Purchasing Power Parity in Türkiye: A Price Index– and Parity Definition–Sensitive Fourier–Bootstrap Unit Root Analysis

Havva KOÇ[1]

Abstract

This study investigates the validity of the Purchasing Power Parity (PPP) hypothesis in Türkiye by employing both linear and nonlinear time series methods. In the analysis, absolute and relative PPP series constructed based on consumer and producer price indices, together with the nominal exchange rate, are examined using monthly data. In the first stage, the linearity properties of the series are tested through a nonlinearity test. Based on the obtained results, Augmented Dickey–Fuller (ADF) and Fourier ADF (FADF) unit root tests are applied to the series exhibiting linear behavior, while the Bootstrap KSS unit root test is employed for nonlinear series. The empirical findings reveal that the relative PPP series based on the consumer price index exhibits a linear and stationary structure, indicating its validity in the long run. In contrast, no evidence of a long-run equilibrium relationship is found for the absolute PPP based on the consumer price index, the absolute and relative PPP series based on the producer price index, or the nominal exchange rate. Overall, the results indicate that the validity of PPP in Türkiye is sensitive to both the price index used and the definition of parity.

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[1] Ph.D, Istanbul Okan University Faculty of Business and Administrative Sciences, Business Administration, havva.koc@okan.edu.tr, ORCID: 0000-0002-0906-1438

Türkiye'de Satın Alma Gücü Paritesi: Fiyat Endeksi ve Parite Tanımına Duyarlı Fourier–Bootstrap Birim Kök Analizi

Havva KOÇ[2]

Öz

Bu çalışma, Türkiye'de satın alma gücü paritesi (SAGP) hipotezinin geçerliliğini doğrusal ve doğrusal olmayan zaman serisi yöntemleri kullanarak incelemektedir. Analizde, tüketici ve üretici fiyat endeksleri temelinde hesaplanan mutlak ve nispi SAGP serileri ile nominal döviz kuru aylık veriler yardımıyla ele alınmıştır. İlk aşamada, serilerin doğrusal ya da doğrusal olmayan yapıda olup olmadıkları doğrusal olmayanlık testi ile sınanmıştır. Elde edilen sonuçlar doğrultusunda, doğrusal yapı sergileyen seriler için ADF ve yapısal kırılmaları dikkate alan Fourier ADF (FADF) birim kök testleri uygulanmıştır. Doğrusal olmayan seriler için ise Bootstrap KSS birim kök testi tercih edilmiştir. Ampirik bulgular, tüketici fiyat endeksi bazlı nispi SAGP serisinin doğrusal ve durağan bir yapı sergileyerek uzun dönemde geçerlilik sunduğu tespit edilmiştir. Buna karşılık, tüketici fiyat endeksi bazlı mutlak SAGP ve üretici fiyat endeksi bazlı mutlak ve nispi SAGP serileri ile nominal döviz kuru için uzun dönemli denge ilişkisi desteklenmemektedir. Bu sonuçlar, SAGP'nin Türkiye'de fiyat endeksi ve parite tanımına duyarlı bir yapı sergilediğine işaret etmektedir.

Anahtar Kelimeler: Satın Alma Gücü Paritesi, Enflasyon, Döviz Kuru, Fourier ADF, Bootstrap KSS

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[2] Dr., İstanbul Okan Üniversitesi İşletme ve Yönetim Bilimleri Fakültesi, İşletme, havva.koc@okan.edu.tr, ORCID: 0000-0002-0906-1438

Introduction

Examining the Purchasing Power Parity (PPP) hypothesis for Türkiye provides an important analytical framework for understanding exchange rate dynamics and the inflation process. The Turkish economy has long been characterized by high and volatile inflation, frequent exchange rate adjustments, and an open production structure. This environment leads the relationship between the exchange rate and domestic prices to display more complex, asymmetric, and nonlinear dynamics than those observed in advanced economies. Therefore, the extent to which the nominal exchange rate offsets cross-country price differentials in the long run becomes a critical issue for assessing the empirical validity of PPP in Türkiye.

In Türkiye, the nominal exchange rate is not only relevant for external balance but also plays a central role in inflation formation, the cost channel, expectations, and pricing behavior. The import-dependent production structure causes exchange rate shocks to pass through rapidly and strongly to producer prices, while consumer prices respond more slowly and only partially. This divergence intensifies the gap between producer and consumer price indices and makes it necessary to evaluate the absolute and relative definitions of PPP separately under different price indices.

In addition, structural transformations, changes in policy regimes, and external shocks observed in the Turkish economy generate nonlinear adjustment processes and smooth structural changes in exchange rate and price series. In this context, the first main research question is as follows: Do real exchange rate and PPP series in Türkiye exhibit linear or nonlinear behavior? The answer to this question constitutes a critical preliminary step in determining which econometric methods should be used to test PPP.

Within this framework, the study addresses the following questions. Are PPP series that display linear behavior stationary under conventional linear unit root tests and Fourier-based unit root tests that flexibly model structural breaks? In contrast, do PPP series and the nominal exchange rate that exhibit nonlinear behavior display long-run stationarity when tested using the bootstrap-based KSS unit root test, which explicitly accounts for nonlinear dynamics?

Another key research question concerns whether the empirical validity of PPP varies with the choice of price index (CPI and PPI) and the definition of parity (absolute and relative). This question aims to reveal the extent to which structural divergence between price indices in Türkiye affects PPP results. Finally, does the long-run behavior of real exchange rate series conform more closely to the strict equilibrium condition implied by absolute PPP, or to the mean-reverting equilibrium framework emphasized in the empirical literature? This question complements the analysis by evaluating the link between theoretical expectations and empirical findings.

Accordingly, the study not only tests the validity of purchasing power parity for Türkiye under different price indices and parity definitions, but also proposes a unified research design in which the testing strategy is endogenously determined by whether the series exhibit linear or nonlinear propertiesBy first testing for nonlinearity and then selecting appropriate unit root tests, the study addresses the method–result interaction often overlooked in the PPP literature. This approach demonstrates how results obtained under linear assumptions may change once nonlinear dynamics and smooth structural changes are taken into account. Thus, using the case of Türkiye, the study provides an original contribution to the literature at both methodological and empirical levels by showing that the empirical validity of PPP is sensitive not only to the price index and parity definition, but also to the econometric method employed and the structural characteristics of the series.

Despite its contributions, this study has certain limitations that should be acknowledged. First, the analysis focuses exclusively on Türkiye, which may limit the generalizability of the findings to other economies with different structural and institutional characteristics. Second, the study examines long-run PPP validity within a univariate framework and does not incorporate multivariate settings that could account for additional macroeconomic factors influencing exchange rate dynamics. These limitations suggest that the results should be interpreted with caution and point to potential avenues for future research.

1. Theoretical Framework

PPP is a fundamental approach in international economics that argues that nominal exchange rates are determined by price level differentials across countries. The hypothesis was introduced by Cassel in 1918 and is based on the assumption that, in the long run, exchange rate movements should reflect differences in inflation rates across countries (Cassel, 1918, p. 413; Sarno & Taylor, 2002, p. 66). Within this framework, when changes in the nominal exchange rate offset price differentials, the real exchange rate is expected to fluctuate around a constant equilibrium level.

The PPP hypothesis relies on the assumption that goods and services should have the same purchasing power across countries. In a hypothetical environment without transportation costs, trade barriers, or price rigidities, price levels expressed in a common currency are expected to converge. In this respect, PPP is regarded as a generalized version of the law of one price (Krugman et al., 2017, p. 430).

In the literature, PPP is examined in two forms: absolute and relative. Absolute PPP argues that the real exchange rate should fluctuate around a long-run equilibrium value equal to one. Accordingly, the real exchange rate is defined as in equation (1):

$$R_t = E_t\left(\frac{P_t^*}{P_t}\right) \quad (1)$$

In equation (1), E_t denotes the nominal exchange rate, P_t represents the domestic price level, and P_t^* denotes the foreign price level.

The absolute PPP approach requires the real exchange rate to follow a stationary process fluctuating around a long-run equilibrium equal to one (Gerber, 2008, p. 337). In this context, the empirical validity of absolute PPP is evaluated based on whether the real exchange rate exhibits mean-reverting behavior. Stationarity of the real exchange rate indicates that price differentials across countries are offset by the nominal exchange rate in the long run and that absolute PPP holds.

Taking the logarithm of equation (1), absolute PPP can be expressed as in equation (2):

$$\ln R_t = \ln E_t + \ln P_t^* - \ln P_t \quad (2)$$

Rearranging equation (2), the real exchange rate under absolute PPP is expressed as in equation (3) (Patterson, 2000, p. 257):

$$r_t = e_t + p_t^* - p_t \quad (3)$$

The absolute PPP framework therefore requires the real exchange rate to follow a stationary process in the long run.

In contrast to the strict assumptions of absolute PPP, relative PPP provides a more flexible framework. Relative PPP argues that changes in the nominal exchange rate should be equal to differences in inflation rates across countries. This approach focuses on changes in price levels rather than their levels. Relative PPP is expressed as in equation (4):

$$\Delta r_t = \Delta e_t + \Delta p_t^* - \Delta p_t \quad (4)$$

In equation (4), the operator Δ denotes first differences of the series. Relative PPP does not require the real exchange rate to be equal to one. However, it expects changes in the real exchange rate to remain limited and to display mean-reverting behavior in the long run (Çağlayan & Saçaklı, 2006, pp. 123–124). Accordingly, the empirical validity of relative PPP is evaluated based on the stationarity of changes in the real exchange rate.

Krugman et al. (2017, p. 435) emphasize that PPP should not be expected to hold strictly in the short run. Transportation costs, trade barriers, price rigidities, and local market structures may cause exchange rates to deviate from price levels in the short term. However, such deviations are expected to be constrained in the long run through arbitrage mechanisms in goods and services markets. Therefore, PPP is regarded not as a short-run equilibrium condition but as a reference framework for explaining long-run exchange rate behavior.

The empirical validity of PPP is directly linked to whether the real exchange rate is stationary. Stationarity of the real exchange rate implies that price differentials across countries are balanced by the exchange rate in the long run and that PPP holds. In contrast, the presence of a unit root in the real exchange rate indicates that parity does not hold in the long run. For this reason, unit root tests are widely used in the PPP literature as a primary tool for empirical testing.

However, exchange rate and price series often exhibit nonlinear dynamics and smooth structural changes. This feature may cause conventional linear unit root tests to be inadequate in assessing the validity of PPP. Therefore, this study employs both linear and nonlinear unit root tests to provide a comprehensive assessment of PPP under different price indices and parity definitions.

2. Literature Review

Although the PPP hypothesis is one of the oldest and most fundamental approaches explaining the relationship between exchange rates and price levels, its empirical validity has long remained a subject of debate in the literature. Early studies largely examined PPP within the framework of the law of one price and long-run equilibrium concepts, and the distinction between absolute and relative definitions gained a central position in the literature (Lawrence, 1976). This perspective emphasizes that PPP should be regarded not as a short-run exchange rate determination model, but as a long-run reference framework.

From the 1970s onward, the collapse of the Bretton Woods system and the transition to floating exchange rate regimes led to a rapid increase in interest in empirically testing PPP. Studies conducted during this period showed that conventional regression-based tests failed to adequately account for simultaneity and endogeneity between prices and exchange rates. Under approaches that explicitly consider endogeneity, more favorable results for PPP were obtained (Krugman, 1978). This finding later became one of the key motivations for the development of the cointegration-based literature.

With the 1990s, the long-run validity of PPP began to be systematically questioned, and different methodological approaches were jointly evaluated. Giovannetti (1992) provided a comprehensive review of studies covering the floating exchange rate period and demonstrated that conflicting empirical results largely stemmed from methodological differences. Similarly, Sharma and Obar (1995) emphasized that data incompatibility, price index selection, and short-run perspectives significantly affect PPP test results, and argued that absolute and relative PPP should be evaluated together.

In the 2000s, the literature increasingly focused on testing PPP using historically long samples. Taylor (2002), employing data spanning more than a century, showed that real exchange rates are mean-reverting in the long run and provided strong evidence in favor of PPP. These findings were later supported by Taylor and Taylor (2004), who argued that nonlinear methods and long samples play a critical role in resolving the PPP puzzle. This issue is widely known in the literature as the "PPP puzzle" originally emphasized by Rogoff (1996).

During the same period, theoretical discussions on why PPP deviations appear persistent also deepened. Pelagatti and Colombo (2012) showed that real exchange rate definitions based on consumer price indices may not inherently exhibit mean-reverting behavior, suggesting that the rejection of PPP may stem from measurement issues. In parallel, Kim and Moh (2009) demonstrated that PPP holds in the long run when tests accounting for nonlinear adjustment processes are employed.

A major turning point in the literature occurred with the incorporation of nonlinear dynamics and threshold effects into PPP analyses. Klaassen (1999), using a Markov regime-switching framework, showed that real exchange rates revert to PPP in specific regimes. More recent studies have provided new evidence in favor of PPP using threshold autoregressive models, smooth transition regimes, and asymmetric adjustments (Xie et al., 2025; Frömmel et al., 2022). In addition, global crises and changes in policy regimes have become an important area of discussion in the PPP literature. Zurbruegg and Allsopp (2004) showed that the long-run trends of PPP changed after the East Asian crisis but did not disappear entirely. Similarly, Mishra and Sharma (2010) evaluated the preconditions of regional monetary integration using a generalized PPP framework.

In recent years, the PPP literature has expanded beyond the exchange rate–price relationship to a broader framework that includes income distribution, inequality, and welfare comparisons. Majumder et al. (2015) developed a preference-based framework and examined the relationship between PPP and income inequality, showing that ICP-based measures may systematically reflect purchasing power differently. Deaton and Aten (2017) analyzed the effects of revisions in the ICP 2011 results on global income comparisons and highlighted the policy implications of PPP measurements. This line of research has been further extended by recent studies examining the relationship between purchasing power, innovation, and economic performance (Ruiz et al., 2024).

After reviewing the international PPP literature, it is also important to examine empirical evidence specifically for Türkiye. A substantial number of studies have tested the validity of PPP for Türkiye using

different econometric approaches, data frequencies, and price index definitions. Table 1 summarizes the main empirical studies focusing on Türkiye.

Table 1. Empirical Studies on PPP for Türkiye

Author(s)	Time	Method	Findings
Güney & Tunalı (2015)	1990:01-2014:12	Linear unit root tests and cointegration analysis	Mixed evidence for PPP
Şener et al. (2015)	1980:01-2021:12	Linear (structural break) unit root tests	PPP is not valid
Cevis & Ceylan (2015)	2003:1-2013:8	Linear unit root tests and cointegration analysis	Mixed evidence for PPP
Güriş et al. (2016)	1992:01-2015:05	Nonlinear unit root tests	PPP is valid
Atasoy, (2016)	1996:05-2013:12	Linear unit root tests.	PPP is not valid
Kaya & Çelik (2018)	2002:10-2017:12	ARFIMA	PPP is valid
Aydın, (2019)	1992:01–2018:12	Fourier unit root tests	PPP is valid
Özbek, (2020)	1994:01-2019:01	Linear (structural break) unit root tests	PPP is not valid
Coşkun, (2020)	1994:01-2018:11	Nonlinear unit root tests	PPP is valid
Doğanlar et al. (2020)	2002:01-2018:10	Fourier quantile unit root test	PPP is valid
Koçak & Özbek (2020)	1994:1-2019:1	Linear (structural break) unit root tests.	PPP is valid
Koncak, (2021)	2002:01-2018:12	Linear, wavelet, and quantile unit root tests	Mixed evidence for PPP across Türkiye's trading partners
Han, (2022)	1994-2022	Linear and nonlinear unit root tests.	PPP is valid
Pazarcı & Kar (2023)	1994:01-2022:09	Linear and nonlinear unit root tests.	PPP is valid
Çiftçi, (2024)	2001Q2-2022Q2	Linear (structural break) unit root tests.	PPP is valid
Karataş, (2024)	1994:01-2023:10	Linear unit root tests and cointegration analysis	PPP is valid

Turgut & Uçan (2024)	1992-2022	Second-generation panel unit root and panel cointegration tests	PPP is valid
Gencer, (2025)	1980Q1-2025Q1	Linear unit root tests.	PPP is not valid
Şanal & Ünal (2025)	2005:01–2025:12	Linear unit root tests, structural break tests, and cointegration analysis	PPP is not valid
Kurtoğlu & Yağmur (2026)	2000:01-2022:12	Linear and nonlinear unit root tests	PPP is valid for most sectors in Türkiye
Yağmur, (2026)	2001:02–2024:07	Linear and Fourier-based unit root tests	Mixed evidence for PPP

Note: Since the focus of this study is Türkiye, the results column reports whether PPP is valid for Türkiye.

As shown in Table 1, the empirical literature on PPP for Türkiye strongly reflects the methodological diversity observed in the general PPP literature. Early studies based on conventional linear unit root tests generally concluded that PPP does not hold (Çağlayan & Saçaklı, 2006). Over time, however, findings changed substantially once structural breaks and nonlinear dynamics were incorporated into the analysis. In this context, Güriş et al. (2016) provided evidence supporting PPP for Türkiye using nonlinear unit root tests, while Şener et al. (2015) showed that limited and break-adjusted PPP definitions offer a more suitable framework for the Turkish economy.

Subsequent studies indicate that empirical results on the validity of PPP are sensitive to the chosen method, price index, and parity definition. While a large share of analyses based on conventional linear unit root and cointegration tests reject PPP (Gencer, 2025), approaches accounting for structural breaks and nonlinear adjustments yield more supportive results (Güriş et al., 2016; Aydın, 2019; Pazarcı & Kar, 2023).

In this context, Karataş (2024) examined PPP for Türkiye under both strong and weak forms and showed the existence of a long-run relationship between the nominal exchange rate and relative prices based on Fourier ADF and ARDL bounds test results. The findings indicate that PPP is more strongly supported in Türkiye, particularly under its relative definition.

More recent studies emphasize that PPP exhibits conditional and method-sensitive validity for Türkiye when Fourier-based tests, long-memory approaches, and second-generation panel methods are employed (Aydın, 2019; Kaya & Çelik, 2018; Karademir & Evci, 2022). In contrast, some studies conclude that PPP remains invalid even after accounting for structural breaks, indicating that disagreement in the literature persists (Gencer, 2025).

Overall, the Turkish literature shows that empirical findings on the validity of PPP are highly sensitive to method selection, price index choice, sample period, and assumptions regarding linear or nonlinear structures. This evidence suggests that evaluating PPP within a single test or a single definition is insufficient, and that a comprehensive analytical framework based on multiple methods and parity definitions is required.

Despite the extensive empirical literature examining PPP for Türkiye, existing studies often rely on a single methodological framework or focus on a single definition of PPP. Moreover, only a limited number of studies jointly evaluate absolute and relative PPP definitions while systematically determining the appropriate econometric framework based on linearity considerations. This study contributes to the literature by examining the validity of PPP for Türkiye using both absolute and relative definitions, while first identifying the appropriate data-generating process through linearity tests and subsequently applying Fourier-based and bootstrap unit root methods within a unified framework.

3. Methodology and Data

This section presents the methodological framework adopted in the empirical analysis and describes the data set used in the study. First, nonlinearity tests are employed to determine whether the series exhibit linear or nonlinear behavior. Next, linear and nonlinear unit root tests are introduced in line with the structural properties of the series. Conventional approaches and methods allowing for structural breaks are used for linear series, while tests based on nonlinear dynamics are applied to nonlinear series.

3.1. Nonlinearity Test

To assess whether the time series exhibit linear behavior, the nonlinear framework proposed by Harvey, Leybourne, and Xiao (2008, p. 4) is employed. This approach is based on testing a linear autoregressive model against nonlinear alternatives. The main idea is that the linear model constitutes a special case of a nonlinear model, and nonlinearity is examined by testing whether the nonlinear terms are jointly equal to zero.

For stationary series, Harvey, Leybourne, and Xiao (2008, p. 5) model nonlinearity within the regression framework in equation (5), where the linear AR model is augmented with second- and third-order terms:

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

Linearity is tested under the restriction $\beta_2 = \beta_3 = 0$. The validity of this restriction is evaluated using a Wald-type statistic based on the residual sum of squares obtained from the unrestricted nonlinear model and the restricted linear model. The test statistic is defined in equation (6):

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

For processes containing a unit root, that is, $I(1)$series, nonlinearity is defined in terms of first differences. In this case, the auxiliary regression model in equation (7) is used:

$$\Delta y_t = \lambda_1 \Delta y_{t-1} + \lambda_2 (\Delta y_{t-1})^2 + \lambda_3 (\Delta y_{t-1})^3 + \varepsilon_t \quad (7)$$

Under this specification, linearity is tested under the restriction $\lambda_2 = \lambda_3 = 0$. The corresponding Wald statistic is defined as in equation (8):

$$W_1 = T\left(\frac{RSS_1}{RSS_u} - 1\right) \quad (8)$$

In equation (8), RSS_u denotes the residual sum of squares from the unrestricted nonlinear model, while RSS_0 and RSS_1 represent the residual sums of squares obtained under the relevant linear restrictions.

Harvey, Leybourne, and Xiao (2008, p. 6) propose a unified testing strategy that allows joint consideration of the test statistics defined for $I(0)$ and $I(1)$ processes when the order of integration of the series is unknown. This nonlinearity test enables a decision on whether linearity can be rejected and provides a key decision rule for selecting appropriate unit root tests in subsequent stages of the analysis.

3.2. ADF and FADF Unit Root Tests

In this study, the Augmented Dickey–Fuller (ADF) test is applied to examine whether time series identified as linear contain a unit root. The ADF test is an extended version of the Dickey–Fuller test that includes lagged difference terms to eliminate possible autocorrelation in the error terms. The test is implemented by augmenting the regression equation defined in levels with lagged first differences (Dickey & Fuller, 1979, p. 427).

Within this framework, the model without a constant and trend is defined as in equation (9):

$$\Delta y_t = \delta y_{t-1} + \sum_{i=1}^{p} \beta_i \Delta y_{t-i} + \varepsilon_t \quad (9)$$

When a constant term is included, the ADF regression takes the form given in equation (10):

$$\Delta y_t = \mu + \delta y_{t-1} + \sum_{i=1}^{p} \beta_i \Delta y_{t-i} + \varepsilon_t \quad (10)$$

The model including both a constant and a deterministic trend is expressed as in equation (11):

$$\Delta y_t = \mu + \beta t + \delta y_{t-1} + \sum_{i=1}^{p} \beta_i \Delta y_{t-i} + \varepsilon_t \quad (11)$$

In the ADF test, the null hypothesis is defined as $H_0: \delta = 0$, indicating the presence of a unit root. The alternative hypothesis implies that the series is stationary. The computed test statistic is compared with Dickey–Fuller critical values to determine stationarity. The lag length p is selected based on information criteria. However, the ADF test does not explicitly model structural breaks in the deterministic component, which may reduce its power (Mert & Çağlar, 2023, p. 99).

For this reason, the Fourier–ADF (FADF) unit root test developed by Christopoulos and León-Ledesma (2010) is also employed, as it allows structural breaks to be modeled without prior knowledge of their number or timing. This test represents deterministic components flexibly using Fourier sine and cosine terms, enabling structural changes to be captured through low-frequency components (Hepsağ, 2022, p. 141).

Following Becker, Enders, and Lee (2006, p. 383), Christopoulos and León-Ledesma (2010, p. 1081) specify the deterministic structure with a constant only, as shown in equation (12):

$$y_t = \alpha + \gamma_1 \sin,\left(\frac{2\pi kt}{T}\right) + \gamma_2 \cos,\left(\frac{2\pi kt}{T}\right) + \varepsilon_t \quad (12)$$

In equation (12), $k$denotes the frequency, Trepresents the number of observations, and $t$denotes time. The appropriate frequency is selected by testing values of $k = 1, \ldots, 5$, and the value that minimizes the residual sum of squares is chosen. The residuals obtained at this stage are defined as in equation (13):

$$\hat{\varepsilon}_t = y_t - \hat{\alpha} - \hat{\gamma}_1 \sin,\left(\frac{2\pi kt}{T}\right) - \hat{\gamma}_2 \cos,\left(\frac{2\pi kt}{T}\right) \quad (13)$$

In the second stage of the test, an ADF-type regression is estimated using the residuals, as specified in equation (14):

$$\Delta\hat{\varepsilon}_t = \delta\hat{\varepsilon}_{t-1} + \sum_{i=1}^{m} \Delta\,\hat{\varepsilon}_{t-i} + \nu_t \quad (14)$$

Within this framework, the null hypothesis $H_0: \delta = 0$indicates the presence of a unit root, while the alternative hypothesis implies stationarity. The FADF test statistic is computed as in equation (15):

$$\text{FADF} = \frac{\hat{\delta}}{SE(\hat{\delta})} \quad (15)$$

The calculated FADF test statistic is compared with the critical values provided by Christopoulos and León-Ledesma (2010). If the absolute value of the test statistic exceeds the critical value, the unit root hypothesis is rejected and the series is concluded to be stationary (Hepsağ, 2022, p. 142).

3.3. Nonlinear Unit Root Test

For series identified as nonlinear, a nonlinear unit root test is applied to examine the presence of a unit root. Kapetanios et al. (2003, pp. 360-362) extend standard ADF-type unit root tests and propose a procedure that tests the unit root null hypothesis against a nonlinear stationary STAR process. This nonlinear structure is represented by the ESTAR process defined in equation (16):

$$y_t = \beta y_{t-1} + \phi y_{t-1} F(\theta; y_{t-1}) + \varepsilon_t \quad (16)$$

In equation (16), $\varepsilon_t \sim iid(0, \sigma^2)$ and $F(\theta; y_{t-1}) = 1 - \exp\{-\theta(y_{t-1} - c)^2\}$ denotes the exponential transition function. Kapetanios et al. (2003) assume $c = 0$. Under this assumption, equation (16) can be written as equation (17):

$$\Delta y_t = \alpha y_{t-1} + \phi y_{t-1}(1 - \exp\{-\theta(y_{t-1})^2\}) + \varepsilon_t \quad (17)$$

In equation (17), $y_t$denotes the raw series, the demeaned series, or the detrended series. The hypotheses tested within the framework of equation (17) are defined as follows:

$H_0: \theta = 0$ (unit root)

$H_1: \theta > 0$ (nonlinear ESTAR stationarity)

If $\theta$is positive, it determines the speed of mean reversion.

However, since the parameter ϕ is not identified under the null hypothesis, direct testing of these hypotheses is not feasible. Therefore, Kapetanios et al. (2003) approximate equation (17) using a first-order Taylor expansion, which yields the auxiliary regression $\Delta y_t = \delta y_{t-1}^3 + \varepsilon_t$ (Güriş, 2020, p. 125). To account for possible autocorrelation in the error terms, lagged differences are included, leading to the test regression specified in equation (18):

$$\Delta y_t = \delta y_{t-1}^3 + \sum p_j \Delta y_{t-j} + \varepsilon_t \quad (18)$$

Based on equation (18), the test statistic used to evaluate the null hypothesis is computed as in equation (19):

$$t_{NL} = \frac{\hat{\delta}}{SE(\hat{\delta})}$$	(19)

Here, $\hat{\delta}$ denotes the OLS estimate of the parameter, and $SE(\hat{\delta})$ represents its standard error. If the absolute value of the t_{NL} statistic is smaller than the critical value reported by Kapetanios et al. (2003), the null hypothesis of a unit root cannot be rejected. If the absolute value of t_{NL}exceeds the critical value, the null hypothesis is rejected and nonlinear ESTAR stationarity is supported (Hepsağ, 2022, p. 149).

The KSS test relies on asymptotic critical values, which may lead to size and power distortions in small samples or in series exhibiting high persistence. For this reason, the sampling distribution of the t_{NL} statistic in equation (19), computed from the regression in equation (18), is obtained using the bootstrap method (Efron & Tibshirani, 1993, p. 45) in this study.

The bootstrap procedure is implemented as follows. First, equation (18) is estimated and residuals are obtained. These residuals are then resampled with replacement to generate artificial time series in each bootstrap replication. Parameter estimates from the original regression are kept fixed, and bootstrapping is conducted only over the error terms. In each bootstrap replication, the KSS test regression is re-estimated, and the lag length is endogenously selected using the Akaike Information Criterion (AIC). The corresponding t_{NL} statistic is computed for each replication, and these statistics are stored to construct the empirical bootstrap distribution. The number of bootstrap replications is set to 10,000.

Bootstrap p-values are calculated based on the relative position of the original sample t_{NL}statistic in equation (19) within the bootstrap distribution. This approach allows inference on the nonlinear unit root hypothesis to be more sensitive to sample characteristics and the dynamic structure of the data.

The bootstrap KSS approach provides more reliable results than the asymptotic KSS test, particularly for time series with nonlinear dynamics and complex structural features. In this study, the selection of deterministic components in the bootstrap KSS test is based on joint consideration of graphical properties of the series and findings from linear unit root tests. Accordingly, a demeaned specification with a constant only is adopted for some series, while a detrended specification including both a constant and a trend is used for series exhibiting deterministic trends. Results are reported in line with these specifications.

This procedure allows the empirical distribution of the test statistic to be obtained without relying on asymptotic critical values. The data used in the empirical analysis are described in the following subsection.

3.4. Data and Variables

The data used to examine absolute and relative PPP relationships for Türkiye consist of time series organized at a monthly frequency. All series cover the period from 2003:01 to 2025:07.

The series are first considered in their original levels. Logarithmic transformations are then applied to construct CPI- and PPI-based absolute and relative PPP series. Detailed information on the variables used in the analysis is presented in Table 2.

Table 2. Variables Used in the Calculation of Absolute and Relative PPP

Variable Code	Variable Name	Country	Description
US_CPI	Consumer Price Index for All Urban Consumers: All Items in U.S. City Average (1982–1984 = 100)	United States	General price index based on the household consumption basket
US_PPI	Producer Price Index by Commodity: All Commodities (1982 = 100)	United States	Index reflecting the general trend in producer prices
TR_CPI	Consumer Price Index (General, Level) – TP.FE.OKTG01	Türkiye	Index representing the general level of consumer prices
TR_PPI	Domestic Producer Price Index (Level) – TP.TUFE1YI.T1	Türkiye	Index reflecting the general level of domestic producer prices
USD/TRY	U.S. Dollar Selling Rate – TP.DK.USD.S.YTL	United States / Türkiye	Nominal exchange rate (Turkish lira per U.S. dollar)

Note: U.S. price indices are obtained from FRED (U.S. Bureau of Labor Statistics). Turkish price indices and exchange rate data are obtained from TURKSTAT.

Table 2 reports the variables used in the construction of absolute and relative PPP measures. All series are observed at a monthly frequency over the period 2003:01–2025:07 and are analyzed in logarithmic form. Absolute and relative PPP series are constructed by the author using the nominal exchange rate together with CPI and PPI data, following the definitions presented in the theoretical framework.

Descriptive statistics for the relevant series are reported in Table 3.

Table 3. Descriptive Statistics

Stats	pppabsolute (cpi)	pppabsolute (ppi)	ppprelative (cpi)	ppprelative (ppi)	lndolartl
Mean	1.454067	1.727226	0.022693	0.023578	1.226249
Median	0.773030	0.873841	0.018810	0.017699	0.756730
Maximum	5.985389	6.514410	0.375440	0.433910	3.693328
Minimum	-0.287116	-0.067890	-0.097744	-0.100890	0.162192
Std. Dev.	1.782711	1.932607	0.049996	0.058108	1.039823
Skewness	1.121031	1.159782	2.207395	2.237965	1.032174

Kurtosis	3.154061	3.136233	13.76233	13.72883	2.813227
Jarque-Bera	57.02946	60.96301	1522.329	1520.346	48.51367
Probability	0.000000	0.000000	0.000000	0.000000	0.000000
Sum	394.0521	468.0781	6.127176	6.366110	332.3135
Sum Sq. Dev.	858.0754	1008.442	0.672395	0.908279	291.9324
Observations	271	271	270	270	271

Table 3 summarizes the main statistical properties of the series. The mean and median values indicate that both absolute and relative PPP series are generally positive over the sample period. Standard deviation values show higher volatility in absolute PPP series, particularly those based on CPI and PPI levels. Skewness and kurtosis statistics reveal that all series deviate from normality. This deviation is especially pronounced for relative PPP series, where high kurtosis values indicate the presence of extreme observations. The Jarque–Bera test statistics are statistically significant for all variables ($p < 0.01$), confirming the rejection of the normality assumption.

The number of observations for relative PPP series is one unit lower (270) due to the use of first differences in their construction. This difference arises from the transformation procedure and does not affect the consistency of the analysis.

4. Findings

Exchange rate and PPP series exhibit cyclical fluctuations and asymmetric movements. This pattern suggests that the series may be better characterized by nonlinear models. To formally assess this issue, linearity is tested using the approach proposed by Harvey et al. (2008). The literature indicates that the 2008 version of the test is more powerful than its 2007 counterpart and should therefore be preferred in empirical applications.

Table 4. Linearity Test Results

Variables	Test Statistic
pppabsolute (cpi)	1.17
pppabsolute (ppi)	11.29***
ppprelative (cpi)	0.05
ppprelative (ppi)	7.97***
lndolartl	7.93*

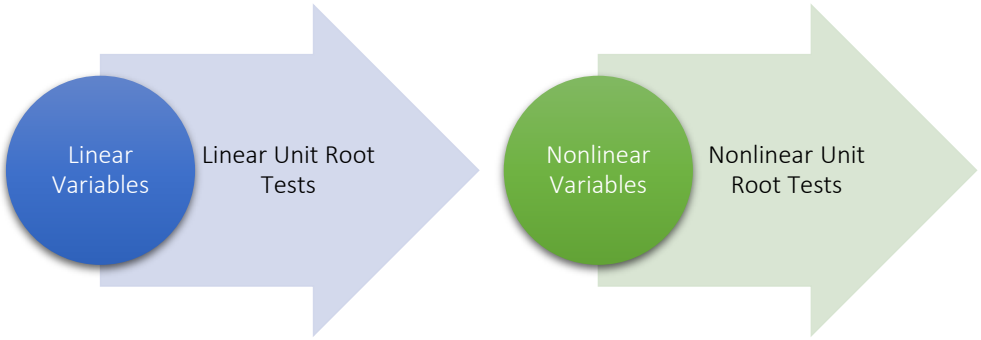
Note: For the Harvey et al. (2008) test, critical values at the 1%, 5%, and 10% significance levels are 9.21, 5.99, and 4.60, respectively. ***, **, and * indicate rejection of the linearity assumption at the 1%, 5%, and 10% significance levels.

Table 4 reports the results of the Harvey et al. (2008) nonlinearity test. The null hypothesis of linearity cannot be rejected for CPI-based absolute PPP and CPI-based relative PPP series. In contrast, PPI-based absolute PPP, PPI-based relative PPP, and the nominal exchange rate (ln USD/TRY) exhibit significant nonlinear behavior.

These findings indicate that CPI-based PPP series in Türkiye can be adequately modeled using linear frameworks. However, nonlinear dynamics appear to dominate PPI-based PPP series and the nominal exchange rate. This result is consistent with the view that producer prices and exchange rates are more sensitive to asymmetric adjustments and nonlinear transmission mechanisms.

The selection of tests used in the analysis is determined by jointly considering the stationarity properties and structural characteristics of the variables. The decision diagram presented in Figure 1 summarizes this procedure.

Figure 1. Decision Diagram



The methodological strategy adopted in this study is guided by the structural properties of the series. In the first stage, the nonlinearity test proposed by Harvey et al. (2008) is applied to identify whether the series exhibit linear or nonlinear behavior. For series displaying linear properties, conventional linear unit root tests are employed. In addition, the Fourier–ADF (FADF) unit root test is applied, as it allows structural breaks to be modeled without prior information on their number or timing. The corresponding results are reported in Table 5.

For series identified as nonlinear, asymptotic critical value–based tests may lead to misleading inference under nonlinear dynamics. Therefore, the Bootstrap KSS nonlinear unit root test is employed, as it enables the empirical distribution of the test statistic to be obtained in a data-driven manner. The results of this test are reported in Table 6.

Table 5: Linear Unit Root Tests (ADF and Fourier-ADF)

Variables	Model	ADF	Fourier ADF			
	C	τ-stat	FADF-m	k	Fm(k)	MinSSR

ppprelative (cpi)		-6.989637*** (-2.872162)	-10.76936*** (-3.78)	1	14.10330 (4.651)	0.60815
		τ-stat	FADF-t	k	Ft(k)	MinSSR
	C&T	-11.37747*** (-3.426682)	-11.70424*** (-3.78)	5	2.96491 (4.669)	0.56338
pppabsolute (cpi)		τ-stat	FADF-m	k	Fm(k)	MinSSR
	C	4.674276 (-2.872121)	0.65339 (-3.78)	1	160.42142 (4.651)	390.53578
		τ-stat	FADF-t	k	Ft(k)	MinSSR
	C&T	0.414158 (-3.426682)	-2.65144 (-4.30)	1	741.28375 (4.669)	20.87141

Note: *, **, and *** denote rejection of the null hypothesis of a unit root (stationarity) at the 10%, 5%, and 1% significance levels, respectively. The optimal lag length is set to 1. The values in parentheses denote the 5% critical values.

Table 5 reports the results of the linear Augmented Dickey–Fuller (ADF) and Fourier–ADF (FADF) unit root tests applied to CPI-based absolute and relative PPP series. Since the validity of PPP is assessed based on the stationarity of level series, first-difference results are not reported.

For the ppprelative (cpi) series, the ADF test statistics obtained under both the constant (C) and constant–trend (C&T) specifications are greater in absolute value than the 5% critical values. This result indicates rejection of the null hypothesis and suggests that the series is stationary under both model specifications.

The Fourier–ADF results support this finding. The FADF-m and FADF-t statistics exceed the 5% critical values for frequency values of $k = 1$and $k = 5$, respectively, leading to rejection of the unit root null hypothesis. Accordingly, the ppprelative (cpi) series follows a stationary process even when potential smooth structural changes are taken into account. The Fm(k) test proposed by Becker, Enders, and Lee (2006) indicates that the trigonometric terms are statistically significant, while the Ft(k) statistic remaining below the 5% critical value implies that Fourier terms are not statistically significant in the trend specification.

For the pppabsolute (cpi) series, the ADF test statistics under both the constant and constant–trend specifications are smaller in absolute value than the corresponding 5% critical values. Therefore, the null hypothesis cannot be rejected, indicating that the series is nonstationary. The Fourier–ADF results are consistent with this outcome. Both the FADF-m and FADF-t statistics for $k = 1$remain below the 5% critical values, and the unit root null hypothesis cannot be rejected. Hence, the pppabsolute (cpi) series does not exhibit stationarity even under the Fourier framework. However, the Fm(k) and Ft(k) statistics suggest that the trigonometric terms are statistically significant.

Table 6. Nonlinear Unit Root Test (Bootstrap-KSS)

Variables	KSS Type	Test statistic	Bootstrap 5% Critical Value	Bootstrap p-value	Opt. Lag
ppprelative (ppi)	Raw	-8.7448	-9.6750	0.1656	0
	Demeaned	-7.3303	-9.6193	0.6041	0
	Detrended	-8.2930	-10.0633	0.3808	1
pppabsolute (ppi)	Raw	3.4924	2.4663	0.3559	1
	Demeaned	2.5336	1.5123	0.3473	1
	Detrended	-0.4930	-1.4467	0.2557	1
lndolartl3	Raw	3.6241	2.0199	0.5558	1
	Demeaned	2.4771	1.0216	0.4869	1
	Detrended	-2.6720	-2.8167	0.0655	1

Note: In the Bootstrap-KSS test, the selection of deterministic components is based on the joint evaluation of the graphical properties of the series and the findings obtained from unit root tests. Accordingly, a demeaned specification is preferred for the PPI-based absolute and relative PPP series, while a detrended specification is adopted for the nominal exchange rate series.

Table 6 reports the results of the Bootstrap-KSS nonlinear unit root tests. The bootstrap critical values are obtained from 10,000 replications. The selection of deterministic components is based on the joint evaluation of the graphical properties of the series and the findings from conventional unit root tests. Accordingly, a demeaned specification is preferred for the PPI-based absolute and relative PPP series, while a detrended specification is adopted for the nominal exchange rate series.

For the ppprelative (ppi) series, the bootstrap p-values are 0.1656, 0.6041, and 0.3808 under the raw, demeaned, and detrended specifications, respectively. In all cases, the test statistics are greater than the corresponding bootstrap critical values, indicating that the null hypothesis of a nonlinear unit root cannot be rejected. For the pppabsolute (ppi) series, the bootstrap p-values are 0.3559, 0.3473, and 0.2557 for the raw, demeaned, and detrended specifications, respectively. These results also indicate that the null hypothesis of a nonlinear unit root cannot be rejected.

Similarly, the results obtained for the nominal exchange rate series lndolartl do not provide strong evidence in favor of stationarity. The bootstrap p-values are 0.5558 for the raw specification, 0.4869 for the demeaned specification, and 0.0655 for the detrended specification. Although the p-value decreases under the detrended specification, it remains above the conventional 5% significance level. Therefore, the null hypothesis of a nonlinear unit root cannot be rejected.

Overall, the findings indicate that Purchasing Power Parity defined on the basis of producer prices in Türkiye does not hold in the long run, either in its absolute or relative form. These results suggest that

3 The nominal exchange rate is expressed in logarithmic form to examine deviations from purchasing power parity. This specification enables an additive representation of the relationship between the nominal exchange rate and domestic and foreign price indices and facilitates a consistent analysis of PPP deviations.

the empirical validity of PPP for Türkiye is sensitive to the price index used and to the nonlinear properties of the data.

5. Discussion

The aim of this study is to evaluate the validity of the Purchasing Power Parity (PPP) hypothesis in Türkiye within a comprehensive framework that accounts for different price indices, parity definitions, and linear and nonlinear dynamics. In this context, the empirical findings are discussed below in relation to the research questions and compared with the existing literature.

Do PPP series in Türkiye exhibit linear or nonlinear behavior? The results of the nonlinearity test proposed by Harvey et al. (2008) indicate that PPP series in Türkiye do not follow a uniform dynamic structure. While CPI-based PPP series display linear behavior, PPI-based PPP series and the nominal exchange rate exhibit pronounced nonlinear dynamics. This finding suggests that price adjustment processes in Türkiye differ substantially between consumer and producer price levels.

These results are consistent with studies in the Turkish literature that emphasize nonlinear dynamics. Güriş et al. (2016) and Han (2022) show that real exchange rate and PPP relationships can be more meaningfully explained under nonlinear frameworks. Similarly, Pazarcı and Kar (2023) demonstrate that PPP results change markedly once structural breaks and nonlinear dynamics are taken into account. In this respect, the findings confirm that linear assumptions cannot be generalized in PPP analyses for Türkiye.

Are linearly behaving PPP series stationary? ADF and Fourier–ADF test results for the CPI-based relative PPP series indicate stationarity. In particular, the Fourier–ADF results show that accounting for smooth structural changes strengthens evidence in favor of stationarity. This finding provides empirical support for the long-run validity of relative PPP based on consumer prices in Türkiye.

This result is in line with evidence obtained using Fourier-based tests in the Turkish literature. Aydın (2019) and Karataş (2024) show that PPP is supported for Türkiye, especially under its relative definition. By contrast, the failure to find stationarity for absolute PPP within a linear framework is consistent with the findings reported by Çağlayan and Saçaklı (2006) and Gencer (2025).

Are nonlinearly behaving PPP series stationary in the long run? Bootstrap KSS test results for PPI-based PPP series and the nominal exchange rate do not provide strong evidence in favor of stationarity, even under a nonlinear framework. This finding indicates that the presence of nonlinear dynamics alone does not guarantee the validity of PPP.

This result is consistent with studies in the Turkish literature that report mixed and conditional findings. Şener et al. (2015) and Coşkun (2020) emphasize that PPP is not supported under all definitions, even when structural breaks and nonlinearities are considered. In contrast, Güriş et al. (2016) report evidence in favor of PPP using nonlinear unit root tests. The present study therefore reinforces the view that disagreements in the literature largely depend on the choice of price index and test methodology.

Is the validity of PPP sensitive to the price index and parity definition? The findings clearly show that the empirical validity of PPP is highly sensitive to both the price index and the parity definition. While CPI-based relative PPP is found to be stationary, absolute PPP and PPI-based definitions are generally not supported. This result aligns with the "conditional validity" view frequently emphasized in the Turkish literature.

Similarly, Güney and Tunalı (2015) and Karademir and Evci (2022) show that PPP results vary with the selected price index. In the international literature, it is widely accepted that absolute PPP often yields weak empirical support due to its strict assumptions, whereas relative PPP offers a more flexible equilibrium concept (Taylor and Taylor, 2004; Taylor, 2002).

Does the real exchange rate converge to a theoretical or an empirical equilibrium? The findings suggest that the real exchange rate in Türkiye does not converge to the strict theoretical equilibrium implied by absolute PPP (R_t=1). Instead, it behaves more consistently with the mean-reverting equilibrium concept emphasized in the empirical literature. The stationarity of CPI-based relative PPP, in particular, implies that the real exchange rate fluctuates around an equilibrium level rather than converging to a fixed value.

This result is consistent with discussions of the "PPP puzzle" in the international literature (Taylor and Taylor, 2004; Rogoff, 2009) and with the emphasis on limited and conditional PPP in the Turkish literature (Şener et al., 2015; Karataş, 2024).

6. Conclusion and Policy Implications

This study examines the validity of the Purchasing Power Parity (PPP) hypothesis for Türkiye using linear and nonlinear time series methods under different price indices and parity definitions. The results show that PPP does not hold in a strong and general sense for Türkiye. Instead, the empirical validity of PPP depends on the price index used, the parity definition, and the econometric methodology applied.

The empirical findings indicate that the CPI-based relative PPP series is linear and stationary. This result suggests the presence of long-run mean-reverting behavior within this framework. In contrast, no long-run equilibrium relationship is found for the PPI-based absolute and relative PPP series or for the nominal exchange rate. These results show that the exchange rate–price relationship in Türkiye is not homogeneous. It cannot be explained by a single adjustment mechanism. Instead, the dynamics differ across price indices.

The divergence between CPI- and PPI-based results can be explained by Türkiye's production structure and pricing dynamics. The Turkish economy depends heavily on imported intermediate goods and energy. Exchange rate shocks therefore affect producer costs quickly. These shocks are strongly reflected in producer price indices. However, the pass-through of these cost increases to consumer prices is slower and more limited. As a result, real exchange rates based on producer prices do not display strong long-run equilibrium properties. In contrast, CPI-based relative PPP shows more stable mean-reverting behavior.

These findings are consistent with several studies in the Turkish PPP literature. Previous research shows that PPP results are sensitive to both econometric methods and price indices. Studies that consider nonlinear dynamics or structural changes often support PPP only under specific specifications (Güriş et al., 2016; Aydın, 2019; Pazarcı & Kar, 2023). In contrast, studies based on conventional linear unit root tests frequently conclude that PPP does not hold for Türkiye (Şener et al., 2015; Gencer, 2025). The results of this study therefore support the view that PPP validity in Türkiye is conditional and method dependent.

From a policy perspective, the findings suggest that exchange rate movements affect producer and consumer prices through different channels and adjustment speeds. Relying on a single price indicator may therefore lead to incomplete policy assessments. Monitoring exchange rate–inflation dynamics through consumer prices may provide a more reliable framework for policy analysis. In addition,

reducing the dependence on imported intermediate inputs could help limit the transmission of exchange rate shocks to domestic prices.

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