

EMU ENLARGEMENT: DO REAL EXCHANGE RATES FOLLOW A NONLINEAR EQUILIBRIUM PROCESS?

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Abstract

This paper sheds light on the importance of the validity of PPP hypothesis for the accession process of the candidate countries towards EMU. The evidence of nonlinear adjustment in real exchange rates insists the estimation of a nonlinear SETAR model. While linear half-life estimates are biased upward (5 years on average), SETAR half-life estimates imply a faster reverting process (1.5 years on average). As a consequence, the evidence in favor of PPP hypothesis and the fast equilibrium adjustment of real exchange rates (setting Euro as the numeraire currency) imply that candidate countries follow a normal integration process towards EMU.

JEL Codes: C22, F31.

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1. Introduction

Following the enlargement of the European Union by 10 new members in May 2004, the next step of economic integration entails their entry into the Economic and Monetary Union (EMU) and the adoption of the single European currency. As a pre-entry step, candidate countries should join Exchange Rate Mechanism II (ERM II) at least two years before adopting Euro. Furthermore, their exchange rate per Euro should not deviate more than +/- 15% during this period. On 16 March 2006, a new agreement between the European Central Bank (ECB) and the National Central Banks of the candidate members set the operating procedures for an exchange rate mechanism in stage three of EMU. So far, seven of the new EU members have joined ERM II (27/12/2004: Estonia, Lithuania, Slovenia; 29/04/2005: Cyprus, Latvia, Malta; 25/11/2005: Slovak Republic), while the remaining countries are about to join ERM II in the near future.¹

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¹ Central rates per Euro are defined as follows: 1€ = 0.585274 Cyprus pound, 1€ = 15.6466 Estonian kroon, 1€ = 3.45280 Lithuanian litas, 1€ = 0.702804 Latvia lats, 1€ = 0.429300 Malta lira, 1€ = 38.4550 Slovak koruna, and 1€ = 239.640 Slovenian tolar.

Since January 1, 2007, Slovenia has been the thirteenth member of the euro zone, while Cyprus and Malta adopted the euro on January 1, 2008.

There are an adequate number of studies which focus on the aftermaths of the EU enlargement as well as the integration process of the candidate countries towards EMU. Most of the empirical studies focus on the examination of the Maastricht convergence criteria and the possibility of real convergence within the enlarged Europe. For example, Breuss et al (2004) find more arguments in favor of EMU enlargement than against. The only problem they refer is the high level of debts in Poland and Malta. Frenkel & Nickel (2005) focus on CEECs and examine the speed of adjustment to demand and supply disturbances in these economies compared to France, Germany and Italy. Similarly, Furceri & Karras (2006) perform a cost-benefit analysis of adopting Euro by examining (a) the business cycle correlation between the candidate's economy and that of the Euro zone and (b) the candidates' inflationary bias. However, there is little empirical work based on direct exchange rate analysis.² Beyond the exchange rate stability criterion, the exchange rate should not be significantly misaligned compared to its equilibrium rate. Purchasing Power Parity (PPP) can be seen as a preliminary measure of exchange rate equilibrium. Moreover, the validity of PPP hypothesis implies prices co-movement and evidence of well-developed trade relations between two countries. Although PPP hypothesis has been thoroughly examined for developed as well as developing countries, the literature is not rich for the prospective EMU countries.

In general, a wide range of alternative methodologies has been applied in testing PPP hypothesis.³ Univariate unit root tests cannot provide supportive evidence of PPP hypothesis (see Alba & Park, 2003 and Holmes, 2000). This is due to the low power of those tests. On the other hand, univariate and multivariate cointegration studies provide somewhat better results, but PPP cannot be accepted in some cases (see Wang, 2000). Panel unit root tests and panel cointegration techniques provide more satisfactory evidence. Nonetheless, rejections of PPP are not missing (see for example Basher & Mohsin, 2004 and Drine & Rault, 2003). The evidence of slow convergence to PPP equilibrium is known in the literature as PPP puzzle (Rogoff, 1996). However, the evidence is more satisfactory when structural breaks are allowed in real exchange rates (Zumaquero, 2002; Sabate et al, 2003; Zurbruegg & Allsopp, 2004). In addition, the PPP puzzle seems to be resolved by estimating nonlinear models (Michael et al, 1997; Sarno, 2000; Liew, 2003; Lothian & Taylor, 2004; Taylor et al, 2001).

In our study, by applying both a linear ADF test and a nonlinear SETAR model, we test the validity of PPP hypothesis for seven prospective EMU members for the period 1990 – 2006 as well as for the three new EMU members. Euro is taken as the numeraire currency. Our study contributes on EMU enlargement literature by shedding light on the importance of PPP hypothesis for the accessing process of the candidate countries towards EMU. A number of important implications can be derived from this analysis, such as exchange rate misalignment and the degree of trade openness within the enlarged Euro area. Furthermore, the estimation of the nonlinear SETAR model gives us the opportunity to estimate the true reverting process towards equilibrium. The structure of the remainder of the paper is as follows. Section 2 presents theoretical issues and evidence regarding nonlinearities in real exchange rates. Section 3

² The majority of the existing studies focuses on CEECs. For more information see Egert (2002), Egert & Lahreche-Revil (2003), Coudert-Couharde (2002) and Bulir & Smidkova (2005). These studies estimate equilibrium exchange rates through FEER, BEER and NATREX methodologies. To find more about these alternative methodologies, see Driver & Westaway (2004).

³ This brief review focuses on studies dealing with PPP hypothesis for developing countries. For studies applied on PPP for developed countries see among others MacDonald (1993), Lothian & Taylor (1996) and Obstfeld & Rogoff (2000).

illustrates the econometric methodology, including the properties of the nonlinear SETAR model and the Hansen's Linearity test. The data set is described in section 4 while section 5 presents our empirical findings. Section 6 summarizes and concludes.

2. Nonlinear Adjustment in Real Exchange Rates: Theory and Evidence

Real exchange rates may exhibit a nonlinear behavior because of heterogeneity of opinion in forex markets (Kilian & Taylor, 2003), heterogeneous Central Banks' objectives (Taylor, 2004) and differences in technology and preferences (O'Connell & Wei, 2002). Heckscher (1916) first introduced the idea that real exchange rate adjustments may be nonlinear because of transaction costs. These developments have direct effects on goods arbitrage and on the validity of the PPP hypothesis. The Law of One Price (LOP) states that homogeneous goods across countries should have the same price once they are converted to a common currency. The intuition behind the LOP is that goods arbitrage can equalize prices across countries. However, in the presence of transaction costs, goods arbitrage becomes unprofitable. As a consequence, PPP may not hold in the long run because of transaction costs, which include transportation cost, tariff and non-tariff barriers. Though, tariff barriers decline over time, other trade frictions (non-tariff barriers) cause significant nonlinearities in the adjustment process of real exchange rates.⁴

Theoretical models (O'Connell, 1998, Obstfeld & Taylor, 1997), studying nonlinear real exchange rate adjustment, show that transaction costs create a band for the real exchange rate within which goods arbitrage is unprofitable (i.e. the marginal cost of arbitrage exceeds the marginal benefit). This is called as proportional or "iceberg" transaction cost. O'Connell (1988) shows that if a good is shipped from one country to another, a fraction k melts on the way, so only the $(1-k)$ of the good arrives. If P is the good's price, the profit from shipping the good from one country to another is $(1-k)P - P$, which is positive for $P < 1/(1-k)$. The profit from shipping the good in the opposite direction is $(1-k)P - 1$, which is positive for $P > 1/(1-k)$. Thus, the "band of no arbitrage" is $(1-k) < P < 1/(1-k)$.

Empirically, researchers model nonlinearities in real exchange rates through the estimation of models that allow the autoregressive parameter to vary. These models are known as Threshold Autoregressive (TAR) models. In line with theoretical studies, TAR models allow for a transaction costs band within which no adjustment take place. As a consequence, real exchange rate adjustment is non-stationary. Outside the band, arbitrage becomes profitable and the process becomes stationary autoregressive. That means that PPP deviations will be persistent if they are small and mean reverting if they are large. Balke & Famby (1997) called this model as a "Band-TAR" model. Furthermore, Obstfeld & Taylor (1997) present two more threshold models. The Equilibrium Threshold Autoregressive (EQ-TAR) model differs from the TAR in the way of reversion. This is towards the center of the band, and not to its edges. The reversion, under the Returning-Drift Threshold Autoregressive (RD-TAR) model, is of the form of random walk with a drift outside the bands. Using monthly disaggregated and aggregated CPI's for 32 countries worldwide from 1980 to 1995, they find that the convergence speed estimated by a linear autoregressive model implies too large half lives, but the convergence speed estimated by a TAR model indicates half lives of 12 months.⁵ Moreover, they provide measures of economic distance and state that they are positively related to the threshold value. In other words, the variability of

⁴ Knetter (1994) shows that non-tariff barriers can successfully explain the deviations of the Deutsche mark/Japanese yen real exchange rate from PPP equilibrium.

⁵ "Half life" is the necessary time for deviations to diminish by one half. For example, if half life is 3 years, deviations will be reduced to one half in 3 years. Hence, the real exchange rate will find its equilibrium in 6 years.

deviations from PPP is positively related to distance. Their results imply that deviations in the outer band generate lower half lives, supporting the theoretical framework of the threshold autoregressive model.

A similar study is that of Sarno et. al.(2004). They apply a TAR model in which the threshold variable is the lagged dependent variable (q_{t-d}). This specification is known as Self Exciting TAR (SETAR) model. The significance of the nonlinear specification of the model is tested against the alternative of a linear model. The results show that transaction costs differ among countries and goods sectors. For example, Japan faces lower transportation cost than European countries, when both importing from the US. They show that the exchange rates follow a unit root process within the band. Outside the band, the process is stationary. Furthermore, they provide a measure of the speed of convergence to equilibrium. For the outer regime, the average half life is about 2 years.

Taylor & Taylor (2004) mention that there is no a unique transaction cost and this causes many threshold barriers. Granger & Terasvirta (1993) present a new generation of TAR models, the so-called Smooth Transition Autoregressive (STAR) models, including the Exponential Smooth Transition Autoregressive (ESTAR) and the Logistic Smooth Transition Autoregressive (LSTAR) models. In these models, adjustments are smooth and in contrast to TAR models, they take place in every period (inside and outside the band). Michael et al (1997) estimate a model of nonlinear mean reversion in which the larger the deviation from PPP, the faster the convergence to equilibrium. As nonlinearity is confirmed, they estimate an ESTAR model by nonlinear least squares. For the full sample, the estimated ESTAR model shows that small deviations entail a random walk behavior, but large deviations cause a mean reverting process. Similarly, Taylor et al (2001) failed to reject non-stationarity for real exchange rates by applying linear univariate and multivariate unit root tests. A number of ESTAR models are jointly estimated by multivariate nonlinear least squares and the results provide significant evidence of nonlinear mean reversion. Moreover, for larger shocks, mean reversion is faster. This implies that for large PPP deviations, half lives are low and for small deviations they are high.

So far the evidence shows that small deviations from PPP follow a random walk process (inside the band) and large deviations are mean reverting (outside the band). However, the story is not always that. O'Connell (1998) applies two models in order to test the nonlinear specification. Firstly, he estimates an EQ-TAR model in which two null hypotheses are tested. Under the first null, real exchange rates follow a random walk process, while the second null states that real exchange rates follow an unconditional AR(1) process. The alternatives state that deviations from PPP are mean reverting. Secondly, he estimates a Nonlinear Regression model in which a higher order term is added to the standard ADF regression. The estimated EQ-TAR model implies that in some cases, large deviations are not mean reverting (in contrast, they are more persistent than small deviations). As a consequence, transaction costs, which are assumed to be responsible for high deviations from PPP, do not explain the PPP puzzle. Identical results are derived from the Nonlinear Regression test. Nonetheless, large deviations are mean reverting only in the case of a panel of some European countries. But, increasing the panel with more countries, the previous statement is no more valid.

3. Econometrics

3.1. Linear Unit Root Test

In a linear framework the real exchange rate is modeled by $s_t = e_t - p_t + p_t^*$, where e_t is the nominal exchange rate, p_t is the domestic price level and p_t^* stands for the foreign price level (all expressed in natural logarithms). Purchasing Power Parity hypothesis is valid if the real exchange rate follows a mean reverting process. Namely, once the real exchange rate describes deviations from the Law of One Price (LOP), the stationary nature of the real exchange rate means that deviations from LOP are transitory. If linearity is the case, a simple unit root test, based on ADF test, is described by:

$$\Delta s_t = \gamma + \delta \cdot t + \rho \cdot s_{t-1} + \sum_{i=1}^k \beta_i \cdot \Delta s_{t-i} + e_t \quad (1)$$

The null hypothesis of non-stationarity ($H_0 : \rho = 0$) is tested against the alternative that the real exchange rate is stationary ($H_1 : \rho < 0$). Following the specification of the ADF test, half-life is estimated by $\ln(0.5)/\ln(\hat{\rho} + 1)$. However, Taylor et al (2001) show that if real exchange rates exhibit a nonlinear behavior, conventional linear unit root tests are biased against rejecting non-stationarity. This means that even if non-stationarity is rejected, the estimated half-lives imply slower mean reversion than the actual one.

3.2. Self-Exciting Threshold Autoregressive (SETAR) model

Consider a two-regime Threshold Autoregressive (TAR) model, originally presented by Tong (1983), of the following form:

$$s_t = \begin{cases} \sum_{i=1}^p \alpha_i \cdot s_{t-i} + \varepsilon_t, & \text{if } s_{t-d} \leq \mathcal{G} \\ \mathcal{G} \cdot (1 - \beta_1) + \beta_1 \cdot s_{t-1} + \sum_{i=2}^p \beta_i \cdot s_{t-i} + \varepsilon_t, & \text{if } s_{t-d} > \mathcal{G} \end{cases} \quad (2)$$

where \mathcal{G} is the threshold parameter, s_{t-d} is the threshold variable and d is the delay parameter. Furthermore, the error is assumed to be normally and identically distributed with zero mean [$\varepsilon_t \sim NID(0, \sigma^2)$]. The above TAR (p, q, d) model,⁶ in which the threshold variable is the lagged dependent variable, is named as Self-Exciting TAR model.

Assuming symmetry in the bottom and upper regimes, the SETAR ($p, 1, d$) model can be written as a symmetric three-regime SETAR ($p, 2, d$) of the form:

⁶ The specification of this model is as follows: p is the lag length of the autoregressive process, q is the number of thresholds and d is the delay parameter.

$$\Delta s_t = \begin{cases} (\beta_1 - 1) \cdot (s_{t-1} - \mathcal{G}) + \sum_{i=2}^p \beta_i \cdot (s_{t-i} - \mathcal{G}) \cdot l(s_{t-d} > \mathcal{G}) \\ + \left[\sum_{i=1}^p \alpha_i \cdot \Delta s_{t-i} \right] \cdot l(|s_{t-d}| \leq \mathcal{G}) \\ + (\beta_1 - 1) \cdot (s_{t-1} + \mathcal{G}) + \sum_{i=2}^p \beta_i \cdot (s_{t-i} + \mathcal{G}) \cdot l(s_{t-d} < -\mathcal{G}) + \varepsilon_t \end{cases} \quad (3)$$

Based on theoretical assumptions, the process is non-stationary inside the band $[-\mathcal{G}, \mathcal{G}]$. Namely, the real exchange rate is not mean reverting if $|s_{t-d}| \leq \mathcal{G}$. Once $s_{t-d} > \mathcal{G}$ or $s_{t-d} < -\mathcal{G}$, the process becomes mean reverting. The above SETAR (p, 2, d) model is written as follows:

$$\Delta s_t = A_t(\mathcal{G}, d)' \cdot B + \varepsilon_t \quad (4)$$

where $A_t(\mathcal{G}, d)'$ is a 1x3 vector that illustrates the behavior of the real exchange rate in the three regimes, and B is a 3x1 vector which involves the autoregressive parameters to be estimated.⁷ Hansen (1996, 1997), assuming that the error term is $NID(0, \sigma^2)$, shows that the Ordinary Least Square (OLS) is an appropriate estimation procedure.⁸ Applying sequential conditional least squares, for any combination of \mathcal{G} and d, the OLS estimator of B is given by:

$$\hat{B}(\mathcal{G}, d) = \left(\sum_{t=1}^n A_t(\mathcal{G}, d) \cdot A_t(\mathcal{G}, d)' \right)^{-1} \cdot \left(\sum_{t=1}^n A_t(\mathcal{G}, d) \cdot \Delta s_t \right) \quad (5)$$

with residuals:

$$\hat{\varepsilon}_t(\mathcal{G}, d) = \Delta s_t - A_t(\mathcal{G}, d)' \cdot \hat{B}(\mathcal{G}, d) \quad (6)$$

and residual variance:

$$\hat{\sigma}^2(\mathcal{G}, d) = \frac{1}{n} \cdot \sum_{t=1}^n \hat{\varepsilon}_t(\mathcal{G}, d)^2 \quad (7)$$

The OLS estimators of \mathcal{G} and d are those which minimize the residual variance:

$$(\hat{\mathcal{G}}, \hat{d}) = \arg \min_{\mathcal{G} \in \Theta, d \in D} \hat{\sigma}^2(\mathcal{G}, d) \quad (8)$$

where $\Theta = [\tau, (1-\tau)]$ and $D = [1, \bar{d}]$. Hansen (1999) shows that by writing the residual variance as $\hat{\sigma}^2(\mathcal{G}, d) = \hat{\sigma}^2 - f^2(\mathcal{G}, d)$, the minimization problem of (8) is equivalent to a maximization problem of $f^2(\mathcal{G}, d)$. In this problem, the search of values of the threshold variable lies between the τ -th and $(1-\tau)$ -th fractiles of the data. However, if p and n are large, this process is too long.

⁷ Following the theoretical assumptions, we would restrict the process to be non-stationary inside the band. However, we estimate the autoregressive parameters of the outer regime as well as these of the inner regime to test robustness of the theoretical model.

⁸ Under this condition, OLS is equivalent to Maximum Likelihood Estimation.

So, we restrict the search to N -values of \mathcal{G} lying on a grid between τ -th and $(1-\tau)$ -th fractiles of S_{t-d} . If $\bar{d} = p$, the procedure runs a search over $p \cdot N$ pairs of (\mathcal{G}, d) . Once the optimal combination of the threshold variable and the delay parameter has been selected,⁹ the OLS estimator of B is given by $\hat{B}(\hat{\mathcal{G}}, \hat{d})$ with residual variance $\hat{\sigma}^2(\hat{\mathcal{G}}, \hat{d})$.

3.3. Hansen's Linearity Test

Here we investigate whether real exchange rates exhibit a nonlinear behavior. In other words, we test the null hypothesis of a true linear AR(p) model against a nonlinear SETAR (p, q, d). Conventional tests of the null of a linear AR model against the TAR alternative have nonstandard distributions because of the presence of nuisance parameters under the null (Davies, 1977). Hansen (1996) shows that the nuisance parameters in a SETAR model are the threshold parameter (\mathcal{G}) and the delay parameter (d). Davies (1977) suggests an alternative LM test statistic which has an unknown distribution under the null. Furthermore, Luukkonen et al (1988) propose the replacement of the transition function with its third-order Taylor approximation when testing linearity against a STAR model.

Hansen (1996, 1997) proposes a bootstrap test procedure, which replicates the asymptotic distribution of the F statistic. The null of the linear AR(p) model against the SETAR(p, q, d) is tested by:

$$F_n(\mathcal{G}, d) = n \cdot \left(\frac{\hat{\sigma}^2 - \hat{\sigma}^2(\mathcal{G}, d)}{\hat{\sigma}^2(\mathcal{G}, d)} \right) \quad (9)$$

where $\hat{\sigma}^2$ is the residual variance of the linear AR(p) model (i.e. restricted), and $\hat{\sigma}^2(\mathcal{G}, d)$ is the residual variance of the SETAR(p, q, d) model (i.e. unrestricted). Hansen (1999) shows that the F -statistic in (9) can be written as:

$$F_n(\mathcal{G}, d) = n \cdot \left(\frac{f^2(\mathcal{G}, d)}{\hat{\sigma}^2 - f^2(\mathcal{G}, d)} \right) \quad (10)$$

which is an increasing function of $f^2(\mathcal{G}, d)$. He shows that the appropriate F -statistic is described by:

$$F_n = \max_{\mathcal{G} \in \Theta, d \in D} F_n(\mathcal{G}, d) \quad (11)$$

Since \mathcal{G} and d are not identified under the null, the F_n statistic does not have an asymptotic X^2 distribution.¹⁰ Hansen (1997) shows that the asymptotic distribution of the F_n statistic can be approximated by the following bootstrap procedure.¹¹ Let u_t^* , $t = 1, \dots, n$ be NID(0, 1) random

⁹ Hansen (1997) argues that as D is discrete, the estimator of the delay parameter is superconsistent.

¹⁰ F -statistic has an asymptotic X^2 distribution for any fixed (\mathcal{G}, d) . However, once we allow for $N \cdot p$ pairs of (\mathcal{G}, d) , we get $N \cdot p$ asymptotic X^2 random variables.

¹¹ Hansen (1999) presents two similar replication procedures to derive robust p -values. The first one yields the asymptotic distribution of the test statistic, while the other one yields the bootstrap distribution. The empirical findings in Hansen (1999) show that there is no significant difference between the asymptotic and the bootstrap p -values.

draws and set $s_t^* = u_t^*$. Then, using the observations s_{t-i} , $t = 1, \dots, n$, & $i = 1, \dots, p$, we get the residual variances of the null and the alternative to estimate the following F statistic:

$$F_n^*(\mathcal{G}, d) = n \cdot \left(\frac{\widehat{\sigma}^{*2} - \hat{\sigma}^{*2}(\mathcal{G}, d)}{\hat{\sigma}^{*2}(\mathcal{G}, d)} \right) \quad (12)$$

The bootstrap approximation to the asymptotic p-value of the test is performed by counting the percentage of bootstrap samples for which $F_n^*(\mathcal{G}, d)$ exceeds the observed $F_n(\mathcal{G}, d)$.

The above analysis assumes that the error term is homoskedastic. Nonetheless, in the presence of conditional heteroskedasticity, the derived distributions provide misleading p-values. Hansen (1999) has presented appropriate algorithms to calculate heteroskedastic asymptotic and bootstrap distributions. If it is not clear whether the error term is homoskedastic or not, Hansen (1999) suggests the use of bootstrap distribution which allows for conditional heteroskedasticity. Moreover, if homoskedasticity is clearly rejected, the most appropriate p-values are those of the heteroskedastic bootstrap distribution. On the other hand, if the evidence of homoskedasticity is strong, homoskedastic bootstrap p-values are more credible. Though, to confirm robustness in our study, we present all types of p-values (i.e. Homo-A, Homo-B, Het-A, Het-B).

4. Data

The dataset involves monthly observations on nominal exchange rates per Euro, Euro area's Consumer Price Index (CPI) and domestic CPI for ten countries. National exchange rates per Euro are taken from Eurostat (ECU rates before 1999), while Consumer Price Indices are taken from IFS statistical database (base year 1995 = 100). Once all variables are expressed in natural logarithms, real exchange rates per Euro are computed as the difference of the price differential (domestic CPI minus Euro area's CPI) from the nominal exchange rate.

The group of countries consists of seven new members of the EU and candidates of EMU membership and three new members of EMU. The examined period is subject to data availability. So, the estimation for Cyprus, Hungary, Poland and Malta covers the period 1990:1-2006:7, for Latvia and Slovenia the estimated period is 1992:1-2006:7, for Czech Republic, Slovak Republic and Estonia is 1993:1-2006:7 and for Lithuania is 1993:6-2006:7.

5. Empirical Analysis

5.1. Linear Unit Root Test

Real exchange rates measure the degree of deviations from the Law of One Price (LOP). Given that testing for PPP makes sense only in its relative form, PPP hypothesis will be valid if the stationary nature of the real exchange rate is confirmed. As a preliminary test, we apply a linear unit root test (ADF) on real exchange rates per Euro. The results are quite satisfactory for the candidate countries. The real Polish zloty/Euro is stationary at 10% significance level, while the evidence of stationarity is stronger for the rest real exchange rates. The evidence of a mean reverting process makes us looking for the speed of the adjustment process. In other words, we need to know how fast deviations from LOP are diminished. The estimated autoregressive parameters imply the half-lives, shown in Table 3.

The estimated half-lives are measured in months. For example, PPP deviations of the Cyprus pound/Euro exchange rate will damp out by 50% in about 69 months (i.e. 6 years approximately). The highest half-life is found, as expected, in the Polish zloty/Euro exchange rate. On the other hand, the lowest half-life is found in Lithuania and Slovak Republic (about 43 months or 3.5 years). However, these values are high and imply a slow mean reverting process.

Table 1: Augmented Dickey-Fuller test

	Exogenous Term	Lags	Statistic	Probability
Cyprus	Constant	0	-6.14	0.0000
Czech Republic	Constant	1	-6.31	0.0000
Estonia	Constant	9	-5.53	0.0000
Hungary	Constant	1	-3.73	0.0042
Latvia	None	1	-3.95	0.0001
Lithuania	Constant	1	-4.66	0.0002
Malta	None	0	-11.78	0.0000
Poland	Constant	1	-2.71	0.0734
Slovak Republic	Constant	1	-6.29	0.0000
Slovenia	Constant	1	-4.15	0.0010

MacKinnon (1996) one-sided p-values

5.2 Testing Linear AR against SETAR

The implied slow mean reversion may be misleading due to the presence of nonlinearities in the adjustment process. This is because conventional linear unit root tests are biased against rejecting non-stationarity (i.e. the autoregressive coefficient is biased upward) when the process is nonlinear. So, we test whether a linear AR model or instead a nonlinear TAR model characterizes the adjustment process. In other words, we test the significance of the threshold effect on the process. Since \mathcal{G} and d are not identified under the null, the F-statistic (expression 11) does not have an asymptotic X^2 distribution. To overcome this problem, we perform asymptotic and bootstrap procedures as described in Hansen (1997, 1999). In fact, the F-statistic can have an asymptotic X^2 distribution for any fixed combination of \mathcal{G} and d . But, the maximization problem of (11) requires a search over $p \cdot N$ pairs of (\mathcal{G}, d) . For our model, we set $p = 6$ and we restrict $N = 100$. This yields to $6 \cdot 100 = 600$ pairs of (\mathcal{G}, d) .

The asymptotic as well as the bootstrap distributions are calculated using 1,000 random draws (replications) which yield the F*-statistics of (12). Then, p-values are computed as the percentage of bootstrap values for which the F*-statistic (12) exceeds the observed F-statistic (11). However, the above p-values are consistent only if the error term is homoskedastic. Hence, we perform an F-type Heteroskedasticity test, which has a standard X^2 distribution [$X^2(6)_{,5\%} = 12.6$, $X^2(6)_{,1\%} = 16.8$]. The Heteroskedasticity test is carried out through an OLS regression of the squared OLS residual on the squares of the lagged real exchange rate, and on dummy variables indicating the regime. Once homoskedasticity is rejected, asymptotically robust to heteroskedasticity distributions are calculated and robust p-values are considered.

The results imply that errors are homoskedastic in the cases of Cyprus, Lithuania, Poland and Slovenia, while for the remaining 6 countries this hypothesis is rejected. The computed p-values,

shown in Table 2, show that linearity can be accepted only in the cases of Estonia and Hungary.¹² For the rest of the countries, the evidence that real exchange rates exhibit nonlinear behaviour is stronger when asymptotic p-values are considered. An exception is the case of Malta and Slovenia, for which bootstrap p-values provide stronger evidence of nonlinear adjustment.

Table 3: SETAR estimation

	d	\mathcal{G}	α	β	A-Hm	B-Hm	A-Ht	B-Ht	F-Het	RRV
Cyprus	1	-3.980	0.983	0.942	0.00	0.12	0.04	0.03	15.126	0.751
Czech Republic	4	2.940	0.985	0.978	0.00	0.00	0.03	0.09	23.45	0.715
Estonia	1	2.120	-----	-----	0.00	0.05	0.12	0.10	42.51	0.740
Hungary	1	2.150	-----	-----	0.00	0.17	0.12	0.19	21.93	0.759
Latvia	4	-2.460	1.008	0.919	0.00	0.00	0.04	0.02	27.28	0.535
Lithuania	5	1.300	0.979	0.940	0.04	0.47	0.18	0.58	3.18	0.865
Malta	4	-4.450	0.978	0.946	0.00	0.06	0.14	0.01	24.50	0.655
Poland	5	-1.790	0.985	0.889	0.00	0.18	0.16	0.17	15.20	0.789
Slovak Republic	1	3.150	0.962	0.904	0.00	0.02	0.05	0.01	23.26	0.711
Slovenia	1	2.630	1.242	0.988	0.09	0.66	0.13	0.58	12.59	0.897

Notes: 1. d is the delay parameter.

2. \mathcal{G} is the threshold variable.

3. α stands for the inner root, calculated as the sum of the estimated autoregressive parameters of the inner

$$\text{regime: } \alpha = \sum_{i=1}^p \alpha_i .$$

4. β stands for the outer root, calculated as the sum of the estimated autoregressive parameters of the outer

$$\text{regime: } \beta = \sum_{i=1}^p \beta_i .$$

5. A-Hm and B-Hm are homoskedastic asymptotic and bootstrap p-values, respectively. A-Ht and B-Ht stand for heteroskedastic p-values.

6. F-Het is the F-type heteroskedasticity test which follows a standard X^2 distribution.

7. RRV is the ratio of the residual variance of the nonlinear SETAR(6, 2, d) model to the residual variance of the linear AR(6) model.

5.3. SETAR Estimation¹³

The evidence from the linearity test implies the estimation of a nonlinear TAR model for all real exchange rates, apart from the Hungarian forint/Euro, Estonian kroon/Euro and Italian lira/Euro, which were found to follow a linear autoregressive process. For the remaining real exchange rates a symmetric 3-regime SETAR (6, 2, d) model is estimated. In all cases, the lag length p is set equal to 6,¹⁴ while the number of thresholds is equal to 2. The symmetric 3-regime SETAR model is equivalent to a 2-regime SETAR if we assume that the process is symmetric in the outer regimes. Thus, if \mathcal{G} is the single threshold (2-regime), the double threshold (3-regime) is described by $(-\mathcal{G}, \mathcal{G})$. The delay parameter (d) illustrates the possibility that market participants

¹² Homoskedastic p-values imply that both real exchange rates are characterized by nonlinearities. However, the evidence of heteroskedasticity makes homoskedastic p-values inappropriate.

¹³ SETAR estimation as well as linearity tests are performed using Hansen's (1999) programs in GAUSS environment.

¹⁴ In selecting the lag length of the autoregressive process, we faced two important restrictions. Firstly, we had to ensure that errors are not serially correlated and secondly we should achieve high power of the linearity test. A high lag length can soak up autocorrelation. However, Sarno et al (2004) find that the power of the test is higher the lower the lag length of the SETAR model.

react with a delay on PPP deviations. The minimum delay order is equal to 1 and the maximum delay order is set equal to 6, i.e. $\bar{d} = p = 6$ and $d \in D(1, 6)$. Moreover, the search of values of the threshold variable lies between the 10% and 90% fractiles of the data and since $p=6$ and N is restricted to 100, the search of the combination of (\mathcal{G}, d) entails $6 \cdot 100 = 600$ pairs of (\mathcal{G}, d) . A final restriction on the estimation of the SETAR model requires 10% minimum percentage of observations per regime.

Table 2 presents the results of the SETAR estimation. The most frequently observed delay order is 1, which indicates that market participants react to deviations with a delay of one month. The highest delay parameter ($d=5$) is observed in the cases of Lithuania and Poland. On average, reaction is delayed by about 3 months when candidate countries are examined.

Once the delay parameter and the threshold variable have been determined, we can estimate the autoregressive parameters inside and outside the band. In other words, we do not restrict the process to follow a random walk inside the band ($-\mathcal{G} < s_{t-d} < \mathcal{G}$). So, we allow the true process to show if theoretical assumptions are valid. For all candidate countries, apart from Latvia and Slovenia, the inner root implies a reverting process. However, the process is faster outside the band. This means that the theoretical assumptions are partly satisfied. Namely, the random walk hypothesis has been established in only two cases but, the hypothesis of faster mean reversion when deviations are large has been confirmed in each case. Hence, we focus on the outer root of the SETAR model, which indicates the degree of nonlinear reversion towards the thresholds.

Compared to the linear model, the implied adjustment process is much faster when a nonlinear model is estimated. This is clearly shown by the estimated half-lives (Table 3). On average, the linear model implies reduction of deviations by 50% in about 62 months (5 years), while the corresponding period, implied by the nonlinear process, is about 18 months (1.5 years). Specifically, the linear half-life estimate for the Cyprus pound/Euro rate is about 69 months and the nonlinear half-life is just 12 months. The fastest process is this observed in Polish zloty/Euro rate, in which the nonlinear half-life estimate is 6 months. The fact that under the linear model this process was the slowest mean reverting process (half-life = 115 months) makes this finding even more impressive. On the other hand, the slowest nonlinear reverting process is observed in the case of Slovenia, half-life = 56 months (4.5 years). But, it is faster than the implied from the linear model (half-life = 63 months or 5.5 years).

Table 5: Half-life estimates

	$\hat{\rho}$	Linear Half-Life	$\hat{\beta}$	Nonlinear Half-life
Cyprus	-0.010	68.968	0.942	11.577
Czech Republic	-0.015	45.862	0.978	31.212
Estonia	-0.013	52.971	-----	-----
Hungary	-0.008	86.296	-----	-----
Latvia	-0.012	57.415	0.919	8.171
Lithuania	-0.016	42.974	0.940	11.286
Malta	-0.012	57.415	0.946	12.433
Poland	-0.006	115.178	0.889	5.918
Slovak Republic	-0.016	42.974	0.904	6.897
Slovenia	-0.011	62.666	0.988	55.828

Notes: 1. Linear Half-life = $\ln(0.5) / \ln(\hat{\rho} + 1)$.

2. Nonlinear Half-life = $\ln(0.5) / \ln(\hat{\beta})$.

3. $\hat{\rho}$ is the estimated autoregressive parameter of the linear ADF test.
4. $\hat{\beta}$ is the estimated outer root of the nonlinear SETAR model.

Finally, as a robustness check we estimated the ratio of the residual variance of the nonlinear SETAR(6, 2, d) model to the residual variance of the linear AR(6) model. For all real exchange rates the ratio (RRV) is less than 1, which means that the variance of the error term of the estimated SETAR model is smaller than that of the alternative AR model. This evidence supports the estimation of the nonlinear SETAR model contrary to the AR. Furthermore, the evidence of heteroskedastic errors in some SETAR models does not affect our estimation since robust to heteroskedasticity p-values have been applied.

6. Conclusion

In this study we examined the adjustment process of real exchange rates per Euro in the enlarged European Union concerning the validity of PPP hypothesis and the degree of trade rigidities in Europe. A linear unit root test (ADF) implies stationary real exchange rates but the estimated half-lives show that the adjustment process is slow. On the other hand, nonlinear (SETAR) half-lives imply much faster reverting processes. This discordance is due to the presence of nonlinearities in the adjustment process. Recall that linear autoregressive parameters are biased upwards in front of nonlinearities. The outer root of the SETAR model implies average half-life of 1.5 years. Rogoff (1996) describes the PPP puzzle as the evidence of slow convergence to PPP equilibrium (3 to 5 years). That means that our estimation resolves this puzzle at least for the examined exchange rates. As a consequence, the validity of PPP hypothesis in the long run assigns evidence of exchange rate equilibrium. Given that a stable and not highly misaligned currency is important for the EMU membership; our findings provide supporting evidence for their assessing process to the Euro zone.

To sum up, this study implies that candidate countries follow a normal integration process towards the European Union. Furthermore, the evidence in favor of PPP hypothesis and the fast reverting process of the real exchange rate imply an equilibrium process for their currencies, which is a crucial requirement for adopting the single European currency. It is worth notable that Slovenia, which recently adopted euro, has the slowest reverting process towards PPP equilibrium among the candidate countries. The slow convergence may be attributed to the applied exchange rate policy vis-à-vis euro before and after its membership into ERM II. Prior to the participation in ERM II, Slovenia adopted an exchange rate policy against euro, which was gradually depreciating the tolar vis-à-vis euro. Since joining ERM II, the tolar/euro exchange rate was very close to the central rate indicating very low volatility. As a consequence, the implied intervention in the foreign exchange market prevents the nominal exchange rate to reflect movements in relative prices.¹⁵ This is in line with Sideris (2007), who states that omission of interventions bias negatively the evidence in favor of PPP equilibrium. Finally, the evidence of nonlinear adjustment – mainly due to transaction costs – seems not to be significant and prohibitive for the entry of those countries into EMU. We just need to consider that these countries, as full members of the EU, face no more any tariff barriers while non-tariff barriers decline over time.

¹⁵ Given the calculation of the real exchange rate, as described in section 4, this is equivalent to slow mean reversion of the real exchange rate.

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