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Empirical Tests of the Relative PPP Hypothesis in new EU Member States: 'An Old Story and Old Problems'?

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Abstract The paper focuses on testing the relative version of the purchasing power parity (PPP) on data for new EU member states over the 1995 to 2009 time period. Three definitions of exchange rates (the Euro, the US Dollar and REER) are used to test the relative version of the PPP hypothesis. Given the large number of potential problems with the verification of PPP hypotheses, univariate (linear and non-linear) and multivariate (panel) unit root tests have been applied. Our results are not unambiguous; however, for robust univariate non-linear unit root tests they indicate that the relative version of PPP holds for the majority of new EU member states. Moreover, panel unit root tests and robustness tests based on decompositions using various specifications and country's characteristics show clear-cut evidence that the economic growth and openness are important determinants, giving additional support to PPP. Our results are robust even after the reduction of the time span to eliminate effects of the ongoing financial crisis.

JEL Classification: E51, F21,

Key words: purchasing power parity, unit root tests, panel unit root tests, new EU Member States

1 Introduction*

The exchange rate economics and empirical studies attempting to verify the related hypotheses have attracted much attention of both empirical and theoretical economists. The reason for that may be very simple; this particular field has experienced rapid theoretical development recently, or it is particularly attractive for empirical economists due to ambiguous results.

One of the most frequently empirically tested hypotheses is the purchasing power parity (PPP). There are two versions of the PPP. The absolute version of the PPP is based on the law of one price (LOP) that is usually tested for individual commodities or baskets of commodities. The relative version of the PPP is a simplification, as it approximates the changes in individual prices by changes in price indices. Particular attention has been devoted to the latter as it is not so difficult to test.

There has been a large number of studies focusing on the PPP, both in developed and developing countries. Empirical results seem to have been in favour of supporting PPP in developed countries. Therefore, recent articles have focused on developed countries such as selected OECD countries (*e.g.* [Chortareas and Kapetanios (2009)]) or EU15 countries (*e.g.* [Christidou and Panagiotidis (2010)]). However, the findings have been mixed for the developing and transition countries, depending on the set of countries, time period, price indices and applied econometric techniques. Some studies have even rejected the PPP hypothesis using univariate unit root tests (hereinafter referred to as *URTs*) and more recently panel unit root tests (hereinafter referred to as *pURTs*).[1] While the former are exposed to criticism due to low power, the latter have solved some problems but simultaneously led to new ones (see (*e.g.* [Bahmani-Oskooee *et al.* (2008)]). Some authors cast doubts on the PPP theory, and its empirical testing, as PPP is a long run concept of exchange rate determination (in the horizon

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[1] LLC and IPS tests have been extensively used in the literature to test PPP hypothesis as a response to problems of *URTs*, see *e.g.* [Alba and Papell (2007)].

of decades for instance), which may span different exchange rate regimes and monetary policy environments.[2]

Why have the transition countries in Europe not seen as much attention so far? This might be for a number of reasons. For example, the availability of data has been limited and the radical and deep structural changes during the 1990s make any analysis difficult.[3] Additionally, some countries did not exist before 1993,[4] which puts limits on available time series. Several studies have tried to overcome this problem by using data for the black market. However, given characteristics of the former regime in most of the new EU member states (hereinafter referred to as NMS),[5] it is not certain how valid these data and their results are. There have also been studies covering selected NMS countries, which focused on issues related to the process of joining the EU [Rahn (2003)] or discussed selected problems associated with the adoption of the euro ([Frait *et al.* (2006)]).

It is a well-known fact that at several points in history, the PPP concept has been used as a guidance for restoring exchange rate parities.[6] The reasons why it is relevant to study PPP for transition countries and in Europe in particular (see (*e.g.* [Alba and Park (2005)]; [Chortareas and Kapetanios (2009)]) may be summarised as follows:

1. The adoption of the euro – if PPP is not a 'yardstick' for a country, then it is much more difficult to think about the right level for fixing an exchange rate.

2. Income convergence – PPP values are used for international comparisons and conversion of domestic aggregates to one artificial currency that is not biased by exchange rate fluctuations.[7]

3. Misalignment of a currency – if the PPP does not hold – with impact on current account

[2]For a brief discussion see *e.g.* [Alba and Papell (2007)].

[3]The same does hold true for developing (transition) countries in general, for an overview see *e.g.* [Bahmani-Oskooee *et al.* (2008)].

[4]The Czech Republic and Slovakia or 1990 in the case of the Baltic States.

[5]Through the text we will use either NMS12 or simply NMS as synonyms for all the NMS countries. NMS10 consists of countries from the 5^{th} (2004) wave of enlargement (*i.e.* without Bulgaria and Romania); NMS8 encompasses only Central and Eastern European transition countries (*i.e.* without Cyprus and Malta) and NMS5 is the Visegrad group of countries (the so-called core of the NMS countries): the Czech Republic, Hungary, Poland, Slovakia and Slovenia.

[6]The most prominent case seems to be in the 1920s, when some countries restored their pre-war exchange rate regimes (gold parities), following recommendation of Gustav Cassel (see [Cassel (1922)]).

[7]The PPP works as a double convertor: it converts domestic prices to international prices and it converts currencies.

and competitiveness of a country.

4. Effects of devaluation or revaluation of a currency (i.e. effects on competitiveness) – They are expected to vanish in the long run if PPP does hold.

As shown above, there are a number of reasons for having a look at PPP. In this paper, we test the relative version of PPP for the NMS countries, using two approaches: firstly, simple univariate cases (*URTs*) and secondly, the whole group of countries in panel settings (*pURTs*). In order to do that, we will use real exchange rate (RER in two definitions following two main world currencies and REER). Even though our results are in many cases inconclusive (mainly for univariate cases), only the more robust non-linear KSS test gives support to PPP. The same does hold for other non-linear *URTs* (the Bierens (1997) test). Our results for a panel of countries show some evidence in favour of the PPP concept (for the Pesaran's CADF test). In particular, PPP holds for countries that are more open, less regulated or growing faster.

Various definitions of exchange rates have been used throughout this text. The Euro, the US Dollar (US $) and the CPI-based real effective exchange rate (REER). As REER are available only for some of NMS countries,[8] and we want to use various specifications, we test the PPP hypothesis only on via employing *URTs*.

To date there has been no empirical study that would use both approaches and the complete set of NMS countries as far as we are aware of. The main contributions of this study can be summarised as follows: PPP is tested vis-à-vis the euro currency[9] and both the *URTs* and the *pURTs* are employed, including high power ones compared to standard ADF (the non-linear KSS and the Bierens (1997) tests) or LLC and IPS for panels (the Pesarans' CADF test), while focusing on quarterly instead of monthly data for all NMS countries. This allows us to do more robustness tests (country characteristics, various exchange rate regimes, etc.) without losing too many degrees of freedom due to lack of data. We also distinguish between time periods before and after the ongoing financial crisis. As *pURTs* used in this paper assume linear adjustment process, the main emphasis of this paper is on *URTs* , while *pURTs* can be

[8]In the IMF IFS database that is the main source of the underlying data used in this paper. REER's are missing for the Baltic States, and Slovenia.

[9]Standard approach is to test PPP against the US dollar or a set of currencies (real effective exchange rate, REER), see *e.g.* [Bahmani-Oskooee *et al.* (2008)] or [Telatar and Hasanov (2009)].

viewed as a sort of robustness check for linear *URTs* we do this exercise only for one currency (the Euro). The empirical methodology used in this paper is however only one of a wide range of possibilities to test (equilibrium) exchange rates and/or misalignments (a measure of over- and undervaluation). Apart from the unit root test approach, other methods for time series can be used (cointegration, (cointegration, dynamic OLS (DOLS), fully modified OLS (FMOLS), ARDL or pooled mean group estimator (PMGE)). A review of studies and empirical methodologies can be found in [Égert and Halpern (2006)] or in [Candelon *et al.* (2007)].

The paper is structured as follows. The second section aims at summarizing the literature in the field and explaining the main problems and our empirical strategy. The third section describes briefly the main tests employed and the dataset. The next section presents and discusses the results of our empirical analysis in the light of various robustness tests. The last section concludes and offers possible extensions of this study.

2 Theoretical foundations

The determination of exchange rates and their changes is one of the most questionable parts of modern international economics. Even though there has been a large number of studies that have dealt with this subject, it is not certain whether our current knowledge is better than few years (or even decades) ago, for brief discussion see (*e.g.* [Alba and Papell (2007)]). It is not obvious why this so; however, it may be due to the fact that an exchange rate is one of the prices in an economy. Such a price is determined by a great number of factors and since their influences may be pushing the price (the exchange rate) in both directions, the results remain uncertain. In addition, a significant factor may be the role of psychological factors that are related to participants acting in foreign markets.

There are several approaches and concepts that put emphasis on the role of various factors (determinants) that may be at play in determining the value of an exchange rate. It is possible to classify them, *e.g.* with respect to the time dimension. Some of them are important in the short run, others in the long run. While the main theory for the short run seems to be the uncovered interest rate parity, there are several classification schemes used for exchange rate determination and its determinants in the long run (equilibrium concepts):[10]

- Firstly, it is the concept of purchasing power parity (PPP) that emphasises the role of changes in price levels between countries[11];
- Secondly, an approach that is based on having macroeconomic balance (both internal and external) and macroeconomic identities without explicitly stating any theoretical grounds for exchange rate determination ([Clark and MacDonald (1998)]) – the fundamental equilibrium exchange rate (FEER). In this approach, the key variables determining the equilibrium exchange rate are the national income and the current account balance;
- Thirdly, the last approach is based on a set of economic indicators that help to explain behaviour of exchange rate – the behavioural equilibrium exchange rate (BEER). The key distinction between FEER and BEER is that the BEER includes a part that can be described as 'behavioural' [Gandolfo (2001)]. The inclusion of individual (fundamental) variables rests upon theoretical underpinnings.[12] [Clark and MacDonald (1998)]'s study includes the ratio of domestic consumer price index to the producer price index (a proxy for the Balassa-Samuelson effect (B-S effect)[13]), the stock of net foreign assets, terms of trade, and the fraction of the supply of domestic to foreign government debt (a risk premium factor). However, the list of potential variables is much longer (see *e.g.*

[10] A recent study written by [Bussiére *et al.* (2010)] distinguishes between:

- the macroeconomic balance approach,
- the external sustainability approach and
- the reduced form equilibrium real exchange rate.

[11] However, there have been discussions associated with price indices that may be used and mainly, theoretical assumptions that are not satisfied in reality. The approaches nos. 1 and 2 can be classified as the FEER concept (following [Williamson (1994)]) as they rely on calculations of an exchange rate that closes gaps between a selected balance (various definitions – broader or narrower) of balance of payments and its 'normal' value. In the former case they are estimated, in the latter, they are derived so that external debt is stable. The approach no. 3 consists of the PPP concept and its extensions.

[12] In order to estimate BEER, the current levels of fundamental variables are used and variables that show cyclical behaviour (having a persistent, but vanishing effect over the course of time) may be employed as well. A refinement of BEER is PEER – the permanent equilibrium exchange rate – that makes use of the decomposition of the BEER into permanent and transitory components. It can be also viewed as an example ot the medium-term equilibrium exchange rate approach compared to the cyclical and current values of variables approach (the short-term approach), *e.i.* BEER.

[13] For details regarding the Balassa-Samuelson effect see *e.g.* [Égert *et al.* (2005)].

[Bénassy-Quéré *et al.* (2009)].)

However, there are various approaches to the classifications of exchange rates. For example, the study of [Kanamori and Zhao (2006)] distinguishes among (all approaches can be also divided into three groups as far as the time dimension is considered, see below)[14]

- partial equilibrium models (absolute and relative PPP and covered and uncovered interest rate parity models) – only one 'relevant' market in an economy is considered;
- general equilibrium models (the Mundell-Fleming model, the Balassa-Samuelson model, the Redux model ([Obstfeld and Rogoff (1995)], [Obstfeld and Rogoff (1996)]) and the Pricing to Market (PT or PTM) model) and
- disequilibrium (hybrid) models (simple monetary models and the Dornbush (overshooting) model).

2.1 The issue of time horizon

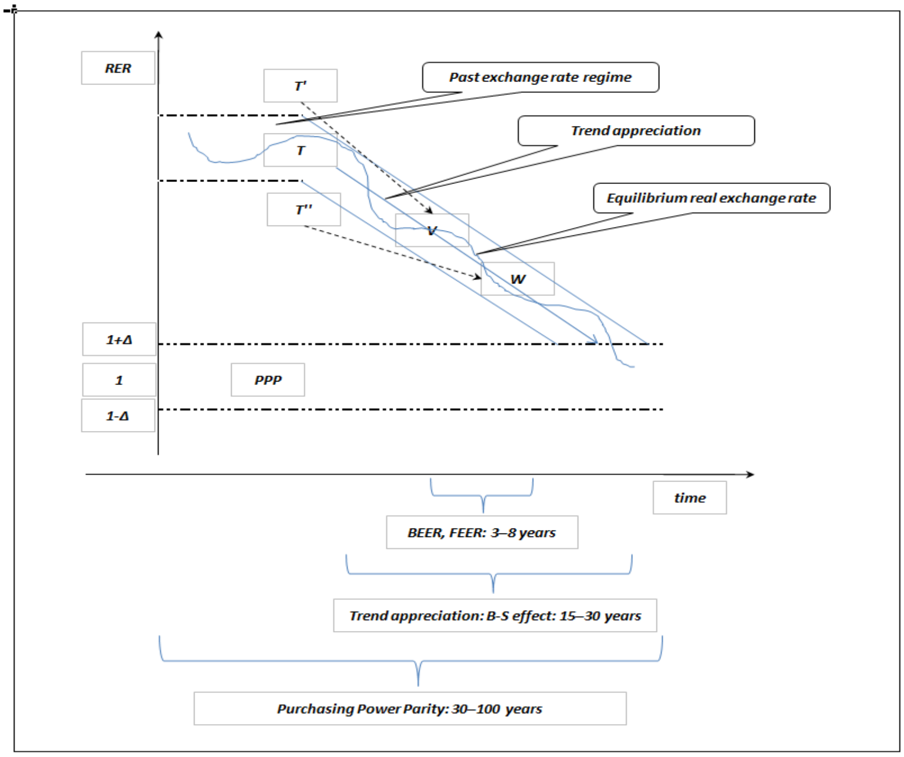
The time dimension that is used seems to be the crucial factor for the exchange rate determination and discussions of equilibrium concepts. [Bénassy-Quéré *et al.* (2009)] distinguish between among possibilities:

- The medium run – only prices of goods and services are flexible and therefore, they will drive an exchange rate towards the level that will result in adjusting trade balance and net foreign assets (NFA) to their 'equilibrium levels'. This case is equivalent to the definition of FEER.
- The long run – prices and stocks can change, an exchange rate is driven by these variables (differences in NFA positions and productivity gaps). This case is consistent with the definition of BEER.

[14] Among other approaches to the exchange rate determination, it may be distinguished between monetaristic's and keynesian models, *i.e.* exchange rate determination explained via money (monetary models where an exchange rate is the relative price of two monies) and assset markets (portfolio models) where an exchange rate is the relative price of bonds) see [MacDonald (2007)] or [Gandolfo (2001)].

- The very long run – all variables can change as all adjustment processes have been completed. This case reflects the PPP definition.

Figure 2.1: Exchange rate determination



Note: RER – level of the real exchange rate. *Source:* [Égert *et al.* (2005), p. 26], own adaptation.

Figure 2.1 shows how one can interpret the link between individual approaches to exchange rate determination (with respect to one classification scheme – time dimension). The PPP concept with its assumptions can be viewed as guidance for the development of an exchange rate in the long run, in the horizon of decades (see [Wu *et al.* (2010)]). The FEER can be used for medium run assessments (given its construction), the BEER for short and medium run. PPP is not indicated as one possible level (equalling to one) but rather as a band ($1 \pm \Delta$).[15] The PPP does stand for the values of ERER (equilibrium real exchange rate) that are compatible with the PPP definition.[16]

Under past political regimes, exchange rates oscillated within a band (if they oscillated at all) and they were reset at the outset of the transformation process in the NMS countries.

[15]Due a number of problems ranging from different tax policies to various combinations of exchange rate pass-through in individual countries.

[16]An early survey of applications of aforementioned equilibrium models in the new EU countries can be found in [Égert and Halpern (2006)].

In some countries it may have been close to the PPP value (given productivity, price and wage levels), while in others below or above this parity (*i.e.* between T' and T'' in the figure 2.1). This deviation may have occurred unintentionally owing to a great deal of uncertainty at that time in NMS countries. However, the RER was generally higher than one. Since then, the trend may have been following fundamental factors of an economy, *i.e.* showing trend appreciation.[17]

There are two other important things to mention: firstly, exchange rate tends to converge towards its equilibrium level (PPP) at rather fast pace (an estimated half life is about 3-5 years, [Rogoff (1996)]) even after allowing for heterogeneity and small sample bias, see [Chen and Engel (2004)]. A faster pace has been found for transition countries, see [Solakoglu (2006)]). Secondly, RER does fluctuate within a band around this equilibrium level even during the transition period (see the figure 2.1). As [Égert *et al.* (2005)] mention, a trend in ERER behaviour as long as 15–30 years may be observed due to changes in structural characteristics of transition economies.[18]

2.2 Literature Review

There have been several studies that focused both on individual countries (for example an early study by [Thacker (1995)], rejecting PPP for Poland and Hungary) and on groups of countries. However, they differ in many aspects: [Bahmani-Oskooee *et al.* (2008)] test PPP *inter alia* for 25 European countries (24 post-communistic European countries and Turkey). Two univariate URTs (ADF and [Kapetanios *et al.* (2003)]'s test, the KSS test) are applied to the REER. They signal non-linear mean reversion to a constant trend for Bulgaria, Slovak Republic, Slovenia, and to a trend for the Czech Republic and Romania.

Twelve CEE countries (the NMS without Cyprus and Malta, but with Croatia and Macedonia) are analysed by [Telatar and Hasanov (2009)]. They apply two standard URTs (ADF, KPSS) and also two URTs accounting for non-linearities (KSS) and asymmetric adjustment

[17] Based on productivity differentials and increase in price levels reflecting usually faster economic growth in transition countries compared to developed ones.

[18] ERER can fluctuate too as it is based on level of net foreign assets (NFA) reflecting current account sustainability. It may also exhibit a kind of overshooting behaviour – lower values in the medium run adjusting current account so that it strengthens in the long run.

(the Sollis' test). They use monthly time series of REER from 1990 to 2007 (with different starting points). They find that PPP holds for five countries with standard *URTs*, for seven countries when nonlinear *pURTs* are employed and for all countries if asymmetric adjustment is allowed. Bilateral PPPs (CPI based) between the Czech Republic, Hungary and Slovenia and their main trading partners (Austria, Germany, France and Italy) were analysed by [Bekö and Boršič (2007)].

They employ univariate URTs (ADF and KPSS) and the Johansen cointegration approach, using monthly data on individual currency pairs for this set of countries over the period of 1992–2006. They do not find any significant evidence for PPP. [Sideris (2006)] focuses on the PPP for 17 CEE countries (without Cyprus and Malta but with selected CIS[19] and Balkan countries) against the US dollar. He makes use of cointegration approaches (Johansen for individual countries and Larson's for a panel). He finds support for both weak and strong versions of PPP.

[Cuestas (2009)] applies non-linear URTs to data (KSS and Bierens test – a generalisation of the ADF test) to REER calculated by the IMF and RER for the US dollar and the euro/ECU (monthly data 1992/1993–2006/2007) for eight CEE countries (without Cyprus and Malta and the Baltic States). While standard URTs reject PPP, KSS and Bierens test do the same for most countries and currency pairs (exceptions are Bulgaria, Croatia and Romania). [Koukouritakis (2009)] focuses on all NMS countries over the period mid-1990s to 2006 (monthly data and the euro) and uses the Johansen cointegration method. He finds that PPP holds for Bulgaria, Cyprus, Romania and Slovenia.

Yearly data from 1992–2003 for 21 post-communistic countries (unbalanced data) and pURTs used by [Solakoglu (2006)]. It finds that PPP holds, even for subgroups of less and more open countries (based on an EBRD classification). Estimated half-lives for his group of countries are around 1.1 year, faster (slower) for more (less) open countries. Another panel data study was conducted by [Matei (2009)]. She focuses on selected NMS countries over the years 1995–2008 (with subdivision before and after EU accession) and uses monthly data. Selected *URTs* and *pURTs* have been used to check the presence of unit roots in the data.

[19] The Commonwealth of Independent States (CIS) is a group of new independent states established after the break-up of the former Soviet union.

[Matei (2009)] finds evidence that PPP does not hold for NMS countries (ambiguous results). However, no robustness test was applied and it is unclear why the countries were selected, as the main focus of the paper is on nominal (price) convergence.

3 Methodology

The purchasing power parity (PPP) is one of the most empirically tested hypotheses is. There are two versions of the PPP. The absolute version of the PPP is based upon the law of one price (LOP) that is usually tested for individual commodities or baskets of commodities. The relative version of the PPP is a simplification, as it approximates the changes in individual prices by the changes in price indices. PPP can be tested in two forms: an absolute or a relative version.[20]

The absolute PPP is a generalization of the 'law of one price'. The LOP can be written as

$$P^i_{d,\,t} = E_{d/f,\,t} \cdot P^i_{f,\,t} \tag{3.1}$$

where $P_{d,\,t}$ is the domestic price level, $P_{f,\,t}$ is the foreign price level both for a good i, expressed in the domestic and the foreign currency respectively and $E_{d/f,\,t}$ is the spot exchange rate.

The absolute PPP can be formally written (assuming inter alia that price baskets in both countries are the same, for discussion see below) as

$$P_{d,\,t} = E_{d/f,\,t} \cdot P_{f,\,t} \tag{3.2}$$

where $P_{d,\,t}$ is the domestic price level, $P_{f,\,t}$ is the foreign price level, expressed in the domestic and the foreign currency respectively and $E_{d/f,\,t}$ is the spot exchange rate. The subscript 't' may be dropped as it is assumed that this relationship holds over time.

The PPP is based on several theoretical assumptions that must be satisfied for it to hold perfectly: no transaction costs, no trade barriers and no non-tradable goods in the strict form

[20] Sometimes these forms are referred to as to the 'weak' and 'strong' version of the PPP hypothesis, see [Taylor and Taylor (2004)].

(see *e.g.* [Kanamori and Zhao (2006)]). However, this is not the case in reality. Apart from these prerequisites that are usually not satisfied, there are other explanations why it does not hold: measurement errors, non-economical factors different from trade barriers, imperfect information and information costs leading to existence of non-equalised prices, various market participants (volume of currency trade associated with trade flows is only a tiny fraction of total transactions in foreign markets). That means that the exchange rate may be driven by other factors such as interest rate differentials (capital flows) and the power of empirical methods used for testing PPP (for details and review of studies see *e.g.* [Sarno and Taylor (2003)]; [MacDonald (2007)]). If that were the case, it would hold that changes in an exchange rate would fully reflect the price differentials between domestic and foreign country over a period of time and real exchange rate ( ) would equal to one. That means (if absolute PPP holds and the real exchange rate is given by the ratio of price levels)[21]

$$q_t = \frac{E_{d/f,t} \cdot P_{f,t}}{P_{d,t}} \tag{3.3}$$

$$q_t = 1 \qquad \left(= \frac{P_{f,t}}{P_{d,t}} \cdot \frac{P_{d,t}}{P_{f,t}} \quad \text{if} \quad q_t = \frac{P_{d,t}}{P_{f,t}} \right) \tag{3.4}$$

A log-linearised form of the relative version of the PPP (hereinafter referred to as simple PPP unless indicated otherwise) can be written as:[22]

$$q_{i,ea,t} = e_{i,ea\,t} - p_{i,t} + p_{ea,t} \tag{3.5}$$

where the lower case letters indicates values in natural logarithms, p. are the individual price indices for the country i and time t (for details see data descriptions),[23] $e_{i,ea,t}$ is nominal exchange rate for country i against the euro expressed as j units of domestic currency against one unit of the euro (*i.e.* direct quotation of the exchange rate).

For countries that joined the Euro area, the exchange rate is calculated as $e_{i,ea,t} = e_{ea,t} + e_i$,

[21] The same can be shown for relative PPP if inflation rates replace price levels and cross term stemming from multiplication is omitted.

[22] Some studies have used one of the approaches, *e.g.* [Juvenal and Taylor (2008)] takes the US economy as the benchmark country.

[23] CPI indices are usually used in tests of PPP. However, CPI is a proxy for changes in national price level. Therefore broad price indices such as the GDP deflator may be preferred, for quarterly or yearly time series in particular. Here problems such as availability, methodological changes of such a time series come into the fore.

where e_i is the Euro area member's national currency conversion rate of one euro. For the US Dollar (US \$), indices are in relation to the US \$ and also price indices are calculated agains the US price index ($p_{us,t}$).[24]

In the case of the real effective exchange rate (REER) the same definition as the equation 3.5 states is used. However, due to data unavailability, REER time series based on CPI (the IMF definition) are available only for eight out of twelve NMS countries.

3.1 Estimation strategy

The relative version of the PPP theory in the equation (3.1) can be tested by checking the properties of $q_{\cdot}$. If $q_{\cdot}$ followed a non-stationary process (*e.g.* I(1)), then the PPP would not hold in the long run due to non-stationary properties.[25] On the other hand, if a unit root is not present in a time series, it means that a deviation from equilibrium is only of a temporary nature and the PPP does hold in the long run.

As there are many potential factors influencing exchange rates, pURTs are also applied to subgroups of the NMS countries (NMS10, NMS8, and NMS5). The reason is that some countries may be viewed as one group (block) by international investors using the same rule for each of them. In addition, some criteria are used to check robustness of our results. We make use of:[26]

- classification of exchange rates regimes (float or peg);
- GDP growth rates;
- inflation rates;
- the impact of a country's openness (trade flows);

[24]As it would be possible to argue that fixing conversion rates and applying them to data prior 1998 is artificial, the same set of tests is applied to exchange rates against the US \$.

[25]A shock influencing this time series would lead to disequilibrium that would not be restored due to increasing variance and non-existence of unconditional mean of this time series, see [Fan and Yao (2003)] or [Tong (1990)].

[26]Only distance is not included as there is no exact point which distances for individual countries could be measured to (conversely, a country such as the USA). For example, longer distances increase transport costs and thus the PPP may not hold.

- volatility of nominal exchange rate and
- progress in transition measured by reform indicator of the EBRD.[27]

3.2 Available methods

A wide variety of methods may be applied in this context. They range from pure time series to combinations of time and panel data techniques. As there are two dimensions, the natural step is to decide whether to use an individual country approach or a panel. This leads to the use of *URTs* and *pURTs*. Empirical studies usually work with one of two possibilities:

- time series analysis based on individual country data – the most commonly used approach (univariate *URTs*), but there are some problems (see below);
- panel data approach – which enables the researcher to make use of information from both dimensions (*pURTs*).

However, estimations of exchange rates may be a difficult task in the case of transition countries in particular, as there is a large number of potential problems (ranging from data availability, its consistency, to short time span, etc., see discussion above). For example, [Maeso-Fernandez *et al.* (2005)] point out that using data from the period before regimes changed does not make much sense, given a large number of differences between centrally planned economies and standard market economies. This reduces the time span that can be used. Some NMS countries created new currencies during the first years of the 1990s, which further reduces the possible time span.

A discussion of the possible data problems in the context of transition countries can be found *e.g.* in [Kim and Korhonen (2005)]. One of the major problems seems to be the fact that all of these countries changed (devaluated) the exchange rates at the outset of transformation processes. The magnitude varied but usually was in terms of dozens of percentage points

[27] The reason for the inclusion of the last proxy seems to be obvious – different stages of economic development result in having exchange rate regime that are 'suitable' for a particular country. It is also shown in the figure 2.1, see above. This set of criteria should offer wide range of possibilities that classifies countries according one of them, which may be arbitrary.

rather than several percentage points. Additionally, as some external shocks were expected,[28] some of the NMS countries kept changing the official level of exchange rates during the 1990s. All these factors turn the estimations of exchange rate models into a challenging task.

3.3 Further methodological notes

There is no agreement among empirical economists which of the expanding set of unit root tests is appropriate for testing PPP. If the relative version of PPP is tested, it is verified that exchange rate osciallates within a 'certain band' around '1'. That is the very long-term level of an exchange rate in an economy if strict assumptions of the PPP theory are satisfied:

$$\Delta q_t = \rho q_{t-1} + \upsilon_t \tag{3.6}$$

where q_t is a time series (*e.g.* an exchange rate), $\rho \in (0, 1)$ is an autoregressive parameter and υ_t is the error term.

Due to difficulties with the time series that can be used and their sensitivity to a large number of factors, 'standard' and non-linear *URTs* are applied to our data. Additionally, *pURTs* are employed too. If a unit root is not found, the next step can be done, which is the calculation of half-lives.[29]

Some studies have shown that unit root tests and cointegration tests may have very low power if the number of observations (T) is low (for an application associated with transition countries and yearly data see *e.g.* [Solakoglu (2006)]). However, it may also be argued that long time series may include (multiple) structural breaks in the case of transition (developing) countries in particular.[30] Additionally, using higher frequency data may not help to increase variability, as the power of a unit root test when the length of time series remains unchanged.

It is a well-known fact that panel data techniques have a large number of advantages compared to cross-section or time series analyses (pooling cross-sections and time dimensions

[28] The break-up of the former Soviet Union, the 1992–1993 ERM crisis in the EC to mention at least the most important ones.

[29] Half-life means a period of time necessary to halve the existing gap of one (economic) variable. A decay rate and a decay constant is necessary to calculate a half-life.

[30] An example can be a change of a policy regime that is very likely in those countries.

for analyzing the null hypothesis of unit roots in each time series against the hypotheses of stationarity), see *e.g.* [Baltagi (2008)]. The variation of individual time series is assumed to improve efficiency and therefore to enhance the power of unit root tests even for shorter time series when used in a panel data analysis.

Another issue related to empirical studies of the PPP hypothesis is the so-called bivariate or trivariate approach. Some authors prove that the results of PPP tests depend on the method used for calculations of RER (see the equation (3.5)) – inflaton differential of substracting and adding changes of price indices.[31] This is particularly important for the cointegration approach (see [Al-Omar and Ghali (2009)]). In this text, we rely on the trivariate approach that seems to be more robust and does not seem to be sensitive to the method of calculating differentials.

3.4 Univariate unit root tests

In the first step, univariate *URTs* are applied to the data. Then we will proceed with a variety of panel unit root tests (first and second generation of tests, see classification below). However, due to a large number of problems with the *URTs*, *pURTs* seem to be preferrable for some applications.[32] Nevertheless, we start with the univariate unit root tests (the Augmented Dickey-Fuller test (ADF), the Phillips-Perron test (PP) and the Kwiatkowski-Phillips-Schmidt-Shin tests, KPSS) and their modified versions adjusted to the case of structural breaks such as the DF-GLS test developed by [Elliott *et al.* (1996)], which is a modified Dickey-Fuller test transformed by a GLS regression; for details about these *URTs* see *e.g.* [Harris and Sollis (2005)]. As our time period does not include the early 1990s, we eliminate the problems with possible structural breaks (at least partially).[33] However, the main reason is the data availability for the NMS countries.

[31] The bivariate approach presumes symmetry between domestic and foreign prices, *i.e.* instead of working with two price indices, a term expressing an inflation differential is used.

[32] Low power of these tests in presence of structural breaks (*e.g.* changes of exchange rate regimes), small sample problems, existence of cross correlation and heterogeneity in a panel [Matei (2009)].

[33] In the early 1990s many countries devaluated currencies, changed exchange rate regimes, etc., which has not occurred so often since the late 1990s.

3.4.1 KSS test

In addition to the standard *URTs*, we make use of a non-linear test that accounts for the non-linear behaviour of RERs [Kapetanios *et al.* (2003)] – I(0) outside of a band but I(1) inside of a band – and therefore, this test is more robust. The KSS test (a version of the standard ADF test) is based on an ESTAR model that can be written as:

$$\Delta x_t = \varrho x_{t-1} \left[1 - \exp\left(-\zeta x_{t-1}^2\right)\right] + \nu_t, \qquad \zeta \geq 0, \tag{3.7}$$

where x_t is the demeaned or detrended (exchange rate) time series, $\left[1 - \exp\left(-\zeta x_{t-1}^2\right)\right]$ is the exponential transition function presenting the non-linear adjustment, if $\zeta > 0$, it affects the speed of mean reversion and ν_t is $i.i.d.$ error term $(\nu[\mu_\nu, \sigma_\nu] = \nu[0, \sigma_\nu])$.

The null hypothesis is that $H_0 : \zeta = 0$ $(\Delta x_t = \nu_t)$ and the term in brackets is zero. The alternative $H_1 : \zeta > 0$ means, that ζ drives the speed of a mean reverting process. As ζ in the equation (3.7) cannot be used to test the $H_0 :$ directly, the parameter ϱ is not identified, reparametrization (a first-order Taylor series approximation) is used instead. That leads to the following regression equation (3.8)

$$\Delta x_t = \psi x_{t-1}^3 + \epsilon_t. \tag{3.8}$$

Generalisation of the equation (3.8) allows for serial correlation of the error term ϵ_t

$$\Delta x_t = \psi x_{t-1}^3 + \sum_{i=1}^{k} \omega_i \Delta x_{t-i} + \epsilon_t' \tag{3.9}$$

where the sum augments the equation (3.8) with k lags, so that the ϵ' term is not serially correlated. The null hypothesis in the equations (3.8) and (3.9) remains unchanged, the alternative is $H_1 : \psi < 0$. As the t-statistics $(t_{NL..})$[34] are not standard normally distributed, the critical values must be tabulated via simulations. In the following text, t_{NL11}, t_{NL12} for the equation (3.8) and t_{NL21}, t_{NL22} for the equation (3.9) are the test statistics for demeaned data and detrended data respectively. The demeaned data are obtained from regressions of

[34] '..' in the expression is left out for individual variants of the KSS test.

time series on a constant and/or on a constant and a time trend (the residuals are saved and used in next steps). If the H_0 is rejected, it means that time series reverses to a constant mean (demeaned data), *i.e.* it supports PPP. Although linear or nonlinear reversion in time series to a trend (detrended data), meaning support for the B-S effect. The selection on the appropriate number of lags follows the same procedure as for other *URTs* tests.

3.4.2 Bierens test

The Bierens (1997) tests ([Bierens (1997)]) helps to overcome problems with structural breaks as non-linear trends are approximated by interrupted (broken) time trends. It assumes non-stationarity under the H_0, and non-linear trend stationarity under the H_1. It extends standard ADF regression with a Chebishev polynomial term $\left(\theta^T P_{t,n}^{(m)}\right)$. The process can be written as:

$$\Delta x_t = \gamma x_{t-1} + \sum_{i=1}^{k} w_i \Delta x_{t-i} + \theta^T P_{t,n}^{(m)} + \nu_t, \tag{3.10}$$

where $\theta^T P_{t,n}^{(m)} = \left(P'_{0,n(t)}, \ldots, P'_{m,n(t)}\right)$ are the Chebishev polynomials and m is the order of the polynomials. Under the $H_0 : \gamma = 0$ and the last m components of θ are zero.

There are three possibilities that can be tested ([Bierens (1997)]):[35]

1. all coefficients $\left(\gamma, \hat{t}(m)\right)$ are tested via t-test;
2. $\hat{A}(m)$ test, $\hat{A}(m) = \frac{n\hat{\gamma}}{\left|1 - \sum_{j=1}^{r} \hat{\omega}_i\right|}$ or;
3. the joint hypothesis $\left(\hat{F}(m)\right)$ that under the $H_0 : \hat{\gamma} = 0$ and the last m components of θ are zero.[36]

As [Cuestas (2009)] mentions, rejection of the left side hypothesis for the first and second tests means linear or non-linear trend stationarity. (It cannot be decided which of the cases is true.) Rejection of the right side means non-linear trend stationarity. The third test is a

[35] As the tests nos. 1 and 2 do not accommodate all information available, the test no. 3 is added.

[36] An alternative is a χ^2 test proposed in [Bierens (1997)] with a standard null distribution. The text also introduces three tests that are independent of the assumed AR structure for the error term ν_t.

one-sided test that does not give us any answer regarding the trend as right side rejection is only the rejection of the H_0. All possibilities are summarised in the table 3.1.

Table 3.1: Alternative hypotheses (H_1) for the Bierens (1997) test

Test	Left-side rejection	Right-side rejection
$\hat{t}(m)$	ST, TST or NTST	NTST
$\hat{A}(m)$	ST, TST or NTST	NTST
$\hat{F}(m)$	-	ST, TST or NTST

Note: ST – (mean) stationary, TST – (linear) trend stationary, NTST – non-linear (trend) stationarity. The $\hat{F}(m)$ test is only a one-sided test, the $\hat{t}(m)$ and $\hat{A}(m)$ are specified for both sides. *Source:* [Cuestas (2009), p. 92], own adaptation.

3.5 Panel unit root tests

The panel unit root tests are extensions of the *URTs*. Due to their construction, they offer more than a simple inclusion of cross-sectional dimension. They differ as to what transformations are used and they assume linearity of the underlying process. All commonly used panel unit root tests assume the presence of unit roots specified as a standard AR(1) process that is common for all units (i) in a panel or individual non-stationary processes under the null hypothesis; however, the alternative for individual *pURTs* differs.[37]

To begin with, let us assume a standard autoregressive process (AR(1)) in the panel context can be expressed as follows (see [Stata (2009)]):

$$x_{i,t} = \alpha_i + \varrho_i x_{i,t-1} + \mathbf{w}'_{i,t}\beta_i + \varepsilon_{i,t}, \tag{3.11}$$

where $x_{i,t}$ is a particular time series, α_i represents the fixed effects, $\mathbf{w}'_{i,t}$ is a term that may contain a linear time trend or panel specific means, ϱ_i, is the parameter of an autoregressive process, $\varepsilon_{i,t}$, is a error term, $i = 1, \ldots, N$ is the cross-section dimension, $t = 1, \ldots, T$ is the time dimension.

[37] For a review of early and more recent methods and their discussion see *e.g.* [Banerjee (1999)] or [Breitung and Pesaran (2008)].

The equation (3.11) can be transformed into the following form:

$$\Delta x'_{i,t} = \alpha_i + \rho_i x'_{i,t-1} + \mathbf{w}'_{I,t}\beta_i + \epsilon'_{i,t}, \tag{3.12}$$

Standard *pURTs* are employed to the individual time series ($x_{i,t}$) and work with the null hypothesis being tested (H_0) in the form:

$$H_0 : \varrho_i = 1, \forall_i \tag{3.13}$$

and with the alternative hypothesis (H_1)

$$H_1 : \varrho_i < 1. \tag{3.14}$$

In the case of the equation (3.12), the null is ($H_0 : \rho_i = 0, \quad \forall_i$), the alternative ($H_1 : \rho_i < 0$).[38]

Regarding individual *pURTs*, we focus on selected test of the first generation. One of the oldest is the Lin-Levin-Chu test ([Levin *et al.* (2002)], LLC)[39] works with the equation (3.12) but adds a term allowing for serial correlation so that the empirical counterpart of $\epsilon_{i,t}$ will be white noise.[40]

The Im-Pesaran-Shin test ([Im *et al.* (2003)], IPS)[41] does not assume one common autoregressive parameter ρ in a panel. This seems to be often the case in empirical applications. The IPS test makes use of the Dickey-Fuller test calculated for individual panels and not for a panel as a whole (as the LLC test does). While the H_0 remains unchanged (a unit root in each panel), the alternative works with a fraction of panels that are stationary in the whole panel. As serial correlation is present in our data, a robust version of this test is appropriate. The test statistics W_{t-bar} follows an asymptotically standard normal distribution.

Another test is the Maddala and Wu test ([Maddala and Wu (1999)], M-W).[42] This is also called the 'Fisher test', due to its construction based on a meta-analysis approach. That means

[38]Only the Hadri LM test (see below) is based on the opposite of this, *i.e.* the null hypothesis assumes stationarity.

[39]This test rests upon previous work of the authors -– the Levin-Lin tests (LL) from 1992 and 1993.

[40]For example, say $u_{I,t} \approx N[0, \mathbf{\Sigma}_u]$. Another important assumption is that $E[\epsilon_{i,t}, \epsilon_{j,v}] = 0, \forall_{t,v}$ and $i \neq j$.

[41]The Im, Pesaran and Shin test replaced previous version of the IPS test from 1997.

[42]Details for this test can be found in [Banerjee *et al.* (2005)].

that the results of N individual (univariate *URTs* are used to compute a test for the whole panel. The M-W test works either with the Dickey-Fuller or the Phillips-Perron test. As in the IPS case, while the H_0 remains unchanged (a unit root in each panel), the alternative says that at least one panel is stationary in the whole panel.

The Hadri LM test (H-LM)[43] takes the same approach as the KPSS test. The null and the alternative hypotheses are swapped – H_0 means data stationarity, H_1 assumes that at least one panel to be I(1) (therefore called the Hadri LM stationarity test). According to [Hadri (2000)] this test works well for medium N and large T dimensions.

One of the second generation *pURTs* is the Pesaran's CADF test ([Pesaran (2007)], CADF) which is analogous to the IPS test as it allows checking for unit roots in heterogeneous panels. The CADF stands for statistics based on univariate DF or ADF regressions with first differences of individual time series and additional cross section averages of lagged levels. Non-stationarity is assumed under the H_0, under the alternative only a fraction of time series in the panel (ϑ) is stationary (similarity to the IPS test).

Individual *pURTs* differ in their treatments of the autoregressive parameter (ρ_i). IPS, HLM, and M-W, assume different parameters (panel specific), *i.e.* $\rho_i \neq \rho \ \forall_i$, while the LLC works with the assumption that they are the same. It is also important to stress how individual *pURTs* treat changes in T and N dimensions. As in our analysis, the dimension of N (number of countries) is small and T may increase, it is reasonable to assume that *pURTs* of the first generation (LLC, IPS, and H-LM)[44] would perform better than other *pURTs* (for an overview see *e.g.* [Baltagi (2008)]; [Hlouskova and Wagner (2005)]).[45]

Some *pURTs* (IPS, H-LM) work with unbalanced panels as well, thus $T_i \neq T$, other *pURTs* work only with balanced panels. Demeaned versions of panel unit root tests are recommended for panels to eliminate cross-sectional dependence.[46] This test enables us to

[43] An recent extension of this test has been suggested in [Hadri and Korozumi (2010)].

[44] In the case of the IPS and H-LM test it is necessary to rely on sequential limit theory, *i.e.* the number of periods goes to infinity first and then the number of cross-sections. This pattern determines properties of *pURTs* depending on the actual T and N sizes.

[45] Individual panel unit root tests also differ in the test statistics that are used under the null. For example, Gaussian limiting distribution for the IPS test, the non-parametric Fischer test based on χ^2 distribution for the M-W test. That leads to different powers of *pURTs* for various T and N. [Banerjee *et al.* (2005)] show some evidence of the power for individual tests.

[46] If $x'_{i,\,t}$ is a demeaned time series (an exchange rate in our case), it does hold: $x'_{i,\,t} = x_{i,\,t} - x_{.,\,t}$, where $x_{.,\,t} = \frac{1}{N}\sum_{i=1}^{\infty} x_{i,\,t}$, *i.e.* $x'_{i,\,t}$ is the exchange rate in relation to the cross-section average.

test for different long run trajectories and regression may also include different intercepts and trends within a set of countries. Other *pURTs* such as the [Harris and Tzavalis (1999)]'s test, the Bai and Ng (2004) test or the Moon and Perron (2004) test, are not covered in this paper as the main purpose is to apply *pURTs* to data and not to discuss properties of individual *pURTs*. For an overview see *e.g.* [Gegenbach *et al.* (2010)].

In addition, if time series in a panel are assumed to have a common numeraire country's currency,[47] cross-serial correlation is to be expected. Therefore, this setting requires an application of *pURTs* that allows for serial correlation such as the MADF test see [Harwey and Bates (2003)] or the panel corrected standard error test (PCSE) see [Jönsson (2005)].[48] But this does not seem to be true in this case given the fact that our time series are calculated against the euro.[49] As time series of exchange rates in our sample cover a set of different countries,[50] it is not certain whether all will follow a common unit root process or not. Moreover, it seems to be reasonable to assume cross-sectional correlation between them.[51] Since our panel is large with a medium dimension of cross sections, we will apply and compare results for all main *pURTs* (the LLC, the IPS, the M-W, and the Pesaran's test); however, the main emphasis will be placed on results of the Pesaran's CADF test.[52]

The latest versions of both tests (LLC and IPS) offer tools to solve some practical problems, such as cross-sectional correlation (as cross-sectional independence of innovations is assumed). Regarding the cross-sectional dependence, [Bussiére *et al.* (2010)] summarise findings of the study [Pesaran and Tosetti (2007)] that tries to shed some light on this issue. They distinguish between two types of correlation – 'strong' and 'weak'. While the first one cannot be solved by demeaning time series, the other can. The potential impacts also depend on the country size and time dimensions. In the case of medium and large panels, weak cross-sectional correlation does not pose a serious problem; strong correlation for non-stationary panel has not been

[47]This problem is described *e.g.* in [Banerjee *et al.* (2005)].

[48]While the LLC test may reject the null hypothesis even when one of the time series is stationary, the MADF test is robust against that and the null is rejected only if all time series are I(0). This test can also be applied in the case of unbalanced panels.

[49]Since the euro did not exist before January 1999 and they are based on artificial calculations using the conversion rates for invidual countries and the euro for the period (1995–1998) before euro adoption.

[50]One may think of possible structural differences among them or the necessity to overcome the 'burden' of past decades of communistic regimes.

[51]Since correlation coefficients show relatively high correlation between time series in our panel.

[52]The LLC and IPS tests are due to their construction with the assumption of cross section independence, not perfectly adequate for our analysis.

addressed yet (an attempt is presented in the study by [Bussiére *et al.* (2010)].

3.6 Data

Empirical studies have used different sorts of data as there is no prior information. While some have worked with monthly data [Telatar and Hasanov (2009)], others used quarterly [Matei (2009)] or even yearly data [Solakoglu (2006)]. We have decided to rely on quarterly data as they are sufficiently long and allow us to perform robustness tests. This is also connected with some advantages and disadvantages. The time span is longer for quarterly data than it would have been for monthly data and it is a reasonable way of solving problem of low number of yearly observations for our set of countries. On the other hand, quarterly time series were not available for all countries and time series used in this paper.[53]

Seasonally adjusted data are used for calculations of the RER time series since seasonal patterns may affects the results of *URTs* or *pURTs*. For seasonal adjustments, the ARIMA X-12 method is applied.[54] We do not use dummy variables in *pURTs* as they would require us to calculate new critical values for individual test statistics and properties of these tests are unknown [Chortareas and Kapetanios (2009)].[55]

Nominal exchange rates for individual pairs of currencies (against the Euro and the US $) are obtained from database Eurostat, UNECE Statistical Database, DataStream, and IMF IFS (quarterly periodic averages). As the euro exchange rate is not available before 1999Q1 (only the ECU), an implicit proxy derived from bilateral exchange rates (UNECE) is used instead,[56] see figures the section A.5) in the Appendix. The last time series is the REER that is CPI based and it is calculated by the IMF. Values for regulation index are taken from EBRD

[53]Surprisingly even for countries such as Malta or Cyprus that can hardly be characterised as transition countries.

[54]As some time series were at monthly frequency, as the first step they were converted into quarterly time series (following the IMF IFS methodology) and in the next step, seasonally adjusted using the ARIMA X-12 method.

[55]However, the main concern regarding seasonal fluctuations would be in the case of monthly time series but even for those some studies do not used seasonally adjusted time series, see *e.g.* [Alba and Papell (2007)]; [Chortareas and Kapetanios (2009)]. even though the time dimension is not large ($T < 50$), but rather medium. On the other hand, some studies (*e.g.* [Christidou and Panagiotidis (2010)] use monthly seasonally adjusted values.

[56]As there have been denominations and changes of individual currencies, our data set includes comparable time series. Due to space constraints details from author are available upon request.

Transition Reports (various years).

Harmonised consumer price indices (HICP) are taken from the Eurostat and UNECE databases for individual countries, with the base year 2005 = 100. The same data for the Euro area stem from the Eurostat database and the ECB statistical data warehouse. The consumer price index reflects the demand side and can be viewed as a proxy for changes in the total price level of an economy.

The producer price indices (PPI) stem from the Eurostat, IMF IFS and UNECE databases (NACE Rev. 2, 2005 = 100). However, this time series is available for Malta only since 2005, which means that this country could not be included in additional robustness tests. The PPI is based on the supply side as it measures changes in prices of tradable (partially non-tradable) commodities. Selected summary statistics for our time series are included in the Appendix (in the section A.6)). The cut-off date for the data was November 2010.

4 Empirics

4.1 Univariate unit root tests

4.1.1 The Euro

For the univariate *URTs* of the PPP concept, the data for individual countries are employed. The main specifications rest upon the RER, based on consumer price indices. The first step is to conduct purfor our sample of countries. Starting values for lag selection are based on [Schwert (1989)] criterion[57] and confirmed by checking values suggested by the H-QIC criterion. In the case of the PP, KPSS and DF-GLS tests[58], the optimum number of lags is selected automatically if this option is allowed. As we are not sure about the character of individual

[57]This rule rests upon a criterion that calculates the optimal number of lags (Ł) as: Ł= $INT\{12 \cdot (\frac{T}{100})^{0.25}\}$, where T is the length of a time series, and INT means that only the whole part of a number is considered. In our case for $T = 60$ is the value $10.561 \approx 10 \Rightarrow 10$ lags was the starting value; see *e.g.* [Greene (2008), p. 752]. The iterative procedure follows; if the last difference is not significant, the test is run for the same specification with one lag less until a significant lag is found. Sometimes the numerator of the fraction is with $T + 1$, however, this does not change for large number of observations T. In our case is the value $10.605 \approx 10$ lags lags

[58]Optimal lag values were based on the Ng-Perron seq t statistics.

time series, models with a constant or a constant and a time trend are employed. The results are presented in table 4.1.

Table 4.1: Univariate unit root tests

	ADF^a)		PP^a)		KPSS^b)		DF-GLS	
	constant	trend	constant	trend	constant	trend	constant	trend
Bulgaria	-0.239	-5.048***	-2.892**	-6.383***	0.995***	0.178^d)	1.504	-0.539
Cyprus	-3.871***	-2.757	-1.781	-3.191*	-1.512	0.234***	0.787	-0.811
Czech Rep.	-1.020	-2.975	-0.925	-3.088	1.070***	0.069	0.867	-3.743***
Estonia	-0.924	-1.872	-4.807***	-6.271***	1.000***	0.184^d)	1.797	-2.174
Hungary	-1.496	-2.147	-0.562	-2.671	1.050***	0.153***	-0.077	-1.095
Lithuania	-5.027***	-4.025***	-3.719**	-3.199*	0.880***	0.224***	1.295	-1.657
Latvia	-2.369	-2.733	-2.268	-1.909	0.704^d)	0.155**	0.174	-1.739
Malta	-2.691*	-1.995	-1.969	-1.472	0.525**	0.145*	-0.373^c)	-1.079
Poland	-2.164	-2.212	-2.264	-2.408	0.714^d)	0.216^d)	-0.047	-1.694
Romania	-1.339	-1.325	-1.295	-1.708	0.890***	0.117	-0.548	-1.923
Slovenia	-2.375	-3.739**	-0.975	-2.607	0.876***	0.107	-0.671	-3.259**
Slovakia	0.247	-2.688	0.401	-2.375	1.080***	0.231***	1.509	-2.213

Note: a) Z(t) values reported. b) values of the test statistics. c) DF-GLS suggested 0 lags. d) significant at 2.5% level. ***, **, and * significant at 1%, 5% and 10% respectively. Critical values for the KPSS test (level stationary): 10% : 0.347, 5% : 0.463, 2.5% : 0.574 and 1% : 0.739; trend stationary: 10% : 0.119, 5% : 0.146, 2.5% : 0.176, and 1% : 0.216. Trend = a constants and a time trend included. Source: own calculation.

The ADF test offers a mixed picture, as some of the time series are stationary. The PP test robust against structural breaks indicates that three exchange rates may be stationary (Bulgarian, Estonian and Lithuanian) – while for Lithuania it does confirm the ADF results, it is the very opposite for Estonia. The results of the KPSS test (the H_0 is stationarity) indicate that almost all time series are non-stationary. Ambiguous results for Cyprian, Czech, Romanian and Slovenian currency indicate rejections of the PPP hypothesis in the long run. The results of the DF-GLS test allows us to reject the null hypothesis of I(1) only for the Czech and Slovenian exchange rate in one specification. [59] If the DF-GLS statistics rejects the I(1) hypothesis, PPP holds.[60] As the results for the alternative price index (PPI) are similar, they are not shown.[61]

Non-linear *URTs* may solve problems of breaks within time series due to changes of ex-

[59] The DF-GLS statistics is superior to the ADF statistics as its power (lower probability of accepting wrong null hypothesis of non-stationarity) and size properties are better [Wu *et al.* (2010)].

[60] The number of lags in augmented versions of bothe tests are chosen according to the Durbin-Watson and the Durbin's alternative test for autocorrelation. If one of them indicates presence of autocorrelation, another lag is added unless both indicate no presence of autocorrelation.

[61] Results are available upon request.

change rate regimes over time. First non-linear test, the KSS test, does reject the H_0 only for the demeaned time series for Slovenia but for all detrended time series apart from Bulgarian, Latvian, Lithuanian and Romanian ones. The figure is therefore different compared to previous results based on standard *pURTs*. It gives much more support to PPP and it is similar to findings of other studies, *e.g.* [Telatar and Hasanov (2009)]. It also implies that barriers to adjustment processes exist. For example, transaction costs change the speed of mean reversion (larger deviations will be followed by faster gap narrowing).

Table 4.2: Univariate unit root test – KSS test

	KSS[a)] demeaned[b)]			KSS[a)] detrended[c)]		
	t_{NL11}	t_{NL12}		t_{NL21}	t_{NL22}	
Bulgaria	-0.5459	0.0184	(3)	-2.0418	0.6479	(0)
Cyprus	-3.4896***	4.7599	(6)	-4.8282***	-5.8687***	(5)
Czech Republic	-0.3878	-1.1351	(1)	-4.1947***	-4.2334***	(1)
Estonia	-0.8791	-0.7506	(3)	-6.1489***	-7.3137***	(2)
Hungary	-0.9020	-2.0717	(2)	-4.8154***	-6.6128***	(3)
Lithuania	-0.2466	0.0666	(0)	-1.5282	-3.5109**	(2)
Latvia	-0.5893	0.0806	(2)	-3.4366***	-2.8364	(2)
Malta	-2.8975*	7.7016	(1)	-5.3124***	-4.0146***	(1)
Poland	-2.5024	-0.3365	(1)	-6.4519***	-3.3005*	(1)
Romania	-0.0051	0.0173	(0)	-0.0428	-0.0918	(1)
Slovenia	-4.6006***	-6.0313***	(1)	-6.141***	-5.2708***	(6)
Slovakia	-0.0083	-0.2674	(1)	-4.5413***	-4.0299***	(1)

Note: Optimal number of lags in parentheses. [a)] values of the test statistics reported. ***, **, and *** significant at 1%, 5% and 10% respectively. Critical values for the KSS test ([Kapetanios *et al.* (2003), p. 364, tab. 1]): [b)] -3.48, -2.93, -2.66. [c)] -3.93, -3.40, -3.13.
Source: own calculation.

The results of the other nonlinear URTs, the Bierens (1997) test, are shown in table 4.3. As there are several size distortions in the case of this test, the critical values are based on the Monte Carlo simulation with 10000 replications (a Gaussian $AR(k)$ process for Δx_t, where k is determined by the AIC or H-Q criterion from previous steps and initial values are taken from particular time series.) If individual tests are not concordant, more lags are included in the model. The order for the Chebishev polynomials (m) must be chosen long enough, as a lack of lags compared to structural breaks might result in lower power of the test [Bierens (1997)]. However, there is no simple rule for its determination. In our case, we follow the suggestion of [Cuestas (2009)], *i.e.* the lag length m is chosen so that it yields more evidence against the null (H_0).

Our results show a rejection of the left-sided hypothesis for the Czech, Estonian and Latvian currencies, which does not allow us to conclude whether they are (mean) stationary, stationary with a linear trend or a stationary around a nonlinear trend. Conversely, Lithuanian and Slovenian currencies indicate stationarity around a nonlinear trend. There is only one significant result for the Bulgarian, Cyprian and Romanian currencies, the other one are (marginally) insignificant. Interestingly, the results for Bulgarian or Hungarian currency are found highly significant in [Cuestas (2009)],[62] but similar for other countries.

Table 4.3: Univariate unit root test – the Bierens (1997) test

	Test	t. statistics	P-value		Test	t. statistics	P-value
Bulgaria	$\hat{t}(m)$	-4.9998	[0.1555]	Latvia	$\hat{t}(m)$	**-4.0550**	**[0.9317]**
	$\hat{A}(m)$	-15.9013	[0.5654]		$\hat{A}(m)$	**-392.6386**	**[0.0696]**
	$\hat{F}(m)$	**25.2365**	**[0.9696]**		$\hat{F}(m)$	9.7555	[0.3363]
Cyprus	$\hat{t}(m)$	-0.4551	[0.1523]	Malta	$\hat{t}(m)$	-6.7392	[0.6305]
	$\hat{A}(m)$	**-16.3117**	**[0.0794]**		$\hat{A}(m)$	-610.5297	[0.3904]
	$\hat{F}(m)$	15.5347	[0.6404]		$\hat{F}(m)$	9.8155	[0.7073]
Czech Republic	$\hat{t}(m)$	**-10.0111**	**[0.0124]**	Poland	$\hat{t}(m)$	-6.8029	[0.5217]
	$\hat{A}(m)$	-69.5700	[0.8578]		$\hat{A}(m)$	-159.5950	[0.3371]
	$\hat{F}(m)$	**13.2114**	**[0.9504]**		$\hat{F}(m)$	6.0903	[0.6680]
Estonia	$\hat{t}(m)$	**-9.6901**	**[0.0260]**	Romania	$\hat{t}(m)$	-8.4230	[0.1117][a)]
	$\hat{A}(m)$	-185.6986	[0.1606]		$\hat{A}(m)$	**-221.5326**	**[0.0683]**
	$\hat{F}(m)$	**36.4082**	**[0.9878]**		$\hat{F}(m)$	7.3677	[0.8527]
Hungary	$\hat{t}(m)$	-0.9820	[0.8579]	Slovenia	$\hat{t}(m)$	**-8.6992**	**[0.0679]**
	$\hat{A}(m)$	-5.2482	[0.8986][a)]		$\hat{A}(m)$	**-25.2222**	**[0.9018]**
	$\hat{F}(m)$	22.6888	[0.6578]		$\hat{F}(m)$	**30.0060**	**[0.9545]**
Lithuania	$\hat{t}(m)$	**-5.0224**	**[0.9667]**	Slovakia	$\hat{t}(m)$	-7.1495	[0.3297]
	$\hat{A}(m)$	**-81.0954**	**[0.9302]**		$\hat{A}(m)$	-486.4810	[0.5140]
	$\hat{F}(m)$	6.9682	[0.3892]		$\hat{F}(m)$	6.2722	[0.3458]

Note: p-values in brackets. Rejection of the H_0 is in bold. [a)] Marginally rejected.

Source: own calculations.

Our results for the *URTs* are rather inconclusive, unless we check for possible sources of nonlinearities. In addition, the values of test statistics may be affected by the properties of time series, so the next step of our analysis is to employ the *pURTs*.[63] As there is a large number of different tests, only some of them are utilised in this paper. In the next step, we will make

[62] It may have been due to inclusion of the time period including the early 1990s.

[63] A recent study [Telatar and Hasanov (2009)] does not find much support for PPP in CEE with ADF test either.

use of the tests of the so-called first generation (*e.g.* [Levin *et al.* (2002)]; [Im *et al.* (2003)]) and the second generation of *pURTs* [Pesaran (2007)] with particular emphasis on the latter.

4.1.2 The US Dollar

Another set of results of the *URTs* is for the NMS exchange rates against the US Dollar (US $). There are only a few pieces of evidence in favour of PPP for these currency pairs and some tests. It is again the case of Bulgaria and Lithuania that the only two countries, where the ADF and PP and (KPSS partially) indicate that exchange rates may be I(0) as in the case of the pairs against the Euro. However, there is no other evidence for other currencies and tests. The possible explanation may be in a series of structural breaks that may have influenced the power of the univariate *URTs* (periods of 'weak' and 'strong' US $ in the analysed time span).

Table 4.4: Univariate unit root tests (US $)

	ADF[a)]		PP[a)]		KPSS[b)]		DF-GLS	
	constant	trend	constant	trend	constant	trend	constant	trend
Bulgaria	-1.345	-4.279***	-1.862	-5.351***	1.420***	0.216***	1.469	-2.138
Cyprus	-0.781	-1.807	-0.746	-1.530	0.687***	0.311***	-0.814	-0.967
Czech Rep.	0.133	-1.941	-0.046	-1.731	1.270***	0.321***	0.228	-1.024
Estonia	-0.388	-1.804	-0.780	-1.677	1.190***	0.283***	0.450	-1.703
Hungary	-0.304	-2.155	-0.288	-2.052	1.210***	0.276***	-0.570	-1.261
Lithuania	-0.170	-2.384	-1.214	-2.531	1.480***	0.164**	1.799	-2.763*
Latvia	0.358	-1.346	-0.009	-1.152	1.220***	0.317***	1.221	-1.727
Malta	-0.464	-1.700	-0.487	-1.507	0.802***	0.323***	-0.565	-0.839
Poland	-0.661	-2.196	-1.140	-2.272	1.140***	0.284***	-0.365	-2.764
Romania	-0.650	-2.197	-0.673	-2.514	1.310***	0.231***	-0.155	-1.527
Slovenia	-0.978	-1.989	-0.886	-1.524	0.595**	0.318***	-0.764	-0.839
Slovakia	-0.970	-2.458	0.150	-1.640	1.290***	0.344***	-0.433	-1.026

Note: [a)] Z(t) values reported. [b)] values of the test statistics. [c)] DF-GLS suggested 0 lags. [d)] significant at 2.5% level. ***, **, and * significant at 1%, 5% and 10% respectively. Critical values for the KPSS test (level stationary): 10% : 0.347, 5% : 0.463, 2.5% : 0.574 and 1% : 0.739; trend stationary: 10% : 0.119, 5% : 0.146, 2.5% : 0.176, and 1% : 0.216. Trend = a constants and a time trend included. Source: own calculation.

For the case of the non-linear KSS test, some evidence in favour of the PPP can be found (six countries for demeaned time series), indicating that is better than for the Euro pairs. However, there is almost no evidence for detrended time series, which is the very opposite compared with the results for the Euro exchange rates.

As far as the results for the non-linear Bierens test are concerned, they indicate that the

Table 4.5: Univariate unit root test – KSS test for the US $

	KSS[a)] demeaned[b)]			KSS[a)] detrended[c)]		
	t_{NL11}	t_{NL12}		t_{NL21}	t_{NL22}	
Bulgaria	3.24	-3.19**	(1)	6.58	-5.26***	(3)
Cyprus	1.20	-2..98**	(6)	1.33	-1.95	(8)
Czech Republic	0.81	-1.96	(8)	1.79	-1.51	(9)
Estonia	1.06	-2.96**	(6)	1.56	-1.49	(9)
Hungary	1.54	-3.87***	(6)	1.91	-0.87	(8)
Lithuania	2.15	0.15	(7)	2.43	-1.93	(7)
Latvia	0.25	-1.43	(8)	1.85	-1.46	(9)
Malta	1.02	-2.74*	(6)	1.28	-0.75	(10)
Poland	2.12	-2.88*	(5)	2.89	-2.36	(5)
Romania	1.59	-2.37	(1)	2.13	-2.01	(1)
Slovenia	1.13	-1.39	(9)	1.44	-1.22	(10)
Slovakia	0.66	-2.81	(6)	1.41	-2.24	(5)

Note: Optimal number of lags in parentheses. [a)] values of the test statistics reported. ***, **, and *** significant at 1%, 5% and 10% respectively. Critical values for the KSS test [Kapetanios *et al.* (2003), p. 364, tab. 1]: [b)] -3.48, -2.93, -2.66. [c)] -3.93, -3.40, -3.13.
Source: own calculation.

PPP hypothesis cannot be rejected for several NMS countries (Bulgaria, Cyprus, Estonia, Malta, Slovakia and Slovenia). Compared with results of the same test for the Euro pairs, the Czech exchange rate cannot be rejected to be nonstationary. There is also more evidence in favour of the I(0) (i.e. PPP) in the case of Malta and Slovakia. These countries can be now included into the group of I(0) countries, conversely for Bulgaria, Cyprus, Latvia and Lithuania. No change can be observed in the case of Romania, Hungary and Poland.

Before moving to the next series of tests, let's summarize our results for the US Dollar. The result presented in this section showed that there is less evidence in favour of the PPP in the case of US $ currency pairs. Apart from the fact that a certain role may be attributed to external shocks and other influences (leading to structural breaks in time series), it may have been also the role of price indices used in this exercise. National price indices were used in calculating the RER, compared with harmonized price indices in the case of the Euro pairs. The national definition of a price index may contain more specific items (*e.g.* regulated goods and services) and as a result less evidence for PPP is found.

Table 4.6: Univariate unit root test – the Bierens (1997) test for the US $

	Test	t. statistics	P-value		Test	t. statistics	P-value
Bulgaria	$\hat{t}(m)$	**-6.7278**	**[0.0834]**	Latvia	$\hat{t}(m)$	-6.6296	[0.1366]
	$\hat{A}(m)$	-114.9160	[0.8376]		$\hat{A}(m)$	-96.3401	[0.8104]
	$\hat{F}(m)$	**8.3902**	**[0.9837]**		$\hat{F}(m)$	7.4182	[0.8801]
Cyprus	$\hat{t}(m)$	**-7.0561**	**[0.0683]**	Malta	$\hat{t}(m)$	**-7.7843**	**[0.0163]**
	$\hat{A}(m)$	-100.974	[0.1905]		$\hat{A}(m)$	-114.6098	[0.1054][b)]
	$\hat{F}(m)$	**7.3935**	**[0.9308]**		$\hat{F}(m)$	**8.0943**	**[0.9632]**
Czech Republic	$\hat{t}(m)$	-6.2354	[0.1960]	Poland	$\hat{t}(m)$	-5.5389	[0.4298]
	$\hat{A}(m)$	-115.4973	[0.7696]		$\hat{A}(m)$	-179.9285	[0.4716]
	$\hat{F}(m)$	5.5045	[0.6856]		$\hat{F}(m)$	5.2384	[0.6350]
Estonia	$\hat{t}(m)$	**-7.2686**	**[0.0458]**	Romania	$\hat{t}(m)$	-6.0466	[0.2689]
	$\hat{A}(m)$	-59.2106	[0.6872]		$\hat{A}(m)$	**-126.7792**	**[0.0588]**
	$\hat{F}(m)$	**6.9976**	**[0.9122]**		$\hat{F}(m)$	4.4487	[0.4890]
Hungary	$\hat{t}(m)$	-6.0268	[0.2620]	Slovenia	$\hat{t}(m)$	**-7.4196**	**[0.0337]**
	$\hat{A}(m)$	-92.8463	[0.8435]		$\hat{A}(m)$	-109.1637	[0.1147][b)]
	$\hat{F}(m)$	6.4191	[0.8371]		$\hat{F}(m)$	**8.0226**	**[0.9613]**
Lithuania	$\hat{t}(m)$	-3.9243	[0.7985]	Slovakia	$\hat{t}(m)$	-6.5747	[0.1265]
	$\hat{A}(m)$	-61.9370	[0.7528]		$\hat{A}(m)$	**-1360.4636**	**[0.0973]**
	$\hat{F}(m)$	7.5029	[0.7930]		$\hat{F}(m)$	**11.3572**	**[0.9980]**

Note: p-values in brackets. Rejection of the H_0 is in bold. [a)] Marginally rejected.

Source: own calculations.

4.1.3 REER

The last set of results for the *URTs* is for REER. As we mentioned, the sample of NMS countries for the REER specification is reduced due to the lack of comparable data (the Baltic States and Slovenia) since the IMF does not publish REER time series for all the CEE countries. We decided to test the time series only for a reduced set of these countries and do not use various definitions of a REER. We prefer doing that to calculating our own time series or obtaining time series of REERs from other sources as definitions are usually not comparable (different price indices or time frequencies that would have required either aggregation or desaggregation of original time series).

To begin with, univariate *URTs* are used (results are in table 4.7). As to the three standard tests, there is some evidence in favour of PPP in the case of Bulgaria, the Czech Republic (the ADF test is significant at $\approx 12.0\%$) and Hungary (ADF, PP and KPSS). [64]The results of the

[64]Results for KPSS and a specification with a time trend allow us to reject the null I(0) only for Cyprus, Malta and Slovakia.

Table 4.7: Univariate unit root tests (REER)

	ADF a)		PP a)		KPSS b)		DF-GLS	
	constant	trend	constant	trend	constant	trend	constant	trend
Bulgaria	-1.041	-3.655**	-0.973	-3.291*	1.440***	0.108	1.543	-1.664
Cyprus	-0.113	-1.992	-0.233	-2.143	1.220***	0.214 d)	-0.962	-2.127
Czech Rep.	-0.558	-3.048 e)	-0.594	-3.182*	1.540***	0.0964	0.958	-4.300***
Hungary	-0.510	-1.341	-0.480	-3.164*	1.540***	0.116	0.258	-1.026
Malta	0.086	-2.369	0.059	-2.389	1.460***	0.179 d)	0.941 c)	-1.868 c)
Poland	-2.216	-2.623	-2.242	-2.707	1.130***	0.115	-0.747	-2.558 e)
Romania	-1.620	-2.880	-1.268	-2.608	1.300***	0.0794	-0.318	-3.258**
Slovakia	0.507	-2.142	0.868	-2.026	1.530***	0.333***	1.544	-1.501

Note: a) Z(t) values reported. b) values of the test statistics. c) DF-GLS suggested 0 lags. d) significant at 2.5% level. e) marginally insignificant. ***, **, and * significant at 1%, 5% and 10% respectively. Critical values for the KPSS test (level stationary): 10% : 0.347, 5% : 0.463, 2.5% : 0.574 and 1% : 0.739; trend stationary: 10% : 0.119, 5% : 0.146, 2.5% : 0.176, and 1% : 0.216. Trend = a constants and a time trend included. Source: own calculation.

more robust test (DF-GLS) indicate that I(0) can be rejected for the Czech Republic, Romania and marginally for Poland (at ≈ 11.0%).

Table 4.8: Univariate unit root test – KSS test for REER

	KSS a) demeaned b)			KSS a) detrended c)		
	t_{NL11}	t_{NL12}		t_{NL21}	t_{NL22}	
Bulgaria	2.48	-2.01	(1)	3.60	-1.99	(1)
Cyprus	1.74	-3.01**	(1)	2.85	-2.74	(1)
Czech Republic	1.02	-2.10	(5)	2.96	-3.32*	(4)
Hungary	1.57	-1.23	(7)	3.76	-1.98	(8)
Malta	-0.04	-1.97	(1)	1.35	-1.22	(1)
Poland	-2.54	-1.18	(5)	2.82	-2.50	(5)
Romania	1.82	-1.40	(6)	3.21	-3.55**	(10)
Slovakia	-0.88	-2.13	(3)	2.75	-2.48	(4)

Note: Optimal number of lags in parentheses. a) values of the test statistics reported. ***, **, and *** significant at 1%, 5% and 10% respectively. Critical values for the KSS test [Kapetanios *et al.* (2003), p. 364, tab. 1]: b) -3.48, -2.93, -2.66. c) -3.93, -3.40, -3.13. *Source:* own calculation.

The results for the non-linear KSS test (in the table 4.8) show almost no evidence supporting the PPP hypothesis, if REER is used. On the other hand, the results for the other non-linear test do. The results are presented in table 4.9. The test results indicate that the validity of the PPP hypothesis can be confirmed only for two countries – Bulgaria and Romania. In the case of Cyprus and the Czech Republic, it is not possible to decide (following recommendations in [Bierens (1997)] as only one out of three test statistics indicates that PPP holds.) The results for Malta and Slovakia – significant in other cases – are insignificant for REER. There is also no change for Hungary and Poland (rejection of PPP). To sum up, there is even weaker evidence for the REER exchange rate that PPP holds in the NMS countries.

Table 4.9: Univariate unit root test – the Bierens (1997) test for REER

	Test	t. statistics	P-value		Test	t. statistics	P-value
Bulgaria	$\hat{t}(m)$	**-4.0285**	**[0.9186]**	Malta	$\hat{t}(m)$	-6.2790	[0.1826]
	$\hat{A}(m)$	**-46.9439**	**[0.9026]**		$\hat{A}(m)$	-103.8727	[0.1498]
	$\hat{F}(m)$	**2.8675**	**[0.0633]**		$\hat{F}(m)$	6.1814	[0.8735]
Cyprus	$\hat{t}(m)$	-5.3484	[0.5073]	Poland	$\hat{t}(m)$	-6.6419	[0.1241][a)]
	$\hat{A}(m)$	-100.974	[0.1905]		$\hat{A}(m)$	-76.2201	[0.4927]
	$\hat{F}(m)$	**7.3935**	**[0.9308]**		$\hat{F}(m)$	5.6712	[0.7454]
Czech Republic	$\hat{t}(m)$	**-3.7482**	**[0.9229]**	Romania	$\hat{t}(m)$	**-3.7088**	**[0.9466]**
	$\hat{A}(m)$	-238.8240	[0.3113]		$\hat{A}(m)$	**-42.9034**	**[0.9213]**
	$\hat{F}(m)$	3.6408	[0.1585]		$\hat{F}(m)$	**3.1308**	**[0.0638]**
Hungary	$\hat{t}(m)$	-4.3707	[0.8308]	Slovakia	$\hat{t}(m)$	-5.1902	[0.6035]
	$\hat{A}(m)$	-78.0290	[0.4237]		$\hat{A}(m)$	-52.2559	[0.8376]
	$\hat{F}(m)$	5.0651	[0.7077]		$\hat{F}(m)$	750.9913	[0.3151]

Note: p-values in brackets. Rejection of the H_0 is in bold. [a)] Marginally rejected.

Source: own calculations.

4.2 Panel unit root tests

If the hypothesis of unit root in a time series was rejected (for various specifications of the test), we could infer that PPP did hold as a relationship in the long-run. If that was not the case, a time series would be an I(1) process and the PPP would not hold in the long run. As it is unclear which specification is the right one for individual exchange rates, different specifications are used. All the *pURTs* are conducted with panel-specific means (constant), but they differ in respect to the other options (the demeaned version of test is used as cross-correlation of exchange rates was high, with a time trend included or not). Intercepts and deterministic trends may be allowed to vary for individual countries in a panel, and errors may be correlated and heteroskedastic. The optimal number of lags was selected automatically (the Stata command *xtunitroot*). However, one lag seems to be sufficient and is usually applied when the automatic lag selection is chosen. The rationale behind this is rooted in the logic that every quarter brings new information that affects the exchange rate. This change depends on many factors and therefore may go in both directions.[65]

The LLC tests are shown with two statistics – *Unadjusted* t (for models without a time trend or specific means), *Adjusted* $t^\star$ ($t^\star_\delta$ that is bias-adjusted t following an asymptotically normal distribution) for other cases. In the case of the Maddala-Wu test, there are four different test statistics. According to the study by [Choi (2001)], one of them – inverse normal Z statistics (which has the standard normal distribution under H_0) – seems to be the optimal one given the trade-off between size and power of the test. We also use truncated versions of the CIPS statistics (the Pesaran's CADF test) that help to mitigate the occurrence of extreme values of statistics if number of observations is small, for details see [Pesaran (2007)].

The results for our main specification are presented in table 4.10. They offer a mixed picture. Only the CADF test shows support to the stationarity of individual exchange rates, *i.e.* PPP holds in the long run. While the IPS, LLC, and M-W tests are ambiguous or not rejecting the H_0, the H-LM test does not confirm these findings. [Banerjee *et al.* (2005)] present reasons why the null hypothesis may be rejected and therefore, one has to interpret all results with caution. (In the case of the aforementioned tests, the null hypothesis is the non-stationarity

[65]However, the appropriate lag length for this test is essential, see *e.g.* [Stata (2009)].

Table 4.10: Panel unit root tests – baseline specification

test		no trend		trend	
		t. statistics	P-value	t. statistics	P-value
LLC[a)]	Unadjusted t	-4.8890		-6.9911	
	Adjusted $t^\star$ ($t^\star_\delta$)	-2.2347	0.0127	-1.1975	0.1156
IPS[a)]	W_{t-bar}	-0.7993	0.2120	-0.1869	0.4259
H-LM[a)]		102.4918	0.0000	62.5401	0.0000
H-LM[a), b)]		86.4370	0.0000	55.4475	0.0000
M-W[a), c)]	Z	-5.4454	0.0000	0.0030	0.5012
M-W[a), d)]	Z	-0.6834	0.2472	-0.3226	0.3735
CADF[e)]	W_{t-bar}	-2.413		-3.114	
	Z[-bar]	-2.384	0.009	-3.117	0.001

Note: [a)] demeaned time series. [b)] robust option; [c)] DF, drift; Inverse normal Z statistics reported, [d)] PP, drift; Inverse normal Z statistics reported, [e)] truncated – approximation of extreme values of the distribution.

Source: own calculations.

for all panels and the alternative that at least some are stationary.) If the null is rejected, it is a warning sign that the variables and processes influencing and determining behaviour of individual exchange rates may be heterogeneous. Given the aforementioned problems (for discussion see the section 4.4 below), the Pesaran's CADF test (allowing for contemporaneous correlation) seems to be the most reliable one in our case (allowing for different speeds of adjustment). Its results can be roughly compared to those results of the LLC and IPS tests.

However, it does not imply that the PPP has been rejected as within a group of countries or certain subgroups it may behave differently [Dufrénot and Sanon (2005)]. Therefore, various subgroups of countries were created and employed (see the section 4.3.2 below). Another problem (for details see [Sarno and Taylor (2003)] is that the variable nature of the relationship between exchange rates and price indices for individual units of a panel may lead to ambiguous results. Additionally, the results of our empirical analysis must be interpreted with caution, as we have to rely on a limited number of countries (cross sections, N, is medium) while the number of periods T is large in our sample.[66]

[66]There have been some studies that used even fewer time observations, see *e.g.* [Solakoglu (2006)] for a test of the PPP theory in CEE countries or [Harris and Sollis (2005)] for a test of total factor productivity for OECD countries.

4.3 Robustness tests

As our previous sets of results may be influenced by the composition of our group of NMS states, including countries of different levels of economic development, we will check for robustness of our results with the help of four sets of specifications. First, we will try to assess effects of group composition. Second, we distinguish between individual types of exchange rate regimes. Thirdly, we will investigate the influences of selected economic variables on PPP, and finally, we will try to assess the impact of the on-going financial crisis. Regarding the first test, we can see from tables nos. (A.2), (A.3) and (A.4) that there are differences in terms of the groups of countries. While the results for NMS10 are close to the results for NMS, a more similar group of countries represented by NMS8 gives significant support to PPP. The results of the *pURTs* turn insignificant for the last subgroup of NMS (NMS5). However, this may have been due to the limited number of cross sections ($N = 5$ is small), where the *pURTs* are less robust.

4.3.1 ER regimes

Another possibility is to distinguish between countries with respect to their exchange rate regimes. Some countries have preferred more flexible exchange rate regimes, while others chose more constant ones. It is rather difficult to classify individual countries according to this criterion, as some of them have changed their exchange rate regimes several times (*e.g.* Poland). On the other hand, there are countries that have used only one regime (*e.g.* Estonia).[67] As there is no simple criterion regarding the pegged and floating exchange rates, a simple rule is applied – all pegged currencies are grouped together and the same is done for all floating currencies ($N = 5$ pegged and $N = 7$ floating currencies). The classification of the latest available exchange rate regimes for the NMS countries is in the table in the Appendix. Our classification will necessarily bear signs of some arbitrariness and both panels differ in size.[68] The results for two sets of countries, based on the aforementioned selection criterion, are shown in the tables nos. (4.11) and (4.12).

[67] We use IMF data but classifications differ study from study. See *e.g.* an early classification for five NMS countries in [Frait *et al.* (2006)].

[68] $N_{\text{peggers}} = 5$ and $N_{\text{floaters}} = 7$ and therefore, we apply a different criterion to distinguish between exchange rate regimes in the next section.

Table 4.11: Panel unit root tests – pegged exchange rates

test		no trend		trend	
		t. statistics	P-value	t. statistics	P-value
LLC[a)]	Unadjusted t	-4.5763		-7.7632	
	Adjusted $t^\star$ ($t^\star_\delta$)	-2.3819	0.0086	-5.5397	0.0000
IPS[a)]	W_{t-bar}	-2.9937	0.0014	-5.4106	0.0000
M-W[a), b)])	Z	-4.7989	0.0000	-4.4767	0.0000
M-W[a), d)]	Z	-2.9126	0.0018	-5.3597	0.0000
CADF[e)]	W_{t-bar}	-2.968		-3.393	
	Z[-bar]	-2.887	0.002	-2.713	0.003

Note: [a)] demeaned time series. [b)] robust option; [c)] DF, drift; Inverse normal Z statistics reported, [d)] PP, drift; Inverse normal Z statistics reported, [e)] truncated – approximation of extreme values of the distribution.
Source: own calculations.

There seems to be a clear division between countries with pegged and floating currencies, which appears to point at exactly the opposite implications. This may be due to the fact that pegged currencies have been adjusted on a regular basis by inflation differentials, so that PPP may have held and vice versa. However, this division does not seem to be unique as the CADF test allows us to reject the H_0 at 1% significance level for the pegged ones, while this is not the case for floating currencies (ambiguous results). The other test results are not clear-cut, apart from the LLC for floating ones giving weak support to PPP (in one specification). There are many reasons for this. The most important one may be that the floating currencies are *de facto* not floating currencies (only *de jure*). Interventions in the foreign market or speculations may prevent a currency from restoring PPP. Nevertheless, these results should be interpreted with caution, as the cross-sectional dimension is rather low even for the *pURTs*, even though the time dimension is still long. Additionally, even rejecting non-stationarity (CADF, LLC) does not mean that all currencies are stationary.

4.3.2 Characteristics of countries

In this section we focus on different countries' characteristics and their impact on PPP. The empirical studies show their significance for the PPP in developing countries (*e.g.* [Alba and Papell (2007)]. The list of possible factors is long. Some of them are more likely to result in supporting PPP than others. For example, a higher level of openness means that a higher ratio of goods and services is exposed to international competition or higher volume of currencies being exchanged.

Table 4.12: Panel unit root tests – floating exchange rates

		no trend		trend	
test		t. statistics	P-value	t. statistics	P-value
LLC[a)]	Unadjusted t	-3.4715		-4.6255	
	Adjusted $t^{\star}$ ($t^{\star}_{\delta}$)	-1.3435	0.0896	0.3091	0.6214
IPS[a)]	W_{t-bar}	0.5978	0.7250	1.5327	0.9373
M-W[a), b)]	Z	-3.6036	0.0002	1.2722	0.8984
M-W[a), c)]	Z	0.7204	0.7644	1.3920	0.9180
CADF[d)]	W_{t-bar}	-2.176		-2.935	
	Z[-bar]	-1.139	0.127	-1.800	0.036

Note: [a)] demeaned time series. [b)] robust option; [c)] DF, drift; Inverse normal Z statistics reported, [d)] PP, drift; Inverse normal Z statistics reported, [e)] truncated – approximation of extreme values of the distribution.

Source: own calculations.

That should lead to price equalisation and PPP would hold. Higher economic growth is usually linked to higher productivity growth (the B-S effect) and higher inflation. In a group of fast and slow-growing economies, the PPP will be less pronounced than in a group of more homogeneous countries, *i.e.* growing at similar rates [Alba and Papell (2007)]. The volatility of the exchange rate may slow down the process of price adjustments, if barriers to free functioning of market forces are in place. Higher inflation may lead to smoother restoration of the PPP. Regarding the transition process, a more restrictive system (more regulated, with more barriers to free competition, etc.) may hinder economic systems in restoring PPP.

For robustness tests, the average growth rates of consumer prices (based on IMF IFS database) and PPP adjusted GDP (the EKS method, Groeningen database, see [GGCD (2010)] are calculated.[69] For openness, we use data from the IFS (merchandise export and import divided by GDP). The volatility is calculated as the standard deviation of logarithms of nominal exchange rates. The transition indicators are taken from the EBRD database (the transition index measuring various aspects of structural and institution reforms, [EBRD (2009)] and simple averages are calculated. In order to obtain balanced panels (number of countries), we will not distinguish between different rates of inflation or GDP growth as it is common practice in economic literature.

[69] We follow [Alba and Papell (2007)] and growth rates are calculated according to the World Development Report, *i.e.* $g_i = \exp(\beta_i) - 1$ and not according to the formula stated in the text), where β_i for a country i is obtained from a regression (with a constant and a time trend) $\ln Y^{PPP}_{p.c.\,i,\,t} = \alpha + \beta_i \cdot t$. Time span 1995–2009 for all variables and calculation of changes is used

These are the individual thresholds used in grouping our set of countries:[70]

- Economic growth – slow (annual average $< 4\%$), fast (annual average $> 4\%$);[71]
- Inflation – low (annual average $< 7\%$), high (annual average $> 7\%$);[72]
- Openness – low (average < 0.9), high (average > 0.9);[73]
- Transition index – low (average < 3.6), high (average > 3.6).[74]
- Exchange rate volatility – low (< 0.120), high (> 0.120).[75]

The Results for our first characteristic (growth) are presented in table A.6 in the Appendix. Higher economic growth is usually associated with higher productivity growth (and selective inflation due to the B-S effect). As the Euro area is rather similar to the slowly growing countries, we should find support for the PPP. However, this does not seem to be the case (ambiguous results (CADF) or not rejecting the H_0 – LLC and IPS). On the other hand, the results for fast growth allow us to reject the H_0 across tests at 1%. These results are rather surprising, as higher economic growth leads to higher productivity (B-S effect) and inflation, which may interfere with the PPP. A possible explanation for this may be that floating exchange rates enable countries to adjust price levels so that PPP may hold.

The next characteristic is inflation. Low inflation should support the PPP (the Euro area tends to have lower rates), high inflation should not. With respect to our results, the LLC and IPS are insignificant for high inflation, only CADF for 2% or less. In the case of low inflation, the LLC and CADF support the PPP (significant at 1%), while the IPS is ambiguous. These results may be partially influenced by the fact that transition and inflation are negatively correlated (see below). Low inflation may not be a sign of a developed economy, but reflects non-economic interventions of a government resulting in distortions of PPP.

[70] Calculated valued are ordered so that countries can be divided into two groups according to their values.

[71] Fast growing countries: Bulgaria, the Baltic countries, Poland and Slovakia.

[72] High inflation countries: Bulgaria, Estonia, Hungary, Latvia, Poland and Romania.

[73] Highly open countries: Bulgaria, Estonia, Hungary, Lithuania, Malta and Slovenia.

[74] Based on transition indicators, see [EBRD (2009)]. As Cyprus and Malta are not covered, the Czech Republic has been promoted to developed country level and is not covered anymore, they are assigned to the 'high' countries group, together with Estonia, Hungary and Poland.

[75] High nominal exchange rate volatility: Bulgaria, the Czech Republic, Hungary, Lithuania, Romania, and Slovenia.

Openness is a proxy for forces related to international trade and competition, which are the main determinants of exchange rates and therefore PPP. More open countries should show signs of support for the PPP. This is the case of our results. The LLC, IPS and CADF reject the H_0 at 1%, giving massive support to PPP. On the other hand, the results for *pURTs* for less open economies are exactly the opposite (not significant at all standard levels).

Exchange rate volatility is assumed to be positive (medium level) and negative (low and high) for the PPP. Low or high volatility may prevent an exchange rate from restoring the PPP, while medium level may help to mitigate other distortions. We cannot use such a subtle decomposition, as our cross-sectional dimension is limited.[76] The results of the *pURTs*, for high volatile currencies, are either ambiguous (LLC) or insignificant, apart from CADF. Similarly, the results for less volatile currencies are ambiguous (LLC and IPS) too or do not allow us to reject the H_0 (CADF). Volatility is correlated with transition, which may blur our picture.[77]

Table 4.13: Spearman's rank correlation coefficients

	Growth	Inflation	Openness	Transition	Volatility
Growth	1.0000				
Inflation	0.4825	1.0000			
Openness	0.2448	0.0140	1.0000		
Transition	-0.5000*	-0.6338*	-0.0775	1.0000	
Volatility	0.1678	0.5874*	0.0839	-0.7535*	1.0000

Note: * means significant at 10% level. $N = 12$. *Source:* own calculation.

The last characteristic is linked to the transition process. The definition of the used EBRD indices reflects more the level of regulation and inferences of a government in an economy. The results for more developed (*i.e.* less regulated) countries allow us to reject the H_0 at the 1% (LLC), 2% (IPS) and 7.5% (CADF) significance levels. On the contrary, the results for more regulated countries are insignificant (IPS) or ambiguous, offering an explanation that more regulated economies create more obstacles (change environment) and PPP does not hold. However, as it was argued above, there is probably a clear link between some variables that renders any precise analysis difficult. Additionally, if the H_0 is rejected in the case of the LLC

[76] Lower volatility of exchange rates is favourable for the power of *URTs*, so if time series are less volatile connected to each other, results are more robust [Papell and Theodoridis (2001)].

[77] We also calculate volatility index recommended by [Papell and Theodoridis (2001), p. 798]. Volatility between two currencies is calculated as: $\sigma_{ij} = \sum_{t=1}^{T} \frac{|\frac{ER_{t+1}}{ER_t}|}{T}$. Even though the composition of both panels changes slightly with this measure in place, the results remain comparable, see table A.10 in the Appendix.

and CADF test, this means that only ϑ percent of the panel can be in fact stationary. Our proxy for transition is based on the regulation of various aspects of everyday life in transition countries and measured by the EBRD. Hence, this proxy thus may reflect the actual state of affairs in a country only in parts.

Some aspects should be included in order to get a complete picture of this. The characteristics of a country are not independent. Table 4.13 shows the Spearman's rank correlation coefficients. If country characteristics were correlated (there were possible dual links), this would mean that the influence goes into a distinct direction and is not ambiguous. In our sample there are four significant relationships: transition (growth and inflation); volatility (inflation and transition). They are significant at the 10% level. Therefore, in these cases the direction is not clear the direction of influences as less regulation influences positively both economic growth and inflation. Lower volatility is associated with lower regulation.

4.4 What conclusion can be drawn – is the 'PPP puzzle' still alive?

As we have seen, the results are rather ambiguous and do not provide clear guidance regarding the PPP hypothesis for NMS countries. What are the possible reasons for these findings? [Wu *et al.* (2010)] and [Alba and Papell (2007)] summarize the recent studies and highlight that there may be some country characteristics that determine whether the PPP holds or not. These are the inflation rate, openness, volatility of exchange rate, economic growth and distance. However, empirical studies have not confirmed any of these determinants beyond all doubts. The results in this study are not crystal clear, either. Possible problems and/or reasons for the lack of clear-cut evidence in the analysis of the PPP can be divided into three groups.

The **first group** includes problems and issues related to available data. For example, some of them can be labelled as **problems of transition countries**. Our time span starts in mid-1990s, which gives us enough observations in the time dimension, but may also be teh reason why results are rather mixed due to the changes of exchange rate regimes in some countries. In a similar vein, the measures of inflation may have been exposed to similar kind of shocks.

Therefore, the problem may be associated with price indices and not with exchange rates.

Another problem is well known in the literature – **aggregation bias**. It can be associated either with the data used [Broda and Weinstein (2008)] or linked to empirical methods [Imbs *et al.* (2005)] parameter heterogeneity). Additionally, there may be a bias associated with small samples in the data [Chen and Engel (2004)] that may have an impact on results.[78]

The **second group** encompasses various direct and indirect (non-market) measures applied in an economy. One of them can be in the form of **exchange rate arrangements** such as the ERM II. This may have restricted the exchange rates of NMS countries and therefore the results of *URTs*or *pURTs* may be inconclusive. The euro as a benchmark for our analysis may also influence our results, as it was an artificial currency in the 1990s. However, this choice seems to be rational, since the US dollar has lost its importance in the NMS countries and the euro/ECU has gained significance due to European integration process. Moreover, some authors argue that the **RER are not I(1) but rather I(0) process** that has a nonlinear (deterministic) trend or with structural breaks. This may give support to the notion of a 'quasi-PPP' or 'a relaxed version of PPP' (for discussion see *e.g.* [Cuestas and Regis (2008)].

Another example is mentioned in the study by [Brissimis *et al.* (2005)]. The authors claim that **monetary authority's interventions** in the foreign market targeting a certain level of exchange rate may result in the inability to confirm PPP empirically even though it holds. Additionally, [Taylor (2004)] puts forward that interventions may lead to RER displaying non-linear behaviour, *e.g.* with I(1) type of behaviour within a certain band, and I(0) outside.[79] For example, some countries have been using inflation targeting and exchange rate is an important part of this. An exchange rate has direct and indirect impacts on inflation.

Finally, the last group incorporates empirical problems and problems of econometric methods. One of them may be a group of issues related to the problem called fractional integration of time series. This means that time series have a long memory (long range dependence).[80] This poses a problem not only for *URTs* and but also for *pURTs* . This would mean that standard *URTs* are not suitable for those cases.

[78][Robertson *et al.* (2009)] surveys literature and discuss sources of these biases in depth. It also shows how important these biases for a development country are (Mexico compared to the US).

[79]The Bierens (1997) test should account for this.

[80]That is I(d) time series, where $0 < d < 1$. The key threshold is the value of $d = \frac{1}{2}$ dividing time series into two groups (stationary and non-stationary).

It also includes more practical aspects as **different specification of a non-linear adjustment process**. For example, [Bahmani-Oskooee *et al.* (2008)] argue that assumptions for PPP are not met in many countries and as a result, the PPP hypothesis is rejected. Additionally, some market interventions, friction or misbeliefs may hamper market forces from restoring equilibrium. This may lead to the necessity to account for these by employing nonlinear methods such as threshold models. Another problem is related to the *pURTs* of RER if there are **MA roots** in the RER. This leads to over-rejection of the hypothesis of non-stationarity as shown in [Fischer and Porath (2010)]. The **lag selection** is a problem of non-linear tests such as the Bierens (1997) test.[81] This is because the number of lags (k) can be determined by various methods, but the same cannot be easily done for the order of Chebishev polynomials m (however, the actual size of the test depends on it). Hence, the power may be low (see [Bierens (1997)]).

Even though it is not possible to list and discuss all possible problems and issues related to the testing of the PPP, given the space limitations of this paper, the aforementioned ones can help us to answer the question stated in the title of this subsection. The 'PPP puzzle' is still alive and it is not clear when we will have such (empirical) tools that will give us a clear answer.

5 Conclusions

This paper focused on testing the relative version of the PPP in the NMS countries over the time span of 15 years. It tried to shed some light on the 'old PPP puzzle' for a set of transition countries. As there has been a large number of studies with rather ambiguous results, various econometrics methods were employed. We made use of standard *URTs* and selected *pURTs*, and additionally, more robust versions of *URTs*. While standard univariate *URTs* do not provide a crystal-clear answer to our question, the robust versions do for the Euro exchange rate pairs in particular. The results for the non-linear KSS test (ESTAR model), which gives support to PPP in eight out of 12 NMS countries and the results for another nonlinear test

[81] This seems to be the main problem for empirical analyses of time series, see [Harris and Sollis (2005)].

(non-linear in trends, the Bierens (1997) test), also tend to favour the existence of PPP, once the source of non-linearities has been controlled for. In the case of the other currency pairs – the US Dollar and REER, the results are less significant and therefore, they seem to give more emphasis on the importance of the Euro currency for the NMS countries.

Moreover, the *pURTs* offer a piece of evidence, as they make use of both cross-sectional and time dimensions. Our results for Pesaran's CADF test show that PPP does hold for the whole period of 1995–2009, even for a shortened period without the impact of the ongoing financial crisis. The robustness tests take various country's characteristics into account: the economic growth, inflation rates, openness, volatility of exchange rate or phases of transition, do not change the picture. Our results also show that the PPP does hold in countries that are more open, less regulated or growing faster.

This approach also shows strengths and weaknesses of the *pURTs*. While first generation tests are not able to account for all possible problems of exchange rate dynamics (*e.g.* cross section independence), they may have failed in our empirical tests. The second generation is at least capable of dealing with them and its results seemed to be more consistent. Nevertheless, additional information (cross sectional dimension) does not seem to be enough to overcome the assumption of linearity in the case of some economic time series, such as exchange rates. The answer would be to employ even more robust versions of *pURTs* that would allow for non-linear adjustment processes or structural breaks in individual time series in a panel.

There are many possibilities regarding the future research in this area. More detailed analysis based on individual subindices of the HICP index should be conducted as one extension going beyond the scope of this paper.[82] Using selected price subindices that may solve problems associated with aggregation bias. However, these subindices are available only for a limited set of countries and/or time span is very limited, which limits their use.

Possible extensions of this work could be done with respect to several aspects. An extension may be based on using disaggregated price indices (either for CPI or HICP) for our group of countries, different indices (broad or narrow versions of REER) or different benchmark

[82] Additionally, due to lack of availability consumer price subindices for some countries and most of the 1990s, it would lead to radical reduction of our sample and therefore, the necessity to switch from quarterly to monthly time series so that one would gain some power for the *URTs* and *pURTs*.

countries. Moreover, more robust univariate *URTs* such as the CBL test[83] or methods based on panel smooth transition regression models (PSTR, see *e.g.* [González *et al.* (2005)]) that may solve some problems of nonlinear adjustment processes or structural breaks due to their construction may be applied. They would also make possible to use longer time span or data of higher frequencies (*e.g.* months).

[83] Carrion-i-Silvestre, Barrio-Castro and Lopez-Bazo, see [Carrion-i-Silvestre *et al.* (2005)] allowing for several structural breaks in the presence of cross-sectional dependence).

A Outputs

A.1 *Robustness check for PPI*

Table A.1: Univariate unit root tests

	ADF[a)]		PP[a)]		KPSS[b)]		DF-GLS	
	constant	trend	constant	trend	constant	trend	constant	trend
Bulgaria	-2.139	-4.730***	-2.874**	-6.830***	1.000***	0.190[d)]	1.052	-0.524
Cyprus	-1.363	-2.727	-0.657	-2.316	0.663[d)]	0.140*	1.186	-2.633*
Czech Rep.	-0.732	-3.368*	-0.738	-3.458**	1.080***	0.0522	0.257	-4.377***
Estonia	-3.581***	-4.379***	-3.967***	-3.789**	0.792***	0.169**	0.919	-2.145
Hungary	-2.889**	-3.315**	-1.570	-2.568	0.893***	0.207[d)]	0.461	-0.896
Lithuania	-2.144	-4.025**	-2.144	-2.262	0.932***	0.165**	1.202	-1.068
Latvia	-2.199	-2.481	-2.068	-2.045	0.853***	0.130*	0.487[c)]	-1.727
Poland	-2.164	-2.477	-2.603*	-3.056	0.631[d)]	0.0872	-0.157	-1.757
Romania	-0.633	-2.378	-0.998	-2.824	1.030***	0.0549	1.244	-3.704**
Slovenia	-2.341	-2.286	-2.106	-2.030	0.689[d)]	0.0883	-1.297	-2.752
Slovakia	0.187	-1.960	0.577	-1.740	1.04***	0.251***	1.256	-1.627

Note: [a)] Z(t) values reported. [b)] values of the test statistics. [c)] DF-GLS suggested 0 lags. [d)] significant at 2.5% level.
***, **, and * significant at 1%, 5% and 10% respectively. Critical values for the KPSS test (level stationary):
10% : 0.347, 5% : 0.463, 2.5% : 0.574 and 1% : 0.739; trend stationary: 10% : 0.119, 5% : 0.146, 2.5% : 0.176, and 1% : 0.216.
Trend = a constant and a time trend included. Source: own calculation.

A.2 *Results for subgroups of the NMS*

Table A.2: Panel unit root tests – NMS10

		no trend		trend	
test		t. statistics	P-value	t. statistics	P-value
LLC[a)]	Unadjusted t	-4.4856		-6.3462	
	Adjusted $t^{\star}$ ($t^{\star}_{\delta}$)	-1.9190	0.0275	-1.0172	0.1545
IPS[a)]	W_{t-bar}	-0.4870	0.3131	-0.0756	0.4699
M-W[a), b)]	Z	-4.8046	0.0000	0.1754	0.5696
M-W[a), c)]	Z	-0.3712	0.3552	-0.1887	0.4252
CADF[d)]	W_{t-bar}	-2.562		-3.440	
	Z[-bar]	-2.687	0.004	-4.009	0.000

Note: [a)] demeaned time series. [b)] DF, drift; Inverse normal Z statistics reported, [c)] PP, drift;
Inverse normal Z statistics reported, [d)] truncated – approximation of extreme values of the distribution.
Source: own calculations.

Table A.3: Panel unit root tests – NMS8

test		no trend		trend	
		t. statistics	P-value	t. statistics	P-value
LLC[a)]	Unadjusted t	-5.4222		-8.5538	
	Adjusted $t^{\star}$ ($t_{\delta}^{\star}$)	-2.6295	0.0001	-4.5248	0.0000
IPS[a)]	W_{t-bar}	-2.5777	0.0050	-3.9120	0.0000
M-W[a), b)]	Z	-6.0606	0.0000	-3.6264	0.0001
M-W[a), c)]	Z	-2.5001	0.0062	-3.3970	0.0003
CADF[d)]	W_{t-bar}	-2.891		-3.389	
	Z[-bar]	-3.415	0.000	-3.418	0.000

Note: [a)] demeaned time series. [b)] DF, drift; Inverse normal Z statistics reported, [c)] PP, drift; Inverse normal Z statistics reported, [d)] truncated – approximation of extreme values of the distribution.

Source: own calculations.

Table A.4: Panel unit root tests – NMS5

test		no trend		trend	
		t. statistics	P-value	t. statistics	P-value
LLC[a)]	Unadjusted t	-2.4812		-6.7035	
	Adjusted $t^{\star}$ ($t_{\delta}^{\star}$)	-0.9131	0.1806	-3.5104	0.0002
IPS[a)]	W_{t-bar}	-0.3448	0.3651	-2.5588	0.0053
M-W[a), b)]	Z	-3.5630	0.0002	-2.3798	0.0087
M-W[a), c)]	Z	0.1543	0.5613	-1.6723	0.0472
CADF[d)]	W_{t-bar}	-2.801		-2.754	
	Z[-bar]	-2.481	0.007	-1.051	0.147

Note: [a)] demeaned time series. [b)] DF, drift; Inverse normal Z statistics reported, [c)] PP, drift; Inverse normal Z statistics reported, [d)] truncated – approximation of extreme values of the distribution.

Source: own calculations.

A.3 Exchange rate regimes in the NMS countries

A.4 Panel unit root tests – results for country's characteristics

A.5 Exchange rates

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Table A.5: The most recent exchange rate regimes – NMS

	currency regime	period	
Bulgaria	peg (currency board)	July 5, 1997 -	
Cyprus	free float		- December 31, 2008
Czech Republic	free/managed float	June 26, 1997 -	
Estonia peg	(currency board)	June 20, 1992 -	
Hungary	managed float	June 2001-	
Lithuania	peg (currency board)	April, 1 1994 -	
Latvia	peg to the Euro	January 1, 2005 -	
Malta	free float		- December 31, 2008
Poland	free float	April 12, 2000 -	
Romania	managed float	August 1, 2005 -	
Slovenia	free/managed float		- December 31, 2006
Slovakia	peg with bands		- December 31, 2008

Note: Bulgaria till February 1, 2002 to the Deutsche Mark, to the Euro since then. Cyprus ±15% fluctuation margins in ERM II. From January 1, 2009 the Euro. Czech Republic managed float. Estonia till February 1, 2002 to the Deutsche Mark, to the Euro since then. Hungary float either since June 18, 2001 when all remaining barriers to full convertibility of HUF were removed or May 3, 2001 when ±15% band was introduced. Lithuania till February 1, 2002 to the US Dollar, to the Euro since then. Latvia with the normal fluctuation margins ±1%. Malta ±15% fluctuation margins in ERM II. From January 1, 2009 the Euro. Poland free float since 2000. Romania inflation targeting.Slovenia ±15% fluctuation margins in ERM II. From January 1, 2007 the Euro. Slovakia ±15% fluctuation margins in ERM II. From January 1, 2009 the Euro. *Source:* Source: own based on [IMF (2010a)] and CB websites.

Table A.6: Panel unit root tests – country characteristics I (growth)

		no trend		trend	
test		t. statistics	P-value	t. statistics	P-value
Fast growing					
LLC[a)]	Unadjusted t	-4.9332		-8.0105	
	Adjusted $t^{\star}$ ($t^{\star}_{\delta}$)	-2.3501	0.0094	-5.2702	0.0000
IPS[a)]	W_{t-bar}	-3.0735	0.0011	-5.1254	0.0000
M-W[a), b)]	Z	-5.1311	0.0000	-4.0022	0.0000
M-W[a), c)]	Z	-2.8226	0.0024	-4.8606	0.0000
CADF[d)]	W_{t-bar}	-2.929		-3.398	
	Z[-bar]	-3.059	0.001	-2.984	0.001
Slowly growing					
LLC[a)]	Unadjusted t	-3.1929		-4.1683	
	Adjusted $t^{\star}$ ($t^{\star}_{\delta}$)	-1.2409	0.1073	0.4139	0.6605
IPS[a)]	W_{t-bar}	0.5788	0.7186	1.5921	0.9443
M-W[a), b)]	Z	-3.3423	0.0004	1.2660	0.8972
M-W[a), c)]	Z	0.6840	0.7530	1.4513	0.9267
CADF[d)]	W_{t-bar}	-1.960		-2.972	
	Z[-bar]	-0.480	0.316	-1.771	0.038

Note: [a)] demeaned time series. [b)] DF, drift; Inverse normal Z statistics reported, [c)] PP, drift; Inverse normal Z statistics reported, [d)] truncated – approximation of extreme values of the distribution. *Source:* own calculations.

Table A.7: Panel unit root tests – country characteristics II (inflation)

test		no trend		trend	
		t. statistics	P-value	t. statistics	P-value
High inflation					
LLC[a)]	Unadjusted t	-3.3921		-4.8285	
	Adjusted $t^{\star}$ ($t^{\star}_{\delta}$)	-1.4382	0.0752	-0.4481	0.3270
IPS[a)]	W_{t-bar}	0.0554	0.5221	0.4343	0.6680
M-W[a), b)]	Z	-3.4417	0.0003	0.7945	0.7866
M-W[a), c)]	Z	0.2286	0.5904	0.3879	0.6509
CADF[d)]	W_{t-bar}	-2.619		-3.428	
	Z[-bar]	-2.234	0.013	-3.070	0.001
Low inflation					
LLC[a)]	Unadjusted t	-3.5822		-7.9106	
	Adjusted $t^{\star}$ ($t^{\star}_{\delta}$)	-2.5206	0.0059	-5.1826	0.0000
IPS[a)]	W_{t-bar}	-0.8659	0.1933	-3.8076	0.0001
M-W[a), b)]	Z	-4.4536	0.0000	-4.2623	0.0000
M-W[a), c)]	Z	-0.5045	0.3070	-1.9115	0.0280
CADF[d)]	W_{t-bar}	-2.898		-3.888	
	Z[-bar]	-2.977	0.001	-4.379	0.000

Note: [a)] demeaned time series. [b)] DF, drift; Inverse normal Z statistics reported, [c)] PP, drift; Inverse normal Z statistics reported, [d)] truncated – approximation of extreme values of the distribution.

Source: own calculations.

Table A.8: Panel unit root tests – country characteristics III (openness)

test		no trend		trend	
		t. statistics	P-value	t. statistics	P-value
More open					
LLC[a)]	Unadjusted t	-6.8438		-10.4242	
	Adjusted $t^{\star}$ ($t^{\star}_{\delta}$)	-5.2049	0.0000	-7.4424	0.0000
IPS[a)]	W_{t-bar}	-5.2425	0.0000	-7.9655	0.0000
M-W[a), b)]	Z	-7.2878	0.0000	-6.7034	0.0000
M-W[a), c)]	Z	-5.6308	0.0000	-7.6823	0.0000
CADF[d)]	W_{t-bar}	-3.243		-3.545	
	Z[-bar]	-3.895	0.000	-3.403	0.000
Less open					
LLC[a)]	Unadjusted t	-3.1455		-4.1901	
	Adjusted $t^{\star}$ ($t^{\star}_{\delta}$)	-1.0767	0.1408	0.3679	0.6435
IPS[a)]	W_{t-bar}	0.6397	0.7388	1.4964	0.9327
M-W[a), b)]	Z	-3.2646	0.0005	1.2838	0.9004
M-W[a), c)]	Z	0.7564	0.7753	1.3873	0.9173
CADF[d)]	W_{t-bar}	-1.551		-2.603	
	Z[-bar]	0.609	0.729	-0.721	0.235

Note: [a)] demeaned time series. [b)] DF, drift; Inverse normal Z statistics reported, [c)] PP, drift; Inverse normal Z statistics reported, [d)] truncated – approximation of extreme values of the distribution.

Source: own calculations.

Table A.9: Panel unit root tests – country characteristics IV (volatility)

test		no trend		trend	
		t. statistics	P-value	t. statistics	P-value
High volatility					
LLC[a)]	Unadjusted t	-3.5239		-4.8387	
	Adjusted $t^{\star}$ ($t^{\star}_{\delta}$)	-1.6057	0.0542	0.5481	0.2918
IPS[a)]	W_{t-bar}	-0.0820	0.4673	0.4004	0.6556
M-W[a), b)]	Z	-3.5619	0.0002	0.6104	0.7292
M-W[a), c)]	Z	0.0823	0.5328	0.3317	0.6300
CADF[d)]	W_{t-bar}	-2.944		-4.045	
	Z[-bar]	-3.100	0.001	-4.828	0.000
Low volatility					
LLC[a)]	Unadjusted t	-2.9083		-6.4590	
	Adjusted $t^{\star}$ ($t^{\star}_{\delta}$)	-0.6920	0.2445	-2.1603	0.0154
IPS[a)]	W_{t-bar}	-1.4571	0.0725	-2.1481	0.0159
M-W[a), b)]	Z	-4.1389	0.0000	-1.3080	0.0954
M-W[a), c)]	Z	-1.9286	0.0269	-2.1775	0.0147
CADF[d)]	W_{t-bar}	-1.832		-2.784	
	Z[-bar]	-0.137	0.445	-1.237	0.108

Note: [a)] demeaned time series. [b)] DF, drift; Inverse normal Z statistics reported, [c)] PP, drift; Inverse normal Z statistics reported, [d)] truncated – approximation of extreme values of the distribution.

Source: own calculations.

Table A.10: Panel unit root tests – country characteristics VI (volatility 2)

test		no trend		trend	
		t. statistics	P-value	t. statistics	P-value
High volatility					
LLC[a)]	Unadjusted t	-3.3629		-4.8484	
	Adjusted $t^{\star}$ ($t^{\star}_{\delta}$)	-1.4571	0.0725	-0.4384	0.3305
IPS[a)]	W_{t-bar}	0.0768	0.5306	0.4428	0.6710
M-W[a), b)]	Z	-3.4417	0.0003	0.7149	0.7627
M-W[a), c)]	Z	0.2604	0.6027	0.4078	0.6583
CADF[d)]	W_{t-bar}	-2.614		-2.941	
	Z[-bar]	-2.222	0.013	-1.683	0.046
Low volatility					
LLC[a)]	Unadjusted t	-2.9517		-8.8874	
	Adjusted $t^{\star}$ ($t^{\star}_{\delta}$)	) -1.5150	0.0649	-4.8405	0.0000
IPS[a)]	W_{t-bar}	-0.8302	0.2032	-4.9269	0.0000
M-W[a), b)]	Z	-4.2872	0.0000	-5.0855	0.0000
M-W[a), c)]	Z	-0.9698	0.1661	-4.1251	0.0000
CADF[d)]	W_{t-bar}	-3.264		-3.446	
	Z[-bar]	-3.951	0.000	-3.121	0.001

Note: [a)] demeaned time series. [b)] DF, drift; Inverse normal Z statistics reported, [c)] PP, drift; Inverse normal Z statistics reported, [d)] truncated – approximation of extreme values of the distribution.

Source: own calculations.

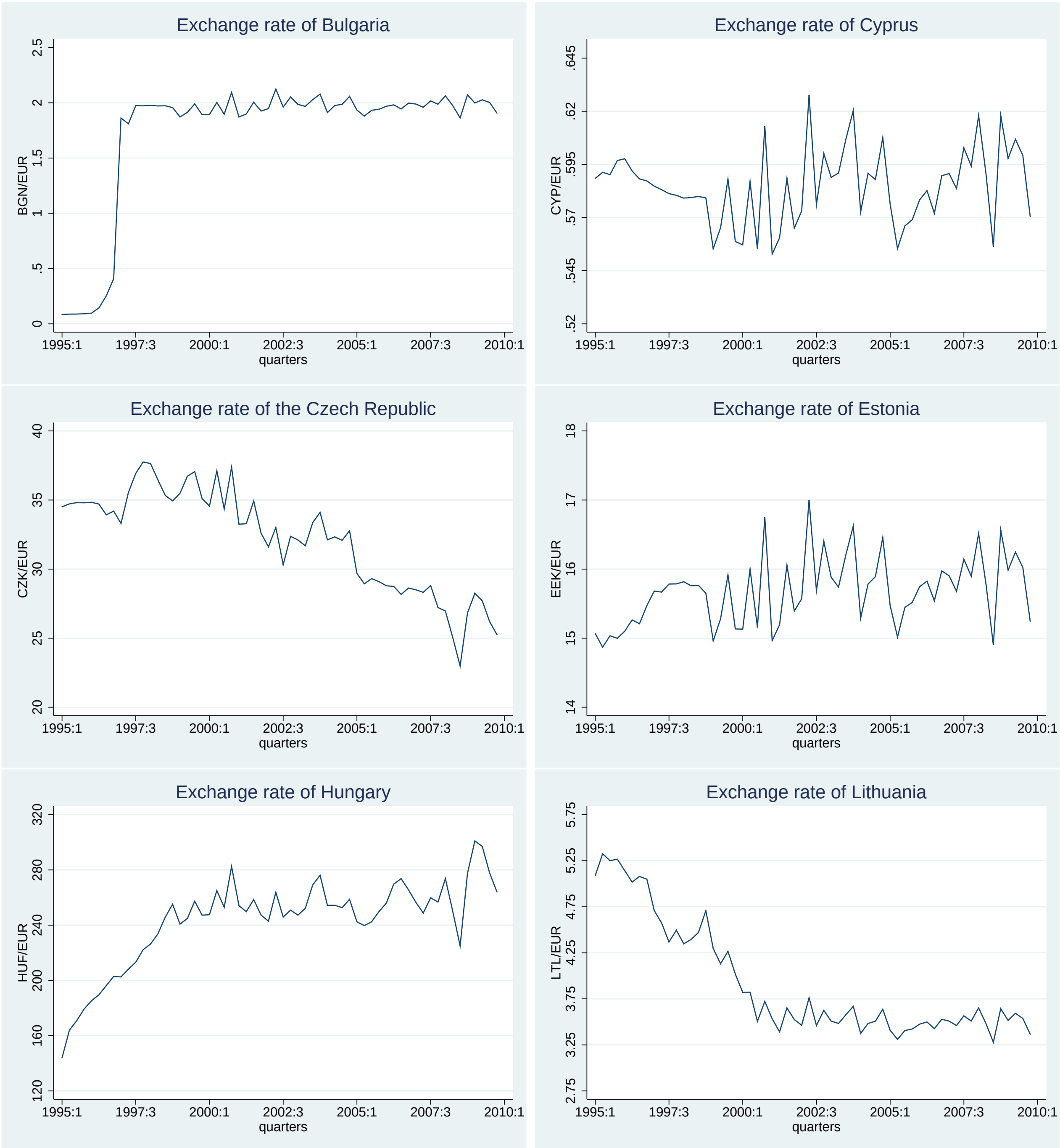
Table A.11: Panel unit root tests – country characteristics V (transition)

test		no trend		trend	
		t. statistics	P-value	t. statistics	P-value
More regulated					
LLC[a)]	Unadjusted t	-3.3979		-4.6735	
	Adjusted $t^{\star}$ ($t^{\star}_{\delta}$)	-1.4169	0.0783	-0.3731	0.3546
IPS[a)]	W_{t-bar}	0.0345	0.5138	0.5031	0.6925
M-W[a), b)]	Z	-3.4917	0.0002	0.7520	0.7740
M-W[a), c)]	Z	0.2056	0.5814	0.4818	0.6850
CADF[d)]	W_{t-bar}	-2.257		-3.275	
	Z[-bar]	-1.269	0.102	-2.633	0.004
Less regulated					
LLC[a)]	Unadjusted t	-4.6769		-8.8660	
	Adjusted $t^{\star}$ ($t^{\star}_{\delta}$)	-2.7093	0.0034	-4.4339	0.0000
IPS[a)]	W_{t-bar}	-2.1473	0.0159	-3.9590	0.0000
M-W[a), b)]	Z	-4.6077	0.0000	-3.2834	0.0005
M-W[a), c)]	Z	-1.9839	0.0236	-3.5084	0.0002
CADF[d)]	W_{t-bar}	-2.377		-2.855	
	Z[-bar]	-1.589	0.056	-1.438	0.075

Note: [a)] demeaned time series. [b)] DF, drift; Inverse normal Z statistics reported, [c)] PP, drift; Inverse normal Z statistics reported, [d)] truncated – approximation of extreme values of the distribution.

Source: own calculations.

Figure A.1: Exchange Rates of the NMS countries against the Euro



Source: see text.

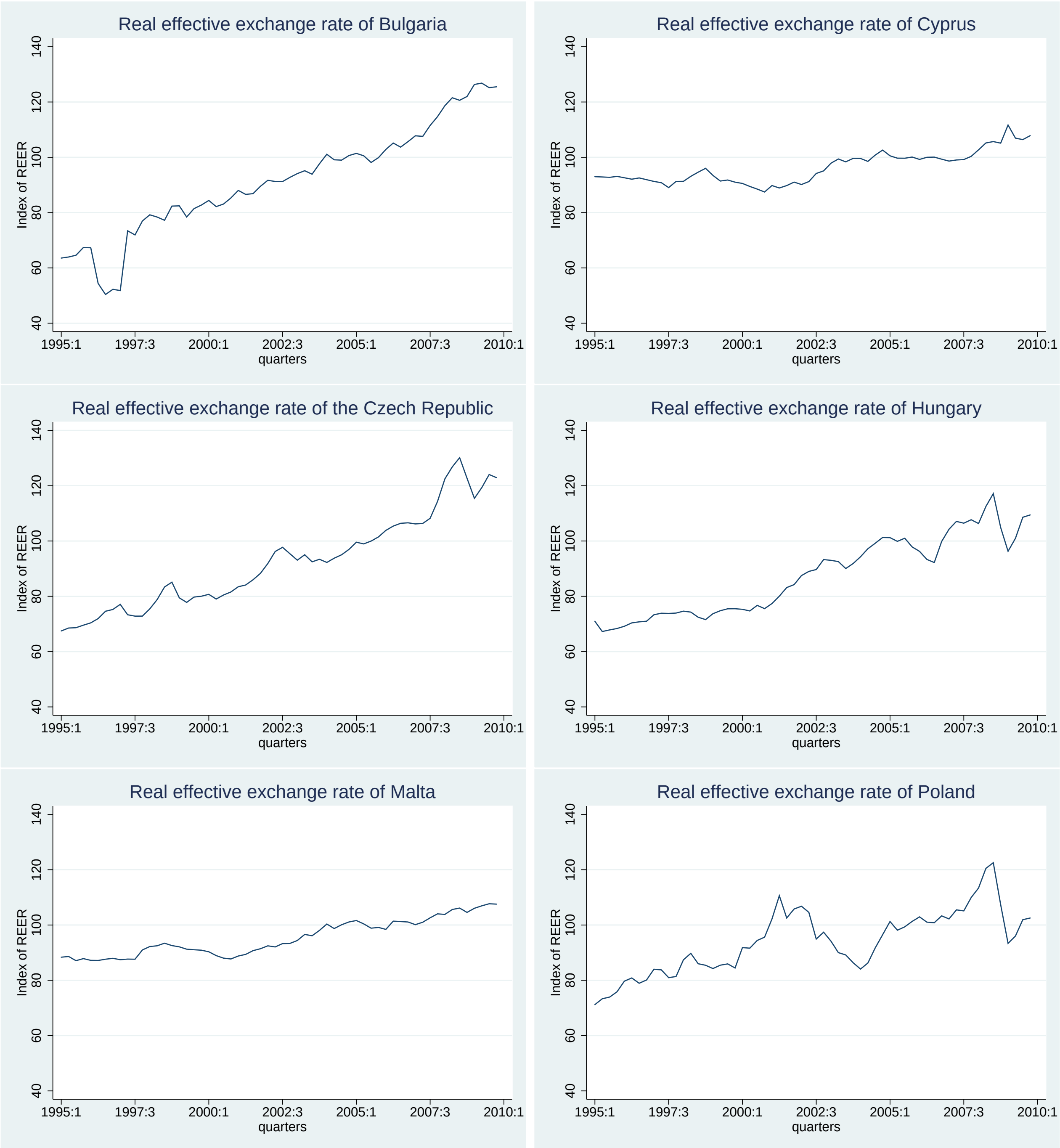
Source: see text.

Figure A.2: Exchange Rates of the NMS countries against the US Dollar

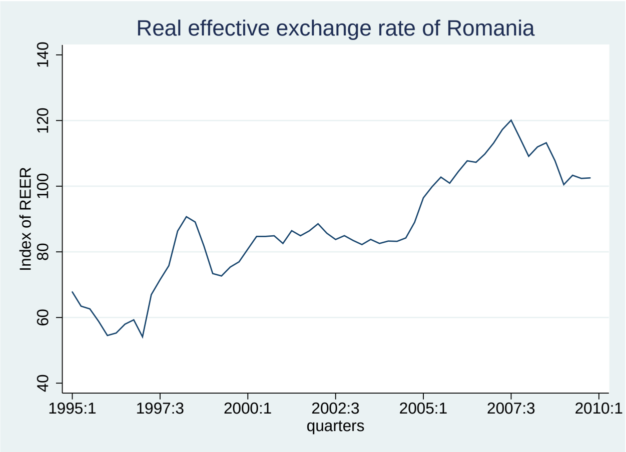
Source: see text.

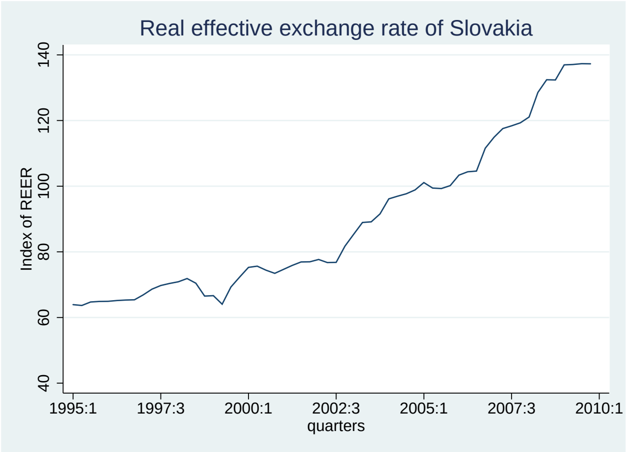
Source: see text.

Figure A.3: Exchange Rates of the NMS countries REER



Source: see text.





Source: see text.

A.6 Statistical appendix

Table A.12: Summary statistics — for the EU specification

		ER[a)]	hicp[b)]	ppi[b)]	rer_hicp[c)]	rer_ppi[c)]
Bulgaria	mean	1.071	4.091	4.057	0.798	0.808
	SD	0.617	1.208	1.189	0.273	0.259
Cyprus	mean	0.581	4.533	4.504	-0.517	-0.489
	SD	0.006	0.120	0.120	0.039	0.064
Czech Republic	mean	31.969	4.533	4.525	3.489	3.489
	SD	3.787	0.160	0.117	0.152	0.139
Estonia	mean	15.588	4.507	4.550	2.806	2.753
	SD	0.197	0.226	0.227	0.136	0.069
Hungary	mean	241.575	4.399	4.454	5.649	5.581
	SD	29.819	0.347	0.355	0.155	0.069
Lithuania	mean	3.900	4.584	4.493	1.319	1.413
	SD	0.632	0.151	0.167	0.209	0.231
Latvia	mean	0.656	4.523	4.537	-0.379	-0.402
	SD	0.052	0.237	0.247	0.151	0.111
Malta	mean	0.429	4.537	..	-0.835	..
	SD	0.016	0.116	..	0.055	..
Poland	mean	3.897	4.463	4.472	1.453	1.439
	SD	0.388	0.241	0.243	0.135	0.089
Romania	mean	2.535	3.816	3.723	3.772	1.500
	SD	1.366	1.141	1.140	2.156	0.279
Slovenia	mean	213.682	4.432	4.461	5.484	5.451
	SD	29.172	0.256	0.204	0.031	0.029
Slovakia	mean	38.710	4.404	4.452	3.805	3.754
	SD	4.154	0.271	0.218	0.257	0.207

Note: SD – standard deviation. [a)] absolute values. [b)] natural logs of seasonally adjusted indices. [c)] natural logs of original values. '..' – not available. Values for the Euro area – mean (SD): hicp: 4.553 (0.091), ppi: 4.573 (0.069).

Source: own calculations.

Table A.13: Summary statistics – for the US specification

		ER[a)]	cpi[b)]	ppi[b)]	reer_cpi[c)]
Bulgaria	mean	1.50	4.057	4.057	4.490
	SD	0.605	1.208	1.193	0.230
Cyprus	mean	0.502	4.521	4.504	4.566
	SD	0.076	0.120	0.149	0.059
Czech Republic	mean	27.900	4.515	4.525	4.509
	SD	6.630	0.160	0.116	0.181
Estonia	mean	13.472	4.487	4.550	..
	SD	2.172	0.225	0.154	..
Hungary	mean	209.22	4.375	4.454	4.459
	SD	44.506	0.347	0.263	0.162
Lithuania	mean	3.361	4.577	4.493	..
	SD	0.674	0.151	0.189	..
Latvia	mean	0.562	4.503	4.537	..
	SD	0.044	0.237	0.218	..
Malta	mean	0.369	4.533	..	4.555
	SD	0.048	0.107	..	0.068
Poland	mean	3.370	4.448	4.471	4.535
	SD	0.629	0.241	0.191	0.123
Romania	mean	2.156	3.763	3.723	4.447
	SD	1.105	1.140	1.189	0.208
Slovenia	mean	184.096	4.418	4.461	..
	SD	34.852	0.251	0.204	..
Slovakia	mean	33.829	4.391	4.452	4.461
	SD	8.382	0.273	0.218	0.250

Note: SD – standard deviation. [a)] absolute values. [b)] natural logs of seasonally adjusted indices. [c)] natural logs of original values. '..' – not available. Values for the US economy – mean (SD): cpi: 4.530 (0.111), ppi: 4.510 (0.138).

Source: own calculations.

Table A.14: Data sources

Description	Variable	Description, base index
IMF IFS database		
..RF.ZF	Exchange rates	(market rate, periodic average, National Currency per US $)
64H..ZF	HICP	2005 = 100
64...ZF	CPI	2005 = 100
..RFCZF	REER	
99BIPZF	GDP deflator	2005 = 100
63...ZF	PPI/WPI	
Eurostat		
National Accounts	GDP deflator	2005 = 100
	ULC deflator	2005 = 100
Database price	HICP	2005 = 100
	PPI	2005 = 100
UNECE		
External economic relations	Exchange rates	
Price indices	CPI	2005 = 100
Price indices	PPI	2005 = 100
ECB		
Statistical Data Warehouse	HICP	2005 = 100
	PPI	2005 = 100
EBRD		
Transition Reports	Transition index	

A.7 Lag specification

Table A.15: Suggested numbers of lags – Euro based time series

country	exchange rates	
	ER_CPI	ER_PPI
BG	3	2
CY	2	2
CZ	3	3
EE	2	1
HU	3	1
LT	6	5
LV	3	2
MT	2	–
PL	4	2
RO	3	2
SI	2	4
SK	5	3

Note: '–' not available. *Source:* own calculation.

Table A.16: Suggested numbers of lags – US $ based time series and REER

country	exchange rates		
	ER_CPI	ER_PPI	REER
BG	1	1	2
CY	2	2	1
CZ	3	3	3
EE	2	1	–
HU	3	1	3
LT	3	5	–
LV	3	2	–
MT	2	–	1
PL	4	2	2
RO	3	3	2
SI	2	2	–
SK	5	5	1

Note: '–' not available. *Source:* own calculation.

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