Real exchange rate behavior in 4 CEE countries using different unit root tests under PPP paradigm

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Abstract. This paper aims to analyze real exchange rate deflated with consumer price index under different unit root tests with and without structural breaks. We consider classical test like Augmented Dickey-Fuller and Phillips-Perron without structural break, but also unit root tests with one break and with two structural breaks, respectively Zivot-Andrews and Clemente-Montañés-Reyes techniques. Our study is based on real exchange rate analysis in 4 selected CEE countries: Czech Republic, Hungary, Poland and Romania against the Euro Zone. By many authors, real exchange rate stationarity is correlated with weak form of purchasing power parity (PPP) validity which claims that price indices between two countries/regions are convergent. The monthly data cover the 2001M01-2011M09 period. The empirical analysis provides mixed results depending on the country and the selected unit root test.

Keywords: real exchange rate, unit root tests, purchasing power parity

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AMS Classification: 90C15

1 Introduction

The Purchasing Power Parity (PPP) theory is one of the most famous and the most controversial theory of exchange rate determination. PPP states that national price levels should be equal when expressed in a common currency. In most papers, the theory is tested using stationarity tests and cointegration. Nowadays, the analysis of the exchange rate sustainability is an important issue especially in view of the acceding process to the Eurozone. In order to avoid future disequilibrium, it is important for policy makers to asses the level of the national price convergence with respect to the euro market and to examine the relationship between exchange rate and prices level.

Considering the above-mentioned factors, the purpose of this study is to test the long-run validity of the Purchase Power Parity for a group of four CEE countries: the Czech Republic, Hungary, Poland and Romania. To increase the relevance of the present research and for a better understanding, we use the consumer price index (CPI) as proxy and explore several unit root tests. We structured our paper as follows: in the first section we analyze the main contributions concerning Purchasing Power Parity, in section 2 we provide a weak form description of the PPP theory, in section 3 we emphasize the methodology and in section 4 we highlight the empirical results of our study. Finally, we point out the main conclusions.

The PPP concept can be traced back to the 16th century, to the School of Salamanca, but the modern form of the theory was developed by Gustav Cassel in 1918. PPP is based on the *law of one price*, which states that once prices are converted to a common currency, the same good should sell for the same price in different countries. [10]

Based on the different econometric techniques applied over time, the empirical studies on PPP can be structured as follows: "early studies", before 1970, unit root test studies, panel data studies and cointegration-based studies.

The most representative for the early stage are the works of Frenkel [6], [7] which mainly use OLS techniques indicating the popularity of PPP theory only in countries with high inflation. The major drawbacks of the mentioned studies relate to the fact that they neglected the non-stationarity of exchange rate and prices series.

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Later, in the second part of `80s, the notion of **stationarity** was introduced in the empirical research in order to highlight the permanent deviations from the PPP level. From this point on, the scholars had the possibility to analyze if a shock in a variable's evolution is permanent or can be absorbed over time. PPP does not hold if real exchange rate is a random walk.

The PPP approaches have been developed over time and contemporary literature is based on stationarity and cointegration using different methodologies in order to find an adequate real exchange rate determination. The long-span studies include tests on longer time periods with various currency arrangements according to international monetary system mutations. Also, the PPP analyses based on panel data and stationarity procedures are very common. One of the first PPP modern approaches of European Central-Eastern countries is the one of Choudhry's [2]. Analyzing a group of four countries (Romania, Poland, Russia and Slovenia) he found that PPP holds in its relative form only for Slovenia and Russia.

In an extensive research on a large group of countries from this region (Bulgaria, Czech Republic, Hungary, Poland, Romania and Slovak Republic in 1991-1998 period) Christev and Noorbakhsh [3] identified a long-run term relationship between prices and the exchange rate despite the law of one price, proportionality and symmetry violation.

The most recent analyses for CEE countries, which applied unit root tests are Kasman et al. [8], Telatar and Hasanov [11], Ali and Ozturk [1]. They used the traditional unit root tests and a unit root test which accounts for structural breaks. The obtained results are mixed.

For example, Kasman et al. [8] applied Lagrange multiplier (LM) test and found little evidence of PPP validity for CEE countries. The results of Telatar and Hasanov [11] research support PPP validity when considered structural changes and nonlinearities. After applying a series of unit root tests, Ali and Ozturk [1] concluded that PPP holds only for a few countries, finding weak evidence in case of other countries.

In order to test the validity of PPP for a group of 12 CEE countries and analyze the convergence of selected states towards the euro area, Kavkler et. al. [9] used a set of first generation panel unit toot tests, based on cross-sectional independency hypothesis. These tests are: Levin, Lin and Chu test, Im, Pesaran and Shin test and Fisher ADF and Fisher PP. The results of this study confirmed the stationarity of the real exchange rate, supporting the PPP theory in the long-run.

2 Purchasing Power Parity weak form description

PPP is developed having as reference the Law of One Price (LOOP) which refers to the equality between two prices of the same good, in two different countries when they are expressed in the same currency:

$$P_{i,t} = NER_t P^*_{i,t}, \qquad i = 1,2,..,n \tag{1}$$

where $P_{i,t}$ is the price of good i expressed in national currency units at moment t, $P^*_{i,t}$ the price of the same good i at moment t expressed in a foreign currency and NER_t is the nominal exchange rate at moment *t.*

If we develop the LOOP absolute form for all goods traded inside a country we obtain the PPP, also in an absolute form, as following:

$$\sum_{i=1}^{N} \alpha_i P_{i,t} = NER_t \sum_{i=1}^{N} \alpha_i P^*_{i,t} \tag{2}$$

where α_i as weights of goods included in a price index are totaling a value equal with the unity.

Integrating other influences, which include the PPP deviations, the above equation in logarithmic form can be expressed as follows (ner_t is the nominal exchange rate, p_t, p_t^* are national price indices and d_t includes deviations caused by other influence factors; all the variables are expressed in a logarithmic form):

$$ner_t = p_t - p_t^* + d_t \tag{3}$$

The deviations are associated with the real exchange rate (rer_t) volatility and the relationship becomes:

$$rer_t = ner_t - p_t + p_t^* \tag{4}$$

A major part of the empirical literature investigates the two forms of PPP theory: the strong and the weak forms. In order to analyze the weak form of the PPP stationarity tests on real exchange rates (rer_t) are applied. PPP holds in the long-run if the real exchange rate is a stationary series. The strong form is mainly investigated by applying cointegration methods and testing the proportionality and symmetry restrictions.

3 Methodology description

We admit that purchasing power parity holds in the long-run if the real exchange rate is a stationary series. A variable is stationary if it has a tendency in returning to a constant value. In other words, its trajectory must be around a mean value or around a linear trend. Economically, this means that any shock on series is temporary and it is absorbed in time. In practice, almost every variable is stationary and must be differenced. Hence, the exchange rate is nonstationary for the most cases and the series is first order integrated (requires just one differentiation). In order to test for the presence of the unit roots in the real exchange rate series were applied classical tests: Augmented Dickey-Fuller Test (ADF) and Phillips-Perron Test (PP). Also, in order to take into account the potential structural breaks in the series, which can lead to the biased results when are performed traditional tests, were applied additionally the Zivot-Andrews Test (ZA) and Clemente-Montañés-Reyes Test (CMR).

3.1 Classical unit root tests: Augmented Dickey-Fuller and Phillips-Perron

Augmented Dickey-Fuller unit root test

The econometric theory refers to a null hypothesis that claims a unit root in series. In our case, the real exchange rate is nonstationary. The most popular stationarity tests were developed by Dickey and Fuller (ADF stationarity test), respectively by Phillips and Perron [5]. The difference between them is given by the less stringent restrictions on error process for Phillips-Perron test. If the obtained t-statistisc and associated probability reflect null hypothesis acceptance, than we conclude that purchasing power parity doesn't hold.

Testing real exchange rate stationarity through Dickey-Fuller (ADF) entails three assumptions: the intercept presence, the presence of an intercept and a time trend, and finally, the absence of any deterministic element. For each supposition, we have built three different relationships, as follows: includes both a drift and a linear time trend (eq. 5), random walk with a drift (eq. 6) and pure random walk (eq. 7) :

$$\Delta rer_t = a_0 + \gamma rer_{t-1} + a_2 t + \varepsilon_t \quad (5)$$

$$\Delta rer_t = a_0 + \gamma rer_{t-1} + \varepsilon_t \quad (6)$$

$$\Delta rer_t = \gamma rer_{t-1} + \varepsilon_t \quad (7)$$

If $\gamma = 0$, than the real exchange rate sequence contains a unit root (the series is nonstationary). The test estimates a regression equation using ordinary least squares, in order to determine an estimated value for γ and associated standard error.

Augmented Dickey-Fuller is developed for p^{th}-order autoregressive process and the estimated equation is the following:

$$\Delta rer_t = a_0 + \gamma rer_{t-1} + \sum_{i=2}^{p} \beta_i \, \Delta rer_{t-i+1} + \varepsilon_t \quad (8)$$

where $\gamma = -(1 - \sum_{i=1}^{p} a_i)$ and $\beta_i = \sum_{j=1}^{p} a_j$. If $\gamma = 0$, we consider the equation being in first difference and having a unit root.

Phillips-Perron unit root test

Phillips and Perron (1988) developed ADF procedure and allowed a weaker set of assumptions regarding the error process. Also, Phillips-Perron test (PP) is powerful in rejecting the null hypothesis.

Considering the following regression equations:

$$rer_t = a_0^* + a_1^* rer_{t-1} + \mu_t \quad (9)$$

$$rer_t = \tilde{a}_0 + \tilde{a}_1 rer_{t-1} + \tilde{a}_2 \frac{t-T}{2} + \mu_t \quad (10)$$

where T is the number of observation and μ_t is the disturbance term, the PP has the followings test statistics: $Z(ta_1^*)$ for testing the hypothesis $a_1^* = 1$; $Z(t\tilde{a}_1)$ for testing the hypothesis $\tilde{a}_1 = 1$, $Z(t\tilde{a}_2)$ for testing the hypothesis $\tilde{a}_2 = 0, Z(\Phi_3)$ for testing the hypothesis $\tilde{a}_1 = 1$ and $\tilde{a}_2 = 0$.

The PP critical values are the same as in ADF stationarity test. In our analysis, we choose to use both unit root tests due to the difficulties in knowing the true data-generating process.

Zivot-Andrews unit root test with one structural break

Lately, many studies on PPP based on stationarity procedures are considering the **structural change** in order to avoid non-rejection of a unit root in that series with structural breaks, when using ADF or PP. Structural changes appear as a result of economic or financial crisis, policy changes and regime shifts.

Zivot and Andrews (ZA) [12] find a solution and identified a break point where the unit root t-statistic is the smallest. The authors tested a procedure with an estimated time of the break assuming it as an exogenous phenomenon. Therefore, they test for a unit root using three models:

- A': one-time change in the slope of the trend function is allowed:

$$\Delta rer_t = c + \alpha rer_{t-1} + \beta t + \gamma DU_t + \sum_{j=1}^{k} d_j \Delta rer_{t-j} + \varepsilon_t \qquad (11)$$

- B': allows one-time change in the slope of the trend:

$$\Delta rer_t = c + \alpha rer_{t-1} + \beta t + \theta DT_t + \sum_{j=1}^{k} d_j \Delta rer_{t-j} + \varepsilon_t \qquad (12)$$

- C': combines one-time change in the level and the slope of the trend function:

$$\Delta rer_t = c + \alpha rer_{t-1} + \beta t + \theta DU_t + \gamma DT_t + \sum_{j=1}^{k} d_j \Delta rer_{t-j} + \varepsilon_t \qquad (13)$$

where DU_t is a dummy variable for a mean shift occurring at a possible break-date and $DT_t$is a corresponding trend shift variable. Also, we mention the following restrictions: $DU_t = \begin{Bmatrix} 1, if\ t > TB \\ 0, \text{otherwise} \end{Bmatrix}$ and $DT_t = \begin{Bmatrix} \text{t} - \text{TB}, \text{if t} > \text{TB} \\ 0, \text{otherwise} \end{Bmatrix}$.

The null hypothesis in all above models is α=0, which implies that $y_t$contains a unit root (it is non-stationary) with a drift and without any structural break. The alternative hypothesis implies α<0 and the series is considered a trend-stationary process with a one-time break at an unknown date in time. ZA test runs a regression for every possible break-date sequence and considers every point as being a potential break-date. The C model is considered as being superior to others. The main ZA unit root test advantage is that we don't need to know the exact date of a structural break.

Montanes-Clemente-Reyes unit root test with TWO structural break

Clemente Montañés and Reyes [4] developed a stationarity test, which, unlike the ZA test, takes account for two structural breaks in series. Clemente-Montañés-Reyes test estimates two models. The first model uses additive outlier and the second uses innovative outliers.

In case of an additive model, CMR test estimates equation 14 and subsequently looks for a minimum t-statistic for *α = 1 hypothesis* in the equation 15:

$$rer_t = \mu + \delta_1 DU_{1t} + \delta_2 DU_{2t} + \widetilde{rer}_t \qquad (14)$$

$$\widetilde{rer}_t = \sum_{i=0}^{k} w_i DT_{b2,t-i} + \alpha \widetilde{rer}_{t-1} + \sum_{i=1}^{k} \theta_i \Delta \widetilde{rer}_{t-i} + \varepsilon_t, \ t=k+2,...,T \qquad (15)$$

In case of the innovative model, the estimated equation is:

$$rer_t = \mu + \delta_1 DU_{1t} + \delta_2 DU_{2t} + \vartheta_1 DT_{b1,t} + \vartheta_2 DT_{b2,t} + \alpha rer_{t-1} + \sum_{i=1}^{k} \theta_i \Delta rer_{t-i} + \varepsilon_t, \quad t=k+2,...,T \qquad (16)$$

It also looks for a minimum t-statistic for *α=1 hypothesis.*

4 Data description and results

In this study we used data with monthly frequency covering the period from 2001M1 to 2011M9. Variables used are real exchange rates (deflated with CPI) for four CEE countries. All used variables are reflected in figure 1:

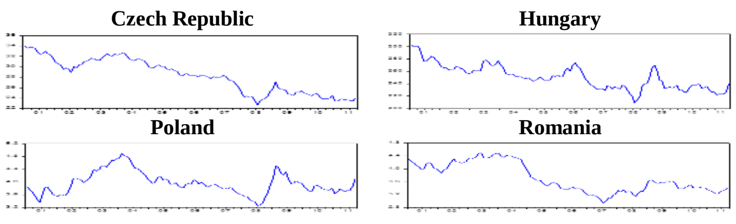

Figure 1 Real exchange rate evolution in Czech Republic, Hungary, Poland and Romania

Purchasing power parity holds in a long-run horizon if the real exchange rate deflated with different price indices is a stationary series. Null hypothesis of one unit root presence is accepted if the probability is bigger than assumed threshold of 5%. The coefficients relevance indicates the type of process: pure random walk, random walk with drift or a process with both a drift and trend time. Using ADF test results, we highlight PPP validity in long-run for Czech Republic and Hungary.

Country	**Augmented Dickey-Fuller**	
	t-statistic (Prob.)	**Conclusion (ADF)**
Czech Republic	-2.178913 (0.0288)	***Stationary in level***
Hungary	-3.919671 (0.0139)	***Stationary in level***
Poland	-2.491318 (0.1200)	Non-stationary in level
	-7.310718 (0.0000)	Stationary in first difference
Romania	-0.837202 (0.3514)	Non-stationary in level
	-7.545337 (0.0000)	Stationary in first difference

Table 1 Results of ADF unit root tests without structural breaks

Phillips-Perron is a complementary type of unit root test and it assumes a weaker set of requirement for the error process:

Null Hyphotesis: Real exchange rate has a unit root		
Country	**Phillips-Perron**	
	t-statistic (Prob.)	**Conclusion**
Czech Republic	-2.016323 (0.0423)	***Stationary in level***
Hungary	-2.702929 (0.0763)	Non-stationary in level
	-7.986771 (0.0000)	Stationary in first difference
Poland	-0.016210 (0.6755)	Non-stationary in level
	-7.396659 (0.0000)	Stationary in first difference
Romania	-1.104596 (0.2434)	Non-stationary in level
	-7.469581 (0.0000)	Stationary in first difference

Table 2 Phillips-Perron unit root test results

Using Phillips-Perron unit root test results, we find PPP validity in long-run just for Czech Republic.

Zivot and Andrews test results on the real exchange rate stationarity show PPP validity while considering structural breaks in intercept, trend or both. The null hypothesis is that the series has a unit root with structural breaks against its alternative that the series is stationary with structural breaks. ZA test is important because it offers information on that series that are non-stationary as a whole, but stationary around a break-point.

Null Hyphotesis: Real exchange rate has a unit root with a structural break in the the intercept/trend/both						
Country	**t-statistic (Prob.)**					
	Break in intercept	**Break point**	**Break in trend**	**Break-point**	**Break in both**	**Break point**
Czech Republic	-3.245670 (0.055505)	2002M10	-2.759783 (0.837176)	2003M09	Regressors are perfectly collinear	-
Hungary	***-4.750789 (0.014275)***	*2008M10*	-4.208707 (0.189965)	2008M05	***-4.726934 (0.028144)***	*2008M10*
Poland	***-3.054747 (0.048677)***	*2005M05*	-3.215168 (0.413291)	2003M02	***-4.039838 (0.012520)***	*2004M06*
Romania	***-4.342412 (0.000001)***	*2004M11*	**2.475955 (0.001648)**	*2007M12*	***--4.455401 (0.001320)***	*2004M11*

Note: Probability values are calculated from a standard t-distribution and do not take into account the breakpoint selection process;

Table 3 Zivot-Andrews unit root with a structural break test results

ZA unit root test results are as follows: PPP holds for all countries, excepting the Czech Republic when pointing a structural break in intercept and both in intercept and trend; in Romania, PPP holds for all of the assumption about the location of the structural break; PPP doesn't hold for any of the assumptions in the Czech Republic case; most of the series do have significant breakpoints, especially in the crisis period (2008 and 2008) and 2004, a period characterized by many changes in price regulation, specific to the emerging countries.

ZA unit root test results reflect different break-points in real exchange rate evolution. Using the C model, excepting the Czech Republic we find break points in all of the other countries. Structural break presence shows the specific mutations for all this emerging countries with many changes in price regulations.

Country	Additive outliers (AO)		Innovative outliers (IO)	
	t- statistic	Optimal breakpoints	t- statistic	Optimal breakpoints
Czech Republic	*-3.701*	*2005M3, 2007M10*	-4.048	*2004M10, 2007M6*
Hungary	*-4.716*	*2004M5, 2007M5*	*-4.298*	*2003M11, 2006M8*
Poland	*-4.003*	*2002M9, 2005M3*	-3.513	*2004M7, 2007M1*
Romania	*-4.898*	*2005M3, 2006M5*	*-4.564*	*2004M9, 2010M5*

** 5% critical values – two breaks: -5.49*

Table 4 Clemente-Montañés-Reyes unit root test results with double mean shift

As we could see from the table above, the Clemente-Montañés-Reyes test with two structural breaks found structural breaks for both cases: AO and IO. The period of financial crisis is the common break point for all series. Even if we identified several break points, we were unable to reject the null hypothesis of a unit root. Therefore the results of the Clemente-Montañés-Reyes unit root test with double mean shift didn't validate the PPP in long run.

5 Conclusions

Our results emphasize a growing structural breaks importance in the real exchange rate analysis using unit root tests. While ADF and PP reflect PPP validity just for one or two cases, Zivot-Andrews unit root test identifies one structural break that divide the time series in two stationary parts. Using ZA test, we highlight structural break importance and we identify their presence during the financial crisis. Contrary to these results, Clemente-Montanes-Reyes test shows that the presence of two different breakpoints leads to PPP weak form rejection.

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