10. What is New about the PPP Theory in the Nordic Countries? Evidence from Panel Unit Root Tests with Sharp Breaks and Gradual Shifts

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Abstract

The Purchasing Power Parity (PPP) theory simply refers to a rate of exchange that eliminates price level differences between countries, equalizing the purchasing power of different currencies. The theory provides some essential tools in determining exchange rates and equilibrium conditions. This study investigates the long run validity of the PPP in five Nordic countries over the monthly data in the 1976-2019 period. We use a panel LM unit root test to detect sharp breaks as well as a novel method based on the Fourier approximation taking into account gradual shifts in the real exchange rates. Firstly, despite the past evidence, results of the panel unit root test with sharp break are mostly consistent with the PPP relationship in the group of Nordic countries. Secondly, we obtain mixed results from the Fourier panel stationarity test based on the number of frequencies, implying notable evidence for the PPP in the whole and pre-Euro periods. Taking together results of the two tests, it is possible to conclude that an empirical approach which captures the nature of structural change in price adjustments is more preferable as compared to conventional tests.

Keywords: Purchasing power parity, Nordic countries, panel LM unit root test, Fourier approximation
JEL Classification: C12, C23

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1. Introduction

The Purchasing Power Parity (PPP) theory simply refers to a rate of exchange that eliminates price level differences between countries, equalizing the purchasing power of different currencies. The theory has its modern origins in Cassel's (1918) study on the determination of official exchange rates. In absolute version, the PPP requires the equalization of exchange rate between two countries with the ratio of average price levels, based on the “law of one price”. This implies that if there is no cost for merchandise trade, the price level of an identical good in two countries will be equal as it expressed in the same currency. The relative form of PPP holds, underlining terms of trade, as so long as the percentage change in the exchange rate offset the differential between inflation rates in two economies. Accordingly, all movements in the currencies are transitory and the real exchange rates are stable in the long run (Rogoff, 1996; Sarno and Taylor, 2002). The PPP has been a highly discussed concept (Yeager, 1958; Balassa, 1964; Samuelson, 1964) in respect to the limitations to reveal a precise mechanism between exchange rates and relative price levels. One of the discussions is related to data aggregation and construction in calculating price indices. Keynes (1930) states that price indices in which traded goods are predominant constitute a weak basis for the PPP. Also, deviations in exchange rates owing to trade restrictions such as transaction costs, tariffs, and nontariff barriers, and speculation in the foreign currencies may cause a divergence from the PPP (Officer, 1976). Despite the current debate, the PPP is inherently an important tool for open economies in terms of providing a benchmark to judge the level of exchange rate against under or overvaluation and serving as a policy guidance to predict long run fluctuations and potential economic impacts (Shapiro, 1983; Dornbusch, 1985).

There is a little consensus in the literature on whether the PPP is valid in the short and long run. In the short run, it is argued that the various forms of rigidities arising from sticky goods prices, high degree of capital movements, the existence of nontraded goods and services, and differential speeds of adjustment in the commodity markets can lead to a substantial deviation in the exchange rates (Zhou, 1997). Such an event ultimately distorts the short run validity of PPP. However, empirical evidence suggests that the bilateral exchange rates tend to move together during the long time periods (Abuaf and Jorion, 1990; Frankel and Rose, 1996; Devereux, 1997; Taylor and Taylor, 2004). Along with the recent advances in econometric techniques, these arguments are largely related to the use of various unit root tests which have different power and size properties. In this context, the most common way to examine the PPP is to test the real exchange rate for stationarity and to determine the presence of mean reversion in data series. Therefore, a non-stationary real exchange rate also rejects the long run validity of the PPP (Breitung and Candelon, 2005; Bahmani-Oskooee *et al*., 2015). Another important issue for a relatively long-time span is the existence of structural breaks or shifts in equilibrium as real exchange rates depend on different exchange regimes. If structural breaks are neglected, a stationary real exchange rate does not necessarily constitute evidence of PPP (Adiguzel *et al*., 2014). Such parametric changes may result not only from sudden and sharp shocks in the trend or level, but also from a slow and gradual process, especially in low-frequency data (Hegwood and Papell, 1998; Leybourne *et al*., 1998). Earlier versions of unit root tests (Perron, 1989; Amsler and Lee, 1995; Lee and Strazicich, 2001, 2003; Im *et al*., 2005, 2010; Kim and Perron, 2009) are able to detect the sharp structural breaks by using dummy variables. In the latter case, a novel Flexible Fourier approximation can also capture the smooth transition in the unknown form of large swings in the exchange rate (Becker *et al*., 2006; Enders and Lee, 2012; He *et al*., 2014; Nazlioglu and Karul, 2017).

Nordic countries have the same characteristics in terms of demography, social and cultural structures, and economic conditions. They are among the leading open economies after the liberalization policies of the 1980s and 1990s. Despite the financial crisis that partially hit these countries in the early 1990s, the Nordic group achieved a remarkable rate of economic growth in the late 20th century. Their long run economic performance, often referred to as the "Nordic Model", is based heavily on rapid industrialization, expansion of international trade, the advancement of the market economy, and sound economic institutions (Krantz, 2006; Kaytaz *et al*., 2019). Considering the significant level of trade openness and thus susceptibility to fluctuations in Nordic economies, policies regarding price adjustments become more essential. Therefore, it may be of interest to reexamine the arguments put forward to the validity of the PPP with more sophisticated methods across Nordic countries.

In the context of PPP, many researchers conducted empirical tests to investigate the theory in datasets containing all or part of the Nordic countries. The time series studies (Bessec, 2002; Akram, 2006; Sollis, 2009; Aloy *et al*., 2011; Cuestas and Regis, 2013; Güriş *et al*., 2016) and some panel data studies (Kalyoncu and Kalyoncu, 2008; Lau, 2009; Christidou and Panagiotidis, 2010) provide mixed results for the validity of PPP in the Nordic countries. However, very little attention was paid to cross country dependencies in testing PPP in such a closely related country group. In this sense, it can be argued that the examination of PPP along with the cross-section dimension can provide a better insight into the structural relations that take place in the long run rather than time series analysis (Salto and Turrini, 2010).

The main goal of this study is to investigate whether the PPP holds in the long run in the Nordic countries. We use monthly real exchange rates for the 1976-2019 period in the panel of Denmark, Finland, Iceland, Norway and Sweden. The originality of the study is twofold. Firstly, to our knowledge, there is no study considering the structural breaks for examining the PPP in the Nordic group. We conduct a panel LM unit root test (Im *et al*., 2005, 2010) to take into account sharp breaks in a data set over a relatively long time period. Secondly, we use a novel method based on Fourier panel stationarity test (Nazlioglu and Karul, 2017) that could better capture the nature of structural changes in the form of gradual shifts as well as robust to the cross-sectional dependency.

The remainder of the paper is as follows. Section 2 introduces the dataset and econometric methodology. Empirical results and a brief discussion are presented in Section 3; and the last section concludes the paper.

2. Data and Methodology

In order to investigate the validity of the PPP relationship, we use the monthly end-of-period nominal exchange rate and consumer price index (2010=100) data to generate real exchange rate series in five Nordic countries. The dataset covers 1976:M1-2019:M10 period which yields 526 observations. All the data are obtained from the IMF (2020) "International Financial Statistics" database. Since the accession of Finland to the Economic and Monetary Union of the EU as of January 1, 1999, the dataset is also examined with two subperiods including "pre-Euro" and "post-Euro" periods. Therefore, we test a total of 3 models: Model (A) (1976:M1-2019:M10), Model (B) (1976:M1-1998:M12), and Model (C) (1999:M1-2019:M10).

Im *et al.* (2005, 2010) suggest two types of unit root tests based on the Lagrange Multiplier (LM) statistics that allows for a sudden break in both level and trend. As stated by Amsler and Lee (1995), the most important advantage of the LM-type tests is that while dealing with structural breaks, adding dummy variables to the unit root regression model does not affect the asymptotic distribution of the test. Also, the asymptotic distribution of the LM test does not depend on the size and location of the breaks. Another feature of the test is that it allows heterogeneous breaks in both the level and trend of the series under the both null and alternative hypothesis[4].

$$y_t = \phi' Z_t + \varepsilon_t$$
$$\varepsilon_t = \theta \varepsilon_{t-1} + e_t \tag{1}$$

In equation (1), $\theta = 1$ is the null hypothesis and Z_t stands for the deterministic term. The Z_t can be respectively defined to demonstrate the breaks in the level, trend and, both level and trend by following equations, where TB represents the break date (Im *et al*., 2005, 2010).

$$Z_t = [1, t, DU_t]' \; ; \; DU_t = \begin{cases} 1, t \geq TB + 1) \\ 0, otherwise) \end{cases} \tag{2}$$

$$Z_t = [1, t, DT_t^*]' \; ; \; DT_t^* = \begin{cases} t - TB, t \geq TB + 1) \\ 0, otherwise) \end{cases} \tag{3}$$

$$Z_t = [1, t, DU_{1t}, \ldots DU_{Mt}, DT_{1t}^*, \ldots DT_{Mt}^*] \; ;$$
$$DU_t = \begin{cases} 1, t \geq TB_{j+1}) \\ 0, otherwise) \end{cases} \; ; \; DT_t^* = \begin{cases} t - TB, t \geq TB_{j+1}) \\ 0, otherwise \;) \end{cases} \; ; \; j = 1 \ldots M \tag{4}$$

Im *et al*. (2010) correct the cross-sectional dependency as suggested by Pesaran (2007). In addition, the dependence of the asymptotic distribution of the test on unnecessary parameters is removed by performing the transformation in equation (5).

$$\tilde{y}_t^* = \left| \begin{array}{l} \dfrac{T}{TB_1} \tilde{y}_t, t \leq TB_1 \\ \dfrac{T}{TB_2 - TB_1} \tilde{y}_t, TB_1 < t \leq TB_2 \\ \vdots \\ \dfrac{T}{T - TB_M} \tilde{y}_t, TB_M < t \leq T \end{array} \right. \tag{5}$$

The following regression model is estimated for each cross-section unit of the panel unit root test based on LM test statistics.

$$\Delta y_t = \phi' \Delta Z_t + \varphi \tilde{y}_{t-1}^* + \sum_{j=1}^{k} d_j \Delta \tilde{y}_{t-1} + \varepsilon_t \tag{6}$$

[4] See Im, et al. (2005, 2010) for details.

In order to test the null hypothesis of $H_0 : \varphi = 0$ for each cross-section unit, the Panel LM test is used as the standardized form of the following average test statistic.

$$\bar{t} = \frac{1}{N}\sum_{i=1}^{N}\tilde{\tau} \tag{7}$$

The standard normal distribution of the panel LM test is given as,

$$LM(\tilde{\tau}^*) = \frac{\sqrt{N}\left[\tilde{t} - \tilde{E}(\bar{t})\right]}{\sqrt{\tilde{V}(\bar{t})}} \tag{8}$$

where: $\tilde{E}(\bar{t})$ and $\tilde{V}(\bar{t})$ are the mean expected value and variance of $\bar{t}$, respectively. Calculation of $\tilde{E}(\bar{t})$ and $\tilde{V}(\bar{t})$ is as follows:

$$\tilde{E}(\bar{t}) = \frac{1}{N}\sum_{i=1}^{N} E\left(\bar{t}\left(\tilde{M}_i, \tilde{\rho}_i\right)\right) \quad \text{and} \quad \tilde{V}(\bar{t}) = \frac{1}{N}\sum_{i=1}^{N} Var\left(\bar{t}\left(\tilde{M}_i, \tilde{\rho}_i\right)\right) \tag{9}$$

In equation (9), $\left(\tilde{M}_i, \tilde{\rho}_i\right)$ is derived from the lag and break parameters in each cross-sectional regression. Thus, the method allows different numbers of lags and breaks for cross-section units (Im *et al*., 2010).

As in this case, the earlier versions of the unit root tests are able to detect the structural breaks through dummy variables, considering only the sudden changes rather than smooth shifts in the series. Such an approach is often incapable of catching the natural form of breaks when the large swings in the series occur in an unknown form. Based on Gallant (1981), Becker *et al*. (2006) demonstrate that the behavior of an unknown function can be captured by a Flexible Fourier transformation. Following the study of Becker *et al.* (2006), Nazlioglu and Karul (2017) propose a Fourier panel stationarity test that takes into account gradual shifts as well as cross-sectional dependency and heterogeneity across cross-sections in the panel. The data generating process of the test is as follows:

$$\begin{aligned} y_{it} &= \alpha_i(t) + S_{it} + \gamma_i F_i + e_{it} \\ S_{it} &= S_{it-1} + \varepsilon_{it} \end{aligned} \tag{10}$$

In equation (10), S_{it} refers to the random walk process with an initial value of zero for each cross-section, and F_i denotes to the unobservable common factor. γ_i represents the loading weights of each cross-section, while $\alpha_i(t)$ is the deterministic term as a function of time (Nazlioglu and Karul, 2017). As pointed out by Becker *et al.* (2006), the Fourier approximation can mimic the structural changes regardless of specifying break dates, the number of breaks, and the form of the breaks. The Fourier transformations, which shows both level and level and trend changes in the deterministic term, respectively, are described as,

$$\alpha_i(t) = c_i + \lambda_{1i}\sin\left(\frac{2\pi kt}{T}\right) + \lambda_{2i}\cos\left(\frac{2\pi kt}{T}\right) \tag{11}$$

$$\alpha_i(t) = c_i + \beta_i t + \lambda_{1i} \sin\left(\frac{2\pi kt}{T}\right) + \lambda_{2i} \cos\left(\frac{2\pi kt}{T}\right) \tag{12}$$

where: λ_{1i} and λ_{2i} are the amplitude and displacement of shifts, respectively, and k is the Fourier frequency. The individual Fourier KPSS test, based on Becker *et al*. (2006), where the null hypothesis of stationarity against the alternative hypothesis of unit root is defined as,

$$\eta_i(k) = \frac{1}{T^2} \frac{\sum_{t=1}^{T} \tilde{R}_{it}(k)^2}{\tilde{\omega}_{ei}^2} \tag{13}$$

where: $\tilde{R}_{it}(k) = \sum_{j=1}^{t} \tilde{e}_{ij}$ is partial sum of residuals and $\omega_{ei}^2 = \lim_{T\to\infty} T^{-1} E(R_{it}^2)$ is the estimated long run variance of error term. Thus, the Fourier panel statistic is obtained by the avarage of individual statistics (Nazlioglu and Karul, 2017).

$$FP(k) = \frac{1}{N} \sum_{i=1}^{N} \eta_i(k) \tag{14}$$

Nazlıoğlu and Karul (2017) argue that while the asymptotic distribution of $\eta_i(k)$ as $T \to \infty$, it depends on k and is invariant to other parameters during the data generating process. The panel stationarity test (FZ_k) can be defined as

$$FZ(k) = \frac{\sqrt{N}(FP(k) - \xi(k)}{\xi(k)} \approx N(0,1) \tag{15}$$

where: $\xi(k)$ and $\xi^2(k)$ are the average of the mean and variance, respectively, of the individual $\eta_i(k)$ statistics. The test has a standard normal distribution when first $T \to \infty$ and then $N \to \infty$. The test statistic performs good size and power even in small samples when the error terms are i.i.d. However, if the error terms are serially correlated, the test has reasonable power and size properties (Nazlioglu and Karul, 2017).

3. Empirical Results and Discussion

In the context of robustness of panel unit root tests, a failure to meet any assumptions may cause a considerable distortion in the size and power of these tests. Based on the fact that the panel LM unit root test (Im *et al*., 2005, 2010) assumes the independence of individual cross-sections, we firstly employ some preliminary tests. In table 1, Breusch and Pagan (1980) LM test (***CD_{LM1}***) examines the cross-section dependency with a chi-square distribution under the normality assumption. In case of large number of N and T, Pesaran (2004) asserts a scaled LM test (***CD_{LM2}***) to diagnose cross-section dependence in a standardized form. Also, Pesaran (2004) suggests an alternative test (***CD***) which has the correct size in very small samples and satisfactory power. Lastly, Table 1 reports an alternative bias-adjusted LM test (***CD_{adj}***) by Pesaran, Ullah, and Yamagata (2008), which ensures satisfactory power in panels with exogenous regressors and normal errors.

According to all test results, the null hypothesis of no cross-section dependency is strongly rejected at 1% significance level for both constant and constant and trend models.

In order to conduct both types of unit root tests, we use the estimation procedure suggested by Nazlioglu (2018) in Gauss software. The results of the panel LM unit root test with sharp breaks are given in Table 2. In model (A), the stationarity at level shift is detected only for Iceland in one break (1981:M12), while the series of Finland (1998:M10, 1999:M5) and Iceland (1983:M4, 1989:M3) are stationary in two breaks. The trend shift stationarity in a single break is valid for Denmark (2009:M4), Iceland (1982:M1) and Norway (2007:M8). However, the null hypothesis of unit root is rejected in all series with trend shift in two breaks. Thus, in model (A), we reach significant evidence that PPP is valid in the long run as a whole data period.

According to test results of Model (B) which involves the pre-Euro period, the PPP does not hold for any country in a single break in the level shift, whereas the results show that the real exchange rates are stationary series in all countries except for Sweden for two breaks in the level. The null of unit root hypothesis cannot be rejected at the 10% level except for Iceland (1978:M9) in a single break for the model with trend, implying invalidation of the PPP relationship. On the other hand, we infer from the Model (B) with two breaks in the trend shift that the real exchange rates are stationary is still reinforced in the pre-Euro period.

Regarding the last model associated with the post-Euro period in Table 2, findings of Model (C) show that the only stationary series belongs to Norway (2011: M4) in a single break in the level shift. Despite this result, it is observed that the PPP relationship maintains in all countries for two breaks in the level shift. In particular, Denmark and Finland are identical to the dates of break (2002:M11, 2008:M11), while Norway (2002:M9, 2012:M3) and Sweden (2002:M12, 2012:M3) follow a similar path in terms of structural shifts. We obtain same results in all exchange rate series with one and two breaks in the trend shift. Therefore, both panel statistics provide clear evidence for the PPP relationship in the post-Euro period. As a result of all empirical findings in Table2, it may be also argued that the panel LM unit root test which takes into account multiple sharp breaks gives more support to the validity of PPP in the Nordic countries.

The results from the Fourier panel stationarity test with gradual shifts are reported in Table 3. Considering the long-time period in the dataset, we use up to three Fourier frequencies (k) because of the possible cycles and large swings in the real exchange rates. According to model (A) with constant term, we cannot reject the null hypothesis of stationarity only for Denmark in all frequencies, indicating the presence of the PPP relationship. However, it is obvious from the model (A) with constant and trend that all the real exchange rate series except for Iceland are stationary for k=2. Thus, it can be concluded that the PPP is likely to be valid for the whole period in the panel.

Table 1

Cross-section Dependency Test Results

Models	(A)				(B)				(C)			
Tests	Constant		Constant and Trend		Constant		Constant and Trend		Constant		Constant and Trend	
	Statistic	p-value	Statistic	p-value	Statistic	p-value	Statistic	p-value	Statistic	p-value	Statistic	p-value
CD_{LM1}	1238.727	0.000	1244.198	0.000	286.969	0.000	294.531	0.000	570.376	0.000	569.805	0.000
CD_{LM2}	274.752	0.000	275.975	0.000	61.932	0.000	63.623	0.000	125.304	0.000	125.176	0.000
CD	-8.482	0.000	-8.472	0.000	-5.342	0.000	-5.487	0.000	-7.592	0.000	-7.480	0.000
CD_{adj}	106.874	0.000	106.672	0.000	24.264	0.000	24.123	0.000	59.424	0.000	59.319	0.000

Table 2

Results of Sharp Break Unit Root Test

Models	(A)								(B)								(C)							
	Level Shift				Trend Shift				Level Shift				Trend Shift				Level Shift				Trend Shift			
Country	One Break	Break Date (Y:M)	Two Breaks	Break Date (Y:M)	One Break	Break Date (Y:M)	Two Breaks	Break Date (Y:M)	One Break	Break Date (Y:M)	Two Breaks	Break Date (Y:M)	One Break	Break Date (Y:M)	Two Breaks	Break Date (Y:M)	One Break	Break Date (Y:M)	Two Breaks	Break Date (Y:M)	One Break	Break Date (Y:M)	Two Breaks	Break Date (Y:M)
Denmark	-3.269	09:2	-3.640	82:4-86:6	-3.465 (***)	09:4	-5.968 (*)	08:8-09:5	-2.805	86:4	-4.384 (**)	81:11-86:10	-2.899	93:8	-5.175 (*)	78:8-78:11	-2.996	07:11	-4.890 (*)	02:11-08:11	-2.837	11:4	-6.028 (*)	08:8-09:5

Models		Finland	Iceland	Norway	Sweden	Panel LM
(A)	Level Shift	-2.848	-3.527 (***)	-3.086	-2.835	-4.431 (*)
		98:12	81:12	06:10	86:5	
		-5.956 (*)	-4.266 (**)	-3.449	-3.234	-8.263 (*)
		98:10-99:5	83:4-89:3	98:10-11:4	82:4-86:9	
	Trend Shift	-2.832	-4.084 (**)	-3.425 (***)	-3.405	-3.150 (*)
		98:12	82:1	07:8	07:3	
		-44.903 (*)	-7.816 (*)	-5.387 (*)	-5.529 (*)	-42.989 (*)
		98:11-99:8	08:8-09:1	10:3-10:10	08:8-11:1	
(B)	Level Shift	-2.646	-2.366	-2.751	-2.670	-2.724 (*)
		86:5	86:10	86:5	86:10	
		-4.238 (***)	-4.168 (***)	-3.977 (***)	-3.898	-8.460 (*)
		83:8-88:2	83:4-88:10	84:7-87:5	82:9-91:2	
	Trend Shift	-2.873	-3.577 (***)	-2.801	-2.891	-1.462 (***)
		92:5	78:9	91:6	91:5	
		-5.046 (*)	-6.541 (*)	-5.410 (*)	-5.116 (*)	-9.081 (*)
		92:4-92:9	82:6-83:8	85:12-86:5	92:5-92:12	
(C)	Level Shift	-3.126	-3.206	-3.636 (***)	3.066	-4.895 (*)
		07:11	03:11	11:4	11:4	
		-4.801 (*)	-4.64 (**)	-4.575 (**)	-4.771 (**)	-10.825 (*)
		02:11-08:11	03:8-09:5	02:9-12:3	02:12-12:3	
	Trend Shift	-2.889	-3.197	-3.534 (***)	-3.313	-2.061 (**)
		11:4	03:10	11:4	12:1	
		-5.670 (*)	-7.675 (*)	-5.175 (*)	-5.185 (*)	-10.808 (*)
		08:8-09:5	08:8-09:1	08:6-11:2	08:8-09:3	

Note: (***), (**) and (*) reject the null hypothesis of unit root at %1, %5 and %10, respectively.
T=200 the critical value of one break; -4.261 for %1, -3.716 for %5, -3.443 for %10 and the critical value of two break, -4.799 for %1, -4.261 for %5, -3.997 for % 10.
T=500 the critical value of one break; -4.261 for %1, 3.675 for %5, 3.410 for %10 and the critical value of two break, -4.698 for %1, -4.191 for %5, -3.934 for % 10.

Table 3

Results of Smooth Break Unit Root Test

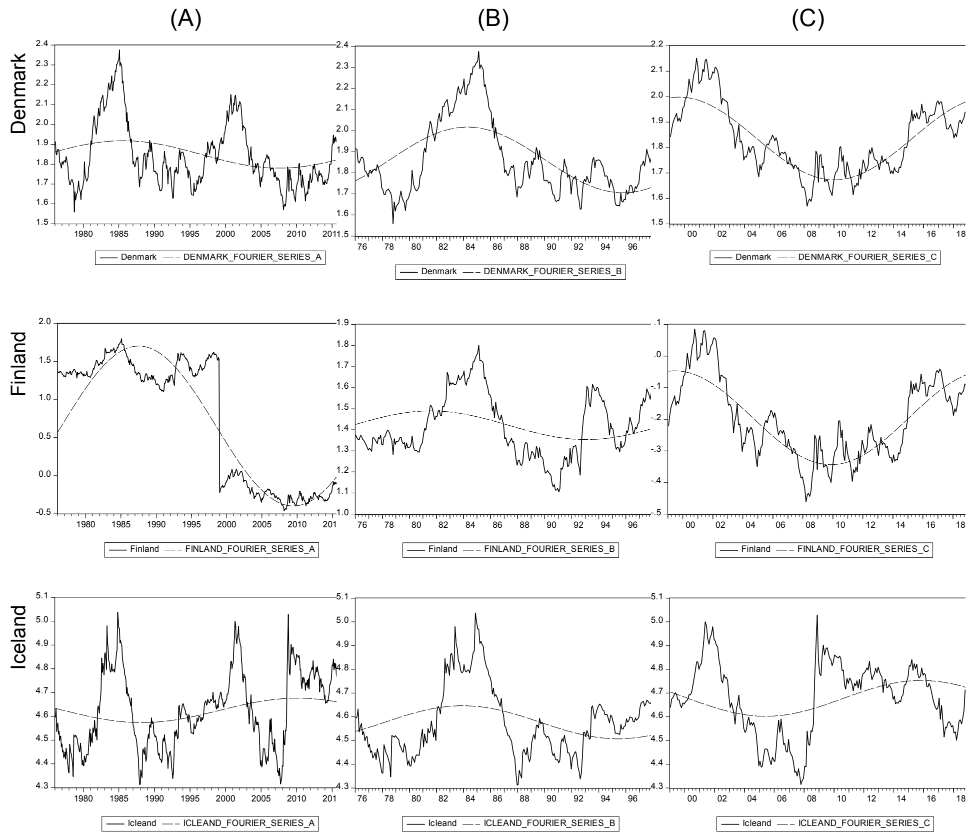
Models	(A)						(B)						(C)					
Country	Constant			Constant and Trend			Constant			Constant and Trend			Constant			Constant and Trend		
	k=1	k=2	k=3	k=1	k=2	k=3	k=1	k=2	k=3	k=1	k=2	k=3	k=1	k=2	k=3	k=1	k=2	k=3
Denmark	**0.118**	**0.950**	**0.281**	0.092	**0.090**	0.176	**0.192**	0.516	1.163	**0.043**	0.184	0.328	0.151	0.928	0.883	0.049	**0.104**	0.127
Finland	0.470	1.476	0.927	0.091	**0.101**	0.212	**0.054**	**0.245**	0.367	0.048	0.241	0.320	0.052	0.676	0.562	0.047	**0.077**	**0.109**
Iceland	0.203	1.013	0.639	0.074	0.106	0.120	**0.027**	**0.044**	**0.143**	**0.027**	**0.041**	**0.057**	0.303	0.587	**0.197**	0.066	0.143	0.184
Norway	0.391	1.351	0.847	0.091	**0.086**	0.192	**0.036**	**0.043**	**0.068**	**0.035**	**0.034**	**0.043**	0.220	0.345	**0.174**	0.071	0.161	0.167
Sweden	0.654	1.589	1.127	0.102	**0.083**	0.209	0.204	0.729	0.996	0.049	0.144	0.136	0.587	0.546	0.620	0.069	0.129	0.188
FZ(k) Test	12.523	19.129	9.587	10.389	2.359	6.613	1.525	2.942	6.171	1.872	4.419	6.336	8.162	8.017	5.226	5.334	4.077	5.157

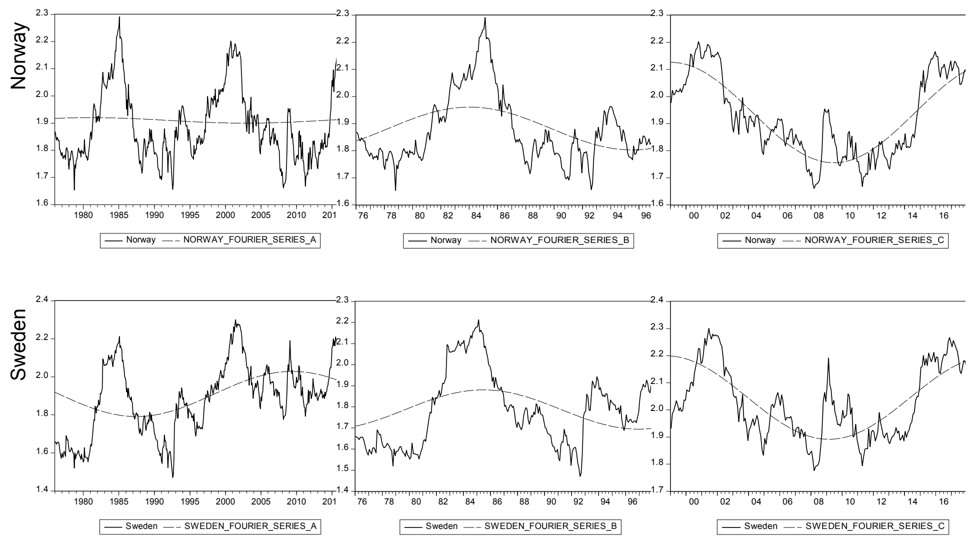
Note: long run variance is estimated with Barlett with Kurozumi rule.
Bold numbers indicate that the null hypothesis of stationarity cannot be rejected at least at the 10% significance level.
The p-values are estimated for a one-sided test based on the normal distribution. The critical values for individual statistics in constant model are 0.1318 (10%), 0.1720 (5%), 0.2699 (1%) for k=1; 0.3150 (10%), 0.4152 (5%), 0.6671 (1%) for k=2; 0.3393 (10%), 0.4480 (5%), 0.7182 (1%) for k=3.
The critical values for individual statistics in constant and trend model are 0.0471 (10%), 0.0546 (5%), 0.0716 (1%) for k=1; 0.1034 (10%), 0.1321 (5%), 0.2022 (1%) for k=2; 0.1141 (10%), 0.1423 (5%), 0.2103 (1%) for k=3. (See Becker et al. (2006, p.389)).

Based on the Model (B) with constant term (pre-Euro period) in Table 3, we find that all the countries except for Sweden have stationary real exchange rate series when the Fourier frequency is equal to one. It is also noticed that the PPP relationship exists in Finland, Iceland, and Norway, when the number of frequencies is two, while the same is valid in Iceland and Norway for k=3. In the model with constant and trend, the PPP still holds for Iceland and Norway in all frequencies. Lastly, the validity of PPP in Denmark is only true if k=1.

Figure 1

Fourier Series with Constant (k=1)



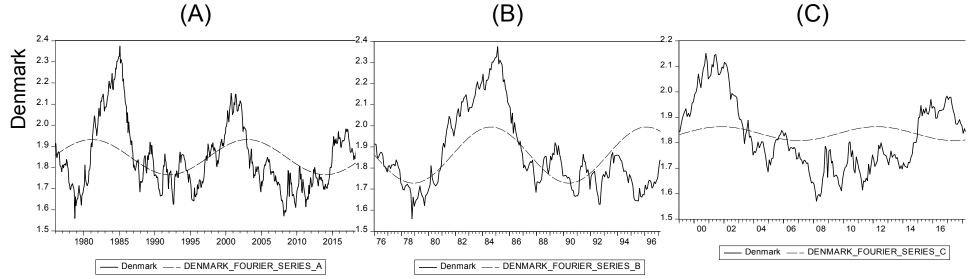


Finally, the Fourier panel stationarity test of Model (C) with constant shows that Iceland and Norway have stationary series, in case k=3. On the other hand, we reach similar results from the model with trend for Denmark (k=2) and Finland (k=2, k=3) in the post-Euro period. Taken together all three models in Table 3, it is possible to conclude that there is notable evidence for the PPP relationship in the Nordic countries particularly in the whole and pre-Euro periods, when taking into account the gradual shifts in the real exchange rates.

Figure 2

Fourier Series with Constant (k=2)

(A) (B) (C)



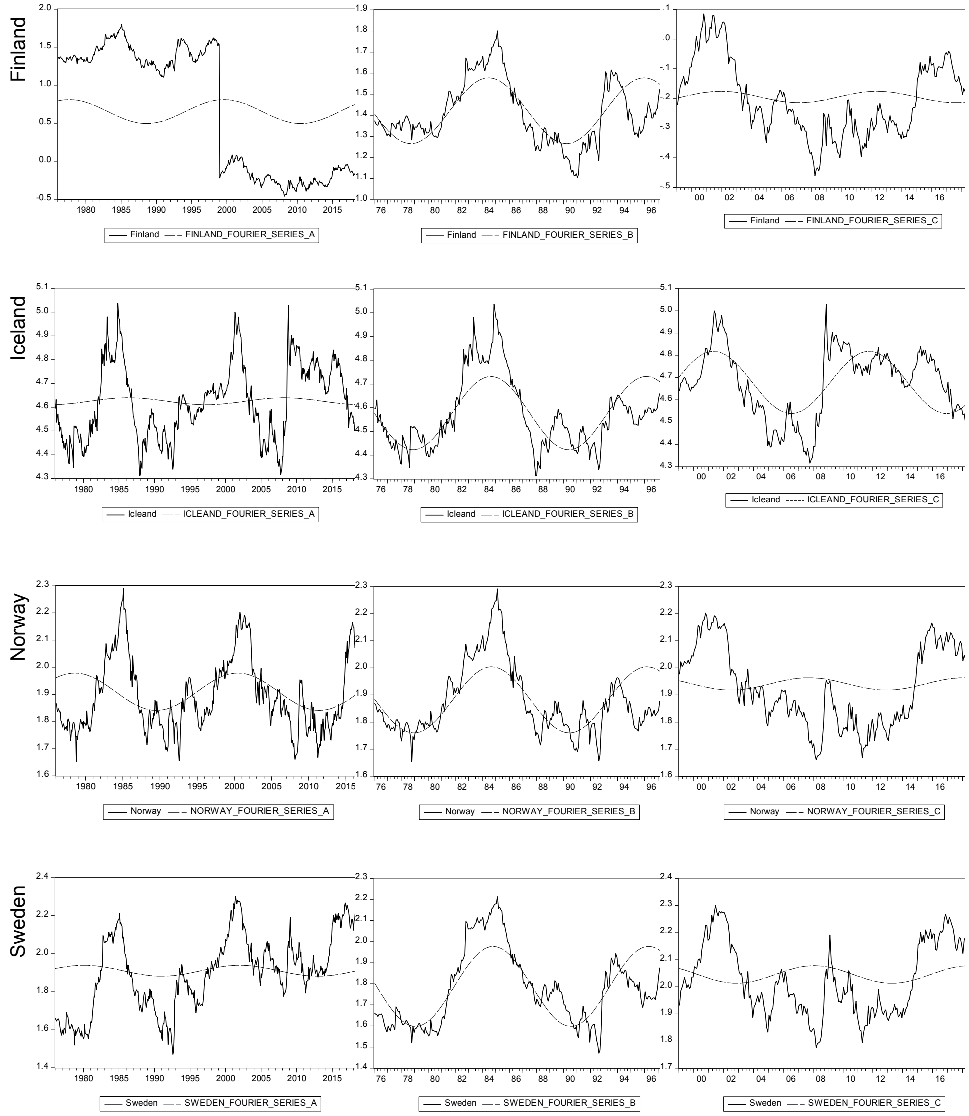
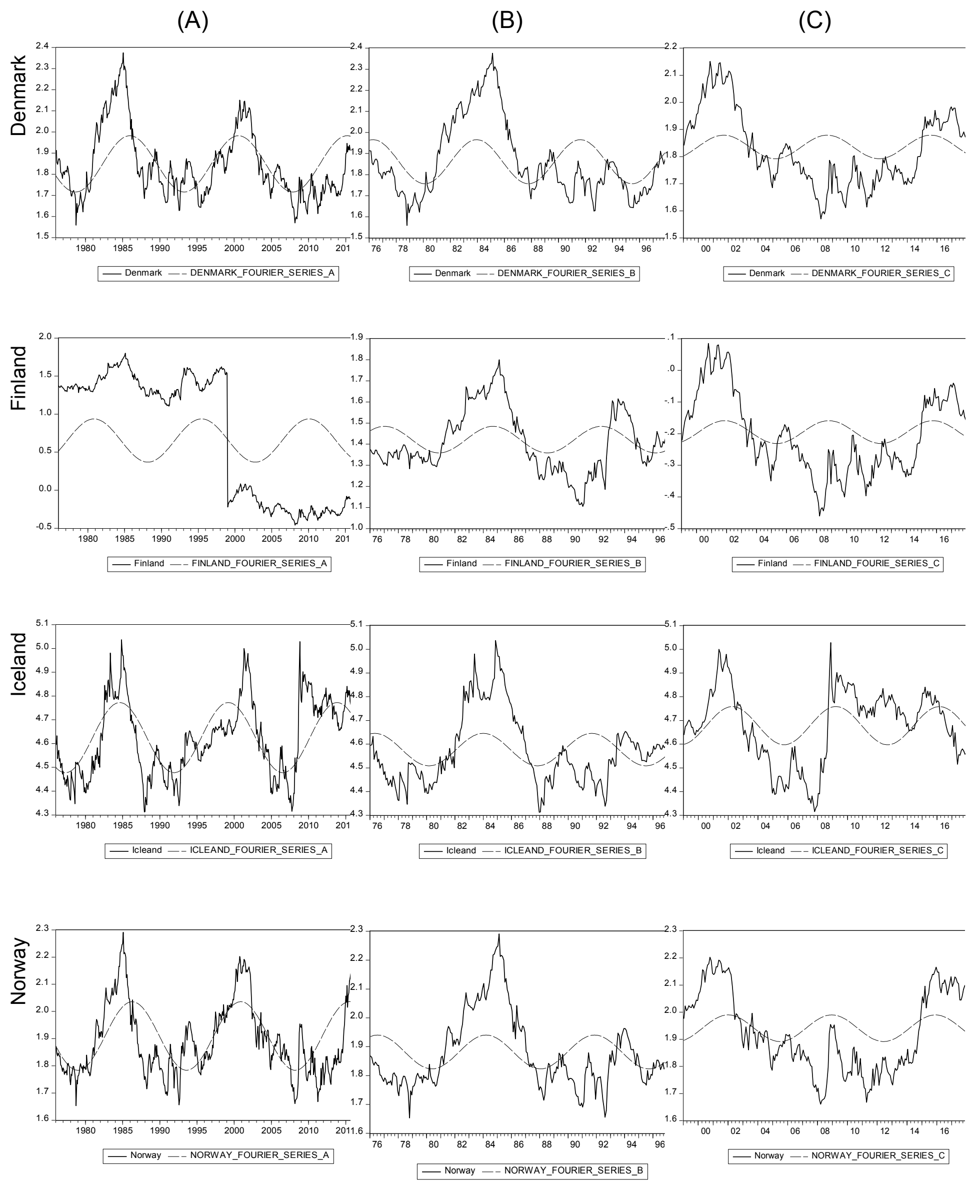

Finland
Finland — FINLAND_FOURIER_SERIES_A
Finland — FINLAND_FOURIER_SERIES_B
Finland — FINLAND_FOURIER_SERIES_C
Iceland
Icleand — ICLEAND_FOURIER_SERIES_A
Icleand — ICLEAND_FOURIER_SERIES_B
Icleand — ICLEAND_FOURIER_SERIES_C
Norway
Norway — NORWAY_FOURIER_SERIES_A
Norway — NORWAY_FOURIER_SERIES_B
Norway — NORWAY_FOURIER_SERIES_C
Sweden
Sweden — SWEDEN_FOURIER_SERIES_A
Sweden — SWEDEN_FOURIER_SERIES_B
Sweden — SWEDEN_FOURIER_SERIES_C

Figure 3

Fourier Series with Constant (k=3)



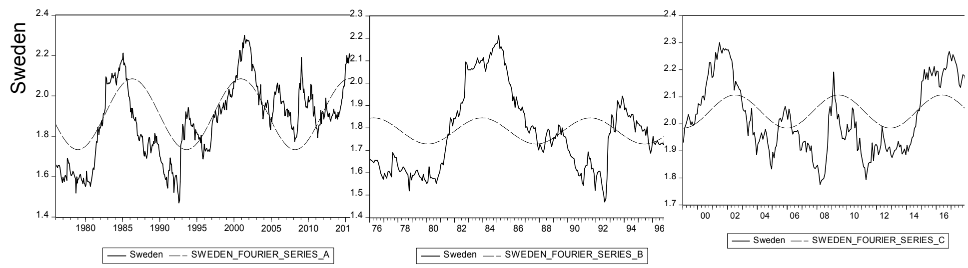
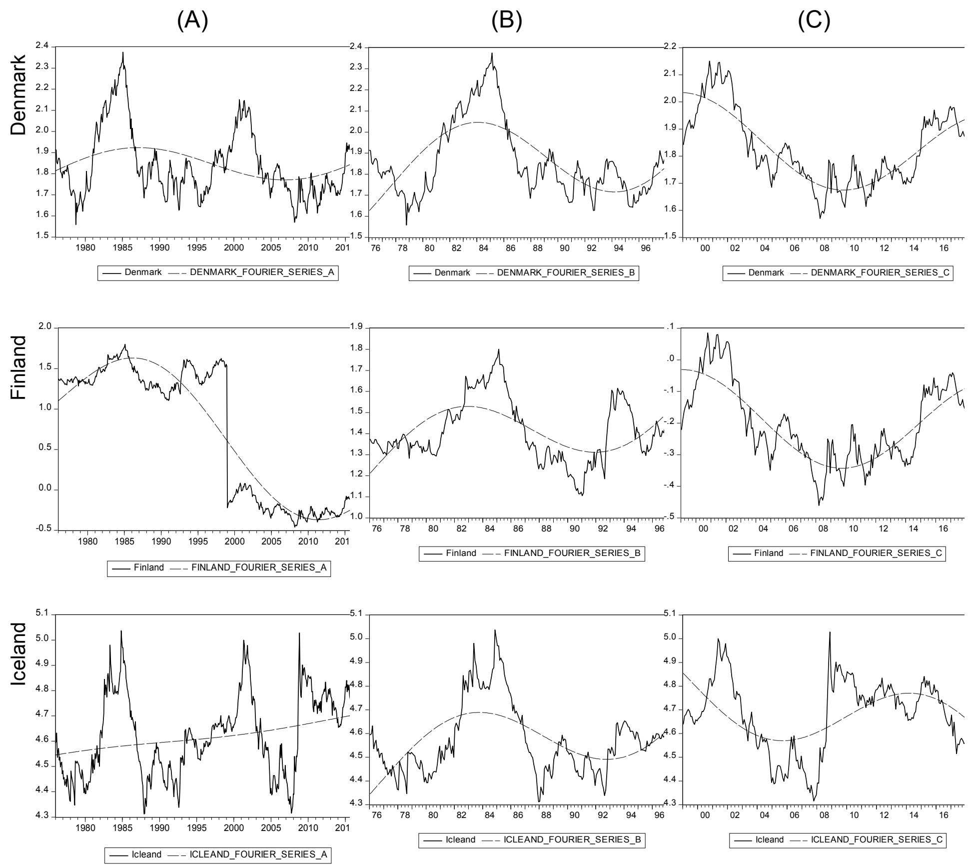
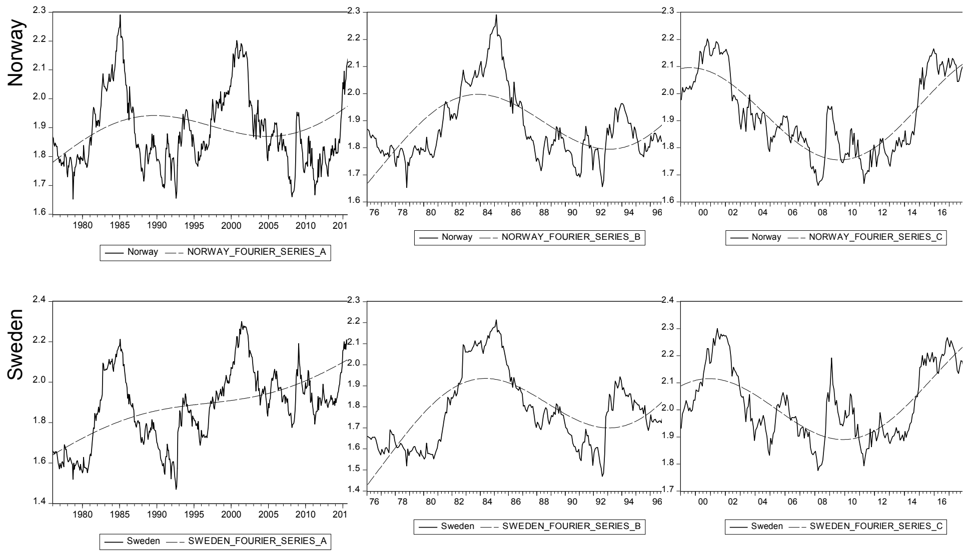


Figure 4. Fourier Series with Constant and Trend (k=1)

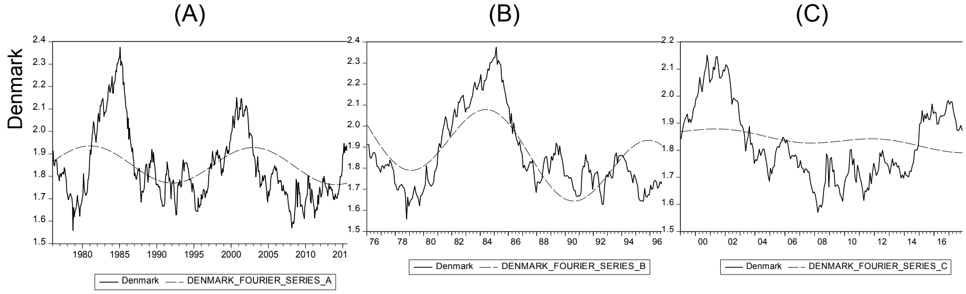


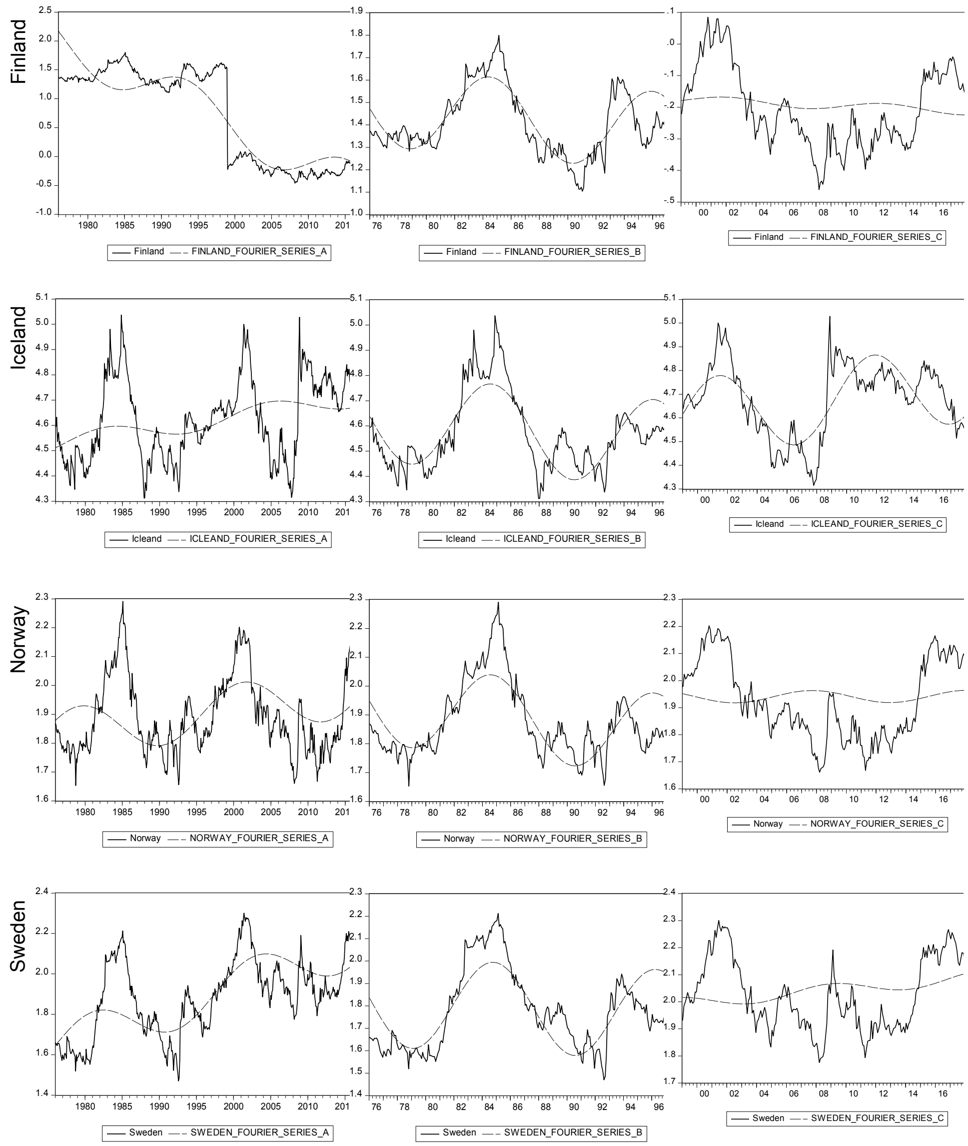


The break dates obtained from the analysis can be evaluated in three main periods: (i) the second half of the 1980s, (ii) the first half of the 1990s and (iii) the second half of the 2000s. In the first period, despite the rapid economic growth experienced in Sweden and especially in Finland, the overheated economy caused a recession in the early 1990s. In this period, the great decline in oil prices in Norway resulted in a slowdown in the economy, and its effects continued until the early 1990s. In addition, liberalization policies in the 1980s caused major financial crises in the economies of three countries (Finland, Sweden and Norway). Denmark has better coped with the effects of the crisis, while the external deficit has reached a significant level in Finland and Sweden. In the second period, Finland, Sweden and Norway adopted the floating exchange rate regime due to the speculative attacks during the crisis. Lastly, the subprime mortgage crisis, which emerged in the USA in the second half of the 2000s and had a global impact, caused a serious contraction in the Nordic countries as well as in other market economies (Honkapohia, 2009, 2012).

Figure 5. Fourier Series with Constant and Trend (k=2)

(A) (B) (C)

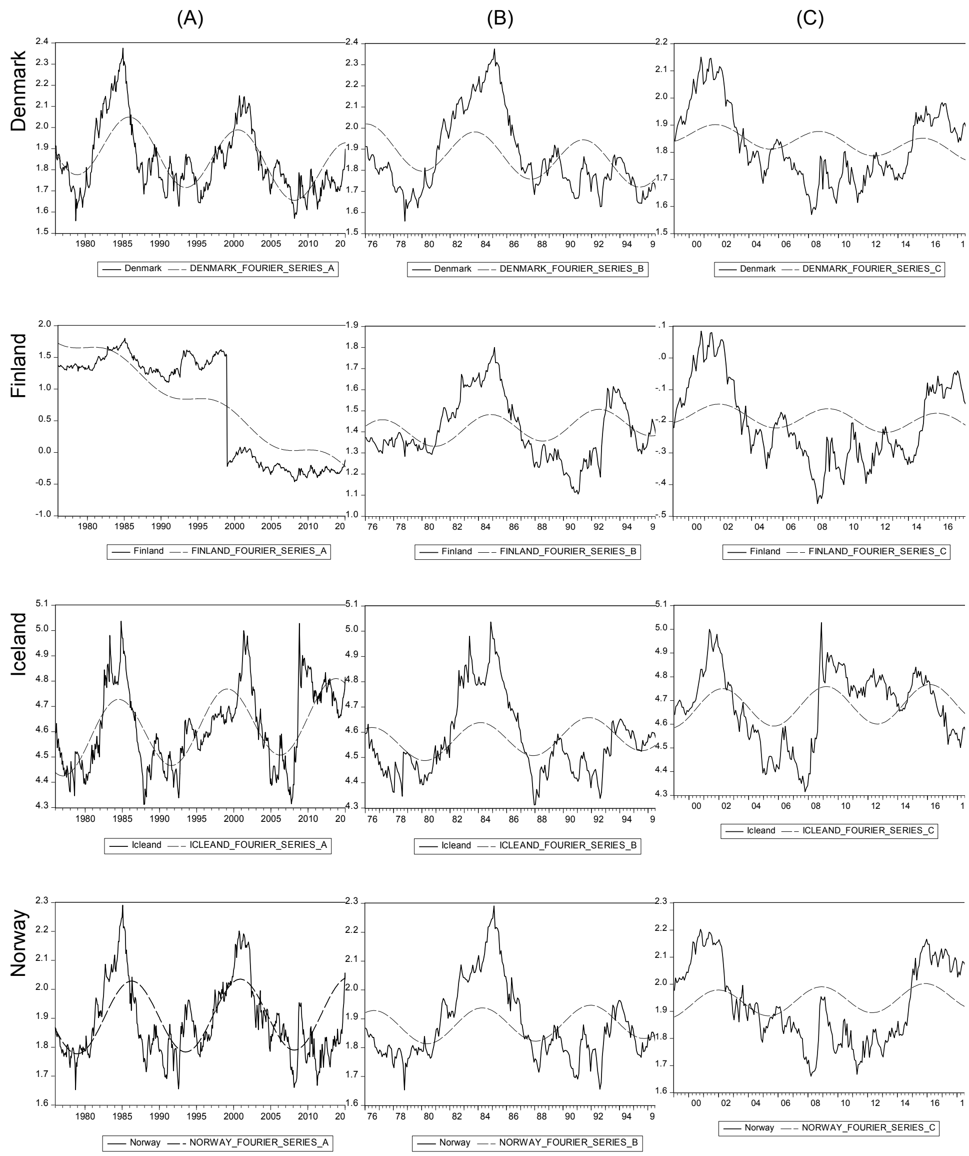


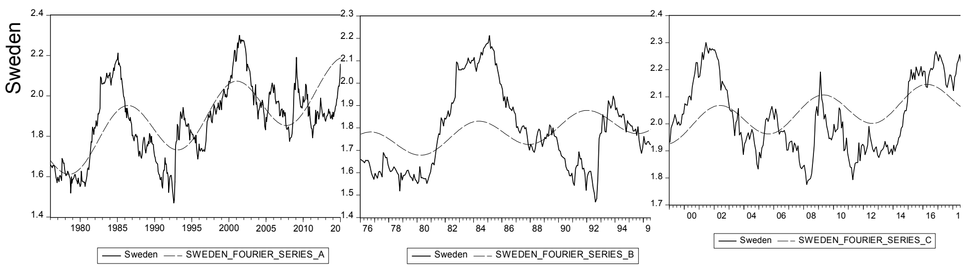


Finland
Finland FINLAND_FOURIER_SERIES_A
Finland FINLAND_FOURIER_SERIES_B
Finland FINLAND_FOURIER_SERIES_C
Iceland
Icleand ICLEAND_FOURIER_SERIES_A
Icleand ICLEAND_FOURIER_SERIES_B
Icleand ICLEAND_FOURIER_SERIES_C
Norway
Norway NORWAY_FOURIER_SERIES_A
Norway NORWAY_FOURIER_SERIES_B
Norway NORWAY_FOURIER_SERIES_C
Sweden
Sweden SWEDEN_FOURIER_SERIES_A
Sweden SWEDEN_FOURIER_SERIES_B
Sweden SWEDEN_FOURIER_SERIES_C

Figure 6

Fourier Series with Constant and Trend (k=3)





Based on the results and past evidence, the validity of the PPP for the Nordic countries varies according to the considered period and the method. Our results overlap with the studies of Akram (2006), Kalyoncu and Kalyoncu (2008) and Christidou and Panagiotidis (2010) while partially supporting the those of Sollis (2009), Lau (2009), and Cuestas and Regis (2013) for Iceland, Norway, and Sweden. However, we reach contradictory results across the Nordic countries compared to a recent study by Guris *et al.* (2016).

4. Conclusion

This study investigates the long run validity of the PPP relationship in a relatively long-time span for different periods. We use both LM-type and Fourier-based unit root tests together, which take into account sudden breaks and gradual shifts in the real exchange rates separately. Our analysis presents novel findings in the group of Nordic countries. Accordingly, the panel LM unit root test results are mostly consistent with the long run PPP relationship in the Nordic countries in all models. In particular, considering multiple shocks in exploring stationarity provides more support to the validity of PPP. However, we obtain mixed results from the Fourier panel stationarity test, implying notable evidence for PPP in the whole and pre-Euro periods. This result further suggests that stationarity of the real exchange rate series depends on the number of Fourier frequencies. Taking together the results of the two types of tests, mean reversion of the exchange rate series in the long run is much seen in case of sharp breaks. Divergence between the findings of these tests become more obvious in the post-Euro period. This result also corresponds to the existing literature based on the differences in power and size properties of the unit root tests. Regarding the past evidence, it may be argued that use of the panel unit root tests which take structural changes into account by sharp breaks and gradual shifts offers a more reasonable policy guidance rather than the conventional approach.

In line with the PPP theory, a larger dataset with different subperiods or the ADF-type unit root tests based on time series or panel data with Fourier approximation can improve the evidence in future studies.

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