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EMPIRICAL INVESTIGATION OF LONG RUN PPP HYPOTHESIS: THE CASE OF TEMPORARY STRUCTURAL BREAK AND ASYMMETRIC ADJUSTMENT

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Abstract:

This study investigates the validity of the long-run PPP hypothesis for 60 economies using trade-weighted REER indices for the period 1994:01-2020:04. In addition to conventional tests, we also apply a battery of new unit root tests that allow for structural breaks and nonlinear adjustment. Our results suggest that test procedures that allow for both a structural break in the deterministic components of the series and nonlinearities in the adjustment towards equilibrium lead to a more frequent rejection of the unit root null hypothesis. In particular, after allowing for a temporary structural break in the series along with nonlinear adjustment towards the gradually changing equilibrium, we were able to reject the null hypothesis of unit root for all countries, thus providing some support for the PPP hypothesis.

Keywords:

PPP, REER, temporary structural break, nonlinear adjustment, the Balassa-Samuelson effect.

JEL Classification: C12, C22, F31

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1. Introduction

Purchasing power parity (PPP) hypothesis is one of the most important issues in open-economy macroeconomic models. Theoretically, absolute version of PPP implies that a basket of goods in one country should cost the same in another country when quoted in the same currency. The relative version of PPP, on the other hand, emphasize that the exchange rates will adjust to offset inflation differentials between countries. Because PPP hypothesis describes equilibrium level of exchange rates, empirical fulfillment of the PPP is also important for policy authorities and market practitioners as well. Test of the empirical fulfillment of the PPP hypothesis are usually based on unit root tests of the real exchange rates (RER). As stated by Lothian and Taylor (1997), Hegwood and Papell (1998) and Papell (2002), while there might be temporary deviations from the PPP hypothesis in the short run due to sluggish adjustment of nominal exchange rates or domestic prices, the long-run validity of the PPP hypothesis implies that real exchange rates revert to a constant mean. Thus, a real exchange rate that reverts to a constant mean is compatible with PPP, whereas a non-stationary real exchange rate would violate the PPP hypothesis.

Balassa (1964) and Samuelson (1964), however, argue that divergent international productivity levels could lead to permanent deviations from PPP by creating differences in wages and prices between countries. Assuming that PPP holds for traded goods only, productivity differentials between countries determine the domestic relative prices of non-tradables, leading to trend deviations from PPP in the long run. Hence, researchers used these ideas to develop models in which real exchange rates contain a time trend justified on the basis of Balassa-Samuelson effects (Obstfeld, 1993; Papell and Prodan, 2006). Thus, trend-stationarity of the real exchange rate series supports the Balassa-Samuelson proposition.

Earlier studies have usually tested PPP hypothesis in a linear context by employing conventional unit root tests. Most of these tests, however, failed to provide empirical evidence in favour of real exchange rate stationarity (Meese and Rogoff, 1988; Edison and Fisher, 1991). Researchers attributed such failures to the low power of linear unit root tests with short time spans of data. Some researchers pointed out that the equilibrium real exchange rates might shift over time and suggested to use unit root tests that allow for structural breaks in the mean (Hegwood and Papell, 1998; Papell, 2002; Sollis, 2005; Papell and Prodan, 2006)[1]. Papell (2002) and Papell and Prodan (2006) state that if structural breaks in the real exchange rate appear to be permanent, then absolute PPP doesn't hold but rather a *qualified* PPP holds. On the other hand, if structural breaks in the real exchange rate are temporary (i.e. if structural changes are offsetting each other), then long-run PPP hypothesis holds in the long run. In this sense, for the exact PPP hypothesis to hold, structural breaks in the series have to be temporary, implying that the mean toward which the real exchange rate reverts is the same both at the start and end of the sample. Following this proposition, some authors developed unit root tests allowing for temporary structural changes in the deterministic component of real exchange rate series. For example, Sollis (2005) proposed unit root test allowing for symmetric and asymmetric smooth transition models to model temporary structural breaks in the deterministic

[1] Another strand of the literature suggested use of panel data to increase power of stationarity tests. See, for example, Frankel and Rose (1996) and Lothian (1997). More recently, Emirmahmutoglu and Omay (2014) provided empirical evidence in favor of the PPP proposition in a panel 15 European countries using asymmetric nonlinear models. However, their results imply that the mere use of panel data is not sufficient to find support for the PPP proposition. In fact, they were able to reject the null hypothesis of unit root only after allowing for higher degrees of nonlinear adjustment as suggested by Sollis (2009).

part of the series. On the other hand, Papell and Prodan (2006) used restricted additive outliers in the deterministic part of the series to model temporary structural breaks.

Another development in empirical studies of the PPP hypothesis is the nonlinear behavior of the real exchange rate. For example, Rogoff (1996) points out that nonlinearities in real exchange rate may arise from frictions due to transportation costs, tariffs and non-tariffs barriers. Further, Kilian and Taylor (2003) states that as the degree of misalignment from PPP rises, the degree of mean reversion of the real exchange rate rises. Sarno and Taylor (2001) and Taylor (2004, 2005) point out that, in addition to trade barriers and transportation costs, official interventions in the foreign exchange markets and nominal rigidities may also lead to nonlinearities in adjustment of real exchange rates to equilibrium. On the other hand, Sollis (2004), Christopoulos and Leon-Ledesma (2010) and Omay et al. (2018) argue that the exact behavior of real exchange rate may well be described by nonlinear adjustments towards equilibrium after allowing for structural breaks. In fact, Sollis (2004), Telatar and Hasanov (2009), Christopoulos and León-Ledesma (2010), Kutan and Zhou (2017), Omay et al. (2018), Omay et al. (2020), among others, provide more evidence on empirical validity of the PPP hypothesis after allowing for simultaneous structural breaks and nonlinear adjustments towards the equilibrium.

In this paper we examine the empirical validity of the PPP hypothesis by employing novel unit root test procedures proposed by Christopoulos and Leon-Ledesma (2010) and Omay et al. (2020). These test procedures allow for rather rich dynamics of real exchange rate series consistent with both empirical observations and theoretical models. In particular, both test procedures allow for gradual breaks in the deterministic components along with nonlinear adjustment towards the equilibrium. Christopoulos and Leon-Ledesma (2010) used flexible Fourier form (FFF) to model structural breaks while Omay et al. (2020) proposed to use an exponential smooth transition (ESTR) function which is theoretically more appealing than the FFF. Adjustment towards equilibrium in both test procedures are modeled using symmetric and asymmetric exponential smooth transition functions proposed by Kapetanios et al. (2003) and Sollis (2009), respectively. As real exchange rates may simultaneously exhibit temporary structural breaks and nonlinear mean reversion, both test methods are likely to yield higher power than those accounting for either nonlinear adjustment or structural breaks alone. In addition to these tests, we also apply conventional ADF test as well as Sollis' (2005) test for comparison purposes. Application of competing test procedures to the same data set also allows one to evaluate aptness of these procedures in testing the PPP proposition. In fact, our results suggest that both structural breaks and nonlinear adjustment must be taken into account in empirical tests of the PPP proposition whereas the ESTR-type functions might be more appropriate for modeling structural breaks in RER series.

Another contribution of the present paper is that it investigates the PPP proposition in a more comprehensive framework. Previous studies focused mainly on a smaller group of countries and/or bilateral RER series. For example, Christopoulos and Leon-Ledesma (2010) considered 15 OECD countries, Omay et al. (2018) 28 EU countries and Omay et al. (2020) 24 OECD countries. In this paper, we test the empirical validity of the PPP hypothesis for 60 economies (59 countries and Euro Area), whose data were available in the BIS (Bank of International Settlements) database. The sample countries account for more than four-fifth of the world's GDP and international trade. Furthermore, rather than using bilateral RER series, we use the broad trade-weighted real effective exchange rate (REER) indices. Bahmani-Oskooee et al. (2007) argued that using REERs allows for a test of the multi-country version of PPP, rather than that of PPP based on bilateral trading partners. In fact, stationarity of the REER series implies that the PPP holds with respect to major trading partners, but not with a specific country. Fluctuations in REER are more crucial for international trade flows rather than bilateral rates. Thus, this paper provides a more comprehensive test of empirical fulfillment of the PPP proposition.

The remaining of the study is organized as follows. The next section discusses the newly developed test procedures used in this paper. Section 3 describes dataset and present empirical findings. The last section concludes the paper.

2. Methodology

In order to model temporary gradual structural changes in the deterministic components of REERs, Christopoulos and Leon-Ledesma (2010) consider following gradually changing Fourier function.

$$y_t = \delta_0 + \delta_1 \sin\left(\frac{2\pi kt}{T}\right) + \delta_2 \cos\left(\frac{2\pi kt}{T}\right) + \upsilon_t \quad (1)$$

Christopoulos and Leon-Ledesma (2010) point out that unit root tests with this form of temporary structural breaks performs especially well relative to other tests when breaks are temporary and when breaks tend to happen in opposite directions. They further argue that the events that led to the appreciation and subsequent depreciation of the dollar in the early 1980s may have generated large equilibrium exchange rate swings.

Christopoulos and Leon-Ledesma's (2010) unit root test is conducted via a two-step procedure. The first step is to obtain the OLS residual series υ_t from regression (1) for values of k between 1 and 5 and selects the k that minimizes the residual sum of squares. The second step is to test for a unit root in υ_t by employing the following ADF and KSS regression models:

$$\Delta\hat{\upsilon}_t = \rho\hat{\upsilon}_{t-1} + \sum_{i=1}^{k}\delta_i \Delta\hat{\upsilon}_{t-i} + \varepsilon_t \quad (2)$$

$$\Delta\hat{\upsilon}_t = \rho\hat{\upsilon}_{t-1}^3 + \sum_{i=1}^{k}\delta_i \Delta\hat{\upsilon}_{t-i} + \varepsilon_t \quad (3)$$

where equation (2) is ADF regression which assumes linear adjustment toward equilibrium while equation (3) assumes nonlinear adjustment towards equilibrium. We denote the test that models adjustment linearly by FADF (the Fourier-ADF test), which uses eq. (2) along with eq. (1). The test procedure that allows for nonlinear adjustment will be denoted by $F - t_{NL}$ (the Fourier-KSS test), which uses eq. (3) with eq. (1).

As pointed out by Omay et al. (2020), the Fourier function given in eq. (1) implies that the deterministic component of series fluctuates continuously between upper and lower bands in a predictable way. However, this predictable fluctuation implies a never-ending arbitrage opportunity in exchange rates, which contradicts the economic theory and common sense[2].

[2] Omay (2015) and Cai and Omay (2021) propose fractional frequency and double frequency Fourier functions, respectively, in unit root test procedures. However, these modifications also imply a predictable fluctuation in the deterministic components. While these functions may capture gradual breaks in deterministic components of many economic variables, the deterministic components implied by Fourier functions are implausible for real exchange rate series.

Therefore, they propose using exponential smooth transition functions to model temporary breaks in real exchange rates. Sollis (2005) and Çorakçı et al. (2017) also used exponential smooth transition functions to model a temporary gradual structural break in the mean of the series. They consider three models for the alternative hypothesis of stationarity against which the unit root null could be tested. The models are as follows:

Model A:

$$y_t = \alpha_1 + \alpha_2 S_t(\gamma, \tau) + \upsilon_t \tag{4}$$

Model B:

$$y_t = \alpha_1 + \beta_1 t + \alpha_2 S_t(\gamma, \tau) + \upsilon_t \tag{5}$$

Model C:

$$y_t = \alpha_1 + \beta_1 t + \alpha_2 S_t(\gamma, \tau) + \beta_2 t S_t(\gamma, \tau) + \upsilon_t \tag{6}$$

with the following exponential smooth transition functions

$$S_t(\gamma, \tau) = 1 - \exp\left[-\gamma (t - \tau T)^2\right], \qquad \gamma > 0 \tag{7}$$

$$S_t(\gamma, \tau) = 1 - \exp\left[-\gamma^2 (t - \tau T)^2\right], \qquad \gamma > 0 \tag{8}$$

The transition function, $S_t(\gamma, \tau)$, is continuous, bounded between zero and one, and symmetric around zero. The transition speed parameter γ determines the smoothness of the transition such that the speed of structural shift increases with γ. While Corakcı et al. (2017) and Omay et al. (2020) use (7) to model temporary structural break, Sollis (2005) uses square of transition speed parameter as in the transition function (8) to introduce higher degree of nonlinearity in the deterministic part of the series and ensure positivity of the transition speed. τ determines the timing of the transition midpoint such that $S_t(\gamma, \tau) = 0$ when $t = \tau T$, and $S_t(\gamma, \tau)$ approaches 1 when t moves further from τT. These features of the transition function imply that the structural changes in the deterministic components of the series are temporary.

Equations (4-6) together with (2) constitute Sollis (2005) unit root tests for Models A, B and C. Corakcı et al. (2017) unit root test is similar to Sollis (2005) test, however, the transition speed parameter is different between the two tests. Omay et al. (2020) use equations (4-6) together with (3) and develop unit root test against the alternative of series (υ_t) being stationary around a temporary structural change in the deterministic component with asymmetric speed of adjustment toward equilibrium. In all of these three test methods, the unit root test statistics are calculated via a two-step procedure. In the first step A, B and C models are estimated by the nonlinear least square and $\hat{\upsilon}_t$ residuals are obtained. The second step tests for a unit root on the residuals $\hat{\upsilon}_t$ by employing equations (2) or (3). The rejection of the unit root null hypothesis $\rho = 0$ indicates that the REER series is mean reverting with temporary structural break in the deterministic component.

3. Data and the Empirical Test Results

This study investigates the empirical validity of the PPP hypothesis for 60 economies (59 countries and Euro-Area), including 27 EU member countries (Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden), 4 non-EU European countries (Iceland, Norway, Switzerland, United Kingdom), Russia, 4 Middle Eastern countries (Israel, Saudi Arabia, United Arab Emirates, Turkey), 13 Asia-Pacific countries (Australia, China, Chinese Taipei, Hong Kong, India, Indonesia, Japan, Malaysia, Philippines, Singapore, South Korea, Thailand, New Zealand), 5 South American countries (Argentina, Brazil Chile, Colombia, Peru), 3 North American countries (Canada, Mexico, United Sates) and 2 African countries (Algeria, South Africa). All data of REERs are CPI-based (2010=100) broad indices obtained from the BIS (Bank of International Settlements) and covering the period 1994:01-2020:04.

To test stationarity of the REER series, we apply the unit root tests described in the previous section. Namely, we use the Fourier-ADF, Fourier-KSS, Sollis (2005) and Omay et al. (2020) unit root tests. In addition, conventional ADF unit root tests (τ_μ and τ_τ) are applied for comparison purposes. Furthermore, since a REER is a weighted average real rate of a country's currency relative to its trading partners, it may contain a time trend justified on the basis of Balassa-Samuelson-type effects. Especially, structural reforms and/or relatively higher speeds of adoption of technological innovations in some countries may bring about rapid productivity gains for those countries. Hence, Models B and C in Sollis (2005) and Omay et al. (2020) unit root tests are used to test for a version of PPP allowing for a time trend to capture the Balassa-Samuelson-type effect. Empirical results of these tests are reported in Table 1.

Table 1. Unit root test results for real effective exchange rates.

	τ_{μ}	τ_{τ}	k	$FADF$	$F\!-\!t_{NL}$	e_{α}	$e_{\alpha(\beta)}$	$e_{\alpha\beta}$	$t_{E\alpha}$	$t_{E\alpha(\beta)}$	$t_{E\alpha\beta}$
Algeria	-1.214	-3.121	1	-1.554	-1.470	-4.491**	-2.402	-3.010	-12.636***	-18.598***	-18.598***
Argentina	-1.388	-2.668	1	-1.864	-1.613	-3.648	-4.049	-5.416**	-4.330**	-3.678	-3.879**
Australia	-1.413	-1.158	1	-3.103	-2.056	-3.370	-3.373	-3.715	-3.359	-4.305**	-4.269**
Austria	-2.963**	-3.074	2	-2.820	-2.315	-2.946	-2.975	-3.464	-4.052**	-7.031***	-7.095***
Belgium	-2.885**	-2.977	2	-3.580**	-3.074*	-4.092*	-4.624**	-4.684*	-3.176	-5.465***	-5.478***
Brazil	-1.607	-1.584	2	-2.073	-3.197*	-1.983	-2.841	-3.843	-3.546*	-7.523***	-7.446***
Bulgaria	-1.758	-1.696	1	-1.285	-2.693	-3.683	-4.161	-4.895*	-2.191	-8.612***	-8.613***
Canada	-1.575	-1.499	1	-3.343	-3.989**	-3.406	-3.406	-3.933	-2.547	-4.688**	-4.732***
Chile	-2.524	-3.071	2	-3.589**	-3.148*	-2.829	-4.297*	-4.383	-2.938	-4.390**	-4.291**
China	-1.536	-1.960	1	-2.200	-1.827	-3.048	-3.266	-3.271	-1.428	-4.251**	-4.264**
Chinese Taipei	-1.797	-1.068	1	-2.770	-2.328	-4.595**	-4.896**	-4.848*	-5.663***	-5.816***	-5.831***
Colombia	-2.146	-2.054	2	-3.120*	-2.708	-2.750	-2.861	-4.877*	-3.017	-4.641**	-4.690***
Croatia	-2.266	-2.078	1	-2.800	-3.570*	-4.043*	-4.213	-4.212	-3.309	-4.034*	-4.034**
Cyprus	-1.356	-1.204	1	-4.318**	-4.645***	-4.827***	-5.023**	-5.024**	-3.515*	-6.304***	-6.336***
Czech Republic	-1.765	-1.072	1	-1.304	-0.664	-2.020	-3.457	-5.021**	-2.924	-10.655***	-10.654***
Denmark	-2.818*	-2.853	1	-3.505*	-3.220	-2.850	-4.383*	-4.733*	-3.655*	-5.206***	-5.208***
Estonia	-4.247***	-3.802**	1	-1.364	-1.190	-2.051	-2.500	-3.043	-3.140	-8.043***	-4.462**
Euro Area	-2.266	-2.368	2	-2.387	-2.180	-1.795	-2.915	-4.203	-3.053	-6.063***	-6.034***
Finland	-2.329	-3.536**	2	-2.473	-2.760	-2.293	-4.928**	-4.769*	-4.078**	-4.790***	-4.845***
France	-1.590	-2.369	2	-1.010	-0.950	-1.905	-2.906	-4.016	-2.178	-7.741***	-7.772***
Germany	-2.380	-2.910	2	-1.730	-2.559	-2.383	-3.649	-3.000	-3.020	-6.466***	-6.476***
Greece	-1.594	-1.369	1	-2.586	-2.008	-3.283	-3.451	-3.607	-3.379	-3.933*	-3.935**
Hong Kong	-1.447	-1.380	1	-3.323	-3.898**	-3.144	-3.232	-4.581*	-2.405	-7.943***	-8.119***
Hungary	-1.351	-0.461	1	-1.530	-2.812	-2.513	-4.270	-4.361	-3.557*	-10.124***	-10.125***
Iceland	-2.492	-2.558	2	-2.835	-4.052***	-3.631	-3.528	-4.505	-5.317***	-8.112***	-7.990***
India	-3.272**	-3.899**	1	-3.824**	-3.503*	-2.928	-5.671***	-5.998***	-3.253	-6.700***	-6.627***
Indonesia	-3.315**	-3.030	1	-3.425	-4.753***	-4.148*	-4.875**	-5.169**	-4.774***	-8.068***	-8.113***
Ireland	-1.481	-1.202	1	-2.628	-2.655	-3.614	-3.711	-4.385	-2.483	-5.787***	-5.849***
Israel	-1.691	-1.258	1	-3.160	-2.684	-3.125	-3.205	-4.601*	-3.139	-6.758***	-6.783***
Italy	-3.136**	-3.053	1	-3.912**	-5.725***	-4.562**	-4.604**	-3.274	-5.246***	-13.495***	-13.476***
Japan	-2.081	-3.398*	1	-3.806**	-3.563*	-2.558	-4.275	-4.736*	-3.118	-7.009***	-7.010***
Korea	-3.078**	-3.083	2	-3.473**	-3.690**	-3.538	-3.540	-3.637	-5.170***	-7.402***	-7.408***
Latvia	-2.598*	-2.428	1	-1.949	-2.044	-2.815	-2.430	2.431	-2.452	-5.772***	-5.765***
Lithuania	-4.367***	-3.148*	1	-1.317	-0.635	-3.633	-4.577**	-4.451	-3.195	-4.628**	-4.671***
Luxembourg	-1.989	-3.072	1	-3.261	-2.227	-3.259	-4.374*	-4.347	-2.489	-5.246***	-5.295***
Malaysia	-2.167	-3.117	2	-2.483	-3.689**	-2.943	-3.658	-3.247	-7.593***	-15.254***	-15.730***
Malta	-1.624	-1.349	1	-2.091	-3.314*	-3.697	-4.968**	-5.353**	-3.194	-6.347***	-6.387***
Mexico	-1.653	-2.024	1	-3.792**	-4.712***	-3.895*	-4.063	-4.408	-5.337***	-7.543***	-7.581***
Netherlands	-2.673*	-2.651	2	-3.031*	-3.305**	-4.310**	-4.276	-5.484**	-3.473*	-7.344***	-7.342***

Table 1. Unit root test results for real effective exchange rates (Continued).

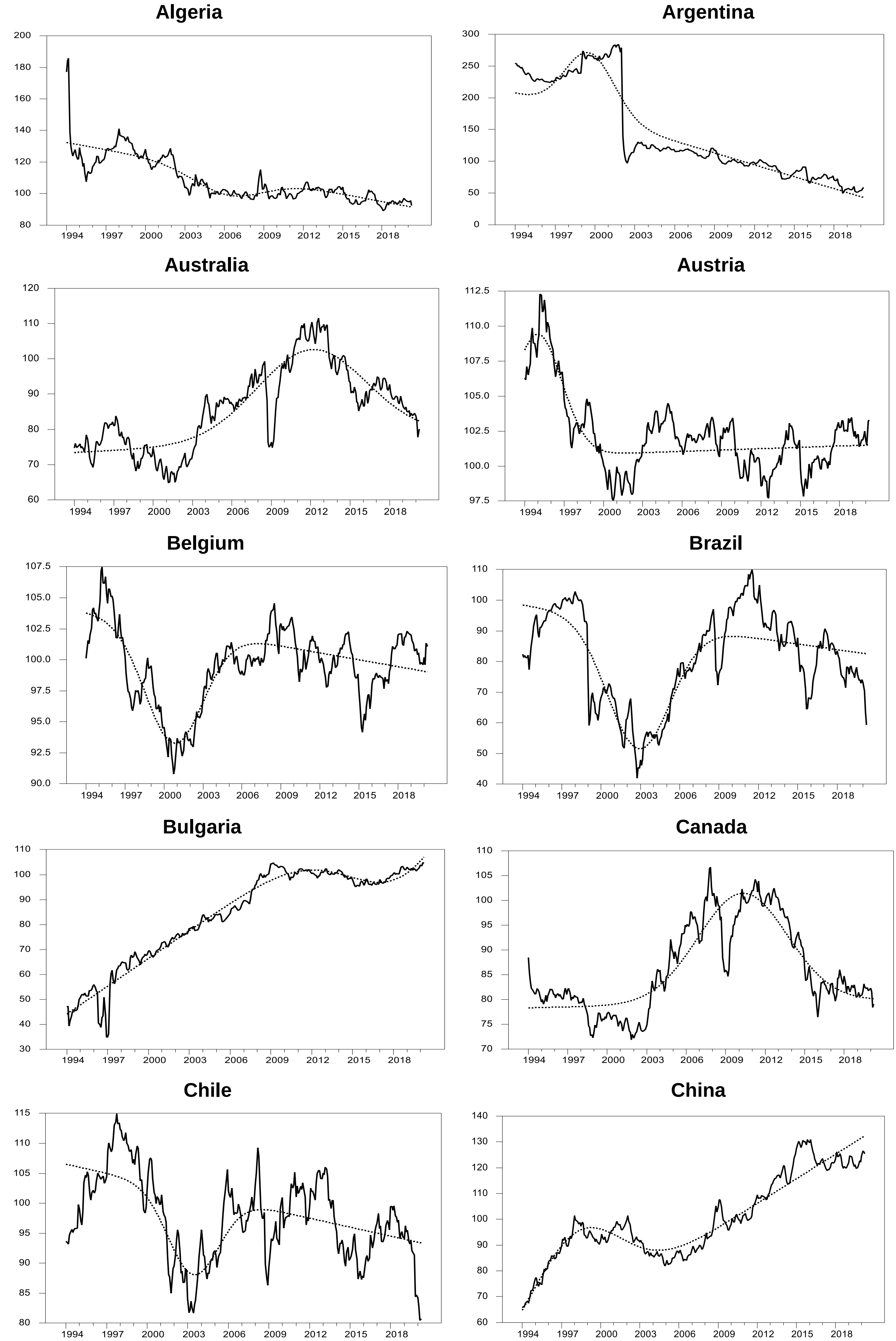
New Zealand	-2.242	-2.620	1	-3.308	-3.228	**-3.874***	-3.772	-3.810	-2.391	**-6.012*****	**-6.031*****
Norway	-0.142	-0.744	1	-2.113	-3.155	-2.676	-3.574	-3.544	-3.015	**-9.610*****	**-9.616*****
Peru	-1.697	-2.177	1	**-4.143****	**-3.486***	**-4.191****	**-4.328***	-4.302	**-3.531***	**-4.986*****	**-4.993*****
Philippines	-1.416	-2.061	1	-3.209	-1.946	**-4.017***	-4.048	-4.160	**-5.047*****	**-5.196*****	**-5.131*****
Poland	**-2.817***	-2.470	1	**-3.517***	**-4.072****	-2.525	-4.047	-1.758	-2.862	**-10.504*****	**-10.492*****
Portugal	-1.307	-0.899	1	-1.905	-1.773	-1.921	-2.956	-3.162	-2.829	**-6.457*****	**-6.515*****
Romania	-1.704	-1.616	1	-1.687	**-3.378***	-3.438	-3.797	-3.824	**-5.391*****	**-11.451*****	**-11.333*****
Russia	-2.504	-2.405	1	**-4.090****	**-3.531***	**-3.971***	-4.050	-4.306	**-3.659***	**-3.998***	**-3.983****
Saudi Arabia	-1.361	-1.227	1	-2.794	-2.849	-3.256	-3.302	-3.895	-3.030	**-6.166*****	**-6.166*****
Singapore	-1.327	-1.718	1	-2.448	-3.006	-2.707	-2.533	-4.469	-2.125	**-4.000***	**-3.963****
Slovakia	-1.114	-1.253	1	-0.368	-1.388	-2.972	**-4.502***	**-5.208****	-2.454	**-6.628*****	**-6.661*****
Slovenia	-1.800	-1.588	1	-3.121	-2.843	-1.744	**-4.803****	-2.384	**-3.624***	**-8.191*****	**-8.196*****
South Africa	2.218	-3.073	2	-2.316	-2.340	-1.521	-3.631	-3.877	**-3.548***	**-4.994*****	**-4.993*****
Spain	-1.683	-1.455	1	-2.748	**-3.463***	-2.569	-3.469	**-5.669*****	**-3.519***	**-4.969*****	**-4.959*****
Sweden	-0.937	-3.110	1	-1.421	-1.101	-1.079	-3.755	-3.728	-1.079	**-5.075*****	**-5.143*****
Switzerland	-1.740	-2.137	1	-3.413	**-6.298*****	-2.288	-2.818	-3.397	**-5.558*****	**-16.295*****	**-16.286*****
Thailand	-2.204	-2.618	1	**-3.536***	**-9.478*****	**-4.245****	**-4.419***	**-5.265****	**-6.880*****	**-12.611*****	**-12.592*****
Turkey	-1.944	-0.806	1	**-3.700***	**-4.148****	-3.574	**-4.345***	-4.397	**-4.455*****	**-6.289*****	**-6.304*****
United Arab Emirates	-1.559	-2.923	3	-1.139	-1.242	-1.295	-2.973	-3.108	-2.010	**-6.422*****	**-6.410*****
United Kingdom	-1.553	-2.877	1	-3.392	**-3.492***	**-4.001***	-4.001	-3.307	**-3.776***	**-5.150*****	**-5.406*****
United States	-1.612	-1.592	1	-2.102	-2.179	-2.761	-2.376	-4.204	-2.107	**-3.982***	**-3.953****

*Note: ***, ** and * denote the rejection of the null hypothesis at 1%, 5% and 10% significance levels, respectively. τ_μ denotes ADF test statistic with constant term and τ_τ denotes ADF test statistic with both constant and trend terms. 1%, 5% and 10% critical values for τ_μ are -3.453, -2.871 and -2.572 respectively, and for τ_τ are -3.991, -3.426 and – 3.136, respectively. $FADF$ and $F-t_{NL}$ denote Christopoulos and Loen-Ledesma's (2010) Fourier-ADF and Fourier-KSS test statistics, respectively. k denotes estimated number of frequencies in $FADF$ and $F-t_{NL}$ tests. For FADF and FKSS tests, finite sample critical test statistics are taken Christopoulos and Leon-Ledesma (2010). e_α, $e_{\alpha(\beta)}$ and $e_{\alpha\beta}$ denote Sollis's (2005) ESTR unit root test statistics for models A, B and C, respectively. Finite sample critical values for e_α, $e_{\alpha(\beta)}$ and $e_{\alpha\beta}$ are taken from Sollis (2005). $t_{E\alpha}$, $t_{E\alpha(\beta)}$ and $t_{E\alpha\beta}$ denote Omay et al. (2020) unit root test statistics for models A, B and C, respectively, and finite sample critical values for $t_{E\alpha}$, $t_{E\alpha(\beta)}$ and $t_{E\alpha\beta}$ are taken from Omay et al. (2020). General-to-specific method is used to select the optimal lag length for all unit root tests.*

As can be seen from the Table 1 the conventional ADF test with constant term rejects the unit root null hypothesis for 12 countries (at 10% or higher significance levels). However, the ADF test including both constant and trend rejects unit root null hypothesis for only 5 countries. On the other hand, the FADF and e_α tests that allow for gradual temporary break in the deterministic component, reject the null hypothesis of unit root for 16 and 15 countries, respectively. Further, $F-t_{NL}$ and $t_{E\alpha}$ tests that allow for gradual temporary break in the deterministic component together with nonlinear adjustment toward equilibrium, reject the null hypothesis of unit root for 26 and 27 countries respectively. The test results reveal that, after taking into account temporary structural break together with asymmetric speed of adjustment, the number of stationary REERs considerably increases. Also notice that the $t_{E\alpha}$ test outperforms ADF, FADF, e_α and $F-t_{NL}$ tests in terms of the number of stationary REERs. Further, test results indicate that $t_{E\alpha}$ has better power over ADF, FADF, e_α and $F-t_{NL}$ tests in terms of the rejection of unit root null hypothesis. At 1% significance levels, $t_{E\alpha}$ test rejects the null hypothesis for 13 REERs, while ADF, FADF, e_α and $F-t_{NL}$ tests reject the null hypothesis for 2, 0, 1 and 7 REERs, respectively. The $e_{\alpha(\beta)}$ and $e_{\alpha\beta}$ tests, which include time trends in unit root tests, reject null hypothesis of unit root for 17 and 19 REERs, respectively. At the 5% significance level, $e_{\alpha(\beta)}$ and $e_{\alpha\beta}$ tests reject null hypothesis of unit root for 9 and 11 REERs respectively. On the other hand, $t_{E\alpha(\beta)}$ and $t_{E\alpha\beta}$ test statistics reject null hypothesis of unit root for all countries and Euro Area except for Argentina in the case of $t_{E\alpha(\beta)}$ test statistic. In particular, $t_{E\alpha(\beta)}$ test statistic rejects null hypothesis of unit root for 48 countries at 1% significance level, 6 countries at 5% significance level and 5 countries at 10% significance level. However, $t_{E\alpha\beta}$ test statistic rejects null hypothesis of unit root for 50 countries at 1% significance level and 10 countries at 5% significance level. Consequently, Omay et al.'s (2020) unit root tests (i.e. $t_{E\alpha}$, $t_{E\alpha(\beta)}$ and $t_{E\alpha\beta}$) that take into account temporary structural break in the deterministic component together with nonlinear adjustment toward equilibrium, reject the null hypothesis of unit root for all countries, and thus strongly support the long-run PPP hypothesis for all countries in the study.

Figure 1 presents REERs of all sample countries along with estimated nonlinear deterministic trend functions. We use model B to obtain fitted trend functions for all countries except for Argentina. Fitted trend function for Argentina is obtained from model C. As can be seen from the figure, the fitted trend functions capture major swings in the series quite well in most of the countries. Visual inspection of those REERs in Figure 1 as well as test results reveal the importance of taking into account structural breaks in analyzing dynamics of real exchange rates.

Figure 1. REERs (solid line) and estimated ESTR trend functions (dashed line).



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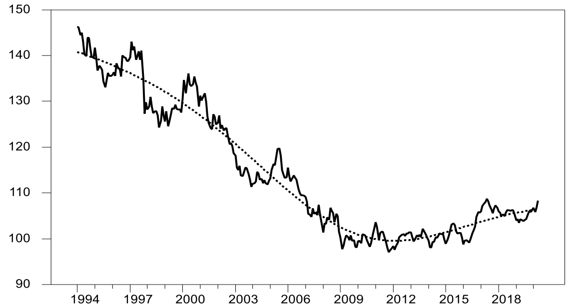

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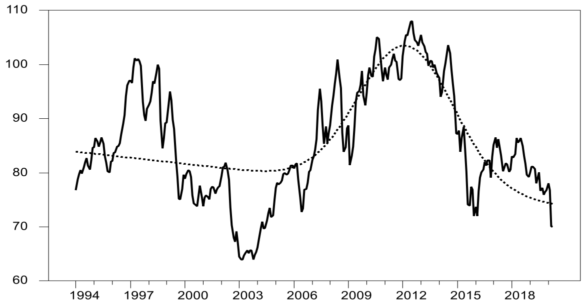

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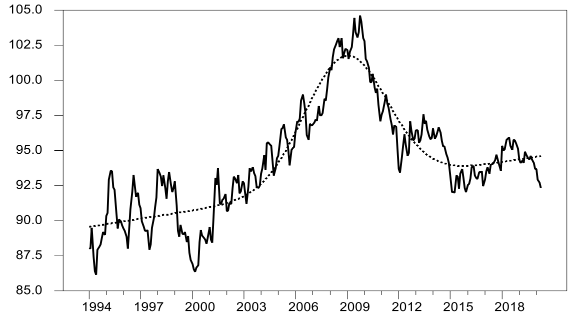

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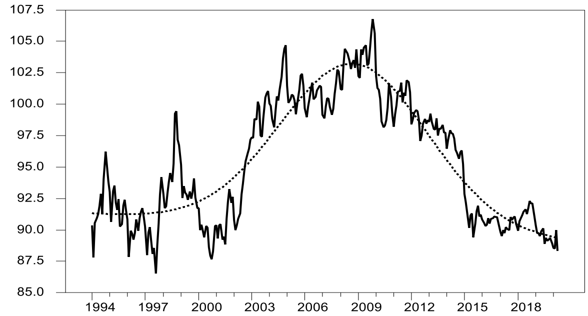

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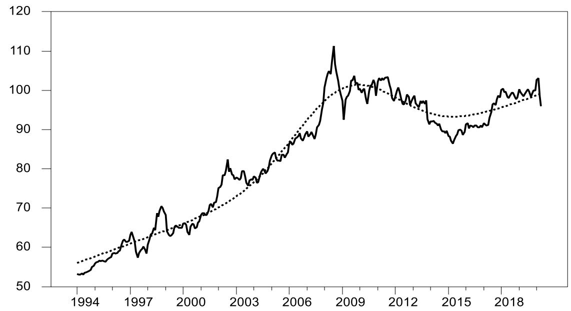

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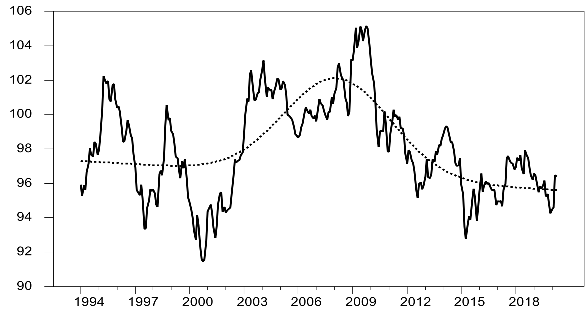

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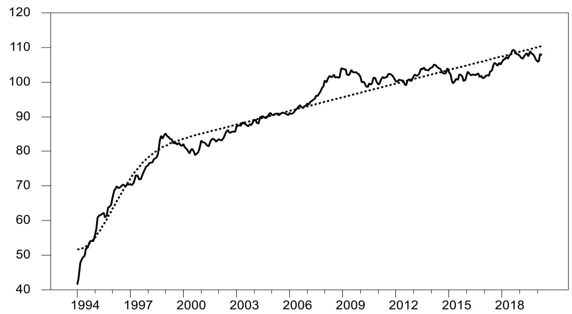
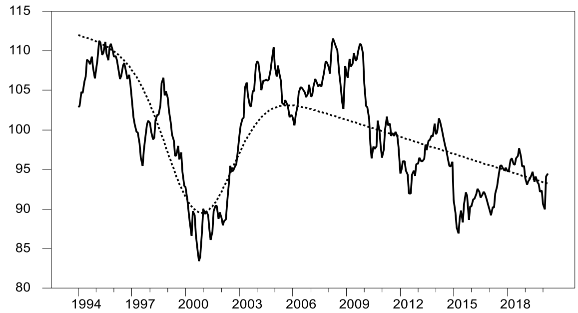


Euro Area



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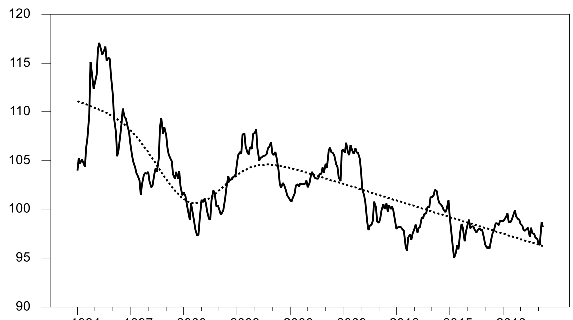

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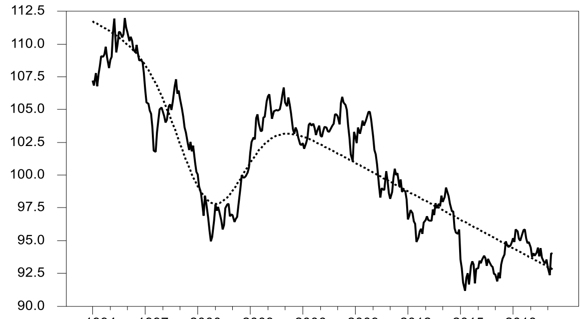

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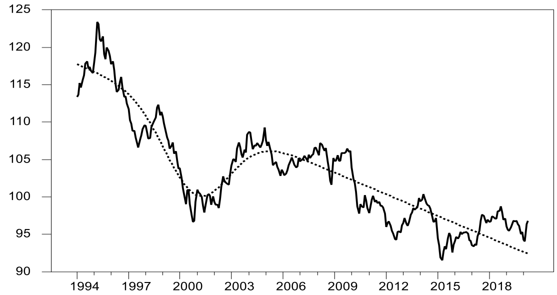

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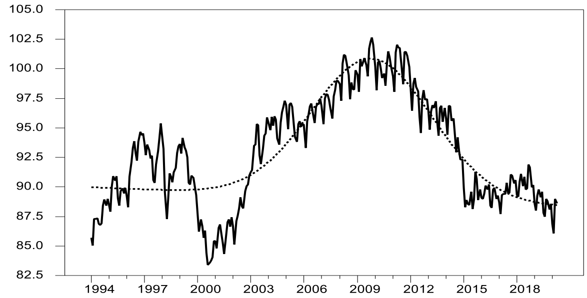

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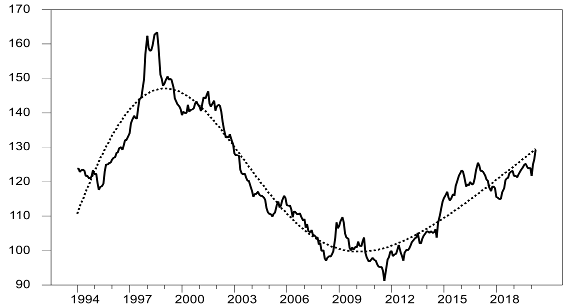

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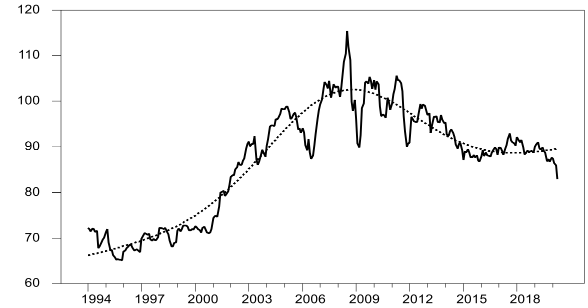

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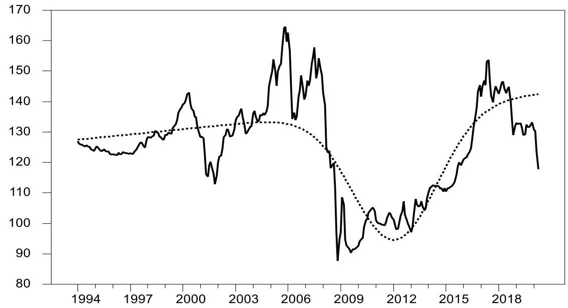

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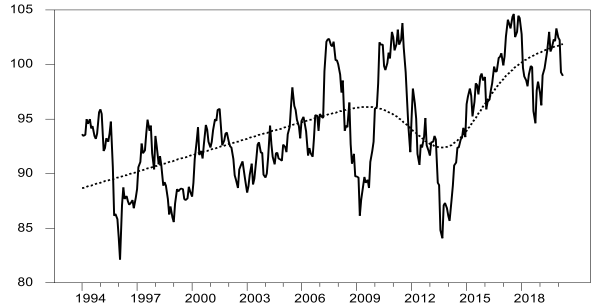

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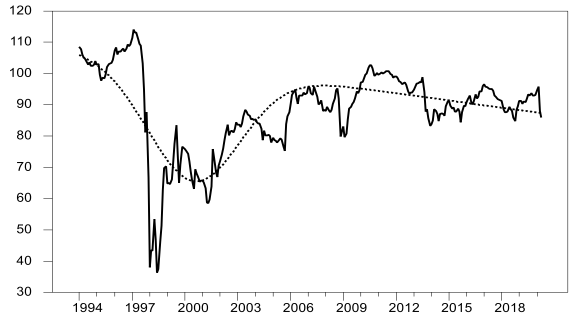

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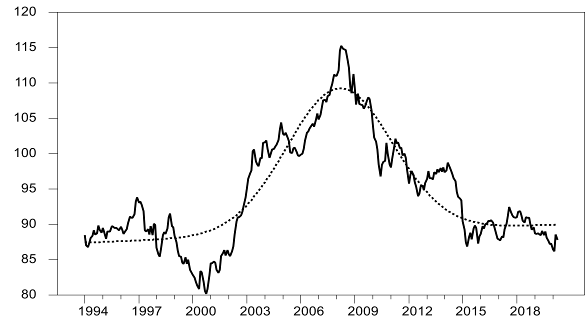

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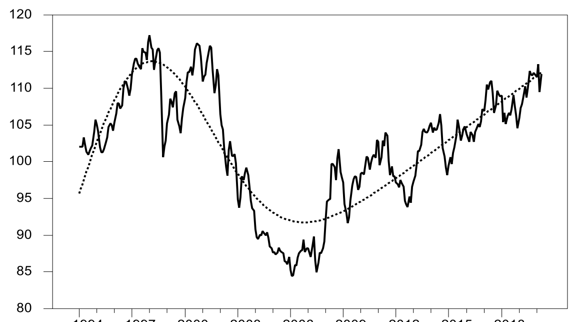

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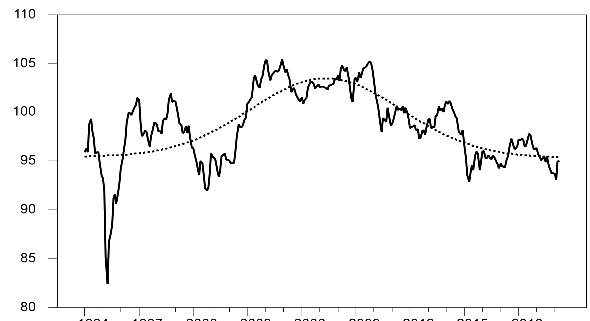

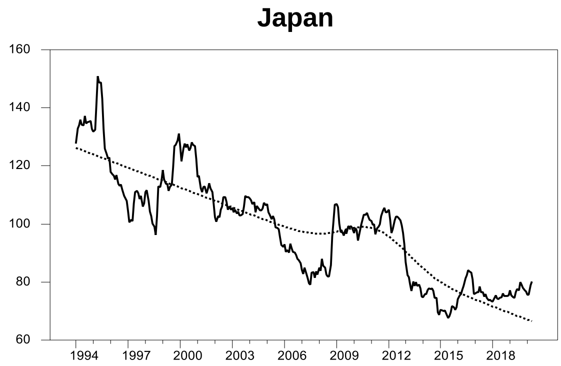
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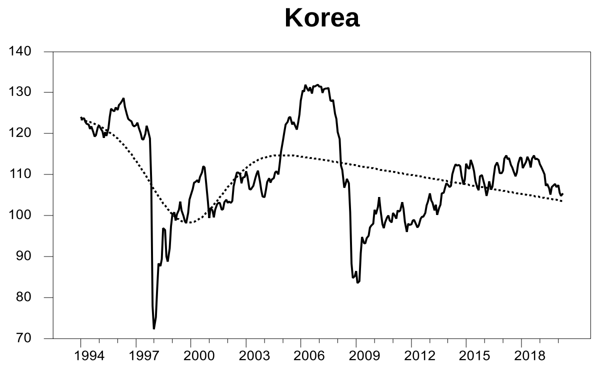
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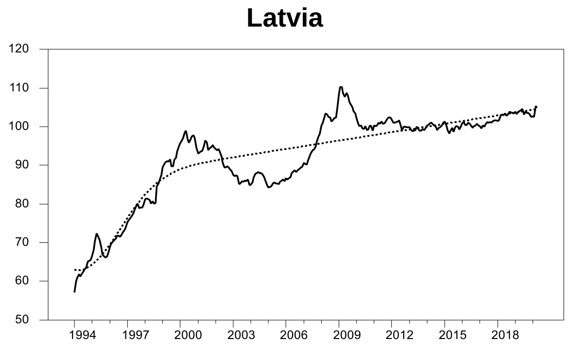
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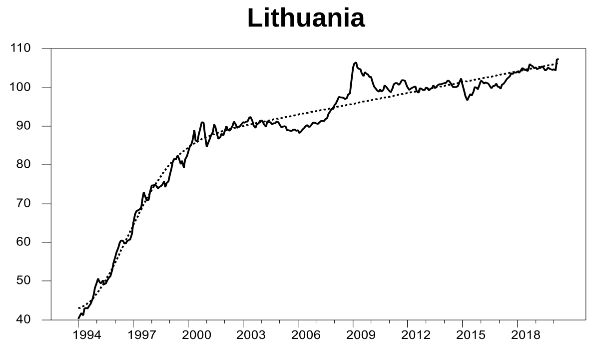
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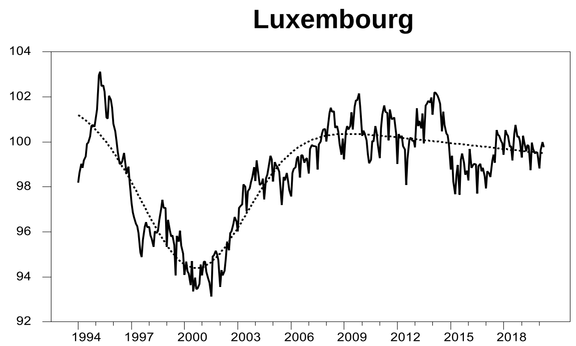
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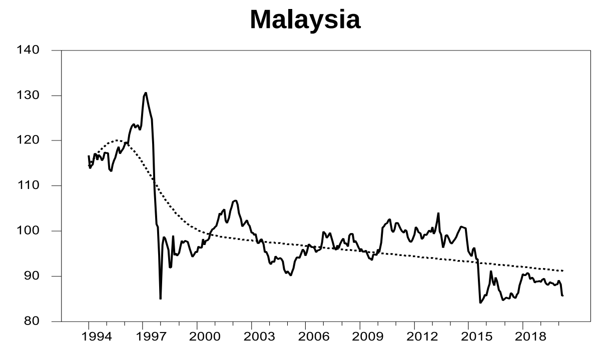
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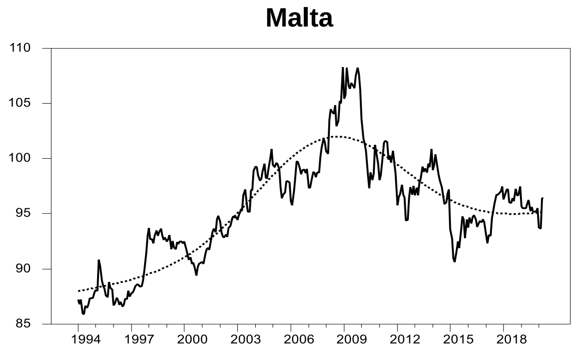
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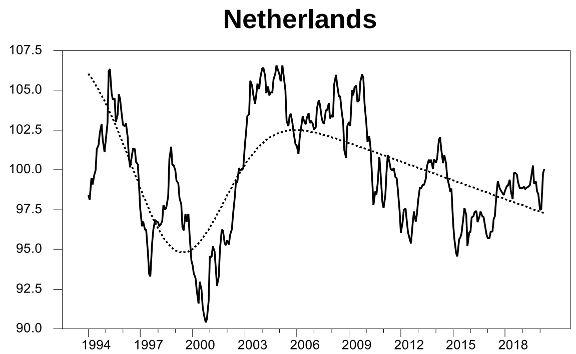
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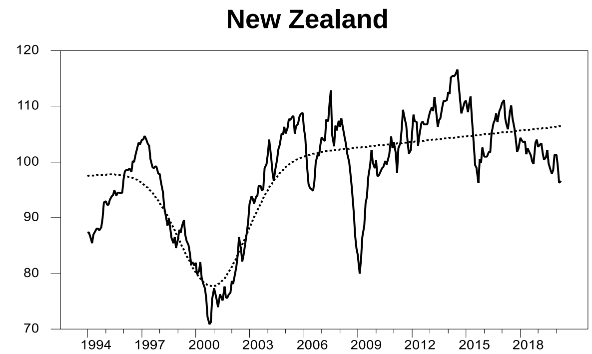
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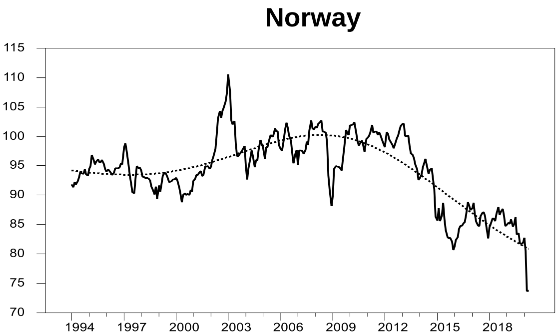
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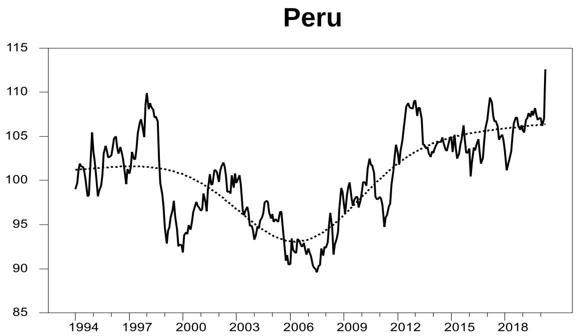
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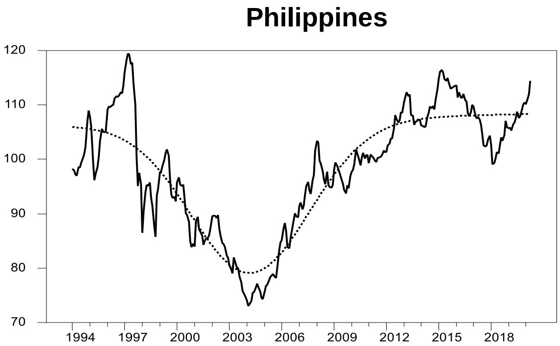
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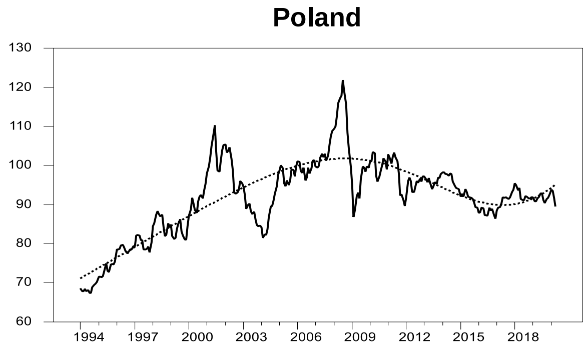
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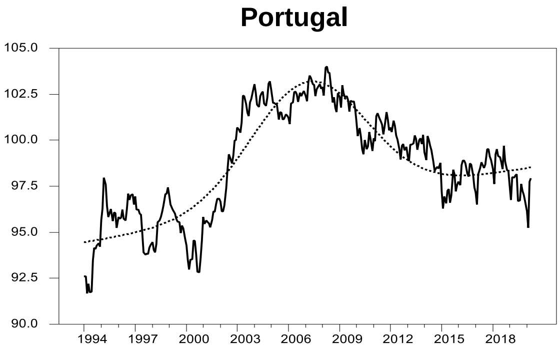
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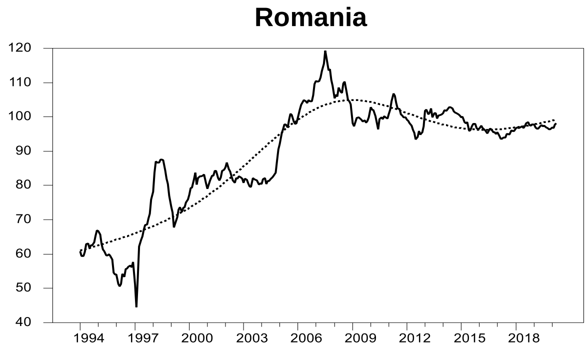
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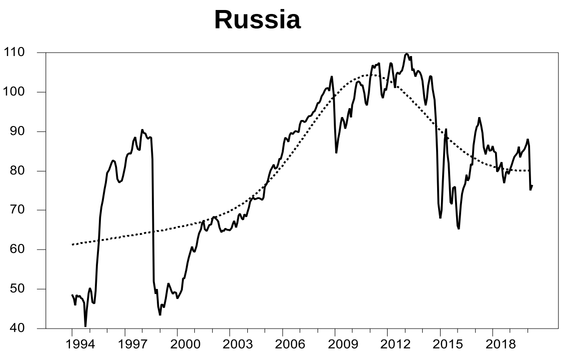
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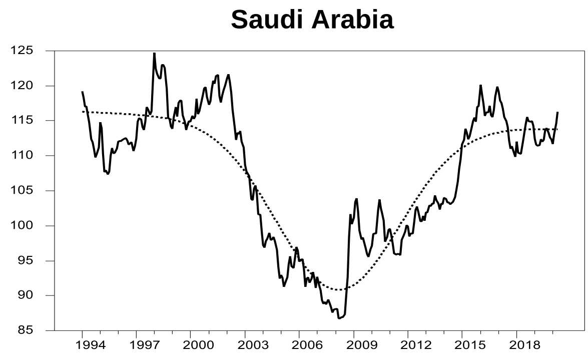
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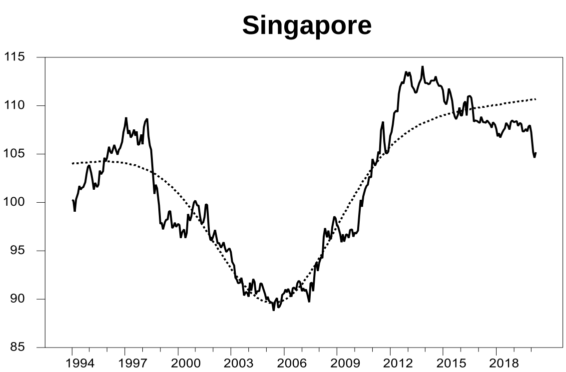
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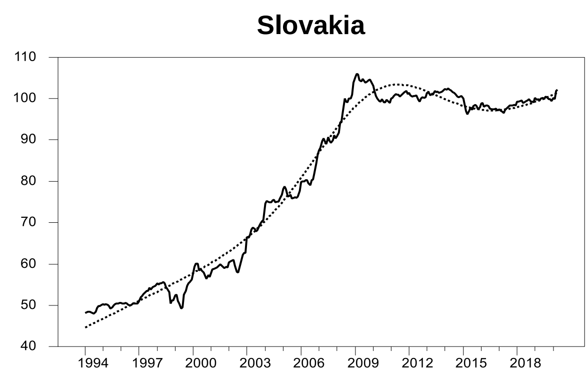
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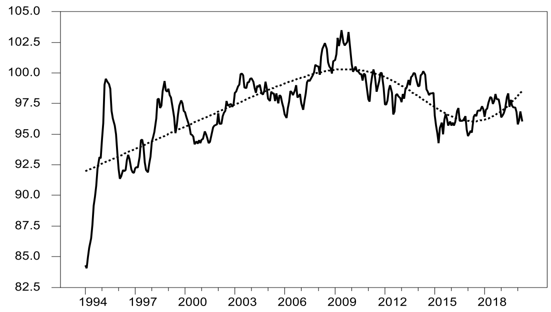

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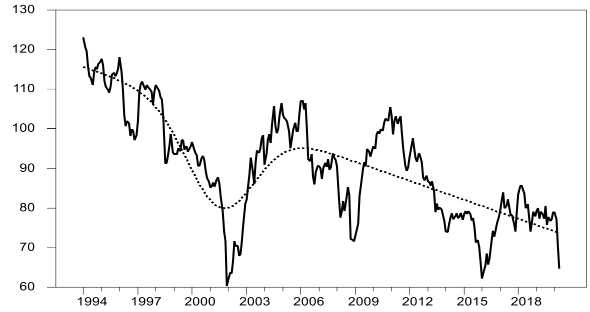

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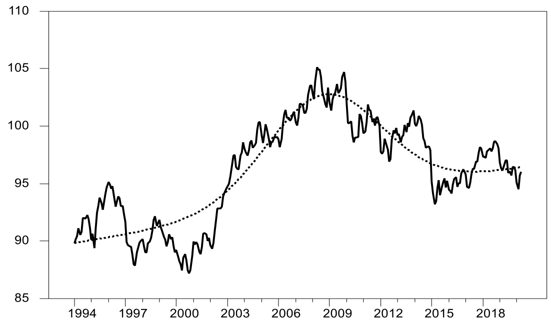

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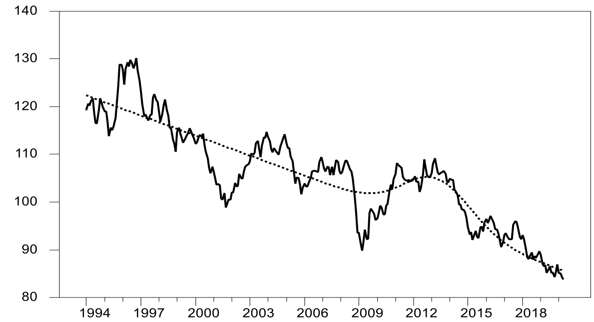

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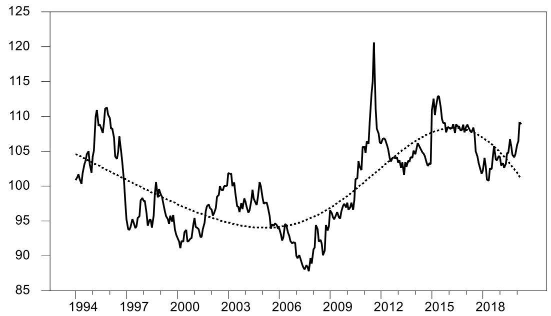

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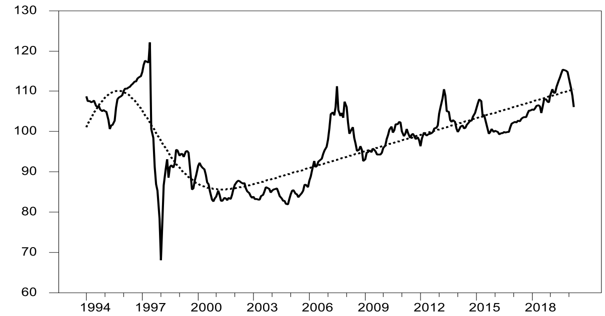

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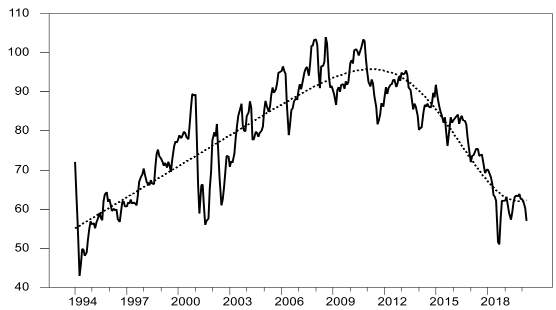

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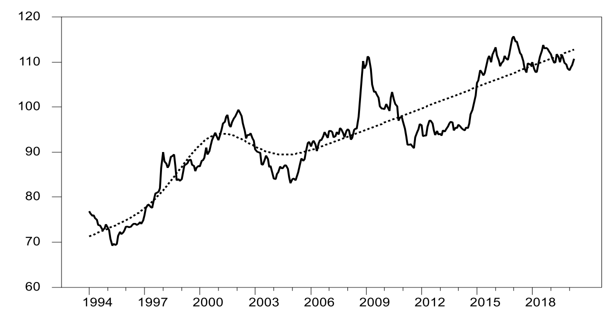

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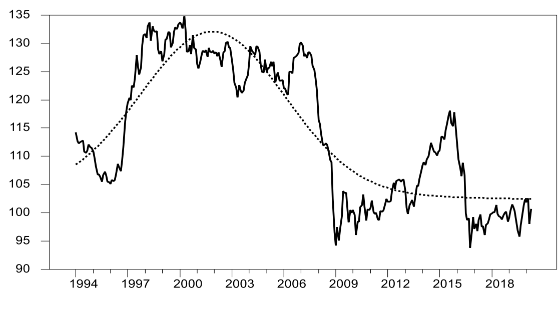

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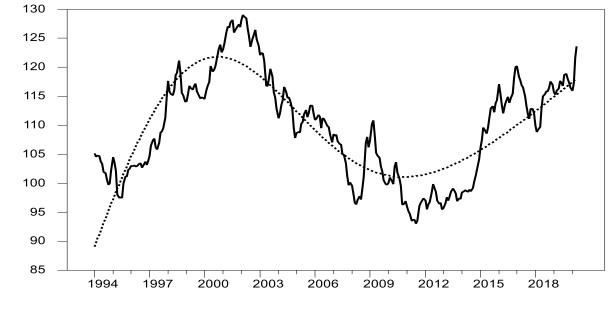

4. Discussion of the results

The unit root test results presented in the previous section have important implications regarding exchange rate dynamics. First, notice that allowing for structural breaks results in more frequent rejection of the null hypothesis of unit root, consistent with the PPP proposition. In fact, while the conventional ADF (τ_μ and τ_τ combined) test rejected the null hypothesis in the case of 13 countries, the FADF test rejected the null of unit root in the case of 16 countries whereas the Sollis' (2005) tests (e_α, $e_{\alpha(\beta)}$ and $e_{\alpha\beta}$) rejected the null hypothesis in the case of 33 countries. This finding is in line with results of Hegwood and Papell (1998) and Papell (2002) and indicates that the equilibrium exchange rates might have shifted in the face economic shocks. Indeed, the world economy has witnessed several regional and global economic and financial crises during last three decades. In addition, most of the sample countries have undergone important structural changes and economic fluctuations during the sample period. These changes have probably caused to a shift in many real economic variables, including exchange rates.

Second, our results indicate that the ESTR-type functions are more appropriate than the Fourier functions for modeling the breaks in real exchange rate series as suggested by Omay et al. (2020). Actually, as we have already mentioned, the Sollis' (2005) tests rejected the null of unit root more frequently than the FADF test. The fact that the ESTR-type functions are more appropriate for modeling the deterministic components also imply that breaks in real exchange rate series are temporary in nature. This suggests that, however important might be the effects of shocks on real exchange rates, these shocks do not alter the equilibrium rate (or path) in the long run. Thus, our findings imply that, although economic shocks may have cause to a shift in the level of real exchange rates, such changes are temporary in nature, and exchange rates will revert to pre-shock level (or path) if sufficient time is allowed.

Third, the results imply that real exchange rate dynamics might be inherently nonlinear as we find that allowing for nonlinear dynamics results in more frequent rejection of the null hypothesis. In fact notice that the test procedure of Omay et al. (2020) provided more evidence in favor of the PPP when compared to Sollis' (2005) procedure. Similarly, the $F-t_{NL}$ test rejected the null hypothesis in more cases than the FADF test. Thus, our findings support results of previous researchers who found that both asymmetric dynamics and gradual breaks govern real exchange rate series (see, for example, Sollis, 2004; Telatar and Hasanov, 2009; Omay et al. 2018).

Finally, our results provide some support for the Balassa-Samuelson effect. Notice that both test procedures of Sollis' (2005) and Omay et al. (2020) reject the null hypothesis of unit root in more cases after allowing for a trend in the series. In particular, the $e_{\alpha(\beta)}$ ($e_{\alpha\beta}$) and $t_{E\alpha(\beta)}$ ($t_{E\alpha\beta}$) rejected the null hypothesis more frequently than e_α and $t_{E\alpha}$ tests. This finding can be interpreted as an evidence of a trend in the real exchange rate series. While conventional exchange rate theories do not allow a trend in real exchange rate series, the presence of a trend can be justified by productivity differentials across countries. Thus, stationarity around a (nonlinear) deterministic trend supports the Balassa-Samuelson effect.

5. Conclusion

This study investigates long-run PPP hypothesis for 60 economies for the period 1994:01-2020:04. Unlike many previous multi-country studies, we use trade-weighted averages of 60 bilateral exchange rates adjusted by relative consumer prices. Use of reel effective exchange rate series is equivalent to testing the validity of the PPP proposition vis-à-vis major trading partners rather than against a single country. Taking account of the fact that both structural breaks and nonlinear adjustments may characterize exchange rate dynamics, we use recently developed test procedures that allow for simultaneous structural breaks and nonlinear adjustment. Specifically, we use unit root test procedures that restrict structural breaks only to temporary changes. For comparison purposes, we also applied the conventional ADF test that takes account of neither structural breaks nor nonlinearities. We find that allowing for structural breaks and nonlinearities results in more frequent rejection of the null hypothesis of unit root, consistent with the PPP proposition. Among the test procedures employed in this paper, the test proposed by Omay et al. (2020) outperforms other tests in terms of rejection of the null hypothesis. Their test procedure rejected the null hypothesis in all 60 series, thus providing evidence in favor of the PPP proposition in all economies. This result implies that their test procedure might be more appropriate in analysis of stationarity of exchange rates.

Our results have clear and nice implications. First, stationarity of the REER series imply that exchange rate management policies will affect foreign trade flows only in the short run as deviations from the equilibrium are not persistent. Second, the effects of these policies might be asymmetric as our results suggest that adjustment towards equilibrium is nonlinear. Third, we found evidence in all countries only after allowing for a structural break. This implies that major shocks have shifted equilibrium exchange rates. Therefore, previous levels of exchange rates might not be proper to evaluate present deviations from the equilibrium, if any. Finally, as equilibrium rates might shift in the future as well, exchange rate policies might have no or unexpected effects. All in all, our results imply that both policymakers and market practitioners must take account of possibility of structural changes and nonlinear dynamics in their decisions.

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