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TESTING PURCHASING POWER PARITY IN THE EUROZONE: A UNIT ROOT ANALYSIS

Zyad Hebisha [1]
Nile University, Cairo, Egypt
Email: Z.Hosny@nu.edu.eg

Abstract The Purchasing Power Parity (PPP) hypothesis is a central and important equilibrium condition in international finance and macroeconomics, proposing that nominal exchange rates and prices have a proportional relationship and will converge to a constant level over the long run. The Eurozone's creation and establishment have provided an ideal framework to test PPP due to the equivalent set of monetary and economic characteristics required to adopt the Euro. This paper examines the empirical validity of PPP within the initial Eurozone countries using unit root testing methodologies. The research problem presented in this paper lies in the low power nature of unit root testing methodologies that lead to the rejection of PPP. The importance of this paper is determining the validity of the hypothesis of PPP, which is significant in understanding the differences in price levels, purchasing power of different currencies between different countries, and the relative stability of exchange rates through a long-run equilibrium relationship between exchange rates and prices.

Keywords: *PPP, exchange rates, prices, empirical analysis, long-run equilibrium*

JEL Codes: *F31, F41, C22*

[1] ORCID iD 0000-0002-7303-0660

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Introduction

The Purchasing Power Parity (PPP) hypothesis henceforth PPP is one of the central and most important equilibrium conditions in international finance and macroeconomics evidenced by the enormous number of research conducted on this topic.[1] PPP proposes that nominal exchange rates and prices (domestic and foreign) have a proportional relationship and will thus converge to a constant level over the long run. The most common methodology used to test PPP is testing the time series nonstationary properties of the examined data series using unit root tests.

In January 1999, the culmination of several monetary and economic stabilization efforts by the European Union (EU)[2] resulted in the Euro, a single common currency to be used by a group of EU countries that fulfill a set of economic characteristics set forth by the EU. Countries qualifying for the adoption of the Euro are referred to as the Eurozone. The Euro was initially introduced and adopted in 11 countries including Austria, Belgium, France, Finland, Germany, Luxembourg, Ireland, Italy, Portugal, Spain, and the Netherlands. To date, seven additional countries currently have adopted the Euro currency including Cyprus, Estonia, Greece, Latvia, Lithuania, Slovakia, and Slovenia.[3] Due to the equivalent set of monetary and economic characteristics set forth by the EU to adopt the Euro, this has created an ideal case study to examine PPP.

Two of the economic conditions required to join the Euro area which are relevant to PPP include price stability and exchange rate stability. The EU requires countries joining the Euro to have an inflation rate that does not exceed greater than 1.5% than the inflation rates of the three best performing Euro area member nations and that the qualifying country participates in the Exchange Rate Mechanism (ERM II) for a minimum of two years without experiencing strong fluctuations from the ERM II central rate while simultaneously devaluing their own national currency against the Euro in the same time period. The creation and the establishment of the Euro has thus created the ideal framework to test PPP.

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[1] For a review of the extensive literature on PPP, see Sarno & Taylor (2002) Taylor & Taylor (2004) Sarno (2005) and Taylor (2006).

[2] Prior to the introduction of the Euro, the EU attempted other monetary and economic stabilization alternatives including the "Snake" in 1972, the European Monetary System (EMS) in 1979, and the Maastricht Treaty in 1992.

[3] The 7 additional countries are not included in this study because they qualified after the introduction of the Euro in January 1999. Greece joined the Euro area in 2001, Slovenia in 2007, Cyprus & Malta in 2008, Slovakia in 2009, Estonia in 2011, Latvia in 2014, and most recently Lithuania in 2015.

Early studies testing PPP employed post-1973 Bretton Woods data which contained a limited amount of information and data due to the low – frequency nature of the data which is of little use for long-run parity conditions and due to the low power of the econometric techniques used in those studies. To overcome the issue of low – frequency data, the approach of using long-span exchange rate and price data were utilized in testing PPP. To avoid the issue of low power of standard econometric techniques, different methodologies were also developed and used, most notably, panel data testing which enhances testing power and increases the number of observations.

Long-span studies began with Frankel (1986) testing the U.S. dollar – Pound Sterling real exchange rate from 1869 to 1984 and rejected the null hypothesis of a unit root. Diebold et al. (1991) analyzed the real exchange rates of Belgium, France, Germany, Sweden, the UK, and the US using real exchange rates constructed by wholesale and consumer price indices under the gold standard exchange rate regime[4] and found PPP holds using fractional integration methodologies. Lothian & Taylor (1996) found that using dollar-sterling and franc-sterling real exchange rate annual data spanning two centuries that the real exchange rate datasets are stationary. Cuddington & Liang (2000) concluded that using the same real exchange rate dataset used by Lothian & Taylor (1996) the real exchange rate is nonstationary and is sensitive to the choice of the lag length in the augmented Dickey-Fuller unit root test and the inclusion of a deterministic time trend variable. Lothian & Taylor (2000) concluded the work conducted by Cuddington & Liang (2000) further cemented their results despite the inclusion of a time trend because of the statistically significant autoregressive coefficients. Kuo & Mikkola (1999) tested long-run PPP by distinguishing between a stationary autoregressive (AR) and nonstationary Autoregressive Integrated Moving Average (ARIMA) process using 134 years of annual data observations and find PPP holds between the U.S. dollar and the UK Pound Sterling real exchange rate. Lothian & Taylor (2000) reaffirmed their previous work in Lothian & Taylor (1996). Yoon (2008) examined the U.S. – U.K. real exchange rates dataset of Lothian & Taylor (1996) (2000) and by allowing for multiple structural breaks reaffirmed their results.

The PPP literature dominantly features the usage of multivariate unit root tests referred to as panel data methodologies or panel tests. In an effort to enhance the statistical power of unit root tests and increase the number of observations, a number of authors have proposed panel tests which have been sporadically used. Abuaf & Jorion (1990) examined a system of dollar-denominated real exchange rates consisting of 10 Autoregressive (AR)

[3] Other studies that examined PPP under the Gold Standard exchange rate regime see Culver & Papell (1995) Hegwood & Papell (2002) and Paya & Peel (2004).

regressions including Belgium, Canada, France, Germany, Italy, Japan, Netherlands, Norway, Switzerland, and the UK over the data sample of 1973 to 1987 and marginally reject the null hypothesis of a unit root by testing the joint nonstationarity of the real exchange rates. Oh (1996) tested PPP using a panel data framework for G6 and OECD countries consisting of 150 countries over 41 years over the flexible exchange rate regime period from 1950 to 1990 concluding PPP is not completely invalidated. Jorion & Sweeney (1996) examined real exchange rates of Belgium, Canada, France, Italy, Japan, Netherlands, Sweden, Switzerland, UK, and Germany. G10 countries were tested using the U.S. dollar as the numeraire, while European currencies were tested using the German mark. The study concluded that during the flexible exchange rate regime period (1973 – 1993) PPP holds using a multivariate framework. Koedijk et al. (1998) analyzed PPP using panel data methods from 1972 to 1996 on countries including Australia, Austria, Belgium, Canada, Denmark, and other developed countries. The study concluded that PPP is most evident when the German mark is used as the numeraire currency and weaker evidence is provided when the U.S. dollar and Japanese yen are used. Alba & Papell (2007) tested PPP using multivariate unit root tests on a mixed panel consisting of 84 developing and developed countries. The test included organizing countries via criterions including trade openness, proximity to the US, growth, inflation, and nominal exchange rate volatility. The U.S. dollar is used as the numeraire currency, and it is found that European and Latin American country panels exhibit stronger evidence towards mean-reversion behavior as opposed to the weak evidence exhibited for African and Asian countries. The study also found that PPP evidence is stronger when countries have lower inflation, are more open to trade, are closer in proximity to the U.S., moderate levels of nominal exchange rate volatility, and have relative growth rates in term of per capita real GDP similar to that of the US. Lopez (2008) also documented strong evidence for PPP using the DF-GLS-SUR and ADF-SUR panel unit root tests. The test consists of quarterly data from 1973 to 2001 under a flexible exchange rate regime and finds that the DF-GLS-SUR test exhibits consistently stronger results as a result of the enhanced power relative to the ADF-SUR unit root test.

Despite the wide employment of these two methodologies to test PPP they have major flaws. As exhibited through monte Carlo simulations by Taylor & Sarno (1998) panel data methodologies contain the null hypothesis that all data series contain a unit root. The rejection of this null hypothesis indicates that when at least one data series is found to be stationary i.e. null hypothesis is rejected, all data series will also be found to be stationary as a result of the nature of panel data methods. Moreover, Shiller & Perron (1985) have exhibited through Monte Carlo simulations that an increase in the power of unit root tests cannot be achieved through changing the frequency of data observations which would only increase the number of data observations. Since PPP is concerned with the long-run properties of exchange rates and prices, a long-span and low-frequency dataset is required to fully capture the long-run properties of the data.

Long-span studies on the other hand are susceptible to a number of problems. Sample-selection bias or survivorship bias per Froot & Rogoff (1995). As noted by Rogoff (1996) long-span studies contain unclear economic implications due to their inclusion of different exchange rate regimes. Long-span studies may also potentially contain structural breaks as documented in Hegwood & Papell (1998). Engel (2000) also found that long-span studies have size biases.

The aim of this research paper is to test the empirical validity of PPP within the initial Eurozone using unit root testing. The initial Eurozone countries consist of Austria, Belgium, France, Finland, Ireland, Germany, Italy, the Netherlands, Portugal, and Spain using historical exchange rate and consumer price indices data from November 1975 through December 1998.

The research problem presented in this paper lies in the low power nature of unit root testing methodologies that lead to the rejection of PPP. In this paper, rather than using the augmented Dickey-Fuller (ADF) unit root test on its own, which contains low power, the DF-GLS and KPSS unit root tests are also used to lessen the drawback of the ADF's low power.

The importance of this paper is determining the validity of the hypothesis of PPP. PPP is significant as it allows one to understand the differences in price levels, purchasing power of different currencies between different countries, and the relative stability of exchange rates through a long – run equilibrium relationship between exchange rates and prices which is used to determine economic policy and exchange rate models.

Literature Review

A Review of Testing Purchasing Power Party on the Euro Currency

Koedijk et al. (2004) studied the effects of the introduction of the Euro currency in 1999 on real exchange rates of Eurozone countries including Austria, Belgium, Finland, France, Germany, Greece, Italy, the Netherlands, Portugal, and Spain. The article examined monthly nominal exchange rates and consumer price indices to construct the real exchange rates from the period of February 1973 – March 2003. The study used the Seemingly Unrelated Regression (SUR) panel data methodology as well as ADF tests finding that there is evidence that PPP holds during the period of 1973 – 2003 when using the German mark as the numeraire currency. When analyzing the panel of countries for evidence of mean reversion after the adoption of the Euro, PPP does not hold when the Euro is the numeraire currency against the major currencies of Canada, Denmark, Japan, Norway, Sweden, Switzerland, the UK, and the US with the exception of Switzerland. Zhou et al. (2008) examined PPP prior to and after the adoption of the Euro currency. The study employed the nonlinear KSS test on quarterly consumer price indices and nominal exchange rates to construct real exchange rates using Germany, France, and the US as their numeraire currencies. The study consisted of 12 Euro area countries including Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, and Spain as well as 3 EU countries: Denmark, Sweden, and the UK and also included none – European developed countries including Australia, Canada, Japan, New Zealand, Norway, Switzerland, and the US. The data samples included the pre – Euro adoption period (1975 – 1998), the post – Euro adoption period (1998 – 2006) and the full sample period spanning from (1975 – 2006). The test results indicated that during the pre-Euro adoption period there was already evidence of PPP. Gadea (2004) analyzed the real exchange rates of the U.S. dollar against EU currencies after the adoption of the Euro. The analysis revealed that between 1974 to 1996, the unit root null hypothesis is rejected for the following currencies: the Austrian Schilling, Belgian Franc, Danish Krona, French Franc, German Mark, and Dutch guilder, however, when extending the data sample to 2001, the unit root null hypothesis cannot be rejected. Lopez & Papell (2007) concluded that prior to 1992 there is a lack of evidence that PPP holds; however, in 19996 convergence towards PPP is quite rapid. In Lopez & Papell's study they also found that when using the U.S. dollar as the denominating currency there is stronger evidence for PPP contrary to some studies.[5] Gadea (2009) analyzed the U.S. dollar against EU currencies in the post-Breton Woods floating exchange rate regime period. The study found that PPP holds during the observed time period. Koukouritakis (2009) examined the PPP hypothesis using the Johansen cointegration procedure between the 12 EU countries including the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia, Bulgaria, Cyprus, Romania, and Slovenia against the Euro currency and concludes that PPP only holds for Bulgaria, Cyprus, Romania, and Slovenia. Christodou & Panaiotidis (2010) tested PPP using univariate and nonlinear unit root tests for 15 EU countries prior to and after the establishment of the Euro against the U.S. dollar. The study found that in both data samples examined which included the Maastricht Treaty and the introduction of the Euro, PPP is rejected for all countries examined except for the UK. Wu & Lin (2011) investigated if PPP holds prior to and after the adoption of the Euro currency.

[5] Fisher & Park (1991) and Papell (1997) found the German mark presents greater evidence for PPP rather than the U.S. dollar as the numeraire currency.

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Their investigation consists of using three panel unit root tests and conclude PPP holds prior to the launch of the Euro but does not hold after the adoption of the Euro. Most recently, Bierne (2012) examined PPP spanning the period from 1999 to 2009 using the Johansen multivariate cointegration and Larsson panel cointegration methodologies. The study consisted of a total of 15 EU-27 countries 11 of which are not in the Euro area including the UK, Sweden, Denmark, Poland, the Czech Republic, Hungary, Latvia, Lithuania, Estonia, Bulgaria, and Romania.

Hypotheses Development

The augmented Dickey-Fuller unit root test of Dickey & Fuller (1979) (1981) and the Dickey-Fuller Generalized Least Squares unit root test of Elliott et al. (1996) are featured in this paper and contain the null hypothesis: $H_0: \alpha = 0$ where the data contains a unit root (i.e., nonstationary) against the alternative hypothesis: $H_a: \alpha < 0$ where the data contains no unit root (i.e., stationary). Considerable research indicates the augmented Dickey-Fuller unit root test suffers from low power when the truncation lag length is set too low. (Perron & Ng, 1996). Dejong et al. (1989) showed that Dickey-Fuller tests have low power against stable autoregressive (AR) alternatives with roots near unity. Diebold & Rudebusch (1991) exhibited Dickey-Fuller tests have low power against fractionally integrated alternatives. Choi & Chung (1995) showed that heteroskedasticity robust unit root test of Phillips-Perron contains greater statistical power in low data sampling frequencies relative to the augmented Dickey-Fuller unit root test. Lopez (1997) showed the augmented Dickey-Fuller unit root test has low power against moving average (MA) error terms present in the data and that test power increases as sample size increases and test power decrease as more lags are added to the testing model. Previous simulation evidence exists in the literature[6] indicates the general-to-specific (GS) sequential t-statistic procedure is superior to data-dependent methods to select the truncation lag value of k for the augmented Dickey-Fuller unit root test. The null hypothesis is there is a unit root in the data. The alternative hypothesis is there is no unit root in the data. Failure to reject the unit root null hypothesis could very likely be due to the low power of the augmented Dickey Fuller unit root test. To increase test power, the DF-GLS unit root test is used. To serve as a benchmark for comparison, all series of real exchange rates are first tested for a unit root using the ADF test. For long-run PPP to hold, the real exchange rate should be stationary and contain no unit root.

[6] See Campbell & Perron (1991) Hall (1994) Ng & Perron (1995) and Enders & Liu (2014).

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The Dickey-Fuller generalized least squares unit root test has been shown to contain greater statistical power in rejecting the null hypothesis of a unit root as presented in Cheung & Lai (1998). The methodology also suffers from the lag length selection problem in where if the lag length is set too low, the test suffers from size distortions and leads to spurious rejections of the null hypothesis. (Ng & Perron, 2001).

Classical unit root statistical hypothesis testing ensures that the null hypothesis of a unit root cannot be rejected unless there is strong statistical evidence against it. When employing the use of these tests in determining the nature of the time series properties of the data, it is informative to perform confirmatory data analysis by testing for the contrary of the nature of the unit root null hypothesis testing methodologies[7].

Methods

The empirical analysis is based on data from two sources: the Bank of England for exchange rate data and the International Monetary Fund for prices represented by consumer price indices data. The data is composed of monthly – ending nominal exchange rates obtained from the Bank of England's historical exchange rate database website and consumer price indices (CPI) obtained from the International Monetary Fund (IMF)'s International Financial Statistics (data.imf.org). The dataset spans from November 1975 reflecting the floating rate period and ends on December 1998, reflecting the adoption of the Euro. The countries and their respective currencies included in this study are the Austrian Schilling (AST), Belgian Franc (BEF), Finnish Markka (FIM), Irish pound (IEP), German Mark (DEM), French Franc (FRF), Italian Lira (ITL), Portuguese Escudo (PTE), and the Spanish Peso (ESP)[8] against the U.S. dollar (USD) and the Pound sterling (GBP). A total of 278 data observations are included. The data is extracted in level values and then transformed into logarithmic values.

Fig. 1. plots the time series of the real exchange rates of Eurozone countries with the U.S. dollar as the foreign currency in logarithmic values. Fig. 2. plots the time series of the real exchange rates of Eurozone countries with the Pound Sterling as the foreign currency in logarithmic values. Table 1 provides summary statistics for the real exchange rates in the data span from November 1975 to December 1998.

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[7] Culver & Papell (1999) and Caner & Kilian (2001) are two of many other works who used this approach in examining PPP.

[8] Luxembourg was one of the countries in the initial Eurozone, but it is excluded from the set of currencies in this analysis due to its currency union with Belgium at the time.

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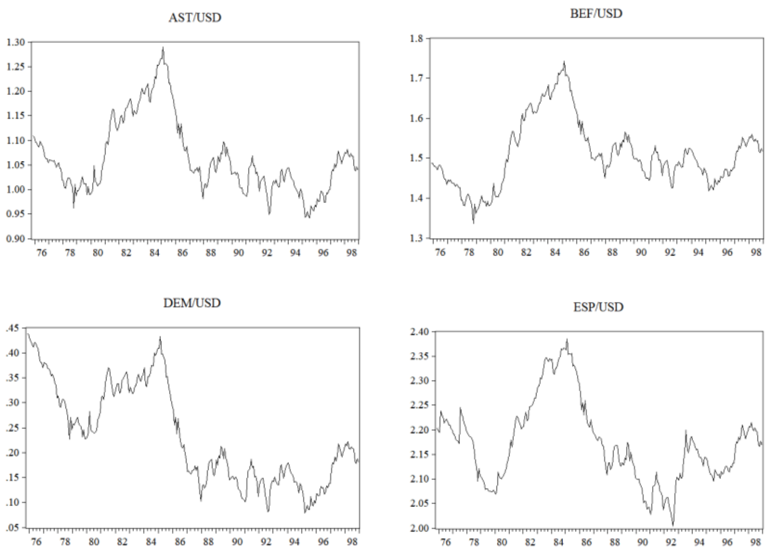
Table 1 Summary Statistics, Eurozone Real Exchange Rates

Variable	Mean	Std. dev.	Minimum	Median	Maximum	Skewness	Kurtosis
AST/USD	1.063756	0.075184	0.941603	1.044455	1.290098	0.960188	3.252992
AST/GBP	1.275381	0.056427	1.158051	1.280426	1.416044	0.196549	2.317513
BEF/USD	1.510024	0.083483	1.336736	1.496919	1.742548	0.656946	2.996213
BEF/GBP	1.721649	0.066169	1.543792	1.738041	1.830253	−0.599431	2.475191
FIM/USD	0.617351	0.064702	0.478808	0.600448	0.784443	0.292618	2.345992
FIM/GBP	0.828976	0.054876	0.673241	0.829746	0.952952	−0.071120	2.569005
FRF/USD	0.703283	0.068154	0.589474	0.689963	0.917990	0.999676	3.621799
FRF/GBP	0.914908	0.047777	0.795465	0.924904	1.002385	−0.242697	2.048810
DEM/USD	0.234329	0.098180	0.079118	0.208765	0.437885	0.358495	1.823333
DEM/GBP	0.445955	0.079473	0.312884	0.430809	0.635212	0.302950	2.141193
ESP/USD	2.173750	0.083082	2.003634	2.168070	2.385657	0.592554	2.834994
ESP/GBP	2.385376	0.050240	2.289728	2.372767	2.497388	0.337428	1.953720
IEP/USD	−0.155660	0.055593	−0.277080	−0.166615	0.012116	0.557437	2.891758
IEP/GBP	0.055958	0.035838	−0.021839	0.053611	0.165347	0.539235	2.576337
ITL/USD	3.209298	0.067146	3.044132	3.202242	3.389244	0.324651	2.857584
ITL/GBP	3.420923	0.045293	3.334653	3.411422	3.541430	0.534245	2.678327
NLG/USD	0.250987	0.071821	0.095807	0.241297	0.475466	0.733816	3.405359
NLG/GBP	0.462612	0.058233	0.292962	0.475711	0.574474	−0.590042	2.501257
PTE/USD	2.296351	0.091058	2.124451	2.275190	2.524946	0.767900	2.866114
PTE/GBP	2.507976	0.071866	2.328184	2.512000	2.646509	−0.180298	2.077553

Note: Summary statistics are presented for monthly real exchange rates constructed using: $q_{it} = s_{it} + q^*_{it} - q_{it}$. Consumer Price Indices (CPI) and numeraire exchange rates are indicated. The number of observations is 278. The full data sample spans from November 1975 – December 1998.



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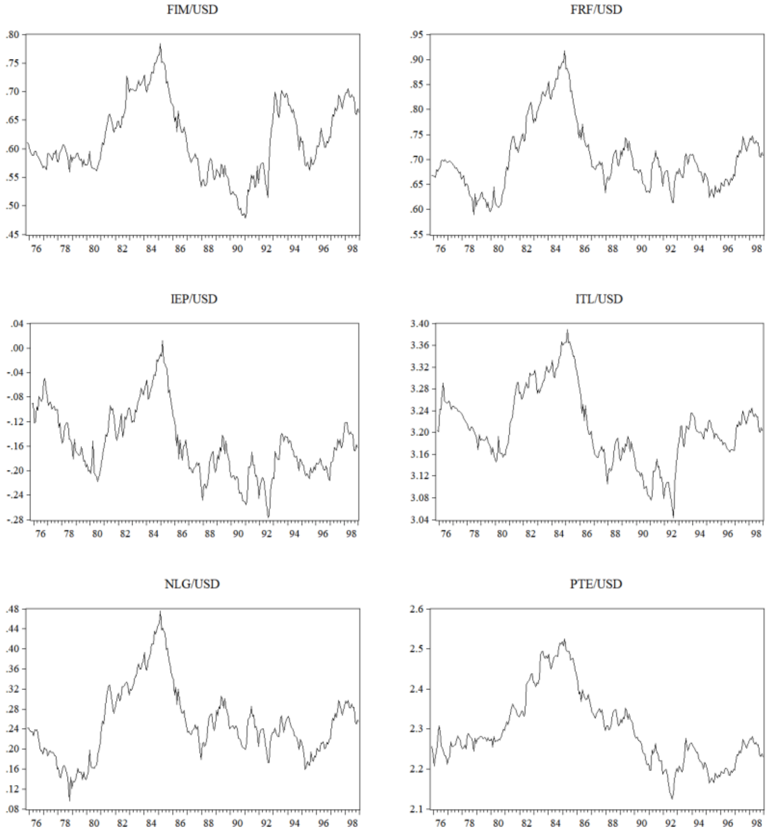

Fig. 1. Eurozone Real Exchange Rates Denominated by the U.S. Dollar.

The above figure depicts the time plots of Eurozone countries real exchange rates denominated by the U.S. dollar (USD) constructed using nominal exchange rates and consumer price indices in logarithmic values from November 1975 to December 1998 including the following: Austrian Schilling (AST), Belgian Franc (BEF), German Mark (DEM), Spanish Peso (ESP), Finnish Markka (FIM), French Franc (FRF), Irish Pound (IEP), Italian Lira (ITL), Dutch Guilder (NLG), and Portuguese Escudo (PTE).

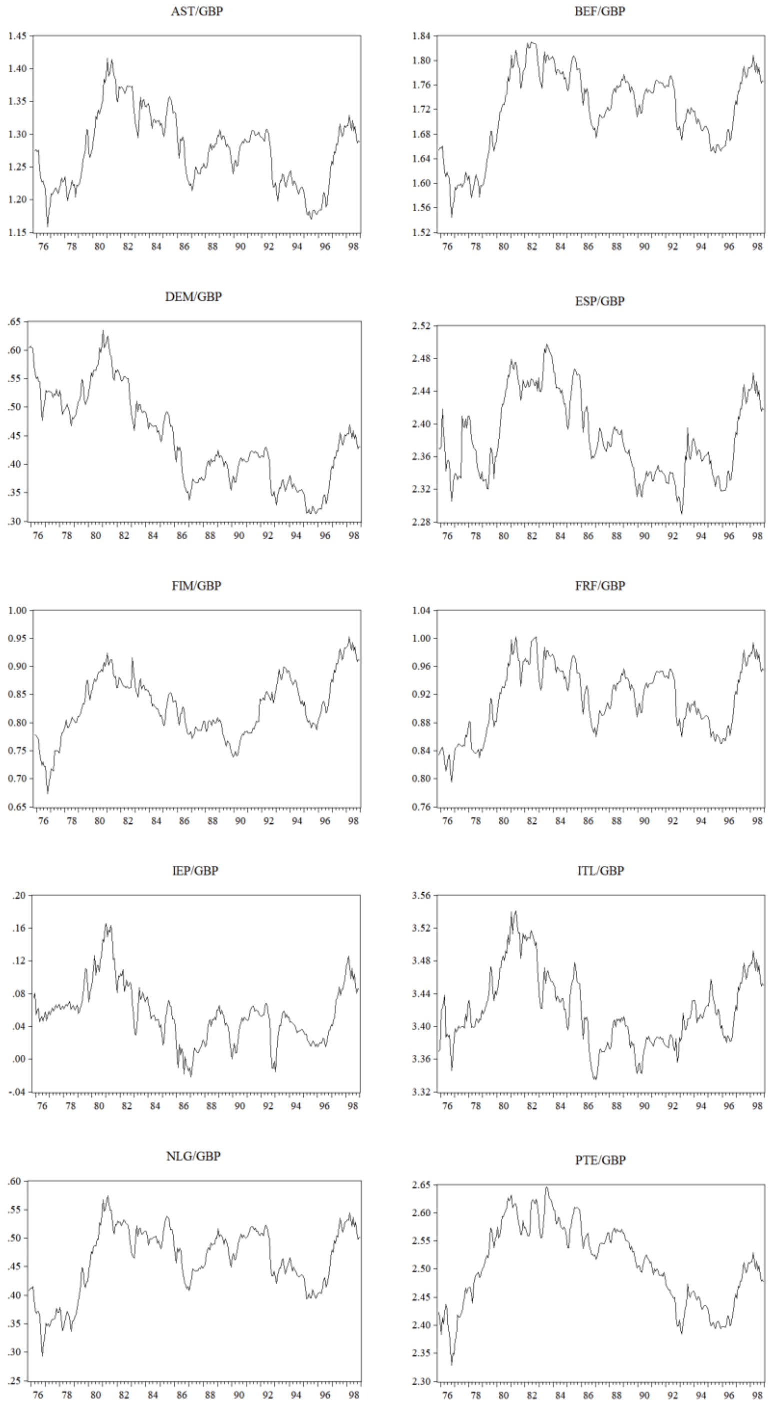

Fig. 2. Eurozone Real Exchange Rates Denominated by the Pound Sterling.

The above figure depicts the time plots of Eurozone countries real exchange rates denominated by the Pound Sterling (GBP) constructed using nominal exchange rates and consumer price indices in logarithmic values from November 1975 to December 1998 including the following: Austrian Schilling (AST), Belgian Franc (BEF), German Mark (DEM), Spanish Peso (ESP), Finnish Markka (FIM), French Franc (FRF), Irish Pound (IEP), Italian Lira (ITL), Dutch Guilder (NLG), and Portuguese Escudo (PTE).

Choice of Tests

The approach used in this paper to empirically test PPP is to use three univariate unit root tests. The augmented Dickey-Fuller unit root test developed by Dickey & Fuller (1979) (1981) and later augmented by Said & Dickey (1984) used for benchmarking. The Dickey-Fuller Generalized Least Squares unit root test developed by Elliott et al. (1996) henceforth referred to as the DF-GLS unit root test used for its enhanced power properties, and a stationarity null unit root test developed by Kwiatkowski et al. (1992) commonly and henceforth referred to as the KPSS test used for confirmatory data analysis.

Empirical Analysis

The PPP hypothesis is based on the law of one price which states similar goods and relative prices should be identical across countries once expressed in a common currency. The hypothesis considers a proportional relationship between the nominal exchange rate and a relative price differential, indicating the real exchange rate is constant over time.

The theory of PPP (in tis absolute form) can be mathematically written as the following in (1):

$$P_{it} = S_{it}P_{it}^{*} \qquad (1)$$

Where P_{it} is the domestic price level of country i, S_{it} is the nominal exchange rate of domestic currency i, and P_{it}^{*} is the foreign price level of country i, all at time t.

The second version of PPP referred to as relative PPP can be written as in (2):

$$\Delta log\ S_{it} = \Delta\ log\ P_{it} - \Delta\ log\ P_{it}^{*} \qquad (2)$$

Where $\Delta log\ S_{it}$ is the nominal exchange rate expressed in domestic currency per foreign currency, $\Delta \log P_{it}$ and $\Delta \log P_{it}^{*}$ are domestic and foreign prices represented, respectively, All variables represented in logarithmic values at time t.

The real exchange rate Q_{it} then becomes a linear combination of the nominal exchange rate, domestic, and foreign price levels. To allow a relative comparison through time, the real exchange is computed in the standard method in (3):

$$Q_{it} = S_{it} P_{it}^{*} / P_{it} \qquad (3)$$

Where Q_{it} is the real exchange rate, S_{it} is the nominal exchange rate, P_{it}^{*}/P_{it} and is the price ratio, all in level values at time t.

Taking logarithm values of the above equation (3) the following (4)is used as the model for testing PPP in this paper:

$$q_{it} = s_{it} + p_{it}^{*} - p_{it} \qquad (4)$$

Where q_{it} is the real exchange rate, s_{it} is the nominal exchange rate, p_{it} is the domestic price level, and p_{it}^{*} is the foreign currency price level. Price levels are represented by consumer price indices (CPI).[9] All variables are expressed in logarithmic values at time t.

ADF Unit Root Test

The augmented Dickey-Fuller unit root test features regressing the first differences value of the real exchange rate q_{it} on a constant mean deterministic regressor, the real exchange rate lagged level value and k lagged first differences is concluded as stationary when the null hypothesis is rejected after finding a is significantly different from zero. The maximum value of k is set to the 15, $k_{max} = 15$. The ADF test involves estimating the following regression in (5):

$$\Delta q_{it} = \mu_i + \alpha_i q_{it-1} + \sum_{i=1}^{k} c_i \, \Delta q_{it-1} + u_{it} \qquad (5)$$

Δq_{it} is the real exchange rate in first differences. μ_i is a mean constant, time trends are excluded to maintain consistency with long-run PPP. u_{it} is an error term. Time trends are excluded to maintain consistency with long-run PPP theory as in (6).

[9] PPP has been tested (most commonly) using consumer price indices see Abuaf & Jorion (1990) Betton et al. (1995) and Edison et al. (1987); Wholesale Price Indices (WPI) see Lothian & Taylor (1996) Michael et al. (1997) and Patel (1990); Producer Price Indices (PPI) see Engel & Kim (1999); Gross Domestic Product (GDP) deflators see Engel (2000) and Sjaastad (1998); Gross National Product (GNP) deflators see Bahmani-Oskooee (1992).

DF-GLS Unit Root Test

Elliott et al. (1996) developed the Dickey – Fuller Generalized Least Square (DF-GLS) regression model based on the augmented Dickey – Fuller regression removing level values for demeaned values to obtain more powerful power properties based on (6):

$$\Delta q_{it}^{d} = \alpha_{it-1}^{d} + \sum_{i=1}^{k} c_i \, \Delta q_{it-1}^{d} + u_{it} \qquad (6)$$

Where q_{it}^{d} is the GLS demeaned real exchange rate. $q_{it}^{d} = q_{it} - \tilde{\beta} z_t$, where $z_t = 1$, $\tilde{\beta} = (\sum \tilde{z}_t^2)^{-1} \times \sum \tilde{z}_t \, \tilde{q}_t$, $\tilde{q}_t = \big(q_1, (q_2 - \alpha q_1) \dots, (q_T - \alpha q_{T-1})\big)'$, $\tilde{z}_t = \big(1, (1-\alpha), \dots, (1-\alpha)\big)'$, $\alpha = 1 + c/T$, and $c = -7$.

4.4 KPSS Unit Root Test

Kwiatkowski et al. (1992) proposed the following model for testing for stationarity around a level or a time trend against the alternative hypothesis of a unit root. The model is represented by (7):

$$y_t = r_t + e_t \qquad (7)$$

r_t is a random walk with $r_t = r_{t-1}$ and e_t is a random error term.

The KPSS test statistic for level stationarity η_μ is computed using (8):

$$\eta_\mu = T^{-2} + \sum_{t=1}^{T} S_t^2 / s^2 \, (l) \qquad (8)$$

Where T is the sample size, l is the lag truncation parameter, $s^2(l)$ is a serial correlation and heteroskedasticity consistent variance estimator, and s_t is the partial sum of the residuals in (9).

$$S_t = \sum_{i=1}^{t} \epsilon_t \;\; t = 1,2 \dots, T. \qquad (9)$$

Results

The augmented Dickey–Fuller unit root test statistics fails to reject the null hypothesis of a unit root with a few minor exceptions. The Finnish Markka denominated by the dollar and the French Franc denominated by the Pound Sterling datasets rejected the null hypothesis at a marginal 10% level of significance with a t-statistic of −2.6016 and −2.6308, respectively. The results for currencies denominated by the dollar are presented in Table 2 and currencies represented by the Pound Sterling are presented in Table 3.

The DF-GLS unit root test statistics reported a greater number of rejections relative to the ADF test including currencies denominated by the U.S. dollar and the Pound sterling. The Austrian Schilling, Belgian Franc, Finnish Markka, Italian Lira, and Netherlands Guilder all reject the null hypothesis at greater levels of statistical significance. The Spanish Peso denominated by the dollar also rejects the null hypothesis however at the conventional 10% of statistical significance. The Austrian Schilling reports a t-statistic of -1.8622, the Belgian Franc -2.2727, the Finnish Markka -2.5900, the Spanish Peso -1.9162, the Italian Lira -2.47298, and the Netherlands Guilder -2.31198. The Austrian Schilling, the Spanish Peso, Irish Pound, Netherlands Guilder. The results for currencies denominated by the dollar are presented in Table 4. Currencies denominated by the Pound Sterling also report a number of rejections at the 10%, 5%, and 1% levels of statistical significance. The Austrian Schilling dataset rejects the null hypothesis at the 5% level of statistical significance with a test statistic value of -2.3670 currencies represented by the Pound Sterling are presented in Table 5.

The KPPS unit root test statistics are reported with four different lag truncation values $l = 4$, $l = 8$, $l = 12$, and $l = 14$. The KPSS unit root test does not reject level stationarity in the following currencies denominated by the U.S. dollar at the 10% level of statistical significance.

The KPSS unit root test rejects level stationarity for the following currencies denominated by the U.S. dollar at the 5% level of statistical significance: the Spanish Peso and the Italian Lira with test statistics values reported at 0.6061 and 0.5973, respectively; while currencies denominated by the Pound Sterling also at the 5% level of statistical significance include the following: the Belgium Franc, Spanish Peso, Irish Pound, Italian Lira, Netherlands Guilder, and the Portuguese Escudo with test statistics values reported at 0.6937, 0.5029, 0.6438, 0.3784, 0.6484, and 0.7344, respectively. The KPSS unit root test rejects level stationarity for the following currencies denominated by the U.S. dollar at the 1% level of statistical significance: the Austrian Schilling, German Mark, Irish Pound, and Portuguese Escudo with test statistics values reported at 0.7482, 2.3069, 0.9426, and 0.9256, respectively.

The results for currencies denominated by the dollar are presented in Table 6. The results for currencies denominated by the Pound Sterling are presented in Table 7.

Table 2 Augmented Dickey – Fuller Test Statistics: United States Dollar-Based Eurozone Real Exchange Rates

$$\Delta q_{it} = \mu_i + \alpha_i q_{it-1} + \sum_{i=1}^{k} c_i \, \Delta q_{it-1} + u_{it}$$

q_{it}	μ	α	k
Austrian Schilling	0.028178 (2.116311)	−0.026548 (−2.124874)	11
Belgian Franc	0.043121 (2.480549)	−0.028407 (−2.471232)	13
Finnish Markka	0.022780 (2.615836)	−0.036600 (−2.601593)*	11
French Franc	0.023600 (2.442569)	−0.033559 (−2.451877)	13
Deutschemark	0.003324 (1.482121)	−0.018125 (−2.054770)	0
Spanish Peso	0.041936 (1.823726)	−0.019381 (−1.833123)	5
Irish pound	−0.007390 (−2.433963)	−0.045017 (−2.450128)	14
Italian Lira	0.100594 (2.453274)	−0.031415 (−2.458349)	11
Netherland Guilder	0.008021 (2.312549)	−0.031279 (−2.342797)	11
Portuguese Escudo	0.036930 (1.634146)	−0.016085 (−1.637156)	12

Note: The above table presents the results from the augmented Dickey – Fuller unit root test. k is selected based on a sequential general-to-specific t-statistic procedure. Coefficients are reported with t-statistics in parentheses. The MacKinnon (1996) critical values for rejection of the null hypothesis of a unit root are −3.453823 at the one percent level, −2.871768 at the five percent level, and −2.572293 at the ten percent level of statistical significance. $*$, $**$, and $***$ denotes statistical significance at the ten, five, and one percent levels, respectively.

Table 3 Augmented Dickey – Fuller Test Statistics: Pound Sterling-Based Eurozone Real Exchange Rates

$$\Delta q_{it} = \mu_i + \alpha_i q_{it-1} + \sum_{i=1}^{k} c_i \, \Delta q_{it-1} + u_{it}$$

q_{it}	μ	α	k
Austrian Schilling	0.039934	−0.031179	7
	(2.370834)	(−2.362634)	
Belgian Franc	0.044128	−0.025383	7
	(2.272717)	(−2.252602)	
Finnish Markka	0.016836	−0.019785	1
	(1.687073)	(−1.646280)	
French Franc	0.037568	−0.040536	7
	(2.660565)	(−2.630809)*	
Deutschemark	0.007505	−0.017727	7
	(1.779172)	(−1.891338)	
Spanish Peso	0.073505	−0.030690	15
	(1.873773)	(−1.865900)	
Irish pound	0.002228	−0.039263	0
	(1.990240)	(−2.326798)	
Italian Lira	0.114516	−0.033399	15
	(1.903242)	(−1.898600)	
Netherland Guilder	0.015475	−0.032661	7
	(2.583246)	(−2.540563)	
Portuguese Escudo	0.053585	−0.021193	15
	(1.944257)	(−1.932865)	

Note: See Table 2 Note.

Table 4 Dickey-Fuller Generalized Least Squares Test Statistics: U.S. Dollar-Based Eurozone Real Exchange Rates

$$\Delta q_{it}^{d} = \alpha_{it-1}^{d} + \sum_{i=1}^{k} c_i \, \Delta q_{it-1}^{d} + u_{it}$$

q_{it}	$DF-GLS$	k_{GS}	$DF-GLS$	k_{IC}
Austrian Schilling	-0.020673 $(-1.862211)^{**}$	11	-0.014002 (-1.349881)	0
Belgian Franc	0.044128 $(2.272717)^{**}$	11	-0.014347 (-1.404234)	0
Finnish Markka	-0.036336 $(-2.590009)^{***}$	11	-0.021078 (-1.672079)	0
French Franc	-0.017137 (-1.529419)	0	-0.017137 (-1.529419)	0
Deutschemark	-0.000511 (-0.113736)	0	-0.000511 (-0.113736)	0
Spanish Peso	-0.020853 $(-1.916187)^{*}$	14	-0.013665 (-1.367721)	0
Irish pound	-0.016581 (-1.365141)	14	-0.016977 (-1.490422)	0
Italian Lira	-0.031479 $(-2.472982)^{**}$	11	-0.020623 (-1.695735)	0
Netherland Guilder	-0.030642 $(-2.311976)^{**}$	11	-0.020505 (-1.689589)	0
Portuguese Escudo	-0.013843 (-1.529788)	12	-0.011052 (-1.227859)	0

Note: The above table presents the results from the DF-GLS unit root test statistic. k is selected based on a sequential general-to-specific t-statistic procedure.[10] Coefficients are reported with t-statistics in parentheses. The MacKinnon (1996) critical values for rejection of the null hypothesis of a unit root are -2.573685 at the one percent level, -1.941974 at the five percent level, and -1.615903 at the ten percent level of statistical significance. $*$, $**$, and $***$ denotes statistical significance at the ten, five, and one percent levels, respectively.

[10] Per Wu (2010) unit root testing is performed using modified Information Criterion (IC) developed by Ng & Perron (2001). The modified Schwarz information criterion (SIC) is reported; however, it should be noted that the modified Akaike Information Criterion also reported equal k lags.

Table 5 DF-GLS Test Statistics: Pound Sterling – Based Eurozone Real Exchange Rates

$$\Delta q_{it}^{d} = \alpha_{it-1}^{d} + \sum_{i=1}^{k} c_i \, \Delta q_{it-1}^{d} + u_{it}$$

q_{it}	$DF-GLS$	k_{GS}	$DF-GLS$	k_{MAIC}
Austrian Schilling	−0.031180 (−2.366965)**	7	−0.027020 (−2.153050)	1
Belgian Franc	−0.011893 (−1.326407)	19	−0.009424 (−1.141503)	1
Finnish Markka	−0.017663 (−1.523359)	18	−0.006938 (−0.721931)	0
French Franc	−0.009037 (−1.082734)	1	−0.009037 (−1.082734)	1
Deutschemark	−0.002410 (−0.512755)	7	−0.002209 (−0.473395)	1
Spanish Peso	−0.026910 (−1.691905)	15	−0.027361 (−1.912539)	0
Irish pound	−0.032649 (−2.134580)	0	−0.032649 (−2.134580)	0
Italian Lira	−0.012435 (−1.015942)	15	−0.016621 (−1.422910)	0
Netherland Guilder	−0.016684 (−1.653828)	7	−0.014055 (−1.455882)	1
Portuguese Escudo	−0.006466 (−0.902671)	15	−0.008993 (−1.219050)	1

Note: See Table 4 Note.

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Table 6 KPSS Test Statistics: United States Dollar – Based Eurozone Real Exchange Rates

$$\eta_\mu = T^{-2} + \sum_{t=1}^{T} S_t^2 / s^2 \, (l)$$

Currency	$l4$	$l8$	$l12$	$l14$
AST	1.306506***	0.748180***	0.534942**	0.483749**
BEF	0.711579**	0.406346*	0.289566	0.240022
FIM	0.396800*	0.229430	0.165833	0.147837
FRF	0.583528**	0.335951	0.241658	0.213705
DEM	4.061280***	2.306943***	1.636025***	1.361047***
ESP	1.062955***	0.606069**	0.432368*	0.382848*
IEP	1.611641***	0.942570***	0.688195**	0.614259**
ITL	1.033729***	0.597278**	0.430875*	0.419397*
NLG	0.639651**	0.368225*	0.264600	0.223489
PTE	1.628863***	0.925593***	0.654009**	0.634626**

Note: The above table represents the results from the Kwiatkowski Phillips Schmidt and Shin (1992) unit root test statistic. l is selected using the Newey & West (1987) heteroskedasticity estimator using the Bartlett kernel. Coefficients are reported with t-statistics in parentheses. The critical values for rejection of the null hypothesis of no unit root are 0.739 at the one percent level, 0.463 at the five percent level, and 0.347 at the ten percent level of statistical significance. Critical values are obtained from KPSS (1992). $*$, $**$, and $***$ denotes statistical significance at the ten, five, and one percent levels, respectively.

Table 7 KPSS Test Statistics: Pound Sterling – Based Eurozone Real Exchange Rates

$$\eta_{\mu} = T^{-2} + \sum_{t=1}^{T} S_t^2 / s^2\,(l)$$

Currency	$l4$	$l8$	$l12$	$l14$
AST	0.778250***	0.451868*	0.327663*	0.290967
BEF	1.204443***	0.693721**	0.498402**	0.440229*
FIM	0.952219***	0.551400	0.400935*	0.357125*
FRF	0.921661***	0.540055	0.394147*	0.350963*
DEM	4.173964***	2.380534***	1.694123***	1.489409***
ESP	0.858283***	0.502992**	0.369162*	0.329642
IEP	1.078489***	0.643817**	0.477293**	0.427678*
ITL	0.642521**	0.378390**	0.276888	0.246608
NLG	1.116341***	0.648388**	0.470316**	0.417734*
PTE	1.282137***	0.734377**	0.522805**	0.459397*

Note: See Table 6 Note.

Discussion

The augmented Dickey-Fuller unit root test's inability to reject the null hypothesis of a unit root comes as to no surprise due to the overwhelming empirical evidence conducted on the power properties the ADF test itself as well as previous empirical tests which employ the unit root test. Although there were a couple of rejections of the null hypothesis by the ADF test, they were at conventional levels, which does not lend support to PPP holding.

The DF-GLS unit root test lag length was constructed using the general-to-specific sequential t-statistic procedure and the modified Bayesian and Akaike information criterions. Lag lengths constructed using the modified information criterion resulted in 0, while the general-to-specific sequential t-statistic procedure selected a higher number of lags with k_{max} set to 15, as such the focus of the results is towards the test statistics values reported by the general-to-specific sequential t-statistic procedure. Rejection of the null hypothesis indicates the real exchange rate exhibits stationary properties and presents evidence for PPP.

The KPSS unit root test which as previously mentioned is used to confirm the rejection of the null hypothesis from the DF-GLS unit root test is not spurious. That is, if the KPSS unit root test does not reject the null of stationarity, then the rejection of the null of nonstationary of the DF-GLS unit root test presents evidence for PPP holding. Using four different values for l, the focus is leaned towards the value of $l8$ since it is the most conservative value for l and rejection of the null hypothesis indicates evidence against PPP after finding a statistical significance of 5% or 1%.

Conclusion

This paper has examined the validity of the PPP hypothesis on the initial Eurozone countries consisting of Austria, Belgium, France, Finland, Germany, Italy, Spain, Portugal, and the Netherlands against the U.S. dollar and the Pound sterling spanning from November 1975 until December 1998. The methodology used in this paper to test PPP is to employ unit root testing, but rather than using the augmented Dickey-Fuller test on its own, the DF-GLS and KPSS unit root testing methodologies are incorporated to hinder the primary drawback of the augmented Dickey-Fuller test which is its lack of power. As expected and evidenced by nearly every other study on PPP using unit root testing, the augmented Dickey-Fuller unit root test could not reject the null hypothesis of a unit root with a few marginal exceptions. The Dickey-Fuller Generalized Least Squares unit root test however was able to reject the null hypothesis of a unit root for a greater number of currencies and using the KPSS test through confirmatory data analysis was able to reach the correct conclusion regarding stationarity. Therefore, PPP holds for the Eurozone currencies for the time analyzed.

The author’s contributions to the literature are as the following: to the author’s knowledge, no other paper has examined PPP using the augmented Dickey-Fuller unit root test, the DF-GLS and KPSS unit root testing methodologies jointly.[11]

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[11] Other studies have used the DF-GLS unit root test to enhance power and the KPSS for confirmatory data analysis, but not all three methodologies together.

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