Are inflation rates in OECD countries actually stationary during 2011-2018? Evidence based on Fourier Nonlinear Unit root tests with Break

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February 2019

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Abstract

We re-investigate the hypothesis of inflation stationarity in 33 Organization of Economic Cooperation and Development (OECD) member countries from 2011 to 2018. We compare two linear fractional-based, two nonlinear Fourier-based and two nonlinear Fourier-Fractional-based unit root tests with five classical unit root tests. Classical unit root tests are biased to the hypothesis of unit root since they do not account for structural breaks and nonlinearities. Incorporating just the Fourier framework into the ADF test does not significantly improve the conventional ADF unit root test. More importantly, we find that accounting for the observed limitations of the classical unit root tests improves the power of test. The rejection ability of the examined unit root tests are greatly enhanced whenever inherent salient features (nonlinearity and fractional integration) are combined with structural breaks. The battery of enhanced unit root tests confirmed the Norwegian inflation rate as the only nonstationary series among the thirty three considered. More than half of the OECD member countries have inflation rates that are somewhat stationary within the investigated period. Robustness check indicated the superiority of test regression with Fourier nonlinearity and break over the classical ADF regression.

Key words: Fourier function; Inflation rates; Nonlinearity; OECD countries; Unit root test

JEL Classification: C22

1. Introduction

The $I(1)/I(0)$ hypothesis of inflation of OECD countries has been a debatable issue in the literature lately (see Yaya, 2018). Various unit root tests have been employed to determine the stationarity level of inflation rates in these countries. The reassessment of stationarity of inflation rates reported by the OECD countries stems from its relevance in forward looking economic policy analysis. Also, further examination of economic variable, with respect to its long term behaviour, is germane due to its contribution in determining the state of well-being of a nation (Cecchetti and Debelle, 2006; Gil-Alana, Shittu and Yaya, 2012; Chang, Ranjbar and Tang, 2013). Empirical works on the long term properties of inflation rate in OECD countries exist.

Starting with the account of Culver and Papell (1997), who considered 13 OECD countries' inflation rates in a panel data modelling framework with sequential trend breaks, the authors found evidence of inflation stationarity in four of the 13 cases. The authors further stated that non-rejections of the null hypotheses of unit roots were due to the fragility of inflation rates, a plausible consequence of small amount of cross-sectional variations. Basher and Westerlund (2008) checked the robustness of the findings of Culver and Papell (1997) by using several panel unit root tests, which permits cross-sectional dependence, structural change, autoregressive behaviour and heteroscedasticity and found stationarity of inflation rate to hold when those structures are considered in the testing regression. Romero-Avila and Usabiaga (2009) investigated the unit root hypothesis of 13 OECD countries over the period 1957 to 2005, taking into consideration the cross-sectional dependence, multiple mean shifts and a bootstrap version of the test, and obtained inconclusive evidences on stationarity level of inflation rates in those countries. Gregoriou and Kontonikas (2009) applied Augmented Dickey-Fuller (ADF) and Ng-Perron unit root tests on inflation rates and accepted hypothesis of unit root in five OECD member countries studied, while Ng-Perron test rejected the hypothesis of unit root in just two cases. Narayan and Narayan (2010) examined the unit root hypothesis of inflation rates in 17 OECD countries. First, the authors, using conventional unit root tests without structural breaks, found non-rejection of the null hypothesis of inflation rates in all the 17 countries. Second, applying the Kapetanios, Phillips, Schmidt and Shin (KPSS) test with multiple breaks, hypothesis of unit root were rejected in 10 cases, and in 17 cases when panel KPSS test was applied. Chang, Ranjbar and Tsang (2013) applied flexible Fourier unit root test of Becker, Enders and Lee (2006) to investigate the mean reverting characteristics of inflation rates of 22 countries, from 1961 to 2011 and found evidences of mean reversion, contrary to the initial decision by the classical unit root tests. Yaya (2018) considered long monthly inflation series of 21 OECD countries, using unit root test based on heteroscedasticity and structural breaks. The results showed more rejections of unit root by this new testing procedure, where the classical unit root tests have failed to detect such rejections. The author further recommended involving batteries of unit root tests that are robust to nonlinearity, structural breaks, seasonality and heteroscedasticity in the decision of unit root in inflation rates, since wrong unit root decision could lead to wrong policy decision.

Since the seminal paper of Dickey and Fuller (1979), which led to the development of Dickey-Fuller (DF) and its augmented version (the ADF) in Dickey and Fuller (1981), many unit root tests have been developed and applied to investigate stationarity of economic series, most of which have their roots from the DF and ADF testing framework. These include the Phillips-Perron (1988) test, GLS-detrended DF test (Elliot, Rothenberg, and Stock, 1996), Kwiatkowski, Phillips, Schmidt and Shin (1992) test, Schmidt and Phillips (1992) test, Elliott, Rothenberg and Stock (1996) test and the Ng and Perron (2001) test. The unit root tests with consideration for one or more structural breaks include the Perron (1989) unit root test, Zivot and Andrews (1992) test, Lumsdaine and Papell (1997) test, Lee and Strazicich (2003) test and Perron (2006) test. Based on nonlinearity, Kapetanios, Schmidt and Snell (2003) test was developed, but criticized in Enders and Lee (2012a,b), since its specification supports abrupt breaks instead of smooth breaks. Becker, Enders and Lee (2006) noted the low power of Bai and Perron (1998) test in detecting abrupt breaks or breaks located towards the end of the series. Fourier unit root test techniques, as applied in Chang, Ranjbar and Tsang (2013), have been found to account for obvious limitations found in reviewed literature.

For smoothness of breaks in a suspected break series, Becker, Enders and Lee (2006), Enders and Lee (2012a,b) and Furuoka (2017) present their tests based on Fourier form nonlinearity, which induces smooth breaks instead of an instantaneous break, as noticed in Perron (2006). These are the Fourier KPSS [hereafter, FKPSS] test of Becker, Enders and Lee (2006) for testing the null of stationarity against the alternative of unit root in a smooth nonlinear fashion. Its extension, FKPSS-Break point [hereafter, FKPSS-BP] by Furuoka (2017) allows, in addition to the smooth break, an abrupt break date to be detected. The Fourier ADF [hereafter, FADF] test of Enders and Lee (2012a,b) and the Fourier ADF-Break point [hereafter, FADF-SB] of Furuoka (2017) test the null of unit root against the alternative that the series is stationary. In contrast to the former that does not account for nonlinearity and the presence of structural break(s) in the series, the recent extension - FADF-SB test accounts for these salient features, which is its merit point over extant tests. In the same vein also, we consider the Perron (2016) ADF with structural break [hereafter, ADF-SB] test in addition to the extant ADF test, as comparative tests given their wide application in testing for unit root in extant literature. The power of test of most extant unit root tests is greatly compromised given that they failed to account for fractional unit roots (Diebold and Rudebusch, 1991; Hasslers and Wolters, 1994; and Lee and Schmidt; among others). This, thus, informed the development of unit root tests that allow for fractional unit roots. These include linear fractional unit root [hereafter, LFrUR] test (Robinson, 1994) and nonlinear Fourier form specification of the fractional unit root [hereafter, FFrUR] (see Gil-Alana and Yaya, 2018), each with structural break.

In this present paper, we consider four unit root tests (ADF, ADF-SB, FADF and FADF-BP) and fractional unit root equivalents to these testing regression models (the LFrUR, LFrUR-SB, FFrUR and FFrUR-SB) to re-investigate the unit root hypothesis of inflation rates in OECD countries from January 2011 to August 2018, with data sample period obtained based on data availability in OECD website. These are monthly datasets amounting to a sample size of 91 data points. This sample size warrants the applicability of these novel unit root testing procedures.

The rest of the paper is structured as follows: Following from the introductory section, the data and methods adopted for the study are discussed in details in the second section, while the analytical results are appropriately presented and interpreted in the third section. The fourth section concludes the paper.

2. Data and methods

We considered monthly series of thirty three (33) inflation rates of OECD member countries, sourced from the organisation website at https://data.oecd.org/price/inflation-cpi.htm. The included countries are: Austria, Belgium, Canada, Chile, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Latvia, Lithuania, Luxemburg, Mexico, Netherlands, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Turkey, UK, and USA. Each time series span between January 2011 and August 2018, covering a total of 91 data points. Time plots of these series are given in Figure 1. In this figure, it is noticeable that one intercept and one slope cannot represent the dynamics of inflation rates in these countries since the plots reveal mixed relationships, especially, if the series were to be sub-divided by periods of shift in natural patterns. These parameters would have changed at one or more times but due to size of the time series, we will only allow for a break date. We conducted Bai and Perron (2003) multiple structural breaks test and we quite found significant multiple breaks, however the reliability of the results are somewhat questionable given the sample size considered. The detailed results are available on requests.

INSERT FIGURE 1 ABOUT HERE

Then we obtained the descriptive statistics and fit one linear trend to justify the appropriateness of the test regression with intercept and trend only. The average inflation rate of the OECD member countries considered in this study range between 0.1799 and 8.6353, with the least and highest rates corresponding to Greece and Turkey, respectively, while these averages range between a minimum and maximum of -2.8523 and 15.8490, respectively (see Table 1). Interestingly, the highest variation[1] in the inflation rates corresponds to Greece, while the least corresponds to Turkey. On the trend equation estimation, we find all, except Japan, inflation rates to exhibit negative trend coefficients, while of the estimated trends, all except Chile, Czech Republic, Lithuania, Japan and Sweden, were statistically significant. Thus, the inclusion of linear trend in the unit root tests regression models is justified.

INSERT TABLE 1 ABOUT HERE

The model specification of the null hypothesis for all six unit root tests considered in this study is given by equation (1)

$$inf_t = \mu + \rho\left(inf_{t-1}\right) + \varepsilon_t \quad (1)$$

where inf_t represents the inflation rate of the country of interest at time t, μ and ε_t are the constant term and the error term, respectively, while ρ, the slope parameter for the first lagged dependent variable, ρ is unity whenever the series has unit root. The unit differencing of equation (1) yields $\Delta inf_t = \mu + (\rho - 1) inf_{t-1} + \varepsilon_t$, where $\Delta = (1 - B)$ and B is the backward shift operator. Four unit root alternative hypotheses to the null in equation (1) specified in equations (2) – (5) represent models A – D, respectively.

$$inf_t = \mu + \beta t + \varepsilon_t \quad (2)$$

[1] This is obtained by computing the coefficient of variation using the percentage ratio of the standard deviation to the mean.

$$inf_t = \mu + \beta t + \sum_{k=1}^{m} \gamma_k \sin\left(2\pi kt/N\right) + \sum_{k=1}^{m} \lambda_k \cos\left(2\pi kt/N\right) + \varepsilon_t \quad (3)$$

$$inf_t = \mu + \beta t + \delta DU_t + \theta D\left(T_B\right)_t + \varepsilon_t \quad (4)$$

$$inf_t = \mu + \beta t + \sum_{k=1}^{m} \gamma_k \sin\left(2\pi kt/N\right) + \sum_{k=1}^{m} \lambda_k \cos\left(2\pi kt/N\right) + \delta DU_t + \theta D\left(T_B\right)_t + \varepsilon_t \quad (5)$$

where β represents the slope parameter for the trend term; k denotes the Fourier frequency, and *m* is the optimal frequency; γ_k and λ_k are the slope parameters in the Fourier functions; t denotes the trend/time component; π is conventionally taken to be approximately 3.1416; N is the sample size, δ is the slope parameter for the structural break dummy, DU_t, where $DU_t = 1$ if $t > T_B$, otherwise, $DU_t = 0$; T_B indicates the point of occurrence of a structural break; the slope parameter for the one-time break dummy is denoted by θ; $D\left(T_B\right)_t = 1$ if $t = T_B$, otherwise $D\left(T_B\right)_t = 0$; while μ remains as previously defined.

Equation (5) above is characterized by the inclusion of the constant term, the trend/time component, the nonlinear Fourier form, the dummy variables indicating structural breaks and a one-time break dummy variable. Equations (2) – (5) are respectively the ADF, FADF, ADF-SB and FADF-SB test models. The error correction forms of the models in equations (2) – (5), which also include augmentation components, is specified as given in equations (6) – (9).

$$\Delta inf_t = \mu + \beta t + \left(\rho - 1\right) inf_{t-1} + \sum_{i=1}^{p} c_i \Delta inf_{t-i} + \varepsilon_t \quad (6)$$

$$\Delta inf_t = \mu + \beta t + \sum_{k=1}^{m} \gamma_k \sin\left(2\pi kt/N\right) + \sum_{k=1}^{m} \lambda_k \cos\left(2\pi kt/N\right) + \left(\rho - 1\right) inf_{t-1} + \sum_{i=1}^{p} c_i \Delta inf_{t-i} + \varepsilon_t \quad (7)$$

$$\Delta inf_t = \mu + \beta t + \delta DU_t + \theta D\left(T_B\right)_t + \left(\rho - 1\right) inf_{t-1} + \sum_{i=1}^{p} c_i \Delta inf_{t-i} + \varepsilon_t \quad (8)$$

$$\Delta inf_t = \mu + \beta t + \sum_{k=1}^{m} \gamma_k \sin\left(2\pi kt/N\right) + \sum_{k=1}^{m} \lambda_k \cos\left(2\pi kt/N\right) + \delta DU_t + \theta D\left(T_B\right)_t$$

$$+\left(\rho - 1\right) inf_{t-1} + \sum_{i=1}^{p} c_i \Delta inf_{t-i} + \varepsilon_t \qquad (9)$$

where c and p in the augmented component represent the slope parameter and the lag length for the augmentation, respectively; while other items remain as previously defined. The optimal lag length is often determined by some information criteria, however, for the purpose of this study, the lag length is set to unity. The optimal Fourier frequency $\left(k = m\right)$, structural break date $\left(T_B\right)$, as well as the break fraction $\left(\lambda\right)$ are selected following Furuoka (2017) proposition.

The fractional unit root alternative tests were obtained by applying Models A [equation (2)], B [equation (3)], C [equation (4)] and D [equation (5)]. However, in this case, d is assumed to be an unknown fractional unit root value, in contrast to the $d = 1$ assumption of equations (6) - (9). Hence, from equations (6), (7), (8) and (9), we can easily write $\Delta^d = \left(1 - B\right)^d$, such that we have equations (10), (11), (12) and (13) corresponding to Models E, F, G and H, respectively, given as:

$$\Delta^d inf_t = \mu + \beta t + \left(\rho - 1\right) inf_{t-1} + \sum_{i=1}^{p} c_i \Delta^d inf_{t-i} + \varepsilon_t \qquad (10)$$

$$\Delta^d inf_t = \mu + \beta t + \sum_{k=1}^{m} \gamma_k \sin\left(2\pi kt/N\right) + \sum_{k=1}^{m} \lambda_k \cos\left(2\pi kt/N\right) + \left(\rho - 1\right) \Delta^d inf_{t-1} + \sum_{i=1}^{p} c_i \Delta^d inf_{t-i} + \varepsilon_t \qquad (11)$$

$$\Delta^d inf_t = \mu + \beta t + \left(\rho - 1\right) inf_{t-1} + \delta DU_t + \theta D\left(T_B\right)_t + \sum_{i=1}^{p} c_i \Delta^d inf_{t-i} + \varepsilon_t \qquad (12)$$

$$\Delta^d inf_t = \mu + \beta t + \sum_{k=1}^{m} \gamma_k \sin\left(2\pi kt/N\right) + \sum_{k=1}^{m} \lambda_k \cos\left(2\pi kt/N\right) + \left(\rho - 1\right) \Delta^d inf_{t-1}$$

$$+\delta DU_t + \theta D(T_B)_t + \sum_{i=1}^{p} c_i \Delta^d inf_{t-i} + \varepsilon_t \quad (13)$$

which are the LFrUR, FFrUR, LFrUR-SB and FFrUR-SB tests, respectively. The fractional integration operator, $\Delta^d = (1-B)^d$, is truncated using the binomial expansion before subsequent estimations are carried out, using the least squares approach. The tests have been shown to have some attractive sample properties (see Gil-Alana and Yaya, 2018). Since estimation strategy for (10) - (13) is adapted from Robinson (1994) with constant, μ and trend, t, we then test the usual null hypothesis,

$$H_0 : d = d_0 \quad (14)$$

where d_0 is any real value in stationary or nonstationary range. The estimation approach is parametric and allows for functional forms of the residuals, ε_t as $I(0)$ or as $AR(1)$ or seasonal $ARMA$ processes. In this case, we only assume $I(0)$ disturbance process, which allows us to use the ordinary least squares (OLS) estimation approach with Lagrange Multipler (LM) statistic. Details about this are shown in Robinson (1994).

3. Results and Discussion

Table 2 presents the computed t statistics for classical unit root tests: the DF and ADF that impose no break restrictions and test the null hypothesis of unit root against the alternative of no unit root, the Z-A, testing unit root hypothesis against no unit root with a break point, and the KPSS test with the null hypothesis of series stationarity and alternative hypothesis of unit root in its testing framework. The DF, ADF and PP are much consistent in their decision of accepting the hypotheses of unit root in inflation rates of OECD member countries for the sampled period since none of the computed t statistics was statistically significant at 5% level. Meanwhile, Z-A test rejected the null of unit root in Iceland and Portugal inflation rates only, having detected break dates (39: 2014M03) and (25: 2013M01), respectively, though significant break dates were detected in all the inflation rates. Since the KPSS sets to test the null of series stationarity against unit root instead, rejection of the null hypotheses of stationarity of inflation rates are found in 31 cases, implying evidence of unit root in the sample based on the decision of this test. The two cases of no unit root were observed in the inflation rates of Canada and Turkey. Generally, these unit root tests agree in their stance of unit root of all the considered inflation series except in four cases as depicted by Z-A test (Iceland and Portugal) and KPSS test (Canada and Turkey). However, in these cases, decisions by the remaining four unit root tests are enough to conclude that unit root exists based on these classical tests (see Table 2).

INSERT TABLE 2 ABOUT HERE

Following the confirmation of unit root stance by the classical unit root tests presented in Table 2, we further subject the inflation series of the OECD member countries to the Fourier unit root and Fourier fractional unit root frameworks, while also examining the importance of accounting for structural breaks that may be inherent in the series. Consequently, Table 3 presents the results for the different Fourier-based extensions of the conventional ADF unit root test, while Table 4 presents the results for Fractional unit root and Fourier-Fractional unit root tests, each with a structural break.

INSERT TABLE 3 ABOUT HERE

The Fourier-based unit root tests presented in Table 3 are FADF, FADF-SB and FADF-SB with corresponding number of rejections of the null hypotheses of unit root being 0, 17 and 27, respectively. The immediate implications of these results is that the stance of stationarity, or otherwise, as depicted by the classical unit root tests might be misleading, given their failure to account for possible presence of structural breaks. A quick glance at equation (in Table 1), we find most of the trend coefficients to be mostly negative and significant. Most of the countries showed negative trend at the earlier time periods but thereafter, exhibited positive trends. This reveals the existence of some breaks in the natural path of the inflation series. In confirmation of the aforementioned stance, we find that the neglect of some of these inherent salient features, such as nonlinearity and structural breaks, has greatly compromised the results obtained from the classical unit root tests. The Fourier-based ADF test without accounting for structural breaks is also no better than the classical unit root tests, as they all finally converge to the same conclusion. However, when structural break is taken into account, the conventional ADF and the Fourier-based ADF unit root tests results provide evidence for rejecting the null hypothesis of unit root in the inflation series of OECD member countries. Consequently, on the basis of the FADF-SB unit root test, which accounts for the highest number of rejections, only the inflation rates of Estonia, France, Latvia, Norway, Slovak Republic and the UK are found to have unit roots, while the others are observed to be truly stationary (see Table 3).

As a way to further validate the stationarity, or otherwise, of the inflation series of OECD member countries, we again subject the series to some linear fractional-based and nonlinear Fourier-Fractional-based unit root tests. These unit root techniques include LFrUR, LFrUR-SB, FFrUR and FFrUR-SB, each accounting for 5, 9, 18 and 21 rejections of the hypothesis of unit root, respectively. These results again show the relevance of accounting for structural breaks, as seen under both techniques of the linear fractional-based and the nonlinear Fourier-Fractional-based unit root tests, where accounting for structural breaks tend to reject more null hypotheses of unit root than those that do not. Also, FFrUR-SB results in six rejections of the hypothesis of unit root less than that of FADF-SB, which is indicative that more than half the OECD member countries have mean reverting inflation rates (see Table 4). Interestingly, only Norway inflation rate seems to have unit root regardless of the unit root test adopted, while the other OECD member countries seemed to be somewhat stationary, depending on the unit root test adopted. Therefore, on the true stationarity stance of any series, the consideration of a battery of unit root tests would most likely prevent wrong conclusions (see Yaya, 2018). Summarily, we state here that accounting for structural breaks in unit root testing does matter, if the true stationarity stance of a series is desired and secondly, inflation rate of OECD member countries are somewhat stationary.

INSERT TABLE 4 ABOUT HERE

Furuoka (2017) presents some robustness checks where the ADF test is taken as a restricted model to FADF or to FADF-SB test. This also checks FADF-SB against FADF test in an F statistic test. The residual sum of squares (RSS) were obtained in both cases, and used to compute the F statistic. We found no significant improvement between model for FADF and ADF, while FADF-SB model improved significantly over the ADF, ADF-SB and FADF model. Thus, results obtained based on Fourier ADF with structural break in both unit root and fractional unit root tests are most quite reliable.[2]

The findings of this study, however, align with several research findings in extant literatures. While our findings provide support for the stationarity of the inflation rates of most of the OECD member countries investigated as do several other studies (Culver and Papell, 1997; Gregorious and Kontonikas, 2009; Romero-Avila and Usabiaga, 2009; Narayan and Narayan, 2010; and Yaya, 2018), we further showed that accounting for inherent salient features (specifically, nonlinearity, fractional order of integration and structural breaks) in the inflation series would enhance the power of the test to reject the null hypothesis of unit root in the inflation rates of the OECD member countries (see Narayan and Narayan, 2010 and Yaya, 2018). Conclusively, except for Norway inflation that consistently exhibits unit root even when

[2] These results are large to capture in a table but are available on request. Furuoka (2017) details different critical points based on frequency of Fourier function, break fractions of the structural break and sample sizes.

salient features are accounted for, all the other investigated OECD member countries have inflation stationary rates.

4. Concluding remarks

In this study, we re-investigate the stationarity of inflation rate series of 33 selected OECD member countries using a battery of unit root testing techniques on a sample size of 91 data points in monthly frequency. The techniques employed include the classical unit root tests (DF, ADF, ADF-SB, PP, Z-A and KPSS), linear fractional-based tests (LFrUR and LFrUR-SB), the nonlinear Fourier-based tests (FADF and FADF-SB) and the nonlinear Fourier-Fractional-based tests (FFrUR and FFrUR-SB). We show the inability of the classical unit root tests to reject the null hypothesis of unit root in the inflation series of the selected OECD member countries. However, when structural breaks are accounted for in the ADF framework, its rejection ability increased. While these results are indicative of the failure of the classical unit root tests to account for inherent salient features, we proceed to examine the series using other unit root tests that incorporate one or more of these salient features. We find rejections of these unit root tests to be greatly enhanced whenever inherent salient features (nonlinearity and fractional order of integration) are combined with structural breaks specifications. Consequently, we find that the importance of accounting for the inherent structural breaks in the inflation rates of the OECD member countries cannot be overemphasized, and ignoring same reduces the ability of the test to reject the null hypothesis of unit root. Of the 33 inflation countries, only Norway is consistently shown to have inflation rate that is non-stationary. Having examined the inflation rates of selected OECD countries using a battery of unit root tests that account for inherent salient features in the series, we can conclusively say that more than two-third the OECD member countries have inflation rates that are somewhat stationary within the period 2011 – 2018.

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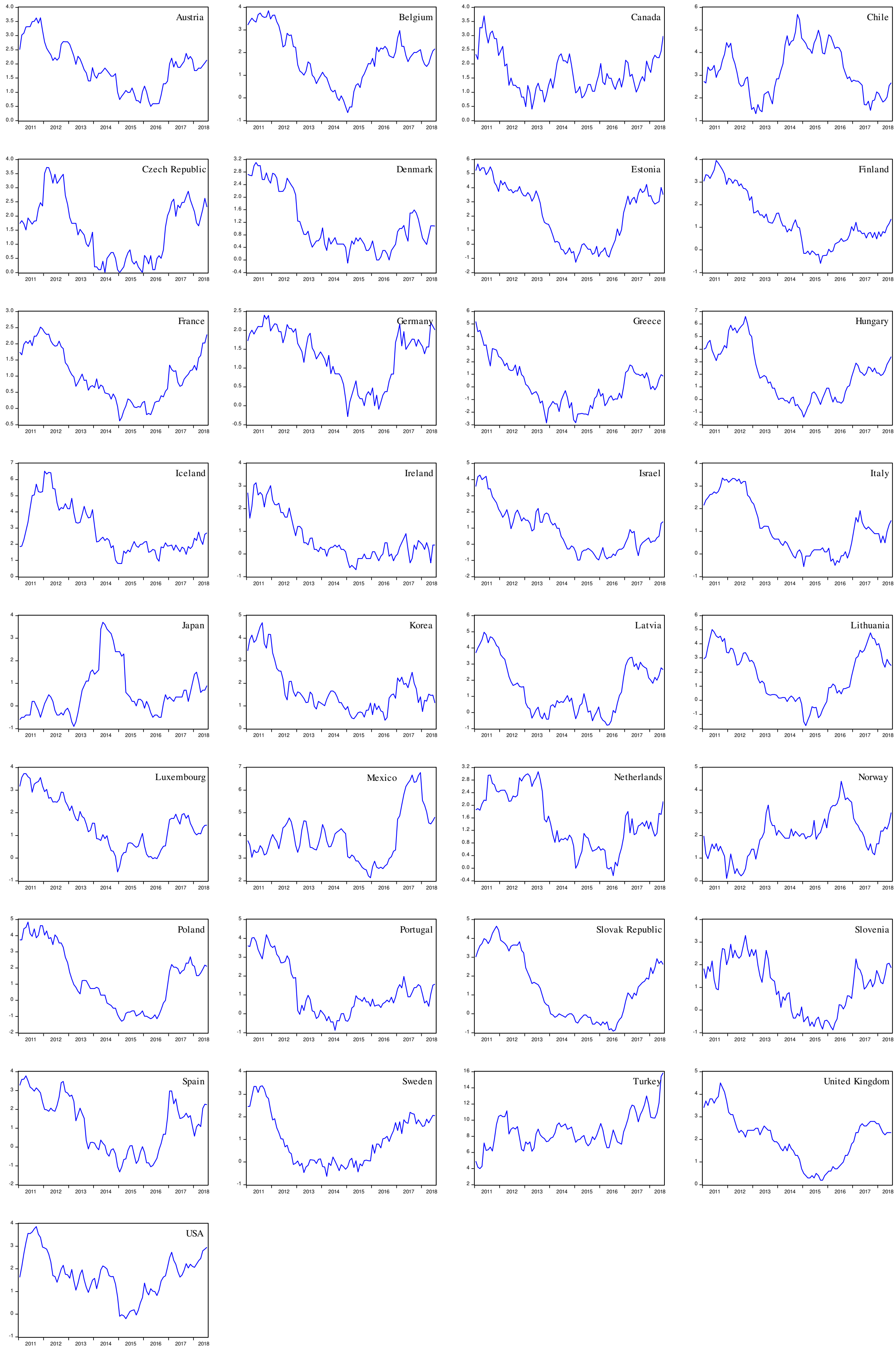

Figure 1: Plots of Inflation rates

Table 1: Summary Statistics and Trend Equation Estimation

Country	Mean	Std. Dev.	Minimum	Maximum	Trend Equation	
					α	β
Austria	1.8940	0.8104	0.4990	3.6315	**2.7222**	**-0.0180**
Belgium	1.7813	1.1355	-0.6468	3.8466	**2.4867**	**-0.0153**
Canada	1.6837	0.7111	0.4092	3.6973	**1.9624**	**-0.0061**
Chile	3.1997	1.1002	1.3039	5.6888	**3.3946**	-0.0042
Czech Republic	1.5373	1.0792	0.0000	3.7155	**1.8968**	-0.0078
Denmark	1.1667	0.9221	-0.1011	3.1049	**2.2505**	**-0.0236**
Estonia	2.1869	2.0879	-1.2762	5.6792	**3.6003**	**-0.0307**
Finland	1.3443	1.2031	-0.5915	3.9581	**2.9896**	**-0.0358**
France	1.0150	0.7973	-0.3829	2.5153	**1.6507**	**-0.0138**
Germany	1.3168	0.7277	-0.2833	2.3976	**1.7668**	**-0.0098**
Greece	0.1799	1.7840	-2.8523	5.2006	**1.4713**	**-0.0281**
Hungary	2.0176	2.0517	-1.4000	6.6000	**3.7153**	**-0.0369**
Ireland	0.7044	1.0066	-0.6931	3.1447	**2.0178**	**-0.0286**
Iceland	2.8517	1.4805	0.8072	6.5197	**4.6301**	**-0.0387**
Israel	0.8763	1.3791	-0.9824	4.2771	**2.6938**	**-0.0395**
Italy	1.1862	1.1932	-0.5587	3.3564	**2.5377**	**-0.0294**
Japan	0.5912	1.0990	-0.9000	3.7000	0.2197	0.0081
Korea	1.7348	1.0753	0.3692	4.6858	**2.8415**	**-0.0241**
Lithuania	1.8238	1.8302	-1.7948	5.0179	**2.3547**	-0.0115
Luxembourg	1.5366	1.1074	-0.6134	3.7322	**2.7875**	**-0.0272**
Latvia	1.5536	1.6293	-0.7918	4.9642	**2.2806**	**-0.0158**
Mexico	3.9293	1.1131	2.1308	6.7730	**3.2368**	**0.0151**
Netherlands	1.5095	0.8994	-0.2376	3.0665	**2.4696**	**-0.0209**
Norway	1.9913	0.9020	0.1072	4.3956	**1.1093**	**0.0192**
Poland	1.3816	1.8649	-1.2872	4.8415	**3.0497**	**-0.0363**
Portugal	1.2475	1.3383	-0.8725	4.1987	**2.4759**	**-0.0267**
Slovak Republic	1.4271	1.7060	-0.9152	4.6419	**3.0304**	**-0.0349**
Slovenia	1.0783	1.1381	-0.8797	3.2874	**1.8707**	**-0.0172**
Spain	1.1930	1.4526	-1.3189	3.7795	**2.2861**	**-0.0238**
Sweden	0.9801	1.1158	-0.6261	3.3746	**1.1320**	-0.0033
Turkey	8.6252	2.1162	3.9860	15.8490	**6.4804**	**0.0466**
UK	2.0440	1.0820	0.2000	4.5000	**2.9095**	**-0.0188**
USA	1.7546	0.9565	-0.1995	3.8684	**2.2013**	**-0.0097**

Note: The numbers in square brackets represent the standard errors of the estimated coefficients. The figures in bold indicate statistical significance at 5% level.

Table 2: Results of Classical Unit root tests

Country	DF	ADF	PP	Z-A	KPSS
Austria	-1.4537	-1.454	-1.3408	-4.5720[2016: 09]	**0.8400**
Belgium	-1.3458	-1.346	-1.2338	-4.4679[2015: 04]	**4.6854**
Canada	-1.6438	-1.644	-1.8608	-4.3436[2013: 05]	0.1891
Chile	-1.9651	-1.965	-1.7790	-4.4122[2013: 11]	**0.9320**
Czech Republic	-1.3063	-1.306	-1.3264	-3.4538[2012: 11]	**0.6075**
Denmark	-1.5215	-1.521	-1.5077	-4.8337[2013: 01]	**0.5553**
Estonia	-0.7668	-0.767	-0.6874	-3.5801[2013: 09]	**22.6529**
Finland	-0.2554	-0.255	-0.4152	-4.5631[2014: 12]	**0.5803**
France	0.3506	0.351	0.3405	-3.7062[2014: 12]	**2.6188**
Germany	-0.9125	-0.913	-1.1730	-4.1796[2016: 09]	**3.8824**
Greece	-1.8754	-1.875	-2.2266	-3.7216[2013: 08]	**15.8997**
Hungary	-1.0250	-1.025	-0.7309	-3.9395[2013: 01]	**5.4964**
Ireland	-2.8059	-2.806	-2.6849	-4.8628[2014: 01]	**0.1629**
Iceland	-1.9948	-1.995	-2.4071	**-6.5948[2014: 03]**	**0.3343**
Israel	-1.7583	-1.758	-1.2599	-4.1926[2014: 12]	**0.2722**
Italy	-0.5854	-0.585	-0.6500	-3.1276[2014: 12]	**1.0171**
Japan	-2.0198	-2.020	-1.8463	-4.1521[2015: 04]	**1.3652**
Korea	-1.9665	-1.967	-1.8998	-3.7608[2012: 11]	**0.3796**
Lithuania	-1.3265	-1.326	-1.1140	-3.3434[2013: 01]	**5.5181**
Luxembourg	-1.4165	-1.417	-1.1458	-4.0376[2014: 12]	**2.1911**
Latvia	-1.5143	-1.514	-1.2979	-4.2876[2014: 08]	**0.8801**
Mexico	-2.2277	-2.228	-1.8839	-4.5520[2017: 01]	**2.1529**
Netherlands	-1.4062	-1.406	-1.4484	-3.6715[2013: 09]	**0.2078**
Norway	-2.2294	-2.229	-2.5105	-2.9247[2012: 09]	**0.6074**
Poland	-0.6947	-0.695	-0.5647	-3.5988[2014: 12]	**2.8278**
Portugal	-1.4559	-1.456	-1.4406	**-5.7705[2013: 01]**	**2.0650**
Slovak Republic	0.0598	0.060	0.2807	-3.2945[2014: 12]	**5.9498**
Slovenia	-1.6501	-1.650	-1.6757	-4.0896[2014: 07]	**2.4542**
Spain	-1.7760	-1.776	-1.3371	-4.0413[2016: 08]	**3.7214**
Sweden	-0.9395	-0.939	-1.0564	-4.3062[2012: 11]	**1.3187**
Turkey	-2.9194	-2.919	-2.2306	-4.5329[2016: 02]	0.1445
UK	-0.9643	-0.964	-0.7467	-3.3726[2014: 11]	**0.3090**
USA	-1.7648	-1.765	-1.3772	-4.9272[2014: 11]	**1.3977**
No of unit root Rejections	**0**	**0**	**0**	**2**	**2**

In bold significance test statistic implying rejection of unit root. For Z-A test, break dates are given in brackets.

Table 3: Results of Unit root tests

Country	FADF	ADF-SB	FADF-SB
Austria	-3.503[1]	**-4.284[2016:09, 0.75]**	**-4.656[2016:12, 0.79, 1]**
Belgium	-3.456[1]	-3.039[2012:10, 0.24]	**-4.657[2015:07, 0.60, 1]**
Canada	-2.332[2]	**-3.889[2012:02, 0.15]**	**-5.488[2015:10, 0.64, 2]**
Chile	-2.285[2]	**-4.301[2013:10, 0.37]**	**-4.693[2013:10, 0.37, 2]**
Czech Republic	-2.544[1]	-3.367[2012:10, 0.24]	**-4.513[2011:12, 0.13, 1]**
Denmark	-4.053[1]	**-4.442[2012:12, 0.26]**	**-5.368[2012:12, 0.26, 2]**
Estonia	-2.809[1]	-3.314[2016:05, 0.71]	-4.214[2017:11, 0.91, 1]
Finland	-2.933[1]	-1.901[2016:03, 0.69]	**-4.583[2014:11, 0.52, 1]**
France	-3.304[1]	-1.591[2012:10, 0.24]	-4.146[2012:10, 0.24, 1]
Germany	-3.268[1]	**-3.973[2016:09, 0.76]**	**-5.064[2016:11, 0.78, 1]**
Greece	-3.984[1]	-3.207[2012:11, 0.25]	**-4.894[2016:11, 0.78, 1]**
Hungary	-2.907[1]	**-4.065[2012:12, 0.26]**	**-4.846[2011:12, 0.13, 1]**
Iceland	-4.120[1]	**-4.466[2013:12, 0.40]**	**-4.901[2011:05, 0.05, 1]**
Ireland	-7.293[1]	**-4.483[2012:10, 0.24]**	**-7.964[2014:03, 0.43, 1]**
Israel	-3.532[1]	-3.051[2016:12, 0.79]	**-5.059[2013:05, 0.32, 1]**
Italy	-2.900[1]	-3.100[2012:09, 0.23]	**-4.830[2016:11, 0.78, 2]**
Japan	-2.956[2]	**-4.243[2015:03, 0.56]**	**-4.587[2015:03, 0.56, 1]**
Korea	-3.582[1]	**-4.206[2011:12, 0.13]**	**-4.644[2011:12, 0.13, 2]**
Latvia	-2.605[1]	-3.143[2016:06, 0.73]	-4.364[2016:06, 0.73, 1]
Lithuania	-3.763[1]	-3.101[2016:11, 0.78]	**-5.444[2018:01, 0.93, 1]**
Luxemburg	-3.830[1]	**-3.947[2016:11, 0.78]**	**-5.335[2016:11, 0.78, 1]**
Mexico	-2.552[2]	**-4.795[2016:12, 0.79]**	**-5.435[2016:12, 0.79, 2]**
Netherlands	-3.471[1]	**-3.846[2013:09, 0.36]**	**-4.508[2013:09, 0.36, 2]**
Norway	-2.287[1]	-3.629[2016:12, 0.79]	-3.658[2016:12, 0.79, 2]
Poland	-3.204[1]	-3.593[2016:08, 0.75]	**-5.237[2016:11, 0.78, 1]**
Portugal	-4.226[1]	**-4.525[2012:09, 0.23]**	**-6.369[2012:12, 0.26, 1]**
Slovak Republic	-3.053[1]	-2.661[2012:10, 0.24]	-4.122[2012:12, 0.26, 1]
Slovenia	-4.244[1]	-3.733[2013:08, 0.35]	**-5.657[2017:09, 0.89, 1]**
Spain	-3.857[1]	**-3.998[2016:07, 0.74]**	**-4.922[2012:06, 0.20, 1]**
Sweden	-2.902[1]	**-4.374[2011:11, 0.12]**	**-5.093[2013:05, 0.32, 1]**
Turkey	-4.285[1]	**-4.145[2016:11, 0.78]**	**-5.661[2012:09, 0.23, 1]**
UK	-2.028[1]	-3.164[2016:08, 0.75]	-3.669[2011:11, 0.12, 2]
USA	-3.745[1]	-3.475[2016:07, 0.74]	**-5.797[2014:11, 0.52, 1]**
No of unit root Rejections	**0**	**17**	**27**

Note: The ADF test results are reported in column two of the table. Column three reports the FADF test results with selected Fourier frequency number in square brackets. Column four reports the ADF-SB results with break date and break fractions in square brackets. Column five reports the FADF-BP tests with Fourier frequency, break date and break fractions in brackets. Critical values of the unit root tests are given Furuoka (2017). Figures in bold denotes significance of the test statistic at 5% level.

Table 4: Results of fractional Unit root tests

Country	LFrUR	LFrUR-SB	FFrUR	FFrUR-SB
Austria	1.0824 (0.8901, 1.2747)	1.0658 (0.8700, 1.2616)	0.9213 (0.6892, 1.1534), 2	**0.8935 (0.6571, 1.1299), 2**
Belgium	1.0677 (0.8882, 1.2472)	1.0540 (0.8582, 1.2498)	**0.8214 (0.5774, 1.0654), 2**	**0.8248 (0.5716, 1.0780), 2**
Canada	**0.8604 (0.6824, 1.0384)**	**0.7752 (0.5592, 0.9912)**	**0.6425 (0.4277, 0.8573), 2**	**0.6256 (0.4008, 0.8504), 2**
Chile	1.1008 (0.9032, 1.2984)	1.1016 (0.9021, 1.3011)	0.9085 (0.6737, 1.1433), 2	0.9085 (0.6739, 1.1431), 2
Czech Republic	1.0181 (0.8454, 1.1908)	1.0015 (0.7430, 1.2600)	**0.8715 (0.6663, 1.0767), 2**	**0.8602 (0.6471, 1.0733), 2**
Denmark	0.9584 (0.7751, 1.1417)	**0.8423 (0.6312, 1.0534)**	**0.7972 (0.5677, 1.0267), 1**	**0.6933 (0.4463, 0.9403), 1**
Estonia	1.0480 (0.8959, 1.2001)	1.0045 (0.7809, 1.2281)	**0.7063 (0.4962, 0.9164), 2**	**0.6181 (0.4013, 0.8349), 2**
Finland	1.0000 (0.9999, 1.0001)	0.9560 (0.8462, 1.0658)	**0.7521 (0.5532, 0.9510), 1**	**0.7929 (0.5879, 0.9979), 1**
France	1.0688 (0.9059, 1.2317)	1.0497 (0.8782, 1.2212)	**0.7893 (0.5672, 1.0114), 2**	**0.7602 (0.5281, 0.9923), 2**
Germany	**0.8894 (0.7308, 1.0480)**	**0.8706 (0.7069, 1.0343)**	**0.5918 (0.3697, 0.8139), 2**	**0.5970 (0.3738, 0.8202), 2**
Greece	0.9067 (0.7475, 1.0659)	**0.8727 (0.7037, 1.0417)**	**0.6817 (0.4587, 0.9047), 1**	**0.6770 (0.4553, 0.8987), 1**
Hungary	1.2343 (1.0426, 1.4260)	1.1694 (0.9607, 1.3781)	1.1056 (0.8761, 1.3351), 2	1.0224 (0.7709, 1.2739), 2
Ireland	0.9985 (0.9952, 1.0018)	0.9567 (0.7678, 1.1456)	**0.8194 (0.6024, 1.0364), 2**	**0.8094 (0.6007, 1.0181), 2**
Iceland	**0.7499 (0.5706, 0.9292)**	**0.6421 (0.4371, 0.8471)**	**0.4129 (0.1426, 0.6832), 1**	**0.3533 (0.0691, 0.6375), 2**
Israel	1.0324 (0.8299, 1.2349)	1.0286 (0.8175, 1.2397)	**0.8444 (0.5859, 1.1029), 2**	**0.8234 (0.5435, 1.1033), 2**
Italy	1.0676 (0.9051, 1.2301)	1.0242 (0.8523, 1.1961)	0.9240 (0.7333, 1.1147), 1	**0.8946 (0.6984, 1.0908), 1**
Japan	1.1258 (0.9288, 1.3228)	1.0968 (0.8916, 1.3020)	0.9723 (0.7459, 1.1987), 2	0.9578 (0.7300, 1.1856), 2
Korea	**0.8968 (0.7261, 1.0675)**	**0.8217 (0.6341, 1.0093)**	**0.6299 (0.4151, 0.8447), 2**	**0.6016 (0.3791, 0.8241), 2**
Lithuania	1.1425 (0.9706, 1.3144)	1.1171 (0.9393, 1.2949)	0.9892 (0.8169, 1.1615), 2	0.9810 (0.7799, 1.1821), 2
Luxembourg	1.2157 (1.0183, 1.4131)	1.1932 (0.9929, 1.3935)	1.0845 (0.8515, 1.3175), 1	1.0796 (0.8497, 1.3095), 1
Latvia	1.0506 (0.8617, 1.2395)	1.0424 (0.8501, 1.2347)	0.9064 (0.6763, 1.1365), 1	0.9056 (0.6743, 1.1369), 1
Mexico	1.2136 (0.9990, 1.4282)	1.2231 (0.9726, 1.4736)	1.1329 (0.8985, 1.3673), 2	1.1623 (0.8952, 1.4294), 2
Netherlands	0.9872 (0.7994, 1.1750)	**0.8921 (0.6851, 1.0991)**	**0.8569 (0.6374, 1.0764), 1**	**0.7667 (0.5290, 1.0044), 2**
Norway	0.9407 (0.7543, 1.1271)	0.9029 (0.7065, 1.0993)	0.9249 (0.7328, 1.1170), 1	0.9008 (0.7028, 1.0988), 1
Poland	1.1487 (0.9809, 1.3165)	1.1091 (0.9349, 1.2833)	0.9815 (0.7712, 1.1918), 1	0.9424 (0.7299, 1.1549), 1
Portugal	0.9776 (0.7973, 1.1579)	0.9275 (0.6772, 1.1778)	**0.6854 (0.4263, 0.9445), 2**	**0.5435 (0.2289, 0.8581), 2**
Slovak Republic	1.1966 (1.0435, 1.3497)	1.1850 (1.0272, 1.3428)	**0.8633 (0.6399, 1.0867), 2**	**0.8485 (0.6172, 1.0798), 2**

Slovenia	**0.8804 (0.7026, 1.0582)**	**0.8217 (0.6241, 1.0193)**	**0.4405 (0.1737, 0.7073), 2**	**0.4506 (0.1844, 0.7168), 2**
Spain	1.1629 (0.9481, 1.3777)	1.1286 (0.9087, 1.3485)	1.0925 (0.8497, 1.3353), 1	1.0778 (0.8381, 1.3175), 1
Sweden	0.9566 (0.8225, 1.0907)	**0.8970 (0.7473, 1.0467)**	**0.5549 (0.3650, 0.7448), 2**	**0.4792 (0.2695, 0.6889), 2**
Turkey	1.0657 (0.8334, 1.2980)	1.0334 (0.7921, 1.2747)	0.9890 (0.6699, 1.3081), 1	0.9093 (0.6500, 1.1686), 2
UK	1.1761 (1.0136, 1.3386)	1.1579 (0.9935, 1.3223)	0.9229 (0.7167, 1.1291), 2	**0.8757 (0.6593, 1.0921), 2**
USA	1.2172 (1.0069, 1.4275)	1.1970 (0.9789, 1.4151)	1.1552 (0.9237, 1.3867), 1	1.1380 (0.9014, 1.3746), 1
No of unit root Rejections	**5**	**9**	**18**	**21**

Note: For each testing framework, evidence of rejection of unit root [I(1)] process at 5% level is in bold, while unbold implies acceptance of the null of I(1) process for the series.