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European exchange rate regimes and purchasing power parity: An empirical study on eleven eurozone countries ☆

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ABSTRACT

It is widely believed that following the adoption of the euro, long run purchasing power parity (PPP) is more likely to hold within the euro countries. By applying the panel unit root test of Pesaran (2007) to real exchange rate data of eleven euro countries for the sample period of January 1957 to May 2013, we find that, contrary to the above intuition, the evidence for the mean-reverting in real exchange rates is much weaker in the post-1998 euro period than in the pre-euro period. In contrast, we find that for the four countries not using the euro: Norway, Sweden, Switzerland, and the UK, the evidence for the mean-reverting in real exchange rates is strong in both the pre- and post-euro (post-1998) periods. Moreover, through our panel estimation of the error correction model using the common correlated effects (CCE) estimators a la Pesaran (2006), we find that the flexibility of nominal exchange rates is crucial for the adjustment of real exchange rates to PPP.

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1. Introduction

Has the introduction of the euro led to more integrated product markets in the eurozone and made the law of one price as implied by the purchasing power parity (PPP) easier to achieve? The conventional wisdom is that lower transaction costs via the adoption of a single currency should encourage greater cross-border trade (arbitrage) among the euro countries and hence induce faster price convergence, c.f., Rose (2000). Furthermore, as has been argued by Engel and Rogers (2004), in a flexible exchange rate regime, volatile movements in nominal exchange rates due to speculative short-term capital flows might lead to frequent currency misalignments that make the PPP equilibrium harder to achieve.[2] By alleviating the speculative attacks and the accompanying currency misalignments, the adoption of the euro might help for the attainment of the law of one price among the euro countries. In contrast, as the purchasing power parity can be achieved not only through arbitrage in the goods market that induces goods prices to adjust, but also through currency trade in the foreign exchange market that induces the nominal exchange rate to adjust, the added benefit of the

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[2] One possibility of the volatile movements of real exchange rate under the floating exchange rate regime is the well-known argument for the "overshooting" exchange rate a la Dornbusch (1976).

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adjustment channel provided by the flexibility of nominal exchange rate might be crucial for the attainment of the parity. Accordingly, the adoption of the euro might work against the attainment of one price among the euro countries since the adjustment of the nominal exchange rate is completely absent here.

In the past empirical literature on real exchange rate adjustment to PPP under different nominal exchange rate regimes, no consensus has been reached.[3] On the one hand, some studies found that the mean-reverting of real exchange rate under the fixed exchange rate regime is more pronounced than under the flexible exchange rate regime, e.g., Mussa (1986) and Parsley and Popper (2001). On the other hand, some recent studies found weaker evidence of mean-reverting of real exchange rate for many euro countries under the euro regime, which represents an extreme form of fixed exchange rate, than under the regimes with more flexible exchange rate, e.g., Rogers (2007), Christidou and Panagiotidis (2010), and Wu and Lin (2011). Furthermore, there are also studies showing no clear-cut difference in the mean-reverting behavior of real exchange rates across fixed and flexible nominal exchange rate regimes, e.g., Grilli and Kaminsky (1991), Lothian and Taylor (1996), and Bissoondeeal (2008), among many others.

In view of the aforementioned conflicting empirical results, in the current paper we examine how changes in nominal exchange rate regime, especially the launch of the euro, affects the adjustment of real exchange rates to PPP equilibrium in euro countries. We focus our study on eleven eurozone countries that are among the first to adopt the euro: Austria, Belgium, Finland, France, Germany, Ireland, Italy, Luxembourg, the Netherlands, Portugal and Spain. One advantage of doing so is that these countries all experienced similar but drastic changes in the nominal exchange rate arrangement during the sample period.[4] In particular, the breakup of the Bretton Woods system in the early 1973, the introduction of the European exchange rate mechanism (ERM) in March 1979, and the launch of the euro in January 1999 all represent clear breaks in nominal exchange rate arrangements and provide ideal natural experiments for the study of PPP. Moreover, because the countries studied belong to a relatively integrated market where the barrier of trade and transportation costs have generally been low, our study should provide more clear-cut results than most previous studies by limiting the impact of the distorting factors on PPP adjustment.[5] Since the launch of the euro has been the focus of many previous studies on the effect of exchange rate regime on PPP convergence, we also utilize this event to examine whether and how real exchange rates behaved differently before and after the launch of the euro for two groups of advanced European countries: the "treatment group" of eleven countries adopting the euro in 1999 and the "control group" of four countries: Norway, Sweden, Switzerland, and the UK, that continued using the flexible exchange rate regimes after the euro launch. This group comparison turns out to shed important light on the possible cause of the slow adjustment of real exchange rates for the euro countries after the launch of the euro.

It is worth noticing that an alternative empirical approach adopted in the past literature is to explore the speed of real exchange rate convergence for countries with different exchange rate arrangements within the same sample period, e.g., Parsley and Popper (2001) and Bissoondeeal (2008). One disadvantage of the approach is that heterogeneity in social, political and economic conditions in the countries studied usually has important implications not only on the exchange rate arrangement adopted but also on the speed of PPP convergence,[6] and failure to take complete account of these conditions will result in a spurious relationship between the exchange rate arrangement and the speed of real exchange rate convergence. In contrast, by focusing on a relatively more homogenous group of countries with common changes in exchange rate regimes, our approach avoids the aforementioned complications.

In the current study, we employ panel unit root tests to examine the mean reverting property of real exchange rate under different exchange rate regimes. As the slow adjustment speed of real exchange rates has been the subject of considerable debate in the literature; cf. Rogoff (1996), we also compute the "half-lives" of real exchange rate adjustments to PPP under different regimes using panel estimation of auto-regression models of real exchange rates. In addition, to explore the roles of nominal exchange rates and relative prices played in the adjustments of real exchange rates in different regimes, we employ panel estimation of error correction models consisting of regressions of nominal exchange rate and relative prices on the lagged real exchange rate and the first difference of lagged dependent variables.

We find from our panel unit root tests and the estimated "half-life" that the mean-reverting property of real exchange rate for the eleven euro countries is weakest in the post-1998 euro regime period while strongest in the floating exchange rate period. In contrast, we find that for the four advanced European countries not using the euro: Norway, Sweden, Switzerland, and the UK, the evidence for the mean-reverting in real exchange rates is strong in both the pre-euro period and the post-euro (post-1998) period. From our panel estimation of the error correction model, we find that the flexibility of nominal exchange rate is crucial for the adjustment of real exchange rate to PPP.

The remainder of this article is organized as follows. Section 2 provides data description and conducts panel unit root tests to examine the mean-reverting property of real exchange rate under different exchange rate regimes. Section 3 uses panel error correction model estimation to explore the roles of relative prices and nominal exchange rates played in the convergence of real exchange rates to PPP under different nominal exchange rate regimes. Section 4 compares the mean-reverting behavior of real exchange rates between a "control group" and a "treatment group" of advanced European countries for the pre- and post-euro periods to check for robustness of our major empirical results. Section 5 provides the concluding remarks.

[3] For a review of the vast literature on PPP, see Taylor and Taylor (2004) and Taylor (2006).

[4] To our surprise, in the past empirical literature on PPP, only a very limited number of works studied PPP hypothesis for the pure eurozone countries. See, for example, Koedijk, Tims, and van Dijk (2004), Christidou and Panagiotidis (2010), and Wu and Lin (2011).

[5] Rogoff (1996) shows that trade barriers and transportation costs can explain why PPP might not hold in a large international framework. Funke and Koske (2008) suggest that focusing the analysis on an integrated market with restricted geographical expansion allows limiting the impact of these distorting factors. In addition, due to the proximity of the eurozone countries, transportation costs play a less important role on a eurozone level than on an intercontinental level.

[6] One example is that low-income countries tend to impose higher tariffs to protect their domestic industries and while at the same time prone to more fixed exchange rate regimes. For a detailed study on the factors affecting the exchange rate regime choice in emerging market economies, see, for example, Ghosh (2014).

2. Real exchange rates and the PPP hypothesis

Defining $e_{ij,t}$ as the logarithm of the nominal exchange rate (expressed as the number of units of country j's currency where one unit of country i's currency can exchange) and $p_{i,t}$ and $p_{j,t}$ as the logarithm of aggregate price level of country i and country j, respectively, we examine the logarithm of the real exchange rate,

$$q_{ij,t} = e_{ij,t} + \left(p_{i,t} - p_{j,t}\right),$$

of eleven eurozone countries over different nominal exchange rate regimes. To construct the real exchange rate series, the monthly data of Consumer Price Indexes (CPIs) and nominal exchange rates for eleven eurozone countries: Austria, Belgium, Finland, France, Germany, Ireland, Italy, Luxembourg, the Netherlands, Portugal and Spain are gathered from International Financial Statistics (IFS) and Datastream. The data covers the period from January 1957 to May 2013 and all series are seasonally unadjusted.[7] We examine the role of nominal exchange rate arrangements on the behavior of real exchange rates by dividing the sample period into four different regimes: the January 1957 to February 1973 Bretton Woods fixed exchange rate regime, the March 1973 to February 1979 floating exchange rate regime, the March 1979 to December 1998 pegged-float regime of European ERM, and the post-1998 euro dollar regime.

Table 1 reports, for each nominal exchange rate regime, the average of sample variances of all pairwise real exchange rates, nominal exchange rates and relative nominal prices, as well as the average of sample covariances between nominal exchange rate and relative nominal prices. We report the sample statistics for the detrended data and the differenced data (all in natural logarithm) in panels A and B, respectively. We also plot the differenced data (i.e., the growth rates) for real exchange rates, nominal exchange rates and relative nominal prices in Fig. 1. Here, to keep the graph simple, we only plot the series constructed using Germany as the benchmark country.

From Table 1 and Fig. 1, two important features of the data stand out. First, it appears that the average volatility of real exchange rates in the post-1998 euro regime period is much less than that for the pre-euro regimes. For example, the sample variance for the differenced real exchange rates in the post-1998 euro regime is merely 0.0000227 while that in the pre-1973 Bretton Woods regime is 0.0002855. Second, for all nominal exchange rate regimes except the euro regime, the volatility of nominal exchange rates is greater than that of relative nominal prices, and this is true even in the Bretton Woods regime where the adjustment of nominal exchange rate was relatively infrequent. This reflects that nominal prices are generally stickier than nominal exchange rates.

We next examine the mean reverting property of the real exchange rates. The PPP hypothesis implies that the real exchange rate is mean reverting over time, i.e. the real exchange rate is a covariance stationary process. Therefore, by investigating the order of integration of the real exchange rate using unit root tests, the PPP hypothesis can be tested. The failure to reject the unit root null is interpreted as evidence against the PPP. In this paper, we employ the cross-sectionally augmented panel unit root test (CIPS test) of Pesaran (2007) to investigate whether the PPP holds or not. As stressed by O'Connell (1998), panel unit root tests can be spuriously favoring PPP if there exist significant degrees of positive error cross-section dependence and this is ignored. The CIPS test of Pesaran (2007) is specially designed to correct for the effect of cross-sectionally dependent errors on the test result. The test takes into account the possible cross-sectionally dependent errors by augmenting the standard ADF regression with the cross-section averages of lagged levels and first differences of the individual series. The cross-sectional augmented ADF equation (CADF) is given by:

$$\Delta q_{ij,t} = a_{ij} + b_{ij} q_{ij,t-1} + c_{ij} \overline{q}_{t-1} + \sum_{k=0}^{p} d_{ijk} \Delta \overline{q}_{t-k} + \sum_{k=1}^{p} \delta_{ijk} \Delta q_{ij,t-k} + \varepsilon_{ij,t}, \tag{1}$$

where a_{ij} is a deterministic term, $\overline{q}_{t-1}$ is the cross-section mean of q_{ij} at time $t-1$, and p is the lag order. Let $t_{ij}(N, T)$ denote the corresponding t-statistic of b_{ij}, where N is the number of cross-sectional (i, j) pairs and T is the number of time periods. The panel unit root test is based on the average of the individual cross-sectionally augmented ADF statistics as follows,

$$\text{CIPS} = \frac{1}{N} \sum_{ij=1}^{N} t_{ij}(N, T)$$

The simulated critical values of CIPS for various sample sizes are reported in Pesaran (2007). As the testing for PPP has been found to be sensitive to the choice of the numeraire country (see, e.g. Lopez (2008); Lopez & Papell (2007); Papell & Theodoridis (2001)), in our empirical estimation we adopt all the pairwise bilateral real exchange rates as our panel samples.[8] With eleven eurozone countries considered, there are 55 pairwise real exchange rate series (i.e., $N = 55$) in our sample. The sample mean and time trend have also been removed from each series for our panel regression estimation.

[7] Our data start from 1957 because, for most countries studied, reasonably good data for nominal exchange rates and CPIs can be obtained from IFS and Datastream. Because CPI data for Ireland are only available after 1969, we use the data from the website of Ireland Central Statistics Office: http://www.cso.ie/px/pxeirestat/database/eirestat/Consumer%20Prices%20Monthly%20Series/Consumer%20Prices%20Monthly%20Series.asp.

[8] The practice has been championed by Pesaran, Smith, Yamagata, and Hvozdyk (2009).

Table 1
Mean of the variance of individual data.

	All	Fixed	Floating	ERM	Euro
	1957:01	1957:01	1973:03	1979:03	1999:01
	2013:05	1973:02	1979:02	1998:12	2013:05
(A) Detrended					
$Var\ (q_{ij})$	0.0076	0.0039	0.0030	0.0061	0.0003
$Var\ (e_{ij})$	0.0381	0.0040	0.0040	0.0090	0
$Var\ (p_j - p_i)$	0.0315	0.0013	0.0008	0.0060	0.0003
$Cov\ (e_{ij}, p_j - p_i)$	−0.0309	−0.0007	−0.0009	−0.0044	0
(B) Differenced					
$Var\ (\Delta q_{ij})$	0.0002855	0.0005126	0.0005426	0.0002158	0.0000227
$Var\ (\Delta e_{ij})$	0.0002473	0.0004468	0.0004918	0.0001793	0
$Var\ (\Delta(p_j - p_i))$	0.0000691	0.0000903	0.0001657	0.0000468	0.0000227
$Cov\ (\Delta e_{ij}, \Delta(p_j - p_i))$	−0.0000154	−0.0000122	−0.0000567	−0.0000051	0

Notes: q_{ij} represents the real exchange rate, e_{ij} represents the nominal exchange rate, and $p_j - p_i$ represents the relative price. All are in natural logarithms.

Table 2 summarizes the results of Pesaran (2007)'s panel unit root test.[9] As the results show, for the whole sample period of January 1957 to May 2013, the unit root null in the real exchange series is rejected at the 1% level. Moreover, the unit root null is overwhelmingly rejected for the floating exchange rate regime of March 1973 to February 1979 and the pegged-float ERM regime of March 1979 to December 1998. Also, the unit root null is rejected at the 10% level for the pre-1973 Bretton Woods regime. In contrast, the evidence for the mean-reverting of real exchange rates is much weaker for the post-1998 euro regime: the unit root null cannot be rejected even at the 10% level. Our finding here confirms the previous empirical results of weaker evidence for PPP following the introduction of the euro, e.g., Rogers (2007), Christidou and Panagiotidis (2010), and Wu and Lin (2011).

The unit root tests above provide no information as to the speed of convergence of real exchange rates to their equilibrium in different exchange rate arrangements. To explore the issue, we estimate the following regression:

$$\Delta q_{ij,t} = a_0 q_{ij,t-1} + \sum_{k=1}^{p} a_k \Delta q_{ij,t-k} + \sum_s D_s \left(a_{0,s} q_{ij,t-1} + \sum_{k=1}^{p} a_{k,s} \Delta q_{ij,t-k} \right) + u_{ij,t} \tag{2}$$

where D_s is the dummy variable with $s = floating, ERM$, and *euro* representing different exchange rate arrangements. The value of D_s is set to one for the corresponding exchange rate regime period and zero otherwise. We estimate Eq. (2) using the panel data of 55 pairwise real exchange rate series. To control for cross-section correlation of residuals, we apply the common correlated effects (CCE) estimators a la Pesaran (2006). The assumption here is that the cross-section correlation of residuals are caused by some unobserved common factors. Pesaran (2006) shows that the CCE estimators are with satisfactory small sample properties even under a substantial degree of heterogeneity and dynamics, and concludes that the standard pooled version of the CCE estimators (CCEP estimators) performs better in small samples than the CCE mean group estimators (CCEMG estimators). We thus adopt the CCEP estimators in our model estimation. We compute CCEP estimators for the parameters in Eq. (2) by including as regressors the cross-section averages of all variables in the regression. The estimation results are used to calculate the half-life of real exchange rate convergence, which corresponds to the time elapsed for the magnitude of response to a unit shock to dissipate by half. To do so, we first rewrite Eq. (2) as an AR$(p+1)$ process:

$$\begin{aligned} q_{ij,t} &= \left(1 + a_0 + a_1 + D_s a_{0,s} + D_s a_{1,s}\right) q_{ij,t-1} + \left(a_2 - a_1 + D_s a_{2,s} - D_s a_{1,s}\right) q_{ij,t-2} \\ &\quad + \cdots + \left(a_p - a_{p-1} + D_s a_{p,s} - D_s a_{p-1,s}\right) q_{ij,t-p} + \left(-a_p - D_s a_{p,s}\right) q_{ij,t-p-1} + u_{ij,t} \\ &= a_1' q_{ij,t-1} + a_2' q_{ij,t-2} + \cdots + a_p' q_{ij,t-p} + a_{p+1}{}' q_{ij,t-p-1} + u_{ij,t} \end{aligned}$$

The above AR$(p+1)$ process can then be written in a vector AR(1) form as

$$Q_{ij,t} = A \cdot Q_{ij,t-1} + U_{ij,t},$$

where $Q_{ij,t} = \begin{bmatrix} q_{ij,t} \\ q_{ij,t-1} \\ \vdots \\ q_{ij,t-p} \end{bmatrix}$, $A = \begin{bmatrix} a_1' & a_2' & \cdots & a_{p-1}' & a_p' \\ 1 & 0 & \cdots & 0 & 0 \\ 0 & 1 & \cdots & 0 & 0 \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & \cdots & 1 & 0 \end{bmatrix}$, and $U_{ij,t} = \begin{bmatrix} u_{ij,t} \\ 0 \\ \vdots \\ 0 \end{bmatrix}$.

[9] We conduct the cross-section dependence (CD) test of Pesaran (2004). We find that the CD statistics are all significant at the 1% level, indicating that the cross-section dependence should not be neglected.

Fig. 1. Changes of nominal exchange rates, relative nominal prices, and real exchange rates.

Table 2
Pesaran (2007)'s panel unit root test.

	All	Fixed	Floating	ERM	Euro
	1957:01	1957:01	1973:03	1979:03	1999:01
	2013:05	1973:02	1979:02	1998:12	2013:05
AIC	(4) −2.60***	(0) −2.11*	(1) −2.41***	(3) −2.63***	(4) −1.78
SBC	(4) −2.60***	(0) −2.11*	(0) −2.14**	(0) −2.39***	(4) −1.78
N	55	55	55	55	55
T	677	194	72	238	173
Sample	37,235	10,670	3960	13,090	9515

Notes: The numbers reported in parentheses is the lag order selected by the AIC or the SBC with the maximum order number being set to 4. ***, ** and * denote the rejection of the unit root null at 1%, 5% and 10% levels, respectively.

Let $s_1 = [1 \quad 0 \quad \cdots \quad 0]$ be a $(p+1) \times 1$ row selection vector. The half-life is the value h such that

$$s_1 A^h s_1' = \frac{1}{2}$$

To estimate the regression in Eq. (2), we select the lag orders according to Akaike information criteria and the optimal lags selected are in the range of 10 to 12. For convenience of comparison, in all the regressions estimated, the lag orders are set to 12. Table 3 summarizes the estimation results of Eq. (2). The full sample estimates (without considering the exchange rate arrangements) are given in Panel A of the table. The estimated coefficient on the lagged real exchange rate, a_0, is −0.02077, and the corresponding t-statistic of −20.94818, indicating a significant mean-reverting tendency of the real exchange rates. The estimated half-life here is 39 months, which is in the range of 3 to 5 years as documented in many previous studies, e.g., Rogoff (1996). Panel B of Table 3 gives the coefficient estimates of Eq. (2) along with computed half-life under various nominal exchange rate regimes. As the table shows, under the Bretton Woods regime, the estimated coefficient on the lagged real exchange rate is −0.03011 and the associated t-statistic is −14.47112. In addition, the computed half-life is 23 months which is notably shorter than that obtained from the full sample

Table 3
Mean reversion of real exchange rate.

Panel A

$$\Delta q_{ij,t} = a_0 q_{ij,t-1} + \sum_{k=1}^{p} a_k \Delta q_{ij,t-k} + u_{ij,t}$$

	a_0	Half-life months (Years)
Coefficient	−0.02077***	39 (3.25)
Std. error	0.00099	
t-statistic	−20.94818	

Panel B

$$\Delta q_{ij,t} = a_0 q_{ij,t-1} + \sum_{k=1}^{p} a_k \Delta q_{ij,t-k} + \sum_{s} D_s \left(a_{0,s} q_{ij,t-1} + \sum_{k=1}^{p} a_{k,s} \Delta q_{ij,t-k} \right) + u_{ij,t}$$

$s =$ *floating*, *ERM*, and *euro*

	a_0	$a_{0,s}$	$a_0 + a_{0,s}$	Half-life months (years)
Fixed				
Coefficient	−0.03011***			23 (1.92)
Std. error	0.00208			
t-statistic	−14.47112			
Floating				
Coefficient		−0.02051***	−0.05062***	18 (1.50)
Std. error		0.00283	0.00458	
t-statistic		−7.24411	−11.04539	
ERM				
Coefficient		0.00690***	−0.02320***	37 (3.08)
Std. error		0.00254	0.00146	
t-statistic		2.71348	−15.84904	
Euro				
Coefficient		0.02473***	−0.00538	135 (11.25)
Std. error		0.00437	0.00385	
t-statistic		5.65384	−1.39771	

***, ** and * denote that the coefficient is significantly different from zero at 1%, 5% and 10% levels, respectively. Sample period: 1957:01–2013:05.

estimate. The table next reports the estimation results for the floating exchange rate regime. Here the estimated coefficient on the lagged real exchange rate, i.e., $a_0 + a_{0,s}$, is −0.05062 and the associated t-statistic is −11.04539. The absolute value of the coefficient estimate here is significantly greater than that of the Bretton Woods regime, indicating a stronger mean-reverting tendency of real exchange rates. Not surprisingly, the corresponding half-life here is merely 18 months, 5 months shorter than that of the Bretton Woods regime. In contrast, as the table also shows, under the ERM pegged-float regime the absolute value of estimated coefficient on the lagged real exchange rate is smaller than that of the Bretton Woods regime, indicating a weaker mean-reverting tendency of real exchange rates. The estimated half-life here is 37 months, which is a bit on the longer side. Finally, as the bottom rows of the table show, under the post-1998 euro regime the estimated coefficient on the lagged real exchange rate here is −0.00538 and the associated t-statistic is −1.39771, indicating a lack of or extremely slow mean-reverting in real exchange rates. This is confirmed by the extremely long half-life estimate for the regime: 135 months.

In sum, our estimation results show that the half-life of real exchange rate convergence is the shortest under the 1973–1979 floating exchange rate regime, where the nominal exchange rates have been most flexible. In contrast, under the euro regime where the adjustment of nominal exchange rate has been entirely absent, the evidence for the mean-reverting of real exchange rates is the weakest and the half-life is extremely long.

3. Relative price and nominal exchange rate adjustment

In this section, we study the roles of relative prices and nominal exchange rates in the mean-reverting of real exchange rates under different nominal exchange rate arrangements. It is of particular interest here to explore whether and how the different degrees of

Table 4
Error correction model estimates.

Panel A

$$\Delta rp_{ij,t} = b_0 q_{ij,t-1} + \sum_s b_{0,s} D_s q_{ij,t-1} + \sum_{k=1}^{p} b_{1,k} \Delta rp_{ij,t-k} + \sum_{k=1}^{p} b_{2,k} \Delta e_{ij,t-k} + u^{rp}_{ij,t}$$

s=floating, ERM and euro
Sample period: 1957:01–2013:05

	b_0	$b_{0,s}$	$b_0 + b_{0,s}$
Bretton Woods			
Coefficient	−0.00251***		
Std. error	0.00046		
t-statistic	−5.43310		
Floating			
Coefficient		−0.00703***	−0.00954***
Std. error		0.00099	0.00088
t-statistic		−7.11422	−10.84205
ERM			
Coefficient		−0.00185***	−0.00435***
Std. error		0.00076	0.00060
t-statistic		−2.44255	−7.23090
Euro			
Coefficient		0.00191***	−0.00060
Std. error		0.00076	0.00061
t-statistic		2.50798	−0.98845

Panel B

$$\Delta e_{ij,t} = c_0 q_{ij,t-1} + \sum_s c_{0,s} D_s q_{ij,t-1} + \sum_{k=1}^{p} c_{1,k} \Delta rp_{ij,t-k} + \sum_{k=1}^{p} c_{2,k} \Delta e_{ij,t-k} + u^{e}_{ij,t}$$

s=floating and *ERM*
Sample period: 1957:01–1998:12

	c_0	$c_{0,s}$	$c_0 + c_{0,s}$
Bretton Woods			
Coefficient	−0.00856***		
Std. error	0.00110		
t-statistic	−7.80050		
Floating			
Coefficient		−0.00743***	−0.01599***
Std. error		0.00235	0.00301
t-statistic		−3.16341	−5.30876
ERM			
Coefficient		−0.00234	−0.01089***
Std. error		0.00180	0.00143
t-statistic		−1.30111	−7.61748

***, ** and * denote that the coefficient is significantly different from zero at 1%, 5% and 10% levels, respectively.
***, ** and * denote that the coefficient is significantly different from zero at 1%, 5% and 10% levels, respectively.

flexibility in nominal exchange rates under alternative exchange rate regimes affect the mean-reverting property of real exchange rates. It is also of interest to examine how sticky are the relative prices in their response to real exchange rate misalignment under different regimes.

To measure the response of relative prices and nominal exchange rates to real exchange rate misalignment, we estimate the following error correction equations:

$$\Delta rp_{ij,t} = b_0 q_{ij,t-1} + \sum_s b_{0,s} D_s q_{ij,t-1} + \sum_{k=1}^{p} b_{1,k} \Delta rp_{ij,t-k} + \sum_{k=1}^{p} b_{2,k} \Delta e_{ij,t-k} + u_{ij,t}^{rp} \tag{3.1}$$

$$\Delta e_{ij,t} = c_0 q_{ij,t-1} + \sum_s c_{0,s} D_s q_{ij,t-1} + \sum_{k=1}^{p} c_{1,k} \Delta rp_{ij,t-k} + \sum_{k=1}^{p} c_{2,k} \Delta e_{ij,t-k} + u_{ij,t}^{e} \tag{3.2}$$

where $rp_{ij,t}$ denotes the relative prices between countries i and j at time t, i.e. $rp_{ij,t} = p_{j,t} - p_{i,t}$. The interaction terms as controlled by the dummy variable D_s are used here to explore the effect of exchange rate arrangements on the error correction adjustments.

In our error correction model estimation, all pairwise series of relative prices and nominal exchange rate among the eleven eurozone countries are employed. For the estimation of relative prices regression in Eq. (3.1), the January 1957 to May 2013 data are employed while for the estimation of nominal exchange rates regression in Eq. (3.2), due to the absence of fluctuations in nominal exchange rates during the euro regime period, the January 1957 to December 1998 data are employed. For all the pairwise data series, the sample mean and time trend have been removed for the estimation. Moreover, to take into account the possible cross-section correlation in residuals, we compute the CCEP estimators for the parameters in each of regressions (3.1) and (3.2) by including as regressors the cross-section averages of all variables in the corresponding regression.

In Table 4, we report the estimation results. The coefficient estimates for the response of relative prices to the lagged real exchange rate under different exchange rate regimes (i.e., b_0 and $b_0 + b_{0,s}$ in regression 3.1) are reported in Panel A of the table. For the adjustment of relative prices to help in restoring PPP equilibrium, negative coefficients are expected here. As the results show, the coefficient estimates are all of the correct sign and are statistically significant at 1% level in the Bretton Woods, the floating, and the ERM regimes. Among these three regimes, the relative prices appear to be most responsive to the real exchange rate misalignment in the floating exchange rate regime while least responsive in the Bretton Woods regime. In contrast, as the last three lines of the panel show, in the euro regime the relative prices did not respond significantly to the lagged real exchange rate. This, along with the absence of nominal exchange rate adjustment, contributes to the weak mean-reverting in real exchange rates in the euro regime.

In Panel B of Table 4, we report the coefficient estimates for the response of nominal exchange rate to the lagged real exchange rate under different exchange rate regimes (i.e., c_0 and $c_0 + c_{0,s}$ in regression 3.2). Again, for the adjustment of nominal exchange rate to help in restoring PPP equilibrium, negative coefficients are expected here. As the results show, the coefficients are all of the correct sign and are all statistically significant at 1% level. It is worth noticing that the coefficients here are generally much greater in absolute term than their relative price counterparts. For example, in the floating exchange rate regime the estimated nominal exchange rate response is −0.01599 while the estimated relative price response is −0.00954. The greater responses of nominal exchange rates to real exchange rate misalignment than their relative prices counterparts are consistent with the findings of Johnson (1990) and Parsley and Popper (2001), among many others. Finally, the results reported in the panel also show that, among the three exchange rate regimes considered, the nominal exchange rates have been most responsive to real exchange rate misalignment in the floating exchange rate regime while least responsive in the Bretton Woods regime. These results are in sharp contrast with those of Parsley and Popper (2001) where the nominal exchange rates have been found to be less responsive to the real exchange rate misalignment under more flexible exchange rate arrangements.

4. Comparison between euro and non-euro countries

The overall evidence from the previous sections points toward the conclusion that for the euro countries, the absence of nominal exchange rate adjustment after the launch of the euro might have been the major factor behind the extremely slow adjustment of real exchange rate to PPP. However, it is entirely plausible that, by pure coincidence, events other than the euro adoption but specific to the post-1998 advanced European economies have contributed to the slow adjustment of real exchange rate during the period. To explore the above possibility, we employ the panel data of all pairwise bilateral real exchange rates for Norway, Sweden, Switzerland, and the UK, i.e., the four advanced European countries not joining the euro, to estimate the convergence speed of real exchange rates for the periods of pre- and post-euro launch. The sample period here is from March 1973 to May 2013 where the nominal exchange rates are mostly flexible.[10]

In Table 5, we report the estimation results (CCEP estimators) of the AR model of real exchange rate as that in Eq. (2). The full sample estimates are given in Panel A of the table. As the results show, the estimated coefficient on the lagged real exchange rate, a_0, is −0.02570, and the corresponding t-statistic is −7.03751, indicating a significant mean-reverting tendency of real exchange rates.

[10] There were relatively short time spans where Norway and Sweden pegged their currencies to ECU (European Currency Unit): October 1990 to December 1992 for Norway and May 1991 to November 1992 for Sweden. The UK entered ERM in October 1990 but was forced to leave the program in September 1992 after the pound sterling came under major pressure from currency speculators.

Table 5
Mean reversion of real exchange rate.

Panel A				
$\Delta q_{ij,t} = a_0 q_{ij,t-1} + \sum_{k=1}^{p} a_k \Delta q_{ij,t-k} + u_{ij,t}$				
	a_0			Half-life months (years)
Coefficient	−0.02570***			33 (2.75)
Std. error	0.00365			
t-statistic	−7.03751			
Panel B				
$\Delta q_{ij,t} = a_0 q_{ij,t-1} + \sum_{k=1}^{p} a_k \Delta q_{ij,t-k} + D_{euro} a_{0,euro} q_{ij,t-1} + D_{euro} \sum_{k=1}^{p} a_{k,euro} \Delta q_{ij,t-k} + u_{ij,t}$				
	a_0	$a_{0,euro}$	$a_0 + a_{0,euro}$	Half-life months (years)
Period: 1973:03–1998:12				
Coefficient	−0.02621***			33 (2.75)
Std. error	0.00430			
t-statistic	−6.09221			
Period: 1999:01–2013:05				
Coefficient		−0.00190	−0.02431***	32 (2.67)
Std. error		0.00798	0.00672	
t-statistic		−0.23766	−3.61962	

***, ** and * denote that the coefficient is significantly different from zero at 1%, 5% and 10% levels, respectively. Sample period: 1973:03–2013:05.

The estimated half-life here is 33 months, which is a bit shorter than the range of 3 to 5 years as documented in many previous studies, e.g., Rogoff (1996). Panel B of Table 5 gives the coefficient estimates of Eq. (2) along with the computed half-life for the pre- and post-euro periods. As the results show, for the pre-euro period of March 1973 to December 1998, the estimated coefficient on the lagged real exchange rate is −0.02621 and the associated t-statistic is −6.09221. The computed half-life here is 33 months, which is the same as that obtained from the full sample estimate. For the post-euro period of January 1999 to May 2013, the estimated coefficient on the lagged real exchange rate, i.e., $a_0 + a_{0,euro}$, is −0.02431 and the associated t-statistic is −3.61962. Moreover, the coefficient estimate of $a_{0,euro}$ is merely −0.0019 and the null hypothesis of $a_{0,euro}$ being equal to zero cannot be rejected at the 5% significance level, indicating that there is no significant difference in the mean-reverting tendency of real exchange rates in the pre- and post-euro periods. It is also worth noticing that for the four non-euro countries the computed half-life of real exchange rate convergence is 32 months for the post-euro period, which is virtually the same as that obtained from the same group of countries for the pre-euro period but much shorter than the one obtained from the eleven euro countries for the post-euro period. The sharp contrast in the mean reverting property of the euro and the non-euro countries during the post-euro period is consistent with the hypothesis that the absence of nominal exchange rate adjustment among euro countries might have been a major reason behind the extremely slow convergence of real exchange rates to PPP found for many euro countries in the euro regime period as documented in many previous studies.

5. Conclusions

In the current paper we examine how changes in nominal exchange rate regime, in particular the launch of the euro, affect the adjustment of real exchange rates to PPP equilibrium in eurozone countries. We find that the panel unit root tests generally reject the unit root null in real exchange rates for the pre-euro exchange rate regimes. In contrast, the tests cannot reject the unit root null in real exchange rates for the post-1998 euro regime. These findings are consistent with previous empirical findings of weaker evidence for PPP following the launch of the euro, e.g., Rogers (2007), Christidou and Panagiotidis (2010), and Wu and Lin (2011).

Our panel regression estimations also indicate that while the half-life of real exchange rate convergence for the floating exchange rate regimes is rather short: 18 months, the half-lives of the ERM regime and the euro regimes are much longer, 37 months and 135 months, respectively. Moreover, from the panel estimation of the error correction model we find that the adjustments of nominal exchange rate generally play a much more important role than the adjustments of relative prices in restoring the real exchange rate equilibrium. This finding is in line with that of Johnson (1990) and Parsley and Popper (2001). However, we also find that among the pre-euro regimes considered, nominal exchange rates have been most responsive to the real exchange rate misalignment in the floating exchange rate regime while least responsive in the Bretton Woods regime. The result is in sharp contrast with that of Parsley and Popper (2001) where the nominal exchange rates have been found to be less responsive to the real exchange rate misalignment under more flexible nominal exchange rate arrangements. Finally, by comparing the mean-reverting property of real exchange rates between the selected euro and non-euro countries, we find that for the post-1998 euro regime period the convergence speed of real exchange rates for the non-euro countries is much faster than that of the euro countries. Moreover, for the non-euro countries considered the convergence speed of real exchange rates is virtually the same for the pre- and post-euro periods. The overall evidence here points toward the conclusion that the flexibility of nominal exchange rates is crucial for the adjustment of real exchange

rates to PPP and that for many euro countries the absence of nominal exchange rate adjustment after the launch of the euro might have been the major factor behind the extremely slow adjustment of real exchange rate to PPP found in many previous studies.

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