long run, but the findings of these studies are also inconclusive. The development of empirical testing has progressed in consecutive stages. Some researchers rejected PPP in the early 1980s due to the real exchange rate's random walk behaviour (Roll, 1979; Frenkel, 1981; Adler & Lehmann, 1983) since if the real exchange rate follows a random walk process, it does not hold in the long run because the deviations are permanent. However, the key improvement in empirical studies has begun with the inclusion of nonstationarity of the variables in the 1980s with Dickey and Fuller's (1979, 1981) unit root test. In particular, a stationary real exchange rate indicates a long-run relationship between prices and the nominal exchange rate, hence validating the PPP. Using this methodology, some studies (Abuaf & Jorion, 1990; Whitt, 1992) argue that PPP holds in the long run. However, in most of these studies, a nonstationary real exchange rate cannot be ruled out, and most of these studies find no evidence in favour of long-run PPP for the sample countries (Corbae & Ouliaris, 1988; Edison & Fisher, 1991). This finding is supported by consecutive studies, such as Flynn and Boucher (1993) by using both Dickey and Fuller's (1981) and Perron's (1989) unit root tests or Serletis and Zimonopoulos (1997) by using Perron and Volgelsang's (1992) unit root test. Cointegration studies and error correction techniques, usually based on Engle and Granger's (1987) or Johansen's (1988, 1991) methodologies, have also contributed significantly to the literature. Cointegration analysis determines the long-run relationship between exchange rates and prices. If two nonstationary series are integrated in the same order, and their linear combination is stationary, they are cointegrated. The two variables have a long-run relationship (Sarno & Taylor, 2002). Although some studies (Baillie & Selover, 1987; Taylor, 1988; Enders, 1988; Mark, 1990; Patel, 1990) find that PPP does not hold in the long run, others (Edison & Klovland, 1987; Kim, 1990; Ardeni & Lubian, 1991; Kugler & Lenz, 1993; MacDonald, 1993; MacDonald & Marsh, 1994)[3] find evidence in favour of PPP in the long run. Edison et al. (1997) also find moderate evidence using Horvath and Watson's (1995) testing procedure for cointegration. Although the new techniques for testing PPP were enhanced during that period, there was great concern about the inadequate power of tests which may be generated by slight sample bias (Lothian & Taylor, 1996; Enders & Granger, 1998; Engel, 2000). The researchers denoted the low power problem of traditional unit root tests applied in this period and concluded that short and medium-sized samples principally reject the PPP hypothesis. Froot and Rogoff (1995) show that using the Dickey-Fuller distribution would take 72 years of data to have adequate power to reject the unit root null at the 5% level. Therefore, long-span studies (Lothian & Taylor, 1996; Hegwood & Papell, 1998) and panel studies (Hakkio, 1984; Abuaf & Jorion, 1990; Levin & Lin, 1992;

[3] *Studies on the cointegration between relevant variables can be extended. Telatar & Kazdagli (1998) and Yazgan (2003) for Turkey; Nagayasu (2002) for 17 African countries; Drine & Rault (2008) for 80 countries; Narayan et al. (2009) for 15 OECD countries; Chang & Tzeng (2011) for nine transition countries; Chang et al. (2012b) for BRICS countries, among others, find evidence on supporting PPP in the long run. However, Basher and Mohsin (2004) reject PPP for developing Asian countries.*

Flood & Taylor, 1996; Wu, 1996; Frankel & Rose, 1996; Coakley & Fuertes, 1997; Lothian, 1997; O'Connell, 1998) have stood out to overcome the lack of power problem of conventional tests. The new findings with longer samples have demonstrated a moderate tendency for the real exchange rate to converge towards a long-run equilibrium, validating PPP in the long run in several cases (Frankel & Rose, 1996; Wu, 1996; Cheung & Lai, 1998). But long-span studies are also criticised in that they may include structural breaks originating from real shocks (Sarno & Taylor, 2002)[4]. These shocks may comprise structural changes such as the transition of exchange rate regimes or experiencing hyperinflation or devaluation period in related countries (Cuestas & Regis, 2013). Perron (1989)'s study has influenced several researchers to include one or multiple breaks in testing PPP using the unit root test (Flynn & Boucher, 1993; Hegwood & Papell, 1998). Other studies, such as Perron and Vogelsang (1992), Zivot and Andrews (1992) and Bai and Perron (2003), have also expanded the econometric methodology of structural breaks for linear models[5]. The validity of PPP has been investigated by several researchers using one or multiple structural breaks. The majority of these studies find support or strong evidence on long-run PPP, including Erlat (2003) for Turkey, Papell and Prodan (2006) for 16 industrialised countries, Jiang et al. (2015) and Corakci et al. (2017) for OECD countries and Bahramian and Saliminezhad (2021) for ASEAN-5 countries. Payne et al. (2005) for Croatia, Darné and Hoarau (2008) for Australia and Acaravci and Ozturk (2010) for 8 transition countries, on the other hand, failed to find strong evidence of the validity of PPP.

Besides the role of structural breaks in determining the long-run validity of PPP, one of the highly interesting issues of the long-run equilibrium of purchasing power parity is the nonlinearity of the exchange rate. Several studies argue that (Sarno, 2000; Sarno & Taylor, 2002; Taylor, 2003) the lack of traditional unit root tests is caused by the nonlinear stationary process of the exchange rate, which cannot find mean reversion of the exchange rate. Several studies (Benninga & Protopapadakis, 1988; Williams & Wright, 1991; Dumas, 1992; Sercu et al., 1995; Michael et al., 1997; Obstfeld & Taylor, 1997; O'Connell, 1998; Taylor & Peel, 2000; Taylor & Sarno, 2001; Sarno et al., 2004; Taylor, 2004; Juvenal & Taylor, 2008) denote that the transaction costs are one of the leading causes for the asymmetric adjustment of the exchange rate, which also inhibit the trade of international goods (Chang et al., 2012b). This insufficiency of traditional methodologies caused the significant development of various types of nonlinear unit root tests (Michael et al., 1997; Leybourne et al., 1998[6]; Caner & Hansen, 2001; Sollis et al., 2002; Kapetanios et al., 2003; Park & Shintani, 2005;

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[4] *The power of unit root tests can be increased by panel unit root tests with using cross-sectional information (Christopoulos & Leon-Ledesma, 2010). However, this technique also includes several problems. One of the potential problems depends on the null hypothesis of this test which involves the generation of the series by unit root process (Taylor et al., 2001). The seemingly unrelated regressions augmented Dickey-Fuller panel (SURADF) investigates the null hypothesis of a unit root in a separate manner is developed to solve this problem (He et al., 2014). The existence of cross-sectional correlation is also another problem which may lead to size distortions and first pointed out by O'Connell (1998).*

[5] *See Perron (2005) for a detailed review of the issue of structural breaks.*

[6] *Chang et al. (2006) use Leybourne et al. (1998)'s highly dynamic nonlinear unit root test and find PPP holds true for six African countries.*

Bahmani-Oskooee et al., 2007; Sollis, 2009; Bec et al., 2010; Kruse, 2011; Emirmahmutoglu & Omay, 2014, among others[7]) and the emergence of nonlinear approaches on testing PPP hypothesis (Sarantis, 1999; Sarno, 2000; Taylor et al., 2001; Baum et al., 2001; Alba & Park, 2005; Assaf, 2006; Cuestas, 2009; Kim & Moh, 2010; Choi et al., 2011; Zhou & Kutan, 2011; Chang et al., 2012a; Bec & Zeng, 2013; Cuestas & Regis, 2013; Bahmani-Oskooee et al., 2016; Karagoz & Sarac, 2016; Vasconcelos & Junior, 2016). Many studies also argue for investigating nonlinearity and structural break simultaneously for PPP because they are not mutually exclusive (Sollis, 2004; Christopoulos & León-Ledesma, 2010; Omay et al., 2018, 2020; Nazlioglu et al., 2022). Therefore, for the last two decades, empirical testing of PPP has gained considerable attention. Numerous novel methodologies have evolved, including non-normality of distribution, structural breaks and/or nonlinearity of the variables. One quite popular methodology is the application of Fourier-type unit root tests, including Fourier-KPSS (FKPSS), which was developed by Becker et al. (2006), Fourier-ADF (FADF) and Fourier-KSS (FKSS) which are set by Christopoulos and Leon-Ledesma (2010), Fourier quantile unit root test which is developed by Bahmani-Oskooee et al. (2017) and Fourier non-quantile unit root test of Bahmani-Oskooee et al. (2020). This literature is followed by a growing body of empirical studies (Yilanci & Eris, 2013; He et al., 2014; Kutan & Zhou, 2015; Omay et al., 2018; Bahramian & Saliminezhad, 2021; Doganlar et al., 2021; Nazlioglu et al., 2021; She et al., 2021) afterwards and PPP is usually valid for all or majority of the countries in these studies.

**Table: 1**
**Studies That Using Unit Root Tests to Test PPP in OECD Countries**

| Studies | Samples | Methodology | Results |
|---|---|---|---|
| Wu (1997) | 11 OECD Countries | Zivot and Andrews (1992) unit root test | Support of long-run PPP for the majority of the countries. |
| Serletis & Zimonopoulos (1997) | 17 OECD Countries | Perron and Vogelsang (1992) unit root test | Unfavourable evidence for long-run PPP. |
| Narayan (2005) | 17 OECD Countries | Sen's (2003) structural break unit root test | PPP holds only for three countries when the currency is based on US dollars. |
| Kalyoncu & Kalyoncu (2008) | 25 OECD Countries | ADF, Im et al. (2003) panel unit root test | Found no support by using ADF but found favourable evidence for long-run PPP with Im et al. |
| Narayan (2008) | 16 OECD Countries | LM test with two structural breaks | Find strong evidence of PPP. |
| Aslan & Korap (2009) | 26 OECD Countries | Maddala and Wu (1999), Choi (2001) and Im et al. (2003) tests | Find support for PPP. |
| Holmes et al. (2012) | 26 OECD Countries | Hadri and Rao (2008) test with structural breaks and cross-dependency | PPP is valid. |
| Cuestas & Regis (2013) | 26 OECD Countries | Harvey et al. (2008) linear and Kruse (2011) nonlinear unit root tests | Find support for PPP for half of the countries in the nonlinear case. |
| Bahmani-Oskooee et al. (2014a) | 34 OECD Countries | Kapetanios et al. (2003) (KSS) unit root test with Fourier function | Find support for PPP for most of the member countries. |
| Jiang et al. (2015) | 34 OECD Countries | Bahmani-Oskooee et al. (2014b) unit root test | PPP is valid for half of the countries. |

[7] *Nonlinear unit root test of Kapetanios et al. (2003) has been very popular among researchers and an increasing number of studies are devoted to test PPP using this testing procedure. Erlat (2004); Liew et al. (2004); Bahmani-Oskooee et al. (2007, 2008); Ozdemir (2008); Wu and Lee (2008); Zhou (2008); Zhou et al. (2008); Telatar and Hasanov (2009); Su et al. (2014); Yildirim (2017); Habimana et al. (2018) are some of these studies, among others. But Choi and Moh (2007) argue that this test has serious problems in practice on large power loss and the source of this power loss is unknown and Li and Park (2018) propose a more robust nonlinear unit root test.*

| | | | |
|---|---|---|---|
| Bahmani-Oskooee & Ranjbar (2016) | 23 OECD Countries | Koenker and Xiao's (2004) quantile unit root test and six other univariate tests | PPP holds for seven out of 23 countries using the quantile unit root test. |
| Bahmani-Oskooee et al. (2017) | 23 OECD Countries | Fourier quantile unit root test | Find support for PPP for most of the member countries. |
| Bahmani-Oskooee & Wu (2018) | 34 OECD Countries | Koenker and Xiao (2004) quantile unit root test with sharp and smooth breaks | Find support for PPP for 18 countries. |
| Omay et al. (2020) | 24 OECD Countries | Asymmetric dynamic nonlinear adjustment towards equilibrium tests | Find support for PPP for the majority of OECD countries. |

For OECD countries, several studies are using various unit root tests, and the fast-growing empirical methodology of unit root testing has also influenced the findings of these studies. The table above displays the selected empirical studies on testing PPP for OECD countries. As can be seen, the results of the studies differ, but most support the view of the validity of PPP in the long run.

## 3. Data, Methodology and Empirical Results

Studies aiming to test the PPP, in general, prefer to use conventional unit root tests such as the Augmented Dickey-Fuller (ADF), Phillips-Perron (PP), and Kwiatkowski-Phillips-Schmidt-Shin (KPSS). However, these tests accept the assumption of linearity of the variables, which has many reasons to be questioned. Dumas's (1992) and Sercu et al. (1995) theoretical models constitute the basis of the idea that exchange rates follow a non-linear path. In these models, it is claimed that the real exchange rate follows a random walk process, and a non-trade band may occur in its arbitrage, where it would not be sufficient to meet the transaction costs. Nonetheless, once the real exchange rate reaches this band due to overvaluation or undervaluation, arbitrage becomes lucrative, international trade is commenced, and the real exchange rate emerges as a stationary process. This indicates that the real exchange rate would follow a non-linear asymmetric unit root process around the PPP equilibrium (Yildirim, 2017).

Enders and Granger (1998) stated that the explanatory power of conventional unit root tests would decrease in an asymmetric adaptation process. Besides the nonlinearity assumption, the potential impacts of various events (2008 global economic crisis, covid-19 pandemic, etc.) on the series are not considered in conventional unit root tests due to the use of long-span data in the study, which also leads to a decline in the explanatory power of these tests. In the presence of structural breaks and nonlinearity in time series data, the power of conventional unit root tests that do not allow these two impacts simultaneously would decline. Therefore, according to the ADF test, the probability of rejecting the null hypothesis implying the existence of a unit root would decrease, and it would not be possible to distinguish the stationary process from the nonstationary process (Hepsag, 2021).

In this study, Hepsag's (2021) unit root test, which is an ESTAR-type test, is employed to fill the gap in the PPP analyses performed in the literature by concurrently considering both nonlinearity and structural breaks. In Hepsag's (2021) unit root test, structural breaks among different regimes are regarded with the logistic smooth transition function, and nonlinearity is considered through the ESTAR model proposed in Kruse (2011). The test was developed as an alternative to Leybourne et al. (1998) and Kruse's

(2011) unit root tests. Hepsag's (2021) unit root test procedure was established by following the study of Leybourne et al. (1998) and defining the three logistic smooth transition models specified in Equations 1, 2, and 3 (Hepsag, 2021).

$$\text{Model A: } y_t = \alpha_1 + \alpha_2 S_t(\lambda, \tau) + v_t \quad (1)$$

$$\text{Model B: } y_t = \alpha_1 + \beta_1 t + \alpha_2 S_t(\lambda, \tau) + v_t \quad (2)$$

$$\text{Model C: } y_t = \alpha_1 + \beta_1 t + \alpha_2 S_t(\lambda, \tau) + \beta_2 t S_t(\lambda, \tau) + v_t \quad (3)$$

$v_t$ denotes the error term; and $S_t(\lambda, \tau)$ represents the logistic smooth transition function determined according to the sample number $T$.

$$S_t(\lambda, \tau) = [1 + exp\{-\lambda(t - \tau T)\}]^{-1} \; \lambda > 0 \quad (4)$$

$\tau$ denotes the timing of the midpoint of the transition, and the velocity of the transition determined by the coefficient $\lambda$.

Assuming that $v_t$ represents a zero-mean I(0) process, Model A represents a stationary process around the mean that ranges from the initial value of $\alpha_1$ to the final value of $\alpha_1 + \alpha_2$. Model B, similar to Model A, expresses a changing process from the initial value of $\alpha_1$ to the final value of $\alpha_1 + \alpha_2$ with the constant slope term.

And finally, while Model C ranges from the constant term $\alpha_1$ to $\alpha_1 + \alpha_2$, the slope simultaneously ranges from $\beta_1$ to $\beta_1 + \beta_2$ at the same transition rate (Hepsag 2021). In the first stage of Hepsag's (2021) unit root test, Models A, B, and C are estimated by the nonlinear least-squares method, and residuals are obtained.

$$\text{Model A: } \hat{v}_t = y_t - \hat{\alpha}_1 + \hat{\alpha}_2 S_t\left(\hat{\lambda}, \hat{\tau}\right) \quad (5)$$

$$\text{Model B: } \hat{v}_t = y_t - \hat{\alpha}_1 + \hat{\beta}_1 t + \hat{\alpha}_2 S_t\left(\hat{\lambda}, \hat{\tau}\right) \quad (6)$$

$$\text{Model C: } \hat{v}_t = y_t - \hat{\alpha}_1 + \hat{\beta}_1 t + \hat{\alpha}_2 S_t\left(\hat{\lambda}, \hat{\tau}\right) + \hat{\beta}_2 t S_t\left(\hat{\lambda}, \hat{\tau}\right) \quad (7)$$

In the second stage, Kruse's (2011) unit root test is performed on these residues. Then, as in Equation 8, the Kruse (2011) ESTAR model is modified to allow a nonzero position parameter $c$.

$$\Delta\hat{v}_t = \gamma \hat{v}_{t-1}(1 - \exp\{-\theta(\hat{v}_{t-1} - c)^2\}) + \varepsilon_t \quad (8)$$

$\hat{v}_t$ denotes residuals estimated in the first stage. In his study, Kruse (2011) suggested applying a first-order Taylor approximation to Equation 8 and obtaining the auxiliary regression equation specified in Equation 9.

$$\Delta\hat{v}_t = \delta_1 \hat{v}_{t-1}^3 + \delta_2 \hat{v}_{t-1}^2 + \sum_{i=1}^{\rho} \psi_i \Delta\hat{v}_{t-i} + \varepsilon_t \quad (9)$$

In Hepsag's (2021) unit root test, the null hypothesis implies the existence of a unit root, whereas the alternative hypothesis implies ESTAR stationarity with a smooth break.

Our empirical analysis involves 38 OECD-member countries, including Australia, Austria, Belgium, Canada, Chile, Colombia, Costa Rica, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Latvia, Lithuania, Luxemburg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, the UK, and the USA. The real effective exchange rates (REER) obtained from the Bank for International Settlements (BIS) over 1994M1-2021M9 are used for the analysis. We commence the empirical analysis by indicating the descriptive statistics for each country in Table 2. According to the results presented in Table 2, the Jarque-Bera test statistic rejects the null hypothesis of normality in all countries except for Chile. This result justifies using Hepsag's (2021) unit root test, an ESTAR-type test.

**Table: 2**
**Summary Statistics**

| Countries | Mean | Median | Max. | Min. | Std. Dev. | Skewness | Kurtosis | Jarque-Bera |
|---|---|---|---|---|---|---|---|---|
| Australia | 4.446 | 4.467 | 4.714 | 4.170 | 0.133 | -0.042 | 2.193 | 9.126* |
| Austria | 4.627 | 4.625 | 4.720 | 4.580 | 0.027 | 1.064 | 4.469 | 92.856* |
| Belgium | 4.600 | 4.605 | 4.677 | 4.508 | 0.031 | -0.591 | 3.269 | 20.448* |
| Canada | 4.450 | 4.419 | 4.670 | 4.273 | 0.101 | 0.385 | 2.008 | 21.875* |
| Chile | 4.571 | 4.574 | 4.744 | 4.387 | 0.074 | -0.100 | 2.507 | 3.929 |
| Colombia | 4.432 | 4.416 | 4.682 | 4.158 | 0.128 | -0.003 | 2.181 | 9.290* |
| Costa Rica | 4.567 | 4.535 | 4.770 | 4.410 | 0.098 | 0.364 | 1.769 | 28.365* |
| Czech Rep. | 4.412 | 4.486 | 4.712 | 3.970 | 0.204 | -0.666 | 2.096 | 35.984* |
| Denmark | 4.584 | 4.581 | 4.655 | 4.515 | 0.028 | 0.216 | 2.547 | 5.436** |
| Estonia | 4.503 | 4.589 | 4.711 | 3.725 | 0.186 | -1.559 | 5.454 | 218.566* |
| Finland | 4.626 | 4.619 | 4.763 | 4.553 | 0.042 | 0.941 | 3.821 | 58.560* |
| France | 4.607 | 4.605 | 4.718 | 4.512 | 0.052 | 0.125 | 1.895 | 17.802* |
| Germany | 4.631 | 4.621 | 4.815 | 4.516 | 0.065 | 0.650 | 2.760 | 24.295* |
| Greece | 4.528 | 4.525 | 4.631 | 4.423 | 0.050 | 0.147 | 1.966 | 16.034* |
| Hungary | 4.456 | 4.489 | 4.748 | 4.175 | 0.138 | -0.485 | 2.096 | 24.380* |
| Iceland | 4.819 | 4.834 | 5.102 | 4.473 | 0.132 | -0.463 | 2.688 | 13.263* |
| Ireland | 4.541 | 4.511 | 4.747 | 4.384 | 0.080 | 0.524 | 2.455 | 19.392* |
| Israel | 4.627 | 4.640 | 4.764 | 4.436 | 0.083 | -0.518 | 2.410 | 19.731* |
| Italy | 4.588 | 4.589 | 4.658 | 4.412 | 0.038 | -0.504 | 4.031 | 28.885* |
| Japan | 4.557 | 4.597 | 5.016 | 4.214 | 0.193 | 0.081 | 2.009 | 13.976* |
| Korea | 4.692 | 4.687 | 4.881 | 4.281 | 0.102 | -0.445 | 3.971 | 24.119* |
| Latvia | 4.522 | 4.586 | 4.702 | 4.045 | 0.136 | -1.348 | 4.160 | 119.642* |
| Lithuania | 4.479 | 4.547 | 4.697 | 3.696 | 0.222 | -1.857 | 5.815 | 301.479* |
| Luxembourg | 4.593 | 4.598 | 4.635 | 4.533 | 0.022 | -0.779 | 2.813 | 34.201* |
| Mexico | 4.580 | 4.607 | 4.892 | 4.133 | 0.148 | -0.285 | 2.396 | 9.585* |
| Netherlands | 4.603 | 4.604 | 4.668 | 4.504 | 0.035 | -0.229 | 2.541 | 5.832** |
| New Zealand | 4.582 | 4.610 | 4.758 | 4.260 | 0.106 | -0.998 | 3.295 | 56.533* |
| Norway | 4.535 | 4.548 | 4.705 | 4.300 | 0.072 | -0.658 | 2.960 | 24.053* |
| Poland | 4.513 | 4.524 | 4.803 | 4.210 | 0.107 | -0.656 | 3.769 | 32.170* |
| Portugal | 4.590 | 4.591 | 4.644 | 4.518 | 0.029 | -0.188 | 2.189 | 11.082* |
| Slovakia | 4.361 | 4.506 | 4.662 | 3.869 | 0.281 | -0.513 | 1.575 | 42.774* |
| Slovenia | 4.576 | 4.580 | 4.639 | 4.431 | 0.030 | -1.474 | 7.369 | 385.544* |
| Spain | 4.565 | 4.573 | 4.655 | 4.468 | 0.045 | -0.280 | 2.073 | 16.284* |
| Sweden | 4.647 | 4.658 | 4.868 | 4.429 | 0.103 | -0.083 | 2.311 | 6.963* |
| Switzerland | 4.610 | 4.615 | 4.792 | 4.475 | 0.061 | -0.067 | 2.131 | 10.714* |
| Turkey | 4.322 | 4.366 | 4.643 | 3.761 | 0.200 | -0.478 | 2.222 | 21.114* |
| The U.K. | 4.726 | 4.710 | 4.903 | 4.542 | 0.108 | 0.091 | 1.459 | 33.390* |
| The U.S.A. | 4.696 | 4.710 | 4.860 | 4.533 | 0.081 | -0.075 | 1.998 | 14.231* |

*Note: * and ** denote p<.05 and p<.10, respectively.*

Nonetheless, the results of the ADF and KPSS tests, which are conventional unit root tests that do not take into account nonlinearity and structural change, and the Fourier KPSS (FKPSS) unit root test, which merely considers structural change but do not take into account

nonlinearity, would also be considered for comparison. The ADF, KPSS, and FKPSS stationarity test results are presented in Table 3.

**Table: 3**
**Results of Conventional and Fourier KPSS Stationarity Tests**

| | ADF | KPSS | FKPSS | | |
|---|---|---|---|---|---|
| Countries | | | Frequency | FKPSS Stat. | $F_t$ |
| Australia | -1.655 | 0.270 | 1 | 0.050* | 490.036 |
| Austria | -2.509 | 0.239 | 2 | 0.650 | 93.293 |
| Belgium | -3.074 | 0.144* | 2 | 0.470 | 177.503 |
| Canada | -1.760 | 0.346 | 1 | 0.185 | 345.628 |
| Chile | -2.468 | 0.112* | 2 | 0.249* | 124.810 |
| Colombia | -1.492 | 0.212 | 2 | 0.771 | 183.823 |
| Costa Rica | -1.447 | 0.249 | 2 | 1.613 | 37.711 |
| Czech Rep. | -1.519 | 0.458 | 1 | 0.764 | 295.077 |
| Denmark | -2.943 | 0.235 | 1 | 0.122* | 58.558 |
| Estonia | -3.356 | 0.392 | 1 | 0.775 | 134.528 |
| Finland | -3.804* | 0.080* | 2 | 1.338 | 43.758 |
| France | -2.394 | 0.134* | 2 | 1.592 | 79.565 |
| Germany | -2.805 | 0.130* | 2 | 1.649 | 70.687 |
| Greece | -1.495 | 0.380 | 1 | 0.200 | 245.153 |
| Hungary | -0.596 | 0.493 | 1 | 0.620 | 639.487 |
| Iceland | -2.504 | 0.167 | 2 | 0.786 | 109.180 |
| Ireland | -1.431 | 0.393 | 1 | 0.114* | 317.215 |
| Israel | -1.497 | 0.378 | 1 | 0.116* | 236.202 |
| Italy | -2.936 | 0.353 | 1 | 0.045* | 172.463 |
| Japan | -4.104* | 0.052* | 3 | 1.911 | 8.498 |
| Korea | -3.184 | 0.087* | 2 | 0.335* | 47.810 |
| Latvia | -2.610 | 0.258 | 1 | 0.606 | 96.740 |
| Lithuania | -4.145* | 0.384 | 1 | 0.749 | 98.986 |
| Luxembourg | -3.109 | 0.170 | 2 | 1.117 | 62.426 |
| Mexico | -2.258 | 0.320 | 1 | 0.083* | 233.344 |
| Netherlands | -2.384 | 0.153 | 2 | 0.216* | 124.096 |
| New Zealand | -2.871 | 0.112* | 3 | 1.548 | 41.997 |
| Norway | -1.719 | 0.422 | 1 | 0.505 | 200.605 |
| Poland | -2.726 | 0.409 | 1 | 0.509 | 168.391 |
| Portugal | -0.829 | 0.438 | 1 | 0.239 | 345.050 |
| Slovakia | -0.866 | 0.452 | 1 | 0.797 | 567.327 |
| Slovenia | -1.846 | 0.396 | 1 | 0.337 | 127.346 |
| Spain | -1.706 | 0.360 | 1 | 0.193 | 342.010 |
| Sweden | -3.287 | 0.091* | 3 | 1.788 | 46.041 |
| Switzerland | -2.246 | 0.269 | 1 | 0.055* | 235.206 |
| Turkey | -0.628 | 0.489 | 1 | 0.147* | 592.596 |
| The U.K. | -2.942 | 0.204 | 1 | 0.076* | 358.553 |
| The U.S.A. | -1.638 | 0.247 | 1 | 0.522 | 74.032 |

*Note: FKPSS unit root test critical values at a 5% significance level are 0.172, 0.415, and 0.448 for 1, 2 and 3 frequency values, respectively.*
** Denote stationarity at the 5% significance level according to the ADF, KPSS and FKPSS tests.*

According to the results of the ADF test, the null hypothesis implying the unit root for the REER variable is rejected for Finland, Japan and Lithuania. Thus the PPP hypothesis is found to be valid, whereas, according to the KPSS unit root test, the null hypothesis implying stationarity cannot be rejected for Belgium, Chile, Finland, France, Germany, Japan, Korea, New Zealand, and Sweden, so it is concluded that the PPP hypothesis is valid. According to the FKPSS test results, the null hypothesis implying stationarity cannot be rejected for Australia, Chile, Denmark, Ireland, Israel, Italy, Korea, Mexico, Netherlands, Switzerland, Turkey, and the UK is concluded that the PPP hypothesis is valid.

The possible reason why the results of the ADF, KPSS, and FKPSS tests are inconsistent involves the low explanatory power due to not considering both nonlinearity

and structural change in the ADF and KPSS tests, as well as nonlinearity in the FKPSS test. Hepsag's (2021) unit root test, an ESTAR-type test, is performed in the study to overcome these limitations. Hepsag's (2021) test results are summarised in Table 4.

**Table: 4**
**Results of Hepsag's (2021) Stationarity Test**

| Countries | $\tau_{SNL\alpha\beta}$ | Lag Length |
|---|---|---|
| Australia | 4.567 | 0 |
| Austria | 11.026 | 1 |
| Belgium | 12.664 | 0 |
| Canada | 7.540 | 0 |
| Chile | 8.869 | 0 |
| Colombia | 20.521* | 1 |
| Costa Rica | 20.457* | 1 |
| Czech Rep. | 10.522 | 0 |
| Denmark | 11.064 | 0 |
| Estonia | 33.115* | 1 |
| Finland | 12.761* | 1 |
| France | 12.771* | 0 |
| Germany | 13.443* | 0 |
| Greece | 16.013* | 1 |
| Hungary | 20.676* | 1 |
| Iceland | 14.042* | 1 |
| Ireland | 8.834 | 0 |
| Israel | 4.312 | 0 |
| Italy | 46.851* | 1 |
| Japan | 16.701* | 1 |
| Korea | 32.373* | 1 |
| Latvia | 6.470 | 1 |
| Lithuania | 15.806* | 1 |
| Luxembourg | 19.504* | 1 |
| Mexico | 63.920* | 1 |
| Netherlands | 5.621 | 0 |
| New Zealand | 4.952 | 0 |
| Norway | 14.390* | 0 |
| Poland | 6.450 | 0 |
| Portugal | 8.079 | 1 |
| Slovakia | 16.266* | 0 |
| Slovenia | 15.908* | 1 |
| Spain | 20.745* | 1 |
| Sweden | 8.441 | 0 |
| Switzerland | 32.458* | 0 |
| Turkey | 41.249* | 1 |
| The U.K. | 7.644 | 0 |
| The U.S.A. | 23.414* | 1 |

*Note: At the 5% significance level, Hepsag's (2021) unit root test critical value is 12,728.*
** Represents stationarity at the level.*

According to Hepsag's (2021) test results, the null hypothesis implies a unit root for Colombia, Costa Rica, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Italy, Japan, Korea, Lithuania, Luxembourg, Mexico, Norway, Slovakia, Slovenia, Spain, Switzerland, Turkey, and the USA is rejected. It is concluded that PPP is valid in these countries. As a result of the analysis, it is concluded that the PPP hypothesis is valid in 8% of the OECD countries according to the ADF test, 24% according to the KPSS test, 31.5% according to the FKPSS test, and 58% according to Hepsag's (2021) test. It is estimated that the difference in explanatory powers of the tests accounts for such differences among the ratios.

## 4. Concluding Remarks

The growing interest in the long-run equilibrium of the exchange rate has resulted in rapidly evolving empirical literature on testing PPP. One of the most prominent techniques to test PPP is checking the stationarity of the real exchange rate, which expects a long-run association of the real exchange rate on returning to a constant equilibrium value. The importance of PPP estimations also relies upon practical purposes, such as determining the appropriate policy response to the misaligned nominal exchange rate and comparing national income levels between countries (Sarno & Taylor, 2002). Therefore, many studies vary from empirical research to policy recommendations. Even though early studies employed more conventional approaches, rapid dynamic changes and structural breaks in the economic system have necessitated the development of more refined methodologies that consider nonlinearity in exchange rates and real-world dynamics. Thus, this study tests PPP by considering both the nonlinearity of the exchange rate and the presence of structural shifts and presenting the findings of conventional approaches for comparison. The study's findings show that the results for the same countries on the validity of the PPP, in the long run, vary depending on the methodology used. In the most recent approach, the validity of the PPP for sample countries is shown to be higher, with PPP holding for 58% of countries. Our findings, considering the case of nonlinearity and structural break, imply that PPP is valid in the long run for 22 of the 38 OECD countries (Colombia, Costa Rica, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Italy, Japan, Korea, Lithuania, Luxembourg, Mexico, Norway, Slovakia, Slovenia, Spain, Switzerland, Turkey, and the USA). It is determined that the impacts of both positive and negative exchange rate shocks on real effective exchange rates in countries where PPP is valid would become temporary and cease to exist in the short run. Besides, PPP can determine the equilibrium exchange rates in these countries and whether the exchange rate is overvalued or undervalued. Subsequently, it is determined that earning unlimited profits from arbitrage on the traded goods in these countries is impossible.

On the other hand, In Australia, Austria, Belgium, Canada, Chile, Czech Republic, Denmark, Ireland, Israel, Latvia, Netherlands, New Zealand, Poland, Portugal, Sweden, and the UK, where the PPP hypothesis is found to be invalid, it is found that real effective exchange rate shocks are permanent. It is determined that these shocks impact the balance of trade. Therefore, positive shocks to the real effective exchange rate (depreciation of the national currency) in these countries may persist and lead to positive changes in the trade balance. Another crucial policy outcome for the countries where the PPP hypothesis is invalid is that the exchange rate policies to be implemented in these countries may generate permanent impacts. In other words, these countries would alter their exchange rate policies and affect their competitiveness in foreign trade. Conclusively, the findings are consistent with the results of similar studies on OECD countries such as Cuestas and Regis (2013), Jiang et al. (2015) and Bahmani-Oskooee and Wu (2018). The ongoing debate on PPP indicates that the relevant area of research will continue to evolve and remain important.

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