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Purchasing Power Parity before and after the Adoption of the Euro

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Abstract: This paper examines the purchasing power parity (PPP) hypothesis for the post–Bretton Woods era including the period after the introduction of the euro. The study applies a new nonlinear unit root test to the bilateral real exchange rates (RERs) of both European and other industrial countries with the French franc and German mark (and the euro after 1998), as well as the US dollar as numeraire currencies. The results of the study provide stronger support for PPP than any earlier studies of bilateral PPP for industrial countries and suggest that (1) PPP tends to hold well within the European Union (EU) even before the adoption of the euro, (2) the evidence for PPP becomes more significant for both EU and non-EU countries when the sample period is extended to the euro era, and (3) convergence toward PPP between the EU countries, especially between the euro-area countries, tends to be nonlinear, while it is likely to be linear for the non-EU industrial countries. JEL no. F31, F33, G15, C22
Keywords: Purchasing power parity; nonlinear stationarity; real exchange rates; single currency area

1 Introduction

This paper revisits the issue of purchasing power parity (PPP) in industrial countries, especially those in the euro area. Besides the well-known theoretical reasons, studying PPP for the euro area is significant for at least three reasons. First, if PPP holds, this means that the effects of a shock to the real exchange rates (RERs) would be only temporary, suggesting that euro-area wide real exchange shocks would not have detrimental effects on trade flows

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within the region at least in the long run.[1] Second, if PPP holds for the euro area, this would imply almost no RER risk due to price level convergence. The latter issue is critical not only for policymakers but also from the point of view of asset pricing and portfolio management (as explained in Koedijk et al. (2004)). Third, if PPP tends to hold better for the euro area after the introduction of the euro in 1999 than for other countries, this would imply that PPP may hold better within a single currency area than, say, within a trade block, such as NAFTA or countries that do not participate in a trade block or a currency zone. One policy implication of the latter is that price level convergence is more likely to take place in a single currency area, such as the euro area, than does between other countries.[2]

However, as pointed out by Koedijk et al. (2004: 1082), "...Remarkably few empirical studies examine the behavior of real exchange rates for the euro area. In particular, only a very limited number of academic papers study the hypothesis of purchasing power parity (PPP) for the euro". These few studies of PPP within the euro area (e.g., Alquist and Chinn 2002; Gadea et al. 2004; Lopez and Papell 2007) rely either on panel or the univariate augmented Dickey–Fuller (ADF) unit root tests to examine the stationarity of RERs and provide limited support for PPP.

Using the ADF tests and quarterly data of the synthetic real dollar/euro exchange rate for the period 1985Q1–2001Q4, Alquist and Chinn (2002) find that the RER is nonstationary, suggesting that PPP does not hold for the euro area.[3] Gadea et al. (2004) analyze the behavior of the RER of the US dollar versus the European Union (EU) currencies in the post–Bretton Woods era and test for a weaker version of long-run PPP in the sense that, apart from the permanent effects of some structural breaks on the RERs, "the rest of the observations show a stationary pattern" (Gadea et al. 2004: 1120). Based on the use of some new unit root statistics, introduced in their paper, with two structural breaks in the 1980s, Gadea et al. (2004) find some support for such a weaker version of PPP for the period 1974–1996. When they include the observations of the post-euro period, however, they do not obtain evidence for PPP for any currency in their sample.

[1] Cushman (1983) and Milesi-Ferretti and Razin (1998) provide evidence on the impact of RER changes on international trade in the European context. Cushman (1983) reports a significant and negative effect of RER risk on international trade flows. Milesi-Ferretti and Razin (1998) find that countries with less appreciated RERs tend to suffer less current account reversals and grow faster than those with higher levels of RER risk.

[2] For a discussion of this and related issues, see Rogers (2007).

[3] This is an updated version of Chinn (2002)'s NBER Working Paper 8824.

Lopez and Papell (2007) apply panel unit root tests to the quarterly real dollar exchange rates for 23 countries from 1973Q1 to 2001Q4. They find strong convergence toward PPP for the majority of the euro area countries starting in 1992 or 1993, coinciding with the adoption of the Maastricht Treaty in 1992. They also test for PPP between euro area and other European countries and find that PPP holds better within the euro zone than between the euro area and other European, negotiating, industrialized, and Mediterranean countries. Moreover, they show that, even within the euro area, evidence for PPP is sensitive to the choice of the numeraire currency. While Lopez and Papell (2007) take into account heterogeneous intercepts and serial correlation in their panel tests, they keep the restriction that the speed of mean reversion is the same for all RERs in the panel. Their tests thus do not provide information on which particular bilateral RERs are stationary, nor on for which country pairs PPP hold. The rejection of nonstationarity in their panel study may result from the stationarity of only a few but not all RERs, i.e., aggregation bias.

Koedijk et al. (2004) also use panel unit root tests to study PPP within the euro zone. Using RERs based on consumer price indices for the same euro area countries as utilized in Lopez and Papell (2007), they collect monthly data against the US dollar for the period 1973M2–2003M3. They employ a Seemingly Unrelated Regression (SUR) methodology that not only allows heterogeneous serial correlation between the error terms but also varying rates of mean reversion across a panel of RERs. When they impose a common speed of mean reversion, their results are consistent with that of Lopez and Papell (2007) in that PPP tends to hold better within the euro area after the Maastricht Treaty of 1992 when the German mark is used as a numeraire currency. However, relaxing that assumption by allowing different rates of mean reversion produces rather diverse results: while PPP still holds for some of the euro area countries, it does not for many others (6 out of 10 cases). They declare that "...the case of convergence [toward PPP] is not as clear-cut as previous studies imply" (Lopez and Papell 2007: 1094). They also find that, save Switzerland, PPP does not hold well between the euro area and other industrial countries.

Although heterogeneous panel unit root tests employed in earlier studies can account for different speeds of mean reversion across RERs, they cannot account for the accumulating empirical evidence that some RERs tend to exhibit a nonlinear mean reversion process. If RERs follow nonlinear stationary processes, the alternative hypothesis of linear stationarity in the ADF tests and panel unit root tests would be misspecified.

There are a few theoretical explanations for why we would expect nonlinear adjustment toward PPP and, correspondingly, the existence of nonlinearity in RERs.[4] One potential source arises from nonlinearities in international goods arbitrage because of factors such as transportation costs and trade barriers, causing a price gap among similar goods traded in spatially separated markets.[5] Another source of nonlinearity in RERs comes from official interventions in the foreign exchange market, which may cause the nominal and RERs to move away from the equilibrium levels. The exchange rates may adjust nonlinearly toward their long-run equilibrium with the speed of adjustment varying with the distance from the equilibrium level. Deviations of the exchange rates from the underlying equlibrium levels, generated by central banks' foreign exchange interventions, may carry nonlinearity to the adjustment of the nominal exchange rate, and, given sticky prices, to the adjustment of the RERs as well.[6]

These two main sources of nonlinearity in RERs proposed in the existing literature may have different impact on the RERs with different numeraire currencies. The first source may have less effect on the behavior of the RERs within the euro area than that of the US dollar based RERs because, while transportation and transaction costs could be significant for all these countries, trade barriers are supposed to be low among the euro countries. The second source could be significant with regard to the RERs of the euro-area countries as many of them experienced frequent official interventions in the foreign exchange market to keep their currency values within the target zone under the Exchange Rate Mechanism during the 1980s and 1990s.[7] Therefore, a comparison of the test results for linear or nonlinear stationarity in the RERs with different numeraire currencies may provide information on relative importance of different sources in generating the nonlinear behavior of the RERs.

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[4] Taylor (2003) reviews related theories and summarizes the available empirical evidence.

[5] A number of recent theoretical studies that emphasize the role of transaction costs have turned to nonlinear dynamic adjustment models to explain the behavior of RERs and hence to test PPP (e.g., Michael et al. 1997; Sarantis 1999; Taylor et al. 2001; Sarno and Taylor 2002; Taylor 2003; Sarno et al. 2004). A general finding from these studies, based on the post-1973 floating rate period data and a battery of real exchange rates, is that some selected rates can be characterized by nonlinear mean reversion.

[6] Refer to Taylor (2003) and Sarno and Taylor (2001) for more explanations.

[7] For a discussion of official intervention during EMS area, see, among others, Dominguez and Kenen (1992) and Brandner et al. (2006). For recent surveys of foreign exchange rate interventions and their effectiveness, see Edison (1993) and Sarno and Taylor (2001).

The mixed evidence found in the earlier studies on the validity of PPP within the euro area added to the accumulating theoretical argument and the evidence that some RERs exhibit nonlinear mean reversion motivate us to use nonlinear unit root tests to further test the validity of PPP within the euro zone and between the euro area and other industrial countries. In our study, we use a testing procedure suggested by Kapetanios, Shin and Snell (hereafter, KSS) (2003) who developed a new technique for the null hypothesis of a unit root against an alternative of nonlinear stationary smooth transition autoregressive (STAR) process. KSS (2003) tests are more powerful than the standard ADF tests for the series that may revert to the mean nonlinearly. Chortareas and Kapetanios (2004), Hasan (2004) and Liew et al. (2004) have recently applied the KSS tests to the bilateral RERs of Japan, India, and a group of Asian countries, respectively. More recently, Bahmani-Oskooee et al. (2007 and 2008) apply the KSS tests to the real effective exchange rates (REERs) of 88 developing countries and 23 OECD countries, respectively. However, to our best knowledge, the direct application of nonlinear unit root tests to the bilateral RERs of the euro area countries is lacking.

Although examining the stationarity of REERs, which indicate movement in the overall value of a country's currency against the country's major trading partners, could be viewed as a test of the multicountry version of PPP, it cannot provide information on evaluating PPP between particular country pairs. The rejection of the null hypothesis of nonstationarity in a REER may come from the situation when the behavior of the REER is dominated by the mean-reverting movement in the country's currency value against one or few major trading partners, instead of all countries included in the measure of REER. Yet, whether PPP holds on a bilateral basis is still interesting, especially for its validity as a building block in modeling economic relations between two countries and for the evaluation of different degrees of economic convergence within a region.

Our study makes several contributions to the PPP literature. First, we test whether the adoption of the euro has contributed to PPP to hold better (Roger 2007). To do so, we consider two sample periods: 1973–1998 and 1973–2006. Second, we utilize the KSS tests to account for the nonlinearity that could be present in RERs, and report both the ADF and KSS tests to compare the inferences produced by each method. A rejection of the null hypothesis of nonstationarity by the KSS tests and failure to reject the null by the ADF tests would be the indication for the presence of nonlinear reversion in RER. Third, in addition to the analysis of PPP for the euro area countries, we also investigate the validity of PPP for the non-euro area countries to explore the possibility of different patterns of mean reversion in RERs within and outside the euro area. Fourth, we use three different currencies as numeraires, namely, US dollar, German mark and French franc (and the euro equivalent after 1998), to investigate the implications of the choice of numeraire currency in examining the (non)stationarity of RERs and to shed light on relative importance of different sources in generating the nonlinear behavior of the RERs.[8] Another reason why we use both German mark and French franc as numeraire currencies is to see whether the 1990 German unification has had an impact on the convergence to PPP.

2 Methodological Issues[9]

The ADF test is perhaps the most commonly used test to identify the order of integration of a time series variable. It sets the null to be nonstationarity of a variable against an alternative of stationarity. A large body of empirical literature fails to reject unit roots in RERs, and thus fails to support PPP (refer to Rogoff (1996) and Sarno (2005) for a comprehensive survey of the empirical literature on PPP). Such evidence does not necessarily refute PPP, however, because conventional univariate unit root tests such as the ADF test have relatively low power to reject a false null hypothesis of unit roots (e.g., Campbell and Perron 1991; Lothian and Taylor 1996, 1997) and are sensitive to the choice of lag length (e.g., Cuddington and Liang 2000). In response to the low power of the conventional tests, KSS (2003) have recently expanded the standard ADF test by keeping the null hypothesis as nonstationarity in a time series variable against the alternative of a nonlinear but globally stationary process. Their new test is based on the following exponential smooth transition autoregressive (ESTAR) specification:

$$\Delta y_t = \gamma y_{t-1}\left[1 - \exp\left(-\theta y_{t-1}^2\right)\right] + \varepsilon_t, \qquad \theta \geq 0(1) \tag{1}$$

[8] Papell and Theodoridis (2001) test the PPP hypothesis during the flexible exchange rates period by conducting panel unit root tests with twenty-one different base currencies. Their results suggest that the selection of numeraire currency is critical for inferences on PPP. They find that PPP holds better for European than for non-European base currencies.
[9] This section draws on Bahmani-Oskooee et al. (2008) who apply the KSS methodology to the REERs of 88 developing countries.

where y_t is the de-meaned or de-trended series of interest, is an i.i.d. error with zero mean and constant variance, and $[1 - \exp(-\theta y_{t-1}^2)]$ is the exponential transition function adopted in the test to present the nonlinear adjustment. The null hypothesis of a unit root in y_t (i.e., $\Delta y_t = \varepsilon_t$) implies that $\theta = 0$ (thus $[1 - \exp(-\theta y_{t-1}^2)] = 0$). If θ is positive, it effectively determines the speed of mean reversion.

The KSS test directly focuses on the θ parameter by testing the null hypothesis of nonstationarity $H_0 : \theta = 0$ against the mean-reverting nonlinear alternative hypothesis $H_1 : \theta > 0$. Because γ in (1) is not identified under the null, we cannot directly test $H_0 : \theta = 0$. To deal with this issue, KSS reparameterize (1) by computing a first-order Taylor series approximation to specification (1) to obtain the auxiliary regression expressed by (2) below:

$$\Delta y_t = \delta y_{t-1}^3 + \text{ error } . \tag{2}$$

Assuming a more general case where the errors in (2) are serially correlated, regression (2) is extended to

$$\Delta y_t = \sum_{j=1}^{p} \rho_j \Delta y_{t-j} + \delta y_{t-1}^3 + \text{ error} \tag{3}$$

with the p augmentations, which are used to correct for serially correlated errors. The null hypothesis of nonstationarity to be tested with either (2) or (3) is $H_0 : \delta = 0$ against the alternative of $H_1 : \delta < 0$. KSS show that the t-statistic for $\delta = 0$ against $\delta < 0$, i.e., t_{NL}, does not have an asymptotic standard normal distribution. They tabulate the asymptotic critical values of the t_{NL} statistics via stochastic simulations.

In this paper, we estimate the t_{NL} statistics using both regressions (2) and (3) and refer to them as t_{NL11} and t_{NL12}, respectively, for de-meaned data, and t_{NL21} and t_{NL22}, respectively, for de-trended data. To obtain the de-meaned or de-trended data, we first regress each series on a constant or on both a constant and a time trend, respectively, and then we save the residuals. We also estimate the conventional ADF test statistics and denote them as t_{ADF1} for the model with a constant only, and t_{ADF2} for the model with a constant and a time trend.

The tests are applied to the bilateral RERs of industrial countries with French and German currencies (and their euro equivalent after the adoption of the euro), as well as US dollar as numeraire currencies. Following the suggestion of KSS (2003: 365), the number of augmentations p for either the ADF tests or the KSS tests is selected based on significance testing procedure in Ng and Perron (1995). The maximum number of p was set to 8 for our quarterly data, and insignificant augmentation terms were excluded.[10]

3 Data, Sample Period, and the Empirical Results

Quarterly consumer price indices are collected from the OECD *Economic Indicators*. End-of-period bilateral nominal exchange rates are obtained from the International Monetary Fund (IMF)'s *International Financial Statistics* online. The sample period runs from 1973Q1 to 2006Q4. Because the maximum number of lag length in (3) was set to be 8 (as suggested in KSS (2003)), the first 9 quarterly observations are used to compute the lagged RER changes for the tests thus the sample period effectively starts from the second quarter of 1975.

RERs are computed for 12 euro area EU countries (Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, and Spain), 3 non-euro area EU countries (Denmark, Sweden, and the United Kingdom) and 7 non-EU industrial countries (Australia, Canada, Japan, New Zealand, Norway, Switzerland, and the United States) The bilateral RERs with US dollar as numeraire are constructed by

$$rer_{i,us} = s_i - p_i + p_{us} ,$$

where s_i is country i's currency price of a dollar, p_i and p_{us} are the price indices of country i and the United States, respectively. Those with French and German currencies as numeraire are

$$rer_{i,fr} = s_i - p_i - s_{fr} + p_{fr} \text{ or } rer_{i,gm} = s_i - p_i - s_{gm} + p_{gm} ,$$

where s_{fr} and s_{gm} are French and German currency prices of a dollar, respectively. p_{fr} and p_{gm} are the price indices of France and Germany, respectively. All these variables are in their logarithmic form. For 1999–2006, the dollar exchange rates of the euro area countries (including France and Germany) are calculated by $s_i = s_{euro} + s_j$, where s_{euro} is the log of the euro price of a dollar and s_j is the log of a euro-zone country's currency conversion rate of a euro (irrevocably fixed at the rates set on January 1, 1999).

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[10] It is found that the tests with a fixed number of augmentations, $p = 8$, or with selected number of augmentations yield very similar results. In other words, the results of the tests are not very sensitive to the models with a few more insignificant augmentation terms. To save space, only the results with selected number of augmentations are reported. The rest of the results are available from the authors upon request.

We report the results of the KSS tests along with those of the standard ADF tests for the bilateral RERs with the French currency as numeraire currency in Table 1. Table 2 and Table 3 report the results for the RERs with the German currency and the US dollar as numeraire currency, respectively. In these tables, six statistics are reported. The test statistic of the standard ADF that only includes a constant is denoted by t_{ADF1}. Two tests outlined by (2) and (3) are applied to de-meaned data. The KSS test with no augmented terms that is based on (2) is denoted by t_{NL11} and the one with augmented terms that is based on (3 is denoted by t_{NL12}. The comparable statistic with a trend in the ADF test is t_{ADF2} and the two KSS statistics without and with augmentation for de-trended data are t_{NL21} and t_{NL22}, respectively. The rejection of the null of nonstationarity by t_{ADF1} and/or by the KSS tests with de-meaned data would be the evidence for level stationarity. Failure to do so but ability to reject the null by t_{ADF2} and/or by the KSS tests with de-trended data supports trend stationarity.

Note that a level stationary RER is consistent with PPP in a strict form, while a trend stationary RER would be consistent with a modified view of PPP, which allows the long-run (equilibrium) RERs to vary around a linear trend. The presence of such a trend in RERs may reflect the well-known Balassa–Samuelson type effects, resulting from the differential rates of productivity growth in traded and nontraded goods sectors of a country relative to that of the country whose currency is used as a numeraire currency in measuring RER.[11] Besides, letting p_j and p_{num} denote the price indices of country j and the numeraire currency country, respectively, and s_j represent country j's currency price of the numeraire currency, convergence toward PPP may take place as the wide dispersion between $(p_j - s_j)$ and p_{num} is reduced over time as they move closer toward each other, resulting in a trend in the distance between $(p_j - s_j)$ and p_{num}. In such a case, a trend stationary RER $(= s_j - p_j + p_{num})$ is also an indication of convergence to PPP.

The results show that during the period 1975–1998, the null hypothesis of nonstationary RER is rejected by either the ADF and/or KSS tests for 17 out of total 21 cases (including 8 out of 11 cases of euro area, 3 non-euro area EU cases, and 6 out of 7 non-EU cases) with the French franc at the 10 percent significance level and 12 out of 21 cases at the 5 percent level of significance. The corresponding figures are 13 and 7 cases with the German mark and 12 and 4 cases with the US dollar at the 10 and 5 percent significance levels, respectively. The results suggest that there is evidence

[11] For more on this see Bahmani-Oskooee et al. (2008).

Table 1: *Unit Root Test Results for the Bilateral Real Exchange Rates with the French Currency as Numeraire* [a]

	t_{ADF1}	t_{NL11}	t_{NL12}	t_{ADF2}	t_{NL21}	t_{NL22}	t_{ADF1}	t_{NL11}	t_{NL12}	t_{ADF2}	t_{NL21}	t_{NL22}
	1975Q2–1998Q4						1975Q2–2006Q4					
EU countries: euro area												
Austria	−2.01	−2.28	−2.43	−4.45***	−3.09	−4.08***	−1.91	−2.55	−2.75*	−4.01***	−3.82**	−5.30***
Belgium	−2.26	−2.38	−2.55	−2.13	−3.02	−3.28*	−2.47	−2.82*	−3.03**	−2.45	−3.19*	−3.22*
Finland	−2.27	−2.30	−2.68*	−2.33	−2.28	−2.65	−2.30	−2.38	−2.66*	−2.82	−2.20	−2.44
Germany	−2.61*	−3.30**	−4.63***	−2.76	−3.34*	−4.69	−2.96**	−3.67***	−5.05***	−3.23*	−3.82**	−5.35***
Greece	−2.15	−2.30	−2.63	−2.70	−2.20	−2.52	−1.27	−1.71	−1.90	−2.93	−2.07	−2.33
Ireland	−1.74	−1.90	−1.98	−1.70	−2.12	−2.52	−1.51	−1.54	−1.68	−2.15	−2.42	−2.95
Italy	−1.81	−2.80*	−2.88*	−2.01	−2.73	−2.86	−1.99	−3.41**	−3.51**	−2.35	−3.24*	−3.40*
Luxembourg	−2.16	−2.06	−2.50	−2.40	−2.98	−3.74**	−1.93	−2.42	−2.95**	−1.84	−2.95	−3.64**
Netherlands	−3.44**	−2.44	−3.31**	−3.86**	−2.99	−4.25***	−3.43**	−3.31**	−4.65***	−3.44**	−2.98	−4.09***
Portugal	−0.87	−1.66	−0.98	−2.27	−3.88**	−2.69	−0.56	−1.50	−0.93	−2.78	−4.60***	−3.20*
Spain	−1.95	−1.77	−1.38	−1.92	−2.10	−1.77	−1.84	−2.53	−2.09	−2.41	−2.10	−1.65
EU countries: non-euro area												
Denmark	−2.30	−3.25**	−3.62***	−3.61**	−4.07***	−5.05***	−1.95	−3.09**	−3.33**	−4.04***	−4.53***	−5.60***
Sweden	−2.36	−2.17	−1.95	−3.52**	−2.25	−1.97	−1.68	−2.67*	−2.21	−4.14***	−2.33	−1.84
UK	−2.30	−2.45	−2.72*	−2.46	−2.73	−2.95	−1.80	−1.72	−1.72	−2.33	−2.56	−2.56
Non-EU countries												
Australia	−2.31	−2.69*	−2.93**	−3.22*	−2.50	−2.70	−2.99**	−2.90*	−2.97**	−3.35*	−3.20*	−3.28*
Canada	−2.24	−1.53	−2.06	−2.72	−1.69	−2.22	−3.17**	−1.81	−2.05	−3.47**	−2.05	−2.64
Japan	−1.87	−2.18	−1.89	−3.12	−3.48**	−4.55***	−2.30	−2.34	−2.24	−1.23	−0.67	−0.68
New Zealand	−3.14**	−3.02**	−3.15**	−3.31*	−3.32*	−3.41**	−2.85*	−3.32**	−3.05**	−3.69**	−3.88**	−3.81**
Norway	−2.96**	−2.56	−3.14**	−3.03	−2.54	−3.10	−3.60***	−3.10**	−3.51***	−3.60**	−3.29*	−3.80**
Switzerland	−2.51	−2.07	−1.95	−4.27***	−4.01***	−4.61***	−2.59*	−2.21	−2.15	−3.64**	−4.02***	−4.64***
US	−2.71*	−1.32	−1.79	−2.72	−1.32	−1.79	−2.97**	−2.10	−2.87*	−2.90	−1.88	−2.54

[a] t_{ADF1} and t_{ADF2} are the standard ADF test statistics for the null of nonstationarity of the variable in the study without and with a trend, respectively, in the model for testing. t_{NL11} and t_{NL12} are the KSS test statistics for the de-meaned data using the models without and with augmentations, respectively. t_{NL21} and t_{NL22} are the KSS test statistics for the de-trended data using the models without and with augmentations, respectively. The 10, 5, and 1 percent asymptotic critical values for t_{ADF1} are −2.57, −2.86, and −3.43, respectively, and those for t_{ADF2} are −3.12, −3.41, and −3.96, respectively. The 10, 5, and 1 percent asymptotic critical values for t_{NL11} and t_{NL12} are −2.66, −2.93, and −3.48, respectively, and those for t_{NL21} and t_{NL22} are −3.13, −3.40, and −3.93, respectively, taken from Kapetanios et al. (2003: 364). *, **, and *** denote rejection of the null hypothesis at the 10, 5, and 1 percent significance levels, respectively.

Table 2: *Unit Root Test Results for the Bilateral Real Exchange Rates with the German Currency as Numeraire* [a]

	t_{ADF1}	t_{NL11}	t_{NL12}	t_{ADF2}	t_{NL21}	t_{NL22}	t_{ADF1}	t_{NL11}	t_{NL12}	t_{ADF2}	t_{NL21}	t_{NL22}
	1975Q2–1998Q4						1975Q2–2006Q4					
EU countries: euro area												
Austria	−1.94	−2.76*	−1.93	−1.14	−1.74	−1.45	−2.20	−2.65	−1.79	−1.84	−2.38	−1.98
Belgium	−1.86	−1.67	−2.03	−2.60	−1.72	−2.29	−2.26	−1.86	−2.24	−2.37	−2.09	−2.75
Finland	−2.51	−2.14	−3.63***	−2.60	−2.12	−3.56**	−2.50	−2.13	−2.88*	−2.96	−2.04	−2.78
France	−2.61*	−3.30**	−4.63***	−2.76	−3.34*	−4.69	−2.96**	−3.67***	−5.05***	−3.23*	−3.82**	−5.35***
Greece	−2.57*	−2.77*	−2.58	−3.23*	−2.48	−2.38	−1.43	−1.56	−1.12	−3.13*	−2.39	−2.21
Ireland	−1.54	−1.90	−2.21	−1.14	−2.15	−2.60	−1.44	−1.81	−2.13	−1.72	−2.45	−3.44**
Italy	−2.05	−2.31	−2.43	−2.08	−2.24	−2.40	−2.35	−2.76*	−2.96**	−2.47	−2.64	−2.85
Luxembourg	−1.55	−1.52	−1.77	−2.55	−1.66	−2.08	−2.26	−1.66	−2.07	−2.21	−2.04	−3.20*
Netherlands	−1.70	−2.72*	−2.92*	−3.00	−3.63**	−3.32	−2.32	−2.34	−3.05**	−2.16	−2.33	−3.04
Portugal	−2.24	−1.72	−2.20	−3.78**	−3.18*	−3.68**	−0.97	−1.36	−1.27	−4.36***	−3.86**	−4.36***
Spain	−2.24	−1.78	−1.83	−2.21	−1.88	−1.98	−2.39	−2.44	−2.55	−2.66	−1.98	−2.03
EU countries: non-euro area												
Denmark	−1.94	−1.23	−1.14	−2.26	−2.03	−1.92	−1.64	−1.99	−1.87	−2.69	−2.46	−2.42
Sweden	−2.09	−2.07	−2.45	−3.43**	−2.49	−2.94	−2.23	−2.98**	−3.41**	−4.06***	−2.63	−3.02
UK	−2.41	−2.25	−2.89*	−2.43	−1.95	−2.48	−1.97	−1.93	−2.07	−2.30	−1.94	−2.08
Non-EU countries												
Australia	−2.15	−2.55	−2.83*	−3.04	−2.51	−2.73	−2.79*	−2.84*	−2.95**	−3.19*	−3.18*	−3.29*
Canada	−2.05	−1.44	−1.92	−2.51	−1.65	−2.12	−2.60*	−1.71	−1.91	−2.87	−1.92	−2.13
Japan	−2.16	−2.48	−2.43	−2.05	−3.06	−3.33*	−2.34	−2.54	−2.30	−1.14	−0.57	−0.40
New Zealand	−2.71*	−3.20**	−2.94**	−2.71	−3.41**	−3.18*	−2.68*	−3.57**	−3.06**	−3.01	−4.09***	−3.71**
Norway	−1.66	−2.13	−2.33	−1.80	−2.21	−2.45	−2.34	−2.80*	−2.74*	−2.35	−2.78	−2.70
Switzerland	−2.92**	−2.54	−2.52	−2.83	−4.97***	−5.34***	−3.15**	−2.40	−2.39	−2.66	−4.71***	−4.83***
US	−2.59*	−1.17	−1.76	−2.62	−1.17	−1.76	−2.92**	−1.75	−2.55	−2.86	−1.59	−2.31

[a] See note to Table 1.

Table 3: *Unit Root Test Results for the Bilateral Real Exchange Rates with the US Dollar as Numeraire* [a]

	t_{ADF1}	t_{NL11}	t_{NL12}	t_{ADF2}	t_{NL21}	t_{NL22}	t_{ADF1}	t_{NL11}	t_{NL12}	t_{ADF2}	t_{NL21}	t_{NL22}
	1975Q2–1998Q4						1975Q2–2006Q4					
EU countries: euro area												
Austria	−2.41	−1.42	−1.94	−2.70	−1.36	−1.85	−2.78*	−1.87	−2.50	−2.84	−2.11	−2.67
Belgium	−2.51	−1.17	−1.50	−2.47	−1.15	−1.49	−2.82*	−1.71	−2.43	−2.73	−1.49	−2.15
Finland	−2.90**	−1.69	−2.49	−2.88	−1.69	−2.49	−2.75*	−2.05	−2.99**	−2.92	−2.16	−3.13*
France	−2.71*	−1.32	−1.79	−2.72	−1.32	−1.79	−2.97**	−2.10	−2.87*	−2.90	−1.88	−2.54
Germany	−2.59*	−1.17	−1.76	−2.62	−1.17	−1.76	−2.92**	−1.75	−2.55	−2.86	−1.59	−2.31
Greece	−2.24	−1.06	−1.62	−2.44	−1.07	−1.62	−2.54	−1.30	−1.91	−2.79	−1.49	−2.20
Ireland	−2.06	−2.53	−2.50	−3.03	−2.35	−2.42	−2.84*	−3.02**	−3.62***	−3.15*	−3.01	−3.53**
Italy	−2.62*	−1.83	−2.34	−2.89	−1.77	−2.26	−2.89**	−2.48	−3.18**	−2.90	−2.49	−3.20*
Luxembourg	−2.09	−1.19	−2.50	−2.05	−1.17	−1.48	−2.78*	−1.77	−2.49	−2.68	−1.51	−2.16
Netherlands	−2.75*	−1.23	−1.81	−2.71	−1.22	−1.80	−3.03**	−1.79	−2.54	−2.95	−1.62	−2.32
Portugal	−1.70	−1.28	−1.60	−2.21	−1.29	−1.59	−2.03	−1.29	−1.68	−2.65	−1.64	−2.06
Spain	−2.61*	−1.35	−2.33	−2.91	0.129	−2.25	−3.04**	−1.75	−2.87*	−3.14*	−1.91	−3.15*
EU countries: non-euro area												
Denmark	−2.11	−1.14	−1.39	−2.21	−1.14	−1.39	−2.87**	−1.52	−1.85	−2.88	−1.59	−1.92
Sweden	−2.88**	−1.60	−2.67*	−2.99	−1.74	−2.84	−2.81*	−2.16	−3.21**	−3.24*	−2.41	−3.64**
UK	−2.79*	−2.11	−2.87*	−3.48**	−1.81	−2.49	−2.68*	−1.90	−2.32	−3.91**	−2.09	−2.56
Non-EU countries												
Australia	−1.76	−1.74	−2.05	−2.41	−1.97	−2.12	−2.30	−1.61	−1.92	−2.22	−2.12	−2.62
Canada	−1.02	0.53	−0.21	−1.85	−0.94	−1.70	−2.23	−1.72	−2.34	−2.44	−1.62	−2.55
Japan	−2.10	−1.92	−2.20	−3.05	−2.56	−3.72**	−2.40	−2.15	−2.49	−2.23	−2.19	−2.70
New Zealand	−2.85*	−1.88	−2.92*	−3.06	−1.88	−2.93	−3.74***	−2.23	−3.54***	−3.71**	−2.23	−3.52**
Norway	−2.73*	−1.52	−1.63	−2.71	−1.53	−1.63	−3.12**	−2.27	−2.64	−3.08	−2.14	−2.45
Switzerland	−2.59*	−1.67	−2.31	−2.97	−1.66	−2.34	−2.98**	−2.25	−2.62	−3.03	−2.34	−3.09

[a] See note to Table 1.

for PPP (at least in its modified version and at the 10 percent significance level) for most of the countries in the study, especially for the RERs of the French franc, before the adoption of the euro. Evidence for stationary RERs is stronger for the rates versus the French franc than those versus the German mark, implying that the 1990 German unification may have somewhat slowed down the convergence toward PPP.

When we consider the period 1975–2006, there is more rejection of the null hypothesis of nonstationarity in the RERs (15, 10, and 13 out of 21 cases with the currencies of France, Germany, and the United States, respectively) at the 5 percent significance level than that using the 1975–1998 data (12, 7, and 4 cases, correspondingly). This may reflect enhanced statistical power of the tests due to the inclusion of additional observations in the sample with the expanded time span of the data. It may also indicate that there is more convergence toward PPP when the floating rate sample period becomes longer, along with more economic integration among the countries in the study.

Comparing the results of the KSS tests with those of the ADF, the results of the KSS tests show more evidence to reject the null of nonstationarity (in about twice the number of cases) than the ADF for the RERs of EU countries versus the currencies of France and Germany. However, when the RERs are expressed with respect to the US dollar, the ADF tests show more evidence to reject the null than the KSS tests. Also, in the full sample period of 1975–2006, the ADF tests show more evidence to reject the null than the KSS for the RERs of non-EU countries versus the currencies of France and Germany. These results imply that convergence toward PPP between the EU countries, especially in the euro area, tends to be nonlinear, yet it is still likely to be linear for the non-EU industrial countries.

Overall, our test results provide strong support for bilateral PPP for industrial countries. For the full sample period of 1975–2006, there is evidence of rejecting the null of nonstationary RER by the ADF and/or KSS tests at the 10 percent significance level for most of the RERs with all three numeraire currencies. For a total of 44 cases (out of 60 bilateral RERs in the study) of rejecting the null of nonstationarity in favor of level or trend stationary RERs, 38 of them show the evidence for level stationarity in these RERs. There is a rejection for the null of nonstationarity at the 10 percent significance level for 10 out of 14 EU countries' and 6 out of 7 non-EU countries RERs with French currency, and 13 out of 15 EU (including 10 out of 12 euro-zone and all 3 non-euro-zone EU countries') and 3 out of 6 non-EU RERs with US dollar. There is also strong evidence for a stationary

RER of New Zealand or Switzerland (two non-EU countries) with any of three numeraire currencies. The results suggest that accounting for nonlinearity provides more support for the rejection of the unit root in the bilateral RERs of members of a currency union, as well as the bilateral RERs of countries outside the union.

4 Conclusions

We examine whether PPP holds better in the years after the adoption of the euro. Toward this end, our empirical study is conducted for the full sample period (1975–2006), including the post-euro period, as well as for the pre-euro sample period (1975–1998). The investigation is carried out by applying both the KSS nonlinear unit root tests and the standard ADF tests to a set of bilateral RERs of industrial countries. Overall, our test results provide stronger support for PPP than any earlier studies of bilateral PPP for industrial countries.

The test results for the pre-euro period of 1975–1998 suggest that there was already evidence for PPP for most of EU countries during this period, although the 1990 German unification may have somewhat slowed down the convergence toward PPP. When the data of the post-euro period is included, the evidence for PPP becomes more significant for both EU and non-EU countries. There is evidence of increasing convergence toward PPP for the longer flexible-rate period and the adoption of the euro may have contributed to this increasing convergence during the period of 1975–2006. Yet, we cannot conclude that the use of the euro has played an essential role for better performance of the PPP hypothesis within the euro area, nor can we say that PPP holds better within a single currency area than between other countries.

Whereas we find evidence of rejecting the null of nonstationary RER by the ADF and/or KSS tests for most of the RERs for period 1975–2006, KSS tests provide more evidence for PPP than the ADF for the RERs of EU countries against the currencies of France and Germany, but not for the RERs against the US dollar, nor for the RERs of non-EU countries with respect to the French franc and the German mark. These results suggest that convergence toward PPP between the EU countries, especially among the euro-area countries, tends to be nonlinear, but is likely to be linear for the non-EU and between EU and non-EU industrial countries. Tracing back to the potential sources of nonlinearity in RERs proposed in the existing literature, the RERs within the EU countries are supposed to be less affected by trade barriers, but more so by official interventions in the foreign exchange market, especially after the introduction of the euro. Our test results may thus reveal an important piece of information that, in generating the nonlinear behavior of the RERs, official interventions in the foreign exchange market seem to have played a more significant role in the recent years over the existence of trade barriers in international goods arbitrage. Our results are preliminary, however. Further empirical evidence from other episodes is necessary to better understand the relative importance of interventions over trade barriers in generating nonlinearities in bilateral RERs.

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