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# Testing Purchasing Power Parity Theorem for Interdependent Cross-Sections: An Application of Second-Generation Panel Cointegration Estimators

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**ABSTRACT**

The aim of recent study is to re-investigate the long-run Purchasing Power Parity (PPP) hypothesis for 27 European states from a new perspective. It is based on its conventional form which assumes perfectly competitive markets and the absence of trade frictions. The analysis uses second panel data for the years 2000 to 2022 and employs both first and second-generation cointegration techniques (PMG, MG, DFE, CS-ECM, CS-ARDL and CCE). No substantial support is obtained in favor of the valid existence of PPP for our subject economies based on initial first-generation findings. Among all employed estimator, only PMG is the one that shows a statistically significant long-run relationship between the exchange rate and the price gap, in line with theoretical expectations. However, cross-sectional dependence tests show strong economic interlinkages between countries, prompting the use of second-generation techniques. All in all, results are conflicting: CS-CEM provide slight supports for PP under contemporaneous averages, whilst CS-ARDL and CCE yield contradictory evidence when lags are included. The study reveals that there is little strong and consistent evidence that PPP is valid over the long term in Europe. Further, the study suggests that exchange rate modeling and economic convergence strategies in Europe should be cautious in relying on PPP assumptions. This prudence is most justified in the absence of adequate consideration of cross-country interconnection and market imperfection.

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## 1. Introduction

The phenomenon of long-run Purchasing Power Parity (PPP) has been extensively studied due to its crucial role in international finance and open economy macroeconomics. It states that, over time, the bilateral exchange rate between two countries reflects their price level differences. Thus, the validity of PPP is closely linked to determining equilibrium exchange rates (Froot, Kim, & Rogoff, 1995; Rogoff, 1996; Sarno & Taylor, 2002). From a policy standpoint, long-run PPP is vital for external sector stability. It serves as a benchmark to assess currency misalignment based on inflation differentials, supports exchange rate theories guiding policy in developing and less-developed countries, and provides a foundation for dynamic international macroeconomic models. Moreover, reliable PPP estimates are key for measuring (a) deviations from equilibrium exchange rates, (b) exchange rate parities, and (c) cross-country income comparisons. Choosing the appropriate econometric estimator is crucial. Past studies show no single empirical method for measuring PPP, leading to various approaches to analyze its nature and shocks. The most common method tests the stationarity of real exchange rates—making unit root tests the standard tools for detecting PPP (in)existence. However, concerns remain about their reliability, which depends on power and efficiency under different data and theoretical conditions. The Dickey-Fuller (1979) family remains the most widely used, despite relying on restrictive assumptions like white noise error terms and asymptotic efficiency (Al-Gasaymeh, Kasem, & Alshurideh, 2015; Bahramian & Saliminezhad, 2021; Chan, Lai, & Liang, 2023; Doganlar, 1999; Doğanlar, Mike, & Kızılkaya, 2021; Guimaraes-Filho, 1999; Jiang, Bahmani-Oskooee, & Chang, 2015; Lopez, Murray, & Papell, 2005; Mclellan & Chakraborty, 1997; Pesaran et al., 2009; Su et al., 2012). These assumptions make them sensitive to sample size distortions—especially when PPP deviations are persistent, increasing the risk of falsely accepting the null. Various studies have identified these limitations, leading to methodological improvements for greater accuracy.

Perron (1988) introduced the first major improvement by allowing structural breaks in the testing equation, adding realism and opening new research avenues in PPP analysis. Since then, structural breaks have become common in real exchange rate studies (Breitung & Candelon, 2005; Dimitriou & Simos, 2013; Kasman, Kasman, & Ayhan, 2010; Narayan, 2008; Papell, 2002). Papell (2002) argued that mixing fixed and flexible exchange rate regimes masks PPP behavior, advocating for unit root tests that allow slope changes while keeping the intercept fixed to detect appreciation or depreciation trends. Further developments include the Breuer, McNown and Wallace (2001) panel test, which accommodates varying autocorrelation and lag structures across countries, helping assess PPP validity while considering cross-sectional dependence. Another research stream views PPP through a non-linear lens, suggesting that exchange rate and price adjustments follow non-linear patterns. Accordingly, some studies use non-linear unit root tests to capture such dynamics (Lau, 2009; Sedefoğlu & Özden, 2024; Su, Cheung, & Roca, 2014; Vasconcelos & Lima Júnior, 2016; Yilanci, Ursavaş, & Mike, 2024; Yıldırım, 2017). Long-run PPP is often rejected over short horizons, especially under floating exchange rate regimes. However, its long-run validity remains debated in international macroeconomics. To examine its legitimacy, many studies employ cointegration methods, which test for long-run co-movement between non-stationary variables by analyzing equilibrium deviations using regression coefficients. Numerous PPP studies focus on regional groups (Alba & Papell, 2007; Drine & Rault, 2008; Frankel & Rose, 1996; Kasman, Kasman, & Ayhan, 2010; Narayan, 2008), often using estimators with common parameter restrictions for geographically close countries with similar structures and trade policies. Yet, cross-sectional heterogeneity is inherent in macroeconomic data. Assuming homogeneity when slope coefficients differ leads to inconsistency (Pesaran & Smith, 1995). Thus, testing for homogeneity is necessary, and in its presence, estimators allowing for individual slope coefficients should be used. Another important issue is cross-sectional interdependence. Using conventional panel estimators when cross-sections are interdependent can lead to biased results (Driscoll & Kraay, 1998; Kapetanios, Pesaran, & Yamagata, 2011). If the source of dependence correlates with explanatory variables, standard estimators become inconsistent. In econometrics, this source is known as 'unobserved components.' When these components strongly influence interdependence, conventional models fail to provide robust and consistent estimates (Chudik & Pesaran, 2013; Eberhardt & Bond, 2009; Sarafidis & Robertson, 2009).

The following questions guide this research: Is the Purchasing Power Parity (PPP) theorem valid for European countries over the long term? Does cross-sectional dependence (CSD) and the diversity among countries affect the testing of the PPP theory in empirical methods? In order to solve these questions, the study examines whether the PPP hypothesis still holds after a long period, using conventional and second generation cointegration models. The purpose is to offer more reliable and consistent evidence on PPP for European economies by dealing with important methodological problems. The novelty and significance of this study lie in its focus on cross-sectional dependence (CSD) — a major issue in macro panel data that has received limited attention in PPP research. Unlike most previous studies, which overlook economic connections and spillovers across nations, this study addresses CSD explicitly, especially in regions like Europe where countries share structural, policy, and demographic traits. To fill this gap, we use (a) statistical tests to detect CSD and (b) cointegration techniques tailored for panel data to examine long-run relationships among panel units. Ignoring CSD increases the risk of bias, making this approach a valuable contribution to applied econometric research on exchange rates. Given the likely presence of heterogeneity and CSD among European states, we employ second-generation cointegration estimators that account for both. First, we estimate the long-run cointegrating relationship between nominal exchange rates and price gaps without assuming cross-sectional dependence. Then, we test for CSD and, if confirmed, re-estimate the relationship using appropriate second-generation methods. Another key contribution is the rigorous methodology: instead of relying on a single estimator, we apply multiple econometric techniques at each stage, enhancing robustness and consistency across varying theoretical frameworks. The rest of the paper is structured as follows: Section 2 give a thorough analysis of the PPP theoretical and empirical literature. In Section 3, model framework is described. Section 4 offers data resources and empirical methodology used in the study. Section 5 reports and discusses the empirical evidence from both first-generation and second-generation cointegration models, as well as the outcomes of cross-sectional dependence analysis. Finally, section 6 concludes the study by summarizing the key findings, discussing their policy relevance, and suggesting paths for future research.

## 2. Literature Review

The empirical validation of the PPP theorem has relied on two core econometric frameworks. The first argues that real exchange rates exhibit a unit root process. The second assesses long-run co-movement between nominal exchange rates and price differentials across countries. Early studies focused on the assumption that real exchange rates follow a random walk in the short run but may demonstrate mean-reverting behavior in the long run. The PPP would only hold in the long run if real exchange rates do not follow a unit root process. However, empirical evidence remains divided, with no unified consensus. Baillie and Selover (1987) and Taylor (1988) perform residual-based cointegration testing for five high-income countries (UK, West Germany, France, Canada, and Japan) using their floating exchange rates. Nevertheless, they found results unfavorable as none of the countries demonstrated PPP as a long-run equilibrium condition. Edison (1987) tests PPP for the UK and U.S. using a long span of time-series data and an error correction model. The findings reflect the significance of structural factors in reaching the true state of PPP. PPP tends to establish in the long run if the monetary model of exchange rates is considered, allowing for symmetry and proportionality. Then, Johnson (1990) tested PPP for Canada and the U.S. for the pre- and post-WWII period using an error correction model and found it evidently existing. The choice of this model captures variations in PPP due to changes in regimes.

Abuaf and Jorion (1990) were among the first to propose that considering non-linearity in bilateral exchange rates may yield more realistic PPP estimates. Conventional unit root and cointegration tests show insufficient power in detecting stationarity when the data generating process is non-linear. Bhatti (1996); Enders and Falk (1998), and later Enders and Chumrusphonlert (2004) provided evidence that non-linear modeling allows adjustments of both foreign and domestic prices and does not require symmetry and proportionality. Blake and Fomby (1997) introduced threshold cointegration methods, allowing threshold adjustments toward long-run equilibrium. These techniques gained popularity as they accommodated the non-linear nature of PPP deviations. Hansen and Seo (2002) introduced a threshold cointegration framework furthering PPP testing under non-linear conditions. The study highlighted regime-switching behavior in exchange rate dynamics. Kapetanios, Shin and Snell (2003) contributed by developing unit root tests that accounted for structural breaks and nonlinearities. These addressed the low power problem of conventional tests in detecting mean-reverting real exchange rates. Enders and Chumrusphonlert (2004) applied threshold cointegration to examine PPP, finding support when accounting for non-linear adjustments. Koenker and Xiao (2004) developed quantile regression-based approaches allowing data heterogeneity. Their contribution laid a foundation for modern nonlinear models in PPP testing. Gouveia and Rodrigues (2004) and Ho (2005) adopted threshold-type models to explore long-run PPP, suggesting its validity under specific regimes. Heimonen (2006) used a similar framework to assess real exchange rate dynamics and reported supportive evidence for PPP in specific regimes.

Bahmani-Oskooee, Kutan and Zhou (2007) and Bahmani-Oskooee and Hegerty (2009) adopted advanced techniques accounting for nonlinearities and structural breaks. Their work confirmed that structural considerations are critical in achieving robust PPP estimates. Lau (2009) further analyzed PPP using nonlinear models and provided mixed results for developing economies, emphasizing that conventional tests are inadequate for non-linear processes. Kruse (2011) introduced non-linear unit root tests for accurate detection of stationarity in the presence of smooth transitions. Su, Tsangyao and Chang (2011) focused on improving estimation of mean-reverting processes in PPP studies, proposing models to control for both smooth and abrupt shifts. Chang, Lee and Hung (2012); Liu et al. (2012), and Lu, Chang and Lee (2012) employed advanced threshold models and reported support for PPP in developed and emerging economies, especially after multiple structural breaks. Cuestas and Regis (2013) further evidenced the importance of regime-switching in real exchange rate data, especially in

Central and Eastern Europe. He, Chou and Chang (2014) explored non-linear PPP characteristics using advanced models, offering support in Asian economies. Su, Cheung and Roca (2014) proposed new unit root testing methods accounting for threshold behavior and structural dynamics, yielding more robust support for long-run PPP. Tiwari and Shahbaz (2014) examined BRICS under non-linear frameworks, reporting positive evidence for PPP after modeling non-linear adjustment paths. Park and Shintani (2016) developed tests sensitive to both non-normal distributions and structural instability, confirming that non-linearity is a common feature. Ma, Li and Park (2017) advanced the quantile unit root methodology, allowing detection of unit root behavior across distribution points, revealing that PPP might hold under specific market conditions. Bahmani-Oskooee, Chang and Ranjbar (2017) pioneered Fourier quantile unit root testing. Their study on 17 OECD countries revealed mixed PPP evidence, especially in lower or higher quantiles, suggesting non-uniform real exchange rate behavior. Li and Park (2018) conducted analysis for 61 countries using a newly proposed non-linear unit root test improving upon the KSS (Kapetanios, Shin, & Snell, 2003) test. They proposed three new tests—the quantile t-ratio, quantile Kolmogorov–Smirnov, and quantile Cramer–von Mises tests. These showed stronger power in rejecting unit root and suggested asymmetric nonlinear mean-reverting behavior. Mike and Kızılkaya (2019) pointed out deficiencies in ADF, PP, and KPSS tests, especially their lack of power under non-Gaussian conditions and inability to account for structural breaks and nonlinearities. They emphasized modern estimators are needed.

Doğanlar, Kızılkaya and Mike (2020) explored real exchange rates in Turkey and concluded that PPP holds under non-linear adjustments, especially with policy-induced shocks and breaks. Yang and Zhao (2020) applied Hansen's (1995) quantile nonlinear unit root (QNUR) test with covariates. This method captures nonlinearity and heterogeneity across quantiles, extending unit root tests. Their results indicated PPP holds in certain distribution regions, especially under large deviations, showing long-run adjustments are both nonlinear and heterogeneous. Covariates significantly improve robustness and support PPP. Ali et al. (2021) supported non-linear frameworks for PPP testing, highlighting that traditional methods might mislead due to linearity and normality assumptions. Xie, Chen and Hsieh (2025) extended the investigation by analyzing PPP across 23 OECD countries and the euro area. Using multiple test frameworks, they showed macroeconomic fundamentals—such as GDP size, eurozone membership, and debt ratios—significantly affect PPP validity. This highlighted heterogeneity in PPP outcomes across countries, complementing (She et al., 2021). Ishaq, Ghouse and Bhatti (2022) emphasized the lack of consensus in literature regarding long-run PPP, stating that it is highly sensitive to factors including exchange rate regimes, price indicators, econometric estimators, and structural elements. They stressed limitations of conventional cointegration approaches like Engle-Granger, Phillips-Ouliaris, and Johansen, especially under non-linear and unstable environments. Chan, Lai and Liang (2023) tested PPP for China against five major trading partners using Fourier quantile unit root tests. They found PPP to hold for China, highlighting the Fourier approach's effectiveness in detecting structural breaks and modeling non-linear behaviors. Vo and Vo (2023) supported the long-run relevance of PPP by analyzing 50 years of cross-country data. They showed arbitrage mechanisms result in relative price equalization, even amid short-term distortions, supporting PPP's long-term effectiveness.

Jie and Liu (2024) studied China and discovered that various data types lead to diverse PPP outcomes. The study suggested a weak case for PPP, but stronger evidence when parallel market exchange rates and market-based price indices were used, highlighting the importance of representative price measures, echoing concerns from earlier estimates. Sedefoğlu and Özden (2024) applied both linear and non-linear unit root tests to analyze Turkey's exchange rate against the U.S., China, and EU. The study revealed non-linear unit root tests confirmed PPP, which linear models missed. Structural breaks and external shocks influenced the Turkish exchange rate, and mean-reverting nature was evident under non-linear frameworks. Yilanci, Ursavaş and Mike (2024) evaluated PPP in Emerging-7 (E7) economies—Brazil, China, India, Indonesia, Mexico, Russia, and Turkey—using a Fourier quantile AESTAR (FAESTAR-QKS) unit root test. The model handled non-normal errors and multiple smooth breaks. Results supported PPP in the long run for all E7 economies except Turkey, highlighting that non-linear features enhance testing robustness. Arghyrou, Lu and Pourpourides (2025) examined PPP deviations. They argued high-risk investor attitudes and uncertain exchange rates, shown by skewness and kurtosis, are reasons for PPP deviations. Their results underscore financial market behavior's role in PPP violations, offering a bridge between price theory and asset pricing. Xie, Chen and Hsieh (2025) returned to practical research by studying REERs in 18 countries using nonlinear threshold models. Their results confirmed asymmetric and size-dependent adjustments are important in validating PPP. They showed that transaction costs and price stickiness cause parity deviations. In conclusion, although recent PPP studies use advanced methods, they often ignore cross-sectional dependence (CSD), crucial in Europe's interconnected economies. This can lead to biased results. To address this, this study applies second-generation cointegration techniques handling CSD and heterogeneity, offering a more reliable evaluation of PPP in Europe. Over time, PPP research evolved from linear models with weak support to sophisticated methods accounting for structural breaks, non-linearity, and quantile approaches, showing stronger evidence that PPP holds when real-world complexities are considered.

## 3. Model Framework

In its simplest version, the proposition of PPP requires that the national prices of two countries when expressed in a common currency should tend to equate. This definition of PPP is synonyms to the belief that the bilateral nominal exchange rate between two countries should be the mirror image of the gap between their national price levels. Therefore, the theoretical formulation PPP between two countries (home and foreign) can be given as:

$$e_{it} = p_{it} - p_{it}^{*} \tag{1}$$

$e_{it}$ is the bilateral nominal exchange rate between home and foreign (expressed as units of home currency against one unit of foreign currency) and $p_{it}$ and $p_{it}^{*}$ are the price levels at home and foreign, respectively, expressed in their national currencies.

## 4. Data Description and Empirical Methodology

### 4.1. Data Description

For confirming the valid existence of PPP, we consider 27 European Union member states that includes Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain and Sweden with U.S. as their largest trading partner. The study covers the period from 2000 to 2022. For bilateral nominal exchange rates that measured in national currency at current prices between EU states and the U.S., and for prices at home (EU) and foreign (U.S.), Consumer Price Index (CPI) with base year 2010 is used. All series used in this study sourced from United Nations Conference on Trade and Development (UNCTAD) database.

### 4.2. Empirical Methodology

The doctrine of PPP has been investigated extensively both theoretical as well as empirically in earlier researches. Nevertheless, no precise conclusions are drawn from such thorough investigations, as large majority of studies reveal mixed evidence on the valid existence of PPP. Also, some important aspects pertaining to panel data sets are typically overlooked in earlier investigations; cross-country heterogeneity and interdependence are few of them.

#### 4.2.1. Determining the Validity of PPP Hypothesis in Long-Run

This study holds significance amongst earlier researches on PPP exploration owing to the amount of special attention it pays to controlling for heterogeneity and cross-sectional dependence, two critical features panel data sets are commonly characterized with. In order to cope with heterogeneity issue, we employ Mean Group (MG), Pooled Mean Group (PMG) and Dynamic Fixed Effects (DFE) estimators, each of which deals with heterogeneity in cross-sectional entities in its own unique way. Starting with MG, unlike conventional pooled estimators that assume homogeneity across cross-sectional units, the MG estimator allows for individual differences. The estimator is capable of computing individual coefficients for each unit and then averages these estimates. Thus, MG prevents from imposing the restriction of common coefficients across all cross-sections and by doing so it facilitates to avoid the bias that can arise if the true underlying relationships differ across panel entities. The estimator is well-suited for panels where the data series are non-stationary, and there might be cointegration among variables. It can estimate both short-run dynamics and long-run relationships effectively. In order to establish the robustness and consistency of our estimates from MG, we also test the PPP hypothesis through PMG and DFE estimators. The PMG estimator combines the features of both the MG estimator and the conventional pooled estimator, striking a balance between accommodating heterogeneity and exploiting commonalities across units. The estimator takes a middle ground between full homogeneity (pooling approach) and full heterogeneity (MG approach) by assuming that long-run relationship between variables are the same across all entities but allows short-run dynamics and error variances to differ across units. The estimator enjoys superiority over MG test by pooling the long-run coefficients, thus leading to device policy actions with better degree of confidence. The short-run dynamics of the estimator follow error correction mechanism, allowing different cross-sections to adjust at different speed towards achieving long-run equilibrium. The model is therefore well-designed to capture the short-run heterogeneity of error adjustment process. Lastly, the DFE estimator is purposefully designed to deal with dynamic relationships, where past values of the dependent variable affect its current values. The DFE estimator extends the traditional fixed effects model by incorporating lagged dependent variables, capturing the dynamic nature of the data. It includes one or more lagged values of the dependent variable as regressors, which helps in modeling dynamic relationships, thus, allowing the model to capture autoregressive processes. The estimator is efficient in controlling for unobserved heterogeneity across cross-sectional units by including fixed effects. The inclusion of fixed effects accounts for time-invariant characteristics that differ across units but are constant over time, thus, serve to mitigate the bias caused by omitted variable.

### 4.2.2. Testing for Cross-Sectional Dependence

The empirical evidence in favor of valid(invalid) existence of PPP yielded from conventional cointegration models might be an outcome of the inability of these estimators to control for the cross-sectional dependence, a feature pertinent to regional studies. Overlooking the cross-sectional dependence may lead to misleading results, as it may bear sizeable impact on the asymptotic and finite sample properties of some important inference processes in panel data estimators (Andrews, 2005; Demetrescu & Homm, 2016; Pesaran, 2015). As second step in our estimation procedure, we therefore determine the true status of cross-sectional dependence amongst our sample countries using the CSD tests proposed by Pesaran, Schuermann and Weiner (2004). The estimable version of Pesaran, Schuermann and Weiner (2004) test is:

$$CD_{Pesaran\,(2004)} = \sqrt{\frac{2}{i(i-1)}}\sum_{k=1}^{i=1}\sum_{j=k+1}^{i} T_{k,j}\,\hat{\rho}_{k,j} \sim N(0,1) \qquad (2)$$

Where $\hat{\rho}_{k,j}$ represents the coefficient of correlation between unit *i* and *j*. As per the above given formulation, CSD is subject to zero mean and constant variance i.e. following a standard normal distribution. The null hypothesis of the test 'no CSD' is tested against the alternative hypothesis of 'significant CSD exists' is tested. In order to establish the robustness and consistency of our results from Pesaran, Schuermann and Weiner (2004) CSD test, we estimate Friedman (1937) CSD test also.

### 4.3.3. Testing for Long-Run PPP using Second Generation Cointegration Models

The occurrence of valid CSD in our panel will legitimize the need for re-estimating our PPP model using second generation cointegration models. These econometric models are purposefully designed to counter the issue of CSD, commonly found in panel data sets, particularly those comprising countries from a common region. Relaxing the assumption of cross-sectional independence amongst panel entities, the second generation cointegration models are capable of outperforming the first generation cointegration estimators for yielding more robust and reliable estimates when the sample data is subject to significant cross-sectional dependence. For our analysis, we employ five estimators from the series of second generation cointegration testing methods. All these five estimators slightly differ from each other but principally they all are meant to account for unobserved common factors, a feature typically found in panel data sets.

(i) *Common Correlated Effects (CCE) Estimator:* Proposed by Pesaran et al. (2009), the CCE estimator is an ideal candidate for estimating large panels where the panel entities tend to suffer from common factors which are difficult to observe directly. The (econometrically) estimable version of CCE estimator is:

$$y_{it} = \alpha_i + \beta_i' x_{it} + \delta_i' f_t + \varepsilon_{it} \quad (3)$$

Where $y_{it}$ and $x_{it}$ are the dependent and the vector of explanatory variables, respectively. $f_t$ accounts for unobserved common factors and $\varepsilon_{it}$ represents the white noise error term. $f_t$ being not directly observable, the model proposes to use proxies of $y_{it}$ and $x_{it}$ in place of unobserved effects.

*(ii)* *Dynamic Common Correlated Effects (DCCE) Estimator:* This estimator is an extension of CCE estimator discussed above. The estimator is devised to treat dynamic panel data models, where the lag of dependent is included as model regressors. The model serves as an ideal estimator under the circumstances where the data demonstrates both dynamics and CSD simultaneously.

$$y_{it} = \alpha_i + \varphi y_{it-1} + \beta_i' x_{it} + \delta_i' f_t + \varepsilon_{it} \quad (4)$$

Where $y_{it-1}$ is the lag of model dependent variable serving as one of the models regressors. The unobserved common factors are controlled in DCCE estimator by augmenting both the current and lagged values of the dependent variable and the regressors.

*(ii)* *Common Correlated Effects Pooled (CCEP) Estimator:* Similar to Dynamic CCE estimator, CCEP test is also an extension of CCE estimator. For panel data sets, the model is of particular significance under the assumption of homogeneous slope coefficients i.e. the model regressors tend to bear a relationship with regressend of homogeneous nature.

$$\Delta y_{it} = \alpha_i + \beta_i' x_{it} + \rho' \overline{X_{it}} + \varepsilon_{it} \quad (5)$$

$X_{it}$ comprises cross-sectional averages of independent variables to account for cross-sectional dependence.

*(iv)* *Cross Sectional Error Correction Model (CS-ECM):* This estimator is also devised to model dynamic relationships over both short- and longer time horizons when cross sectional units are subject to interdependence. This advance estimator is particularly useful in the instance of cointegration i.e. when variables tend to hold long-run association but are deviated from equilibrium in short-run. It reveals the speed of correction from short-run misalignments towards long-run equilibrium model variables impart through their periodic movements.

$$\Delta y_{it} = \alpha_i + \mu_i (y_{it-1} - \beta' x_{it-1}) + \sigma' \Delta x_{it} + \rho' \overline{X_{it}} + \varepsilon_{it} \quad (6)$$

Where $\mu_i$ is the error correction coefficient accounting for the speed of correction of model's variables from their short-run errors/misalignment towards achieving long-run equilibrium. $X_{it}$ comprises cross-sectional averages of the differenced explanatory variables to account for CSD.

*(v)* *Cross Sectional Autoregressive Distributed Lag (CS-ADL) Estimator:* Similar to CS-ECM, this estimator is also meant for modeling dynamic relationship of panel variables over shorter and longer time horizons. Extracted from conventional ARDL approach, the model is customized for panel data sets capable of accounting for CSD by making use of cross-sectional averages. The model allows for flexible lag structure, thus, accommodating dynamic relationship between variables across varying time periods.

$$\Delta y_{it} = \alpha_i + \sum_{p=0}^{P} \beta_p x_{it-p} + \sum_{q=1}^{Q} \gamma_q y_{it-q} + \sum_{p=0}^{P} \pi_p \overline{x_{t-p}} + \sum_{q=1}^{Q} \tau_q \overline{y_{t-q}} + \varepsilon_{it} \quad (7)$$

Where $\overline{x_{t-p}}$ and $\overline{y_{t-q}}$ are the cross-sectional averages of model regressor and regressant, respectively.

For identification of valid existence (inexistence) of PPP, the use of five different modern cointegration tests is motivated by two major reasons (a) these five estimators are offering three different approaches to cointegration. This will lead us to draw our conclusions about PPP in a more comprehensive manner, and (b) we shall be able to determine how robust and consistence our estimates are across different approaches to cointegration model efficient against CSD.

## 5. Results and Discussions

Before getting into empirical investigation of PPP existence, we first need to determine the true order of stationarity of our model variables. For this purpose, we employ Fisher ADF panel unit root test. Upon having obtained the sufficient amount of statistical evidence in favor of both the model series to be unit root in levels, we are now good to go with investigating the PPP hypothesis over longer time horizons. The model series being integrated of order one, this legitimizes to search for the long-run cointegration relationship between bilateral exchange rate and the inter-country price gap series, under the theoretical predictions of PPP theorem. As stated earlier, the investigation of long-run PPP hypothesis will be done across three different cointegration estimators i.e. Pooled Mean Group (PMG), Mean Group (MG) and Dynamic Fixed Effects (DFE) estimators. The results obtained for the long-run equation (only) for three estimators are reported in Table 1. Discussing the results of PMG cointegration estimators first, the test offers a common long-run coefficient or elasticity value for the entire panel. The short-run dynamics of the model offer heterogeneous coefficients against each individual cross section of the panel. PMG testing results are reported in the upper section of Table 1. The estimator yields a long run coefficient of value 4.52 which is statistically highly significant (at better than 1 percent significance level) besides holding an intuitively correct sign. The PPP coefficient holding a value of 4.52 can be interpreted as a unit change in the price gap series (specifically rising prices at home) causes the homes exchange rate against foreign to appreciate (or depreciate in nominal terms) by 4.52 units and vice versa. These results are very much comparable with the estimates obtained by (Pippenger, 1993) who determined the validity of PPP for high income European states using bivariate cointegration methods. On the whole, the PMG estimator yields valid empirical support in favor of PPP hypothesis over longer time horizons when U.S. is the major trading partner of European states. The results are in line with (Ali et al., 2021; Chan, Lai, & Liang, 2023; Sedefoğlu & Özden, 2024; Xie, Chen, & Hsieh, 2025). As discussed earlier the underlying dynamics of PMG estimator captures both long- and short-run behavior of model variables. In our investigation of PPP theorem, we also acquired short-run dynamics of subject variables under error correction representation.

**Table 1: Long-Run Estimates for Investigating PPP Hypothesis using PMG, MG and DFE Cointegration Estimators**

| **Pooled Mean Group (PMG) Estimator** | | | |
|---|---|---|---|
| **Long-Run Coefficient** $P^{US}/P^{H}$ | **Standard Errors** | **Z-Statistics** | **Conclusion** |
| 4.521*** | 0.663 | 6.82 | Significant LR coefficient holding intuitively correct sign, PPP therefore holds valid |

| **Mean Group (MG) Estimator** | | | | |
|---|---|---|---|---|
| **Country** | **Long-Run Coefficient** $P^{US}/P^{H}$ | **Standard Errors** | **Z-Statistics** | **Conclusion** |
| Austria | -8.855*** | 2.928 | -3.02 | PPP hypothesis does not hold valid |
| Belgium | -10.981** | 5.195 | -2.11 | PPP hypothesis does not hold valid |
| Bulgaria | 3.13*** | 0.681 | 4.59 | PPP hypothesis holds valid |
| . | . | . | . | . |
| . | . | . | . | . |
| Finland | -4.430* | 2.424 | -1.83 | PPP hypothesis does not hold valid |
| . | . | . | . | . |
| Germany | -5.39 | 4.425 | -1.22 | PPP hypothesis does not hold valid |
| . | . | . | . | . |
| Latvia | 1.168*** | 0.397 | 2.94 | PPP hypothesis holds valid |
| . | . | . | . | . |
| Malta | -16.90 | 23.45 | -0.72 | PPP hypothesis does not hold valid |
| . | . | . | . | . |
| . | . | . | . | . |
| Romania | 16.48 | 26.59 | 0.62 | PPP hypothesis does not hold valid |
| Slovakia | 3.33** | 1.397 | 2.38 | PPP hypothesis holds valid |

| | | | | |
|---|---|---|---|---|
| . | . | . | . | . |
| . | . | . | . | . |
| Spain | 0.985 | 5.06 | 0.19 | .PPP hypothesis does not hold valid |
| Sweden | -46.36 | 47.67 | -0.97 | PPP hypothesis does not hold valid |
| **Dynamic Fixed Effect (DFE) Estimator** | | | | |
| **Long-Run Coefficient** $\boldsymbol{P^{US}/P^{H}}$ | | **Standard Errors** | **Z-Statistics** | **Conclusion** |
| 38.602 | | 37.675 | 1.02 | Insignificant long-run coefficient, PPP therefore does not hold valid |

*NOTE: ***, ** and * indicate the level of statistical significance of estimated coefficients at 1%, 5% and 10%, respectively.*

The model enjoys profound reputation in empirical studies aiming at exploring the exact speed of adjustment in dependent variables owning to its own subsequent movements plus the movements occurring in other model variables. Results from error correction model suggest a mix of valid and invalid error correction process, however, we do not report the model results owing to the belief that the PPP phenomenon is less likely to hold valid over shorter time horizons, as proven from the earlier studies on this line of research (Khan & Qayyum, 2007; MacDonald, 1999; Rogoff, 1996; Taylor, 1988). The Dynamic Fixed Effects (DFE) cointegration estimator offers a common long-run and a common short-run coefficient for the bilateral exchange rate series in response to changes in inter-country price gap series. It restricts the coefficients of cointegrating vector to be equal across the entire panel; therefore, the estimator yields a common long-run coefficient for the estimated model. The last row of Table 1 reports DFE test results for empirically investigating PPP hypothesis in the longer run. The long-run coefficient value we obtain is 38.602 and it is statistically insignificant. Hence contrary to PMG and ECM test results, the DFE estimator indicates that PPP does not hold valid in the long-run when U.S. is the major trading partner of subject European states. The results are consistent with (Arghyrou, Lu, & Pourpourides, 2025; Ishaq, Ghouse, & Bhatti, 2022; Jie & Liu, 2024; Lau et al., 2012). In contrast to PMG and ECM tests but in line with DFE estimator the results obtained from MG estimators strongly negate the valid existence of PPP for our subject economies. Relative to PMG and DFE estimators, MG estimator offers detailed results in the form of country-specific long- as well as short-run coefficients for the member countries of our panel. The results of MG test are reported in the middle row of Table 1. Our panel comprises 27 countries in total, only three countries (Bulgaria, Latvia and Slovakia) are producing a valid long-run coefficient (highly significant besides holding an intuitively correct sign).

A large number of our panel countries are not yielding valid statistical support in favor of PPP hypothesis. The long-run PPP coefficient for Bulgaria, Latvia and Slovakia are 3.13, 1.16 and 3.33, respectively. These values can be interpreted as a unit change in the inter-country price gap series (specifically rising prices at home) causes the homes exchange rate against foreign to appreciate (or depreciate in nominal terms) by 3.13, 1.16 and 3.33 units, respectively. Looking at the magnitude of our estimated long-run coefficients, the estimates differ significantly from the ones obtained in prior researches (Arize, Malindretos, & Ghosh, 2015; Chang & Tzeng, 2011; Papell & Prodan, 2020; Pedroni, 2001). We now head towards testing our estimated models for the (plausible) presence of CSD. In order to establish robustness of our estimates, we employ two distinct tests of CSD offering different scheme of estimation. Both the estimators share common null hypothesis of "cross-sectional independence" against the alternative hypothesis of "cross-sectional dependence". From tests results reported in Table 2, we tend to reject the null hypothesis with high degree of statistical significance, thus, proving the fact that our sample data set is subject to high degree of CSD.

**Table 2: Tests for Cross Sectional Dependence with U.S. as Major Trading Partner**

| Tests | T- Statistics | p-Value | Decision |
|---|---|---|---|
| Pesaran (2004) | 42.689 | 0.000*** | Significant cross-sectional dependence |
| Friedman (1937) | 293.93 | 0.000*** | Significant cross-sectional dependence |

*NOTE: ***, ** and * indicate the level of statistical significance of estimated coefficients at 1%, 5% and 10%, respectively.*

The evidence of CSD amongst our model variables makes the estimates obtained earlier from PMG, MG and DFE estimators less reliable. This is because the assumption of cross-sectional independence is inherent to both PMG and MG models. However, in the instance of CSD, the model errors tend to correlate across cross-sections if the common factors affecting all sample countries are omitted from the sample (Pesaran, Shin, & Smith, 1999), thus, causing a serious violation of one of the major assumptions of ideal error structure i.e. errors are independently distributed. Our sample clearly suffers from cross-sectional dependence (CSD), justifying the re-testing of the PPP hypothesis using second-generation panel cointegration estimators. As discussed earlier, these estimators' key strength is their ability to control for CSD. We re-estimate the PPP model using five second-generation tests: Common Correlated Effects (CCE), Dynamic CCE (DCCE), CCE Pooled (CCEP), Cross-Sectional Error Correction Model (CS-ECM), and Cross-Sectional Autoregressive Distributed Lag (CS-ADL). Results are reported in Table 3. We test the PPP hypothesis across two specifications: (a) using contemporaneous, one-lag, and two-lagged cross-sectional averages; and (b) including up to one differenced-lagged term of bilateral exchange rates and price gaps. Starting with contemporaneous averages, results remain similar to earlier cointegration tests, even after controlling for CSD. Based on the price gap coefficient, we test the null of "no cointegration" against "valid cointegration." For four of five estimators, we fail to reject the null. Only the CS-ECM model supports cointegration, with moderate significance (5% level) and a coefficient of 0.10 with the correct sign. This is supported by the negative and statistically significant adjustment term (*L.ex_rate*), functioning like an error correction term that captures the exchange rate's speed of adjustment toward long-run equilibrium. A significant differenced-lagged price gap term further confirms this adjustment process.

Adding one lag to cross-sectional averages brings no improvement to our initial estimates. This time, none of the CCE-estimator is yielding significant coefficient for price gap series, thus, refuting PPP hypothesis with even better degree of conviction. It is noticeable that CS-ECM does not allow lag inclusion for cross-sectional averages, thus, preventing us for estimating the model for both the cases of lagged cross-sectional averages (one and two lags). Also, the differenced-lagged terms for both exchange rate and price gap appear to be statistically insignificant. The situation however substantially changes as we allow addition of another lagged term to the cross-sectional averages. This time, two out of 5 estimators are supporting PPP theory in long-run. The CCE and CS-ARDL tests are yielding statistically significant coefficient for price gap, holding a value of -1.45 and -2.00 respectively. Nevertheless, acquiring significant coefficient for price gap series cannot be counted as valid evidence in support of PPP, as both the coefficients are holding an intuitively incorrect sign. While modeling PPP through first generation cointegration estimators, we have seen that theoretically price gap should bear a positive long-run coefficient, we therefore decline the plausibility of valid existence of long-run PPP once again, even though permitting two lags to our cross-sectional averages make some of the estimators to produce statistically significant coefficient for price

**Table 3: CCE and CS Estimators Results with U.S. as Major Trading Partner**

| **CCE Estimators (with Contemporaneous Cross-Sectional Averages)** | | | | | |
|---|---|---|---|---|---|
| | **CCE** | **Dynamic CCE** | **CCE Pooled** | **CS-ECM** | **CS-ADL** |
| $price\_gap$ | 0.30<br>(0.24) | -0.25<br>(0.29) | 0.09<br>(0.31) | 0.10**<br>(0.46) | -0.90<br>(0.63) |
| $\Delta price\_gap$ | - | - | - | -1.00**<br>(0.40) | -2.31<br>(1.73) |
| $\Delta price\_gap(-1)$ | - | - | - | - | 1.05<br>(1.21) |
| $L.ex\_rate$<br>*(the adjustment term)* | - | -0.97<br>(0.15) | -0.21<br>(0.43) | -0.71***<br>(0.29) | -1.08<br>(0.10) |
| $\Delta.ex\_rate(-1)$ | - | - | - | - | -0.10<br>(0.04) |
| *Constant* | -<br>0.14****<br>(0.03) | -0.10<br>(0.26) | 0.10<br>(0.21) | - | - |
| **CCE Estimators (with One Cross-Sectional Lag)** | | | | | |
| $price\_gap$ | -0.15<br>(0.42) | -0.33<br>(0.45) | 0.09<br>(0.33) | - | -0.91<br>(0.67) |

| | | | | | |
|---|---|---|---|---|---|
| $\Delta price\_gap$ | | | | | -2.33<br>(1.55) |
| $\Delta price\_gap(-1)$ | | | | | 0.73<br>(1.00) |
| $L.ex\_rate$ *(the adjustment term)* | - | -1.25<br>(0.16) | -0.20<br>(0.58) | - | -1.50<br>(0.22) |
| $\Delta.ex\_rate(-1)$ | | | | | -0.50<br>(0.06) |
| $Constant$ | -0.01<br>(0.01) | -0.29<br>(0.27) | -0.01<br>(0.33) | - | - |

**Table 4**
**CCE Estimators (with Two Cross-Sectional Lags)**

| | | | | | |
|---|---|---|---|---|---|
| $price\_gap$ | -1.45**<br>(0.76) | -1.25<br>(0.84) | -0.24<br>(0.39) | - | -2.00**<br>(0.88) |
| $\Delta price\_gap$ | | | | | -4.25*<br>(2.61) |
| $\Delta price\_gap(-1)$ | | | | | 1.20<br>(1.39) |
| $L.ex\_rate$ *(the adjustment term)* | - | -1.20<br>(0.25) | -0.25<br>(0.54) | - | -1.50***<br>(0.05) |
| $\Delta.ex\_rate(-1)$ | | | | | -0.47***<br>(0.05) |
| $Constant$ | -0.03<br>(-0.96) | -0.23<br>(0.27) | 0.00<br>(0.32) | - | - |

*NOTE*
*I. Standard errors given in parenthesis.*
*I. ***, ** and * indicates the level of significance of estimated coefficients at 1%, 5% and 10%, respectively.*

## 6. Conclusion

The paper investigates the PPP hypothesis over a longer time horizon for 27 European states using first- and second-generation cointegration methods. It makes a commendable contribution by addressing cross-sectional dependence, an issue overlooked in earlier PPP studies. Unlike previous works, this study estimates the long-run cointegrating relationship between bilateral nominal exchange rates and price gaps under both cross-sectional independence and dependence. Overall, the results are not strongly supportive of long-run PPP. Under the assumption of independence, three estimators—PMG, MG, and DFE—are used. Only PMG provides statistically significant support, yielding a long-run coefficient of 4.52 for the price gap series. However, subsequent tests confirm strong cross-sectional dependence, rendering these initial results less reliable. Re-estimation using second-generation estimators confirms mixed outcomes. Only CS-ECM (with contemporaneous cross-sectional averages) supports PPP, showing a valid sign with moderate significance. When two lags are added, CCE and CS-ARDL yield significant but theoretically invalid (negative) coefficients. Thus, the long-run PPP hypothesis remains largely unconfirmed due to the inconsistent behavior of the price gap coefficient.

### 6.1. Implications and Policy Recommendations

From a theoretical perspective, this study highlights a few important limitations. Given the restricted availability of country-level data for Europe, PPP hypothesis can be analyzed empirically under more realistic settings. Taking into account imperfections in commodity and financial markets—known to obstruct PPP—can be very insightful. Incorporating real and financial sector frictions into PPP modeling can reveal the actual degree of resistance to inter-country price convergence. Additionally, empirical exploration using more finely disaggregated (industry or sectoral-level) price data can offer further insights. Literature supports using industry-level data, especially for tradable sectors, to examine real exchange rate issues more realistically. The research's outcome suggests several suggestions for improving policies. The weak and uneven evidence for PPP suggests that European policymakers should use caution when relying on PPP for exchange rate policies. Due to regional differences in responding to shocks, managing exchange rates, inflation, and price stability must account for cross-border influence. Flexible, country-specific policies are preferable to uniform ones. Enhanced economic surveillance, shared monetary decisions, and structural factors like productivity differences and trade patterns can improve exchange rate modeling and coordination. Finally, the study emphasizes the limitations of conventional linear models in capturing real exchange rate dynamics. More sophisticated, non-linear, and second-generation panel methods are needed to address cross-sectional dependence and heterogeneity. PPP-based forecasts should be supported with actual market activity and structural evidence, especially in highly integrated regions like the EU.

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