



Are shocks to renewable energy consumption permanent or temporary? Evidence from 54 developing and developed countries

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Abstract

The renewable energy sources are considered as the important factor to decrease the level of carbon emissions and to promote the global green economy. Understanding the dynamics of renewable energy consumption, this paper analyzes whether there is a unit root in renewable energy consumption in 54 countries over the period 1971–2016. To this end, the unit root test of Narayan–Popp with two endogenous (unknown) breaks is implemented. The paper finds that renewable energy consumption series are stationary around a level and the time trend in 45 of 54 countries. In other words, renewable energy consumption follows a unit root process only in nine countries: Brazil, China, Colombia, India, Israel, Japan, the Netherlands, Spain, and Turkey. The evidence implies that renewable energy demand policies, which aimed to decrease the carbon emissions, will only have permanent effects in those nine countries.

Keywords Energy demand · Renewable energy consumption · Unit root test · Structural breaks

Introduction

The literature on the stationary (or unit root) tests for energy market indicators has developed as a new research field in the energy since 2006 (Ozturk and Aslan 2011).¹ Since then, the variety of studies has been performed by using different country data, subcomponents of energy sources, time periods, and unit root test techniques. It is important to understand the stochastic properties of energy consumption in order to propose and maintain effective energy policies. Indeed, whether the energy variables are stationary or not is important for the effectiveness of a policy implication to decrease consumption of fossil fuels or

support the consumption of renewable energy. For instance, if renewable energy consumption follows a unit root process, permanent policy implications (e.g., portfolio standards) will be more useful than temporary policy implications (e.g., investment and tax incentives) (Smyth and Narayan, 2015). Therefore, analyzing the stochastic properties of renewable energy consumption is vital to develop effective energy policies to increase the level of renewable energy consumption.

Moreover, if renewable energy usage follows a stationary process, the historical data on renewable energy can be considered in forecasts; otherwise, it is not possible to forecast future value of renewable energy consumption. Depending on the integration of the renewable energy sector in the whole economy, permanent shocks to renewable energy may be transmitted to other industries (Barros et al. 2013). Indeed, renewable energy sources are becoming more important in all around the world, and this has attracted the attention of scientists and policymakers (Apergis and Tsoumas 2011). However, in terms of the stationary patterns of renewable and alternative energy sources, there is limited evidence. This is a noteworthy issue since the renewable energy sources are considered as the important factor to decrease the level of carbon emissions and to promote the global green economy.

Our paper analyzes whether there is a unit root in the consumption of renewable energy in 54 countries for the

¹ See, Smyth (2013) and Smyth and Narayan (2015) for a review of the literature.

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period from 1971 to 2016. To this end, the unit root test of Narayan and Popp (2010) with two structural breaks was applied. A unit root test with one break can be inadequate to model stochastic properties of renewable energy consumption for the period from 1971 to 2016, due to the evidence that there are at least two incidents to provide structural breaks in energy consumption: the Energy Crises in the 1970s and the Global Recession of 2008–2009 (Smyth 2013; Smyth and Narayan 2015). On the other hand, the sample size is small for energy variables, and this fact can lead to bias empirical results if more than two structural breaks in the renewable energy consumption are considered (Omri 2014). In addition, Narayan and Popp (2013) illustrate that the Narayan–Popp unit root test is more powerful than the Lagrange Multiplier (LM) unit root test of Lee and Strazicich (2003) with two structural breaks in general and in the case of the small sample in particular. Based on this evidence, we consider the Narayan–Popp unit root test with two breaks.²

To the best of our knowledge, this is the first paper in the literature that directly analyzes the stochastic properties of renewable energy consumption series in the literature by using the robust unit root test of Narayan and Popp (2010). As we discussed in the literature review, the stochastic properties of renewable energy consumption are highly neglected at the aggregated level and most papers focus on renewable energy consumption on the disaggregated level. Focusing on the aggregated level data on renewable energy consumption in 54 countries for the period from 1971 to 2016, our paper observes that renewable energy consumption follows a unit root process in Brazil, China, Colombia, India, Israel, Japan, the Netherlands, Spain, and Turkey. Our paper also finds that renewable energy consumption series are stationary around both the level and the time trend in 45 of 54 countries when two structural breaks were considered. In short, our paper uses a robust unit root test of Narayan and Popp (2010) and enhances the current knowledge of the unit root characteristics in the renewable energy consumption to the highest number of countries (54) and the coverage time (1971–2016).

The remaining parts of the paper are organized as follows. The “Literature review” section briefly reviews the previous papers on the unit root findings for energy consumption. The “Data and econometric methodology” section expresses the data and the unit root methodology. The “Empirical findings”

discusses the empirical findings and the policy implications. The “Conclusion” section concludes the paper.

Literature review

According to Ozcan (2013), the motivation for analyzing stationarity in energy market indicators was firstly based on the findings by Narayan and Smyth (2007). They use the Augmented Dickey–Fuller (ADF) unit root test in 182 countries, and the evidence indicates that energy consumption is stationary in almost 30% of countries. Chen and Lee (2007) use the Panel Unit Root (PUR) test of Carrion-i Silvestre et al. (2005) (henceforth CBL) that allows for structural breaks to investigate the stationarity of energy consumption per capita for seven regions over the period 1971–2002. They find that all regional-based panels of energy consumption are stationary when multiple breaks are incorporated. Following Chen and Lee (2007), Hsu et al. (2008) reanalyze the stationary properties of energy consumption by implementing the Panel Seemingly Unrelated Regressions Augmented Dickey–Fuller (SURADF) test in 84 countries over the period 1971–2003. They report the mixed evidence of stationarity depending on the regions. Narayan et al. (2010) employ the Lee–Strazicich unit root test with two breaks to examine the energy consumption in Australia in the industry and the regional levels. In most cases, they observe that energy consumption is stationary. Hasanov and Telatar (2011) illustrate that most of the countries have stationary energy consumption series. After applying one break LM unit root test for each sector, Ozturk and Aslan (2011) show that energy consumption in all industries is stationary in Turkey over the period 1970–2006. Aslan and Kum (2011) also provide the further evidence from Turkey by showing that the energy consumption in four of seven energy sector follows a unit root process. Ozcan (2013) confirms the stationarity for most of the Middle Eastern countries for the period from 1980 to 2009. According to the results of the CBL test, energy consumption in 8 of the 13 countries is stationary. Ozturk and Aslan (2015) firstly apply a linearity test to understand the path of electricity consumption in 23 Organization for Economic Co-operation and Development (OECD) countries over the period 1960–2005. Then, they run the LM unit root test in six countries with the linear path and the Kruse test in 17 countries with the nonlinear path. It is found that electricity consumption follows a unit root process in 12 countries. Using panel unit root tests, Magazzino (2016) examines the stationary properties of per capita energy consumption in 19 Eurozone member countries for the period from 1960 to 2013 and observes the mixed empirical results.

Several papers analyze the unit root properties of energy consumption at the disaggregated level. For instance, the

² There is also the recent and the robust unit root test by Narayan and Liu (2015) to model the time trend in the energy variables (time-series). For the implications of the Generalized Autoregressive Conditional Heteroskedasticity (GARCH)-based unit root of Narayan and Liu (2015), see e.g., Charfeddine (2016), Chou and Tseng (2016), Mishra and Smyth (2016), Narayan et al. (2016), Salisu and Adeleke (2016), and Zhang and Yao (2016).

first study examining the unit root properties of the nuclear energy consumption per capita is performed by Zhu and Guo (2016). The paper finds that nuclear energy consumption follows a stationary process for a panel data sample of 27 countries, but the findings are not robust to different sub-samples. A similar finding for nuclear energy consumption is obtained by Gozgor and Demir (2017) that indicates there is a significant unit root only in France. In terms of the coal consumption, Apergis et al. (2010) find that the coal consumption in the United States (U.S.) is stationary for the period of 1982–2007. Shahbaz et al. (2014) also confirm that the coal consumption is stationary in almost all of 47 developed and developing countries over the period 1965–2010. Our paper is similar to those papers for analyzing the cases of various countries around the globe, but it focuses on the renewable energy, which is neglected by the previous papers.

There are also several papers for examining the case of the renewable energy consumption. For instance, Apergis and Tsoumas (2011) examine the integration properties of disaggregated (solar, geothermal, and biomass) energy consumption in the U.S., and the results are sensitive to the inclusion of structural breaks. Barros et al. (2012) perform the fractional integration techniques for renewable energy consumption that capture the effects of the persistence and the seasonality to examine the degrees of persistence in the U.S. by using monthly data from 1981 to 2010. According to the findings, the degree of integration shows non-stationarity with the mean-reverting behavior. Using a similar methodology, Barros et al. (2013) examine whether shocks to the various components of the renewable energy consumption have permanent or temporary effects. The findings imply non-stationarity, but the mean-reverting process is obtained in the consumption of hydropower, solar, wind, and biofuels. By considering the LM unit root test with one break and two breaks models, Gozgor (2016) examines the presence of unit roots in the renewable energy in Brazil, China, and India for the period from 1971 to 2014. The findings of the paper indicate that renewable energy is a unit root process in Brazil, but it is a mean-reverting process in China and India. Finally, Tiwari and Albulescu (2016) analyze whether there is a unit root in the share of renewables in the electricity consumption ratio in 90 countries for the period from 1980 to 2011 by proposing the Fourier Kwiatkowski–Phillips–Schmidt–Shin (KPSS) test. Their findings indicate the presence of stationarity in most of the countries. They also suggest that more detailed country-based analysis is needed (especially in the developed countries) to consider the share of renewables in the electricity consumption. Following this suggestion of Tiwari and Albulescu (2016), our paper looks at the stochastic properties of the renewable energy consumption in detail in 54 developing and developed countries.

Data and econometric methodology

Data

This paper uses renewable energy consumption (million tons oil equivalent) in 54 countries³ over the period 1971–2016. The frequency of the data is annual. The renewable energy consumption data are obtained from the Statistical Review of World Energy of the British Petroleum in 2017. A summary of the descriptive statistics is reported in Table 1 over the period 1971–2016.

According to Table 1, the largest renewable energy consumers over the period 1971–2016 are the U.S., China, and Germany, respectively. When the standard deviations of the renewable energy consumption are analyzed, again, it can be seen that the largest numbers are in the U.S., China, and Germany, respectively. In short, these three countries are the most important renewable energy consumers around the globe. In addition, there are also rapidly growing renewable energy consumers over the period under concern, such as Brazil, India, and Spain.

Methodology: the Narayan–Popp unit root test

The Narayan–Popp unit root test that takes two endogenous (unknown) structural breaks into account. This unit root test is implemented to the renewable energy consumption in our paper. However, umpteen numbers of papers have applied the Lee–Strazicich unit root test with two structural breaks in energy consumption. As a matter of fact, Lee and Strazicich (2003) showed that the usage of two structural breaks in their unit root test can provide a “substantial deviations in size and power” in the case of the small samples. In addition, Narayan and Popp (2013) illustrated that the Narayan–Popp unit root test is more powerful than the Lee–Strazicich unit root test with two structural breaks in general and in the case of the small sample in particular. Furthermore, the Narayan–Popp unit root test can accurately set the structural breaks than the Lee–Strazicich unit root test (Narayan and Popp 2013). That is why the Narayan–Popp unit root test is considered in our paper. Another issue in the unit root test methodology for the renewable energy consumption is that to model structural breaks in the constant and the time trend terms (Smyth and Narayan 2015).

After explaining these issues in the literature, the Narayan–Popp unit root test can be expressed as follows. Let us assume that an unobserved components model is defined as the data generation process (DGP). DGP (y_t) has two components: the deterministic component (d_t) and the stochastic component (μ_t), and they can be represented as such

³ See Table 1 for the countries in the dataset.

Table 1 Descriptive Summary Statistics for the Renewable Energy Consumption (Million Tonnes Oil Equivalent, 1971–2016)

Countries	Mean	Standard deviation	Minimum	Maximum	Countries	Mean	Standard deviation	Minimum	Maximum
Argentina	0.187	0.223	0.013	0.812	Japan	4.002	3.831	0.053	18.82
Australia	0.852	1.345	0.060	5.363	Lithuania	0.036	0.086	0.000	0.362
Austria	0.572	0.698	0.000	2.450	Malaysia	0.054	0.121	0.000	0.350
Azerbaijan	0.002	0.007	0.000	0.038	Mexico	1.233	0.967	0.000	4.116
Bangladesh	0.005	0.011	0.000	0.048	The Netherlands	0.856	1.018	0.000	3.110
Belarus	0.006	0.013	0.000	0.069	New Zealand	0.836	0.628	0.281	2.449
Belgium	0.503	0.899	0.000	3.201	Norway	0.122	0.174	0.000	0.617
Brazil	2.994	4.318	0.143	18.99	Peru	0.083	0.112	0.017	0.560
Bulgaria	0.079	0.201	0.000	0.715	The Philippines	1.467	0.923	0.000	3.090
Canada	1.953	2.243	0.000	9.183	Poland	0.674	1.286	0.034	4.718
Chile	0.416	0.533	0.010	2.287	Portugal	0.791	0.026	1.178	3.722
China	7.481	18.36	0.000	86.12	Romania	0.173	0.507	0.000	2.165
Colombia	0.120	0.110	0.000	0.482	Russia	0.041	0.054	0.000	0.165
The Czech Republic	0.273	0.508	0.000	1.726	Singapore	0.061	0.063	0.000	0.228
Denmark	1.085	1.344	0.000	4.287	Slovakia	0.067	0.138	0.000	0.502
Ecuador	0.018	0.036	0.000	0.139	South Africa	0.107	0.329	0.000	1.754
Egypt	0.083	0.143	0.000	0.589	South Korea	0.436	1.050	0.000	4.307
Finland	1.226	1.143	0.000	3.366	Spain	3.526	5.456	0.012	16.26
France	1.468	2.095	0.302	8.160	Sweden	1.354	1.707	0.036	6.139
Germany	6.931	10.96	0.227	38.10	Switzerland	0.182	0.184	0.000	0.787
Greece	0.304	0.572	0.000	2.079	Thailand	0.338	0.650	0.000	2.817
Hungary	0.144	0.248	0.000	0.782	Trinidad and Tobago	0.004	0.002	0.001	0.010
India	2.351	4.206	0.000	16.46	Turkey	0.444	1.068	0.000	5.169
Indonesia	0.785	0.887	0.000	2.558	Ukraine	0.041	0.101	0.000	0.386
Ireland	0.250	0.446	0.000	1.596	The United Kingdom	2.359	4.383	0.000	17.51
Israel	0.026	0.077	0.000	0.389	The United States	18.07	20.72	0.183	83.76
Italy	3.020	4.074	0.727	15.00	Vietnam	0.007	0.015	0.000	0.070

$$y_t = d_t + \mu_t \quad (1)$$

$$\mu_t = \rho\mu_{t-1} + \varepsilon_t \quad (2)$$

$$\varepsilon_t = \psi^*(L)e_t = A^*(L)^{-1}B(L)e_t \quad (3)$$

where $e_t \sim id(0, \sigma_\varepsilon^2)$ and it is assumed that the roots of lag polynomials $A^*(L)$ and $B(L)$ are with order p and q , respectively. These lag polynomials are outside the unit circle.

Two different specifications for both the trending data are also defined: (i) allows for two structural breaks in the level (this will be defined as the Model 1 (M1)) and (ii) allows for structural two breaks in the level as well as the slope (this will be defined as the Model 2 or (M2)). The deterministic component (d_t) of the model can be represented as such

$$d_t^{M1} = \alpha + \beta t + \psi^*(L) \left(\theta_1 DU'_{1,t} + \theta_2 DU'_{2,t} \right) \quad (4)$$

$$d_t^{M2} = \alpha + \beta t + \psi^*(L) \left(\theta_1 DU'_{1,t} + \theta_2 DU'_{2,t} + \gamma_1 DT'_{1,t} + \gamma_2 DT'_{2,t} \right) \quad (5)$$

with $DU'_{i,t} = 1(t > TB'_{B,i})$, $DT'_{i,t} = 1(t > TB'_{B,i}) \left(t - TB'_{B,i} \right)$, $i = 1, 2$

$TB'_{B,i}$, $i = 1, 2$, as the correct structural break dates. θ and γ represent the magnitude of the level and the slope of breaks, respectively. $\psi^*(L)$ captures the effect that “the series responds to shocks to the trend function the way it reacts to shocks to the innovation process (e_t)” (Narayan and Popp 2010: 1427). These models can be used in the unit root hypothesis and are derived by combining the structural models from Eq. (1) to Eq. (5). See also Narayan and Popp (2010: 1427–32) for the derivation of the unit root test statistics by combining the structural models and the results of the Monte Carlo simulations for generating the critical values both in the small and the finite sample sizes.

Empirical findings

The Narayan–Popp unit root test with two unknown structural breaks is implemented in the renewable energy consumption

Table 2 Results of the Narayan–Popp Unit Root Test for renewable energy consumption (1971–2016)

Countries	ADF (level)	Lag	Break dates	ADF (level and trend)	Lag	Break dates
Argentina	-4.019	3	2000, 2010	-6.575***	1	1993, 2007
Australia	-1.440	3	2002, 2009	-9.236***	3	1998, 2007
Austria	-3.827	3	2002, 2010	-8.543***	0	1984, 2000
Azerbaijan	-4.035	2	1992, 2010	-13.13***	2	1997, 2010
Bangladesh	-4.601**	1	2005, 2009	-8.184***	2	2003, 2008
Belarus	-1.512	0	2007, 2010	-6.897***	1	1996, 2004
Belgium	-4.073	3	1985, 2008	-5.858**	2	2001, 2006
Brazil	5.868	3	1982, 2001	-1.428	3	2004, 2010
Bulgaria	-25.09***	3	2008, 2010	-22.72***	3	2006, 2009
Canada	0.201	1	2006, 2010	-6.287***	3	1983, 2006
Chile	-0.966	1	2006, 2010	-5.131*	0	2004, 2010
China	-2.832	3	1997, 2009	-0.606	2	1976, 1979
Colombia	1.099	3	2007, 2010	-4.447	0	2003, 2010
The Czech Republic	-9.147***	3	2006, 2009	-5.764**	0	1991, 2006
Denmark	-4.949**	0	1998, 2008	-5.664**	3	1993, 2006
Ecuador	-2.092	0	2003, 2010	-13.01***	3	2002, 2010
Egypt	-1.091	3	2001, 2007	-11.32***	1	1999, 2005
Finland	-5.633***	0	1977, 1988	-11.16***	0	1988, 2007
France	-4.653**	3	2004, 2009	-6.379***	2	1999, 2002
Germany	-1.958	0	2004, 2009	-5.981***	3	1998, 2007
Greece	1.478	3	2004, 2010	-8.171***	3	1999, 2009
Hungary	-5.078**	0	2002, 2005	-12.21***	0	2001, 2007
India	1.709	2	2006, 2009	-3.941	3	1993, 2003
Indonesia	-4.142	0	1996, 2006	-5.765**	0	2000, 2008
Ireland	-0.302	3	2001, 2009	-6.320***	3	1993, 2001
Israel	-0.749	2	1997, 2010	1.368	2	1976, 1979
Italy	-2.201	2	2006, 2009	-26.99***	3	1996, 2007
Japan	1.712	0	1996, 2007	-3.995	0	1988, 2010
Lithuania	1.078	3	2007, 2009	-11.22***	3	2004, 2008
Malaysia	-27.95***	0	1976, 2007	-21.97***	3	2008, 2011
Mexico	-1.874	0	1978, 1997	-6.278***	0	1984, 2009
The Netherlands	-4.884**	3	1980, 2002	-4.705	3	1996, 2006
New Zealand	-4.007	2	2005, 2007	-5.948**	2	1987, 2001
Norway	-6.270***	2	2003, 2009	-6.045***	2	1988, 2002
Peru	3.212	2	2003, 2010	-7.149***	2	2000, 2010
The Philippines	-4.808**	1	1978, 1995	-5.122*	1	1981, 1996
Poland	-2.966	3	2006, 2009	-6.620***	3	2001, 2006
Portugal	-6.944***	3	2003, 2005	-7.109***	3	2001, 2010
Romania	-16.32***	3	2007, 2009	-35.03***	3	2002, 2007
Russia	-5.362***	1	2001, 2008	-7.245***	1	1998, 2001
Singapore	-3.145	0	1999, 2010	-4.858*	0	1999, 2009
Slovakia	-2.724	0	2004, 2009	-7.938***	3	2004, 2007
South Africa	-0.427	2	1981, 1988	-14.33***	2	1998, 2010
South Korea	-0.016	3	1994, 1996	-8.753***	3	2003, 2007
Spain	-4.778**	3	2000, 2006	-3.189	2	1992, 1996
Sweden	1.512	1	1986, 2005	-6.860***	1	1999, 2007
Switzerland	-0.328	0	1987, 2010	-4.970*	0	1988, 2008
Thailand	-1.687	3	1999, 2007	-4.980*	3	1996, 2008
Trinidad and Tobago	-6.160***	0	1984, 2008	-5.985***	0	1984, 2008

Table 2 (continued)

Countries	ADF (level)	Lag	Break dates	ADF (level and trend)	Lag	Break dates
Turkey	2.185	2	1998, 2009	−1.953	2	1983, 2010
Ukraine	−14.40***	1	2005, 2010	−18.63***	1	2005, 2009
The United Kingdom	−4.277*	3	2000, 2007	−7.597***	2	1994, 2004
The United States	0.066	0	2006, 2010	−6.524***	0	1987, 2005
Vietnam	1.657	3	2003, 2010	−9.320***	3	2002, 2010
Pesaran (2007)'s CIPS Test	3.824	1	–	3.114	1	–

Notes: The results both include (i) the breaks on the level (left column) and (ii) the breaks in the level and the trend terms (right column). Null hypothesis: the series have a unit root. The optimal number of lags is based on the Akaike Information Criteria. The maximum number of lags is set as 3. The critical values for the breaks on the level: 1%, −5.259; 5%, −4.514; and 10%, −4.143. The critical values for the breaks in the level and the trend terms: 1%, −5.949; 5%, −5.181; and 10%, −4.789

***, **, and * indicate the rejection of the null hypothesis at the 1, 5, and 10% significance levels, respectively

series in 54 countries over the period 1971–2016 and the results are reported in Table 2.

The findings in Table 2 illustrate that the renewable energy consumption series are stationary in 36 of 54 countries when two structural breaks are modeled. In addition, the renewable energy consumption follows a unit root process in 18 countries when the structural breaks in the level are considered.

The findings in Table 2 illustrate that renewable energy consumption series are stationary in 45 of 54 countries when two structural breaks in both the level and the time trend terms are modeled. These findings are in line with the results of Tiwari and Albulescu (2016). In addition, the renewable energy consumption follows a unit root process in nine countries (Brazil, China, Colombia, India, Israel, Japan, the Netherlands, Spain, and Turkey) when the structural breaks in both the level and the time trend terms are considered. The findings for Brazil are in line with the findings of Gozgor (2016). However, we find that both China and India are also effective for promoting renewable energy policies since there is a significant unit root in the renewable energy consumption in the related countries. Following Smyth and Narayan (2015), the results of the structural breaks in the level as well as in both the level and the trend terms are considered as the “benchmark results”.⁴

In addition, we analyze the unit root properties of the renewable energy consumption in the panel data of 54 developed and developing countries using the second-generation cross-sectional dependence PUR test. After showing the cross-sectional dependence among the renewable energy consumption series by implementing the cross-section independence (CD) test of Pesaran (2004), we

apply the cross-sectional augmented panel unit root (CIPS) test of Pesaran (2007). We report the results of the CIPS test using only a constant term as well as both constant and trend terms in Table 2. According to the results from the CIPS test, the renewable energy consumption is a stationary process. Since the findings of individual time-series analysis illustrate that the renewable energy consumption in most countries (45 of 54) is a stationary process, the findings from the CIPS test of Pesaran (2007) can be considered as the statistically robust.

Conclusion

This paper analyzed whether there is a unit root in renewable energy consumption in 54 countries over the period 1971–2016. To this end, Narayan–Popp unit root test with two breaks was applied. To the best of our knowledge, this is the first paper in the literature that directly analyzes the stochastic properties of the renewable energy consumption series in the literature by using the robust unit root test of Narayan and Popp (2010). As we discussed, the stochastic properties of renewable energy consumption have been widely neglected at the aggregated level. We observed that renewable energy consumption at the aggregated level follows a unit root process in Brazil, China, Colombia, India, Israel, Japan, the Netherlands, Spain, and Turkey. We also found that renewable energy consumption series are stationary around both level and the time trend in 45 of 54 countries when two structural breaks were considered.

The empirical results in the paper provide important policy implications. First, policy changes have temporary effects on the renewable energy consumption in 45 countries, but they will persistently affect the renewable energy consumption in Brazil, China, Colombia, India, Israel, Japan, the Netherlands, Spain, and Turkey. In other words, permanent policy implications (e.g., portfolio standard) would be a more effective tool

⁴ As regards the stationarity tests with structural breaks, the Clemente–Montanes–Reyes, the Lee–Strazicich, the Lumsdaine–Papell, and the Zivot–Andrews tests are also considered as the robustness and the sensitivity checks. However, we did not report their results to save space.

than temporary policy stances (e.g., investment and tax incentives) in Brazil, China, Colombia, India, Israel, Japan, the Netherlands, Spain, and Turkey. Temporary policy stances can be more successful in other 45 countries. Second, there could be potential for shock spillover from the renewable energy consumption to macroeconomic variables (e.g., economic growth, inflation, and real exchange rates) in Brazil, China, Colombia, India, Israel, Japan, the Netherlands, Spain, and Turkey. Similarly, these possible relationships between renewable energy consumption and the related macroeconomic variables can be analyzed with the co-integration techniques in the related nine countries. Third, since renewable energy consumption follows a unit root process, it is impossible to forecast the future path of the renewable energy consumption in Brazil, China, Colombia, India, Israel, Japan, the Netherlands, Spain, and Turkey. However, this issue can be achieved in other 45 countries, which are considered in the paper.

Future papers on this subject can investigate the unit root properties of the energy consumption series (including the renewable energy and its sub-components) using the recent GARCH-based unit root test of Narayan and Liu (2015).

References

- Apergis N, Tsoumas C (2011) Integration properties of disaggregated solar, geothermal and biomass energy consumption in the US. *Energy Policy* 39(9):5474–5479. <https://doi.org/10.1016/j.enpol.2011.05.015>
- Apergis N, Loomis D, Payne JE (2010) Are fluctuations in coal consumption transitory or permanent? Evidence from a panel of US states. *Appl Energy* 87(7):2424–2426. <https://doi.org/10.1016/j.apenergy.2009.12.005>
- Aslan A, Kum H (2011) The stationary of energy consumption for Turkish disaggregate data by employing linear and nonlinear unit root tests. *Energy* 36(7):4256–4258. <https://doi.org/10.1016/j.energy.2011.04.018>
- Barros CP, Gil-Alana LA, Payne JE (2012) Evidence of long memory behaviour in US renewable energy consumption. *Energy Policy* 41:822–826. <https://doi.org/10.1016/j.enpol.2011.11.052>
- Barros CP, Gil-Alana LA, Payne JE (2013) Disaggregated renewable energy consumption: persistence and long memory behavior. *Energy Econ* 40:425–432. <https://doi.org/10.1016/j.eneco.2013.07.018>
- Carrión-i-Silvestre JL (2005) Del barrio-Castro T, Lope-Bazo E. Breaking the panels: an application to the GDP per capita. *Econ J* 8(2):159–175. <https://doi.org/10.1111/j.1368-423X.2005.00158.x>
- Charfeddine L (2016) Breaks or long range dependence in the energy futures volatility: out-of-sample forecasting and VaR analysis. *Econ Model* 53:354–374. <https://doi.org/10.1016/j.econmod.2015.12.009>
- Chen PF, Lee CCI (2007) Energy consumption per capita broken stationary? New evidence from regional-based panels. *Energy Policy* 35(6):3526–3540. <https://doi.org/10.1016/j.enpol.2006.12.027>
- Chou KW, Tseng YH (2016) Oil prices, exchange rate, and the price asymmetry in the Taiwanese retail gasoline market. *Econ Model* 52:733–741. <https://doi.org/10.1016/j.econmod.2015.10.012>
- Gozgor G (2016) Are shocks to renewable energy consumption permanent or transitory? An empirical investigation for Brazil, China, and India. *Renew Sust Energ Rev* 66:913–919. <https://doi.org/10.1016/j.rser.2016.08.055>
- Gozgor G, Demir E (2017) Evaluating the efficiency of nuclear energy policies: an empirical examination for 26 countries. *Environ Sci Pollut Res* 24(22):18596–18604. <https://doi.org/10.1007/s11356-017-9486-3>
- Hasanov M, Telatar EA (2011) Re-examination of stationarity of energy consumption: evidence from new unit root tests. *Energy Policy* 39(12):7726–7738. <https://doi.org/10.1016/j.enpol.2011.09.017>
- Hsu Y-C, Lee C-C, Lee C-C (2008) Revisited: are shocks to energy consumption permanent or temporary? New evidence from a panel SURADF approach. *Energy Econ* 30(5):2314–2330. <https://doi.org/10.1016/j.eneco.2007.09.007>
- Lee J, Strazicich MC (2003) Minimum Lagrange multiplier unit root test with two structural breaks. *Rev Econ Stat* 85(4):1082–1089. <https://doi.org/10.1162/003465303772815961>
- Magazzino C (2016) Is per capita energy use stationary? Panel data evidence for the EMU countries. *Energy Explor Exploit* 34(3):440–448. <https://doi.org/10.1177/0144598716631666>
- Mishra V, Smyth R (2016) Are natural gas spot and futures prices predictable? *Econ Model* 54:178–186. <https://doi.org/10.1016/j.econmod.2015.12.034>
- Narayan PK, Liu R (2015) A unit root model for trending time-series energy variables. *Energy Econ* 50:391–402. <https://doi.org/10.1016/j.eneco.2014.11.021>
- Narayan PK, Popp S (2010) A new unit root test with two structural breaks in level and slope at unknown time. *J Appl Stat* 37(9):1425–1438. <https://doi.org/10.1080/02664760903039883>
- Narayan PK, Popp S (2013) Size and power properties of structural break unit root tests. *Appl Econ* 45(6):721–728. <https://doi.org/10.1080/00036846.2011.610752>
- Narayan PK, Smyth R (2007) Are shocks to energy consumption permanent or temporary? Evidence from 182 countries. *Energy Policy* 35(1):333–341. <https://doi.org/10.1016/j.enpol.2005.11.027>
- Narayan PK, Narayan S, Popp S (2010) Energy consumption at the state level: the unit root null hypothesis from Australia. *Appl Energy* 87(6):1953–1962. <https://doi.org/10.1016/j.apenergy.2009.10.022>
- Narayan PK, Liu R, Westerlund J (2016) A GARCH model for testing market efficiency. *J Int Financ Mark Inst, Money* 41:121–138
- Omri A (2014) An international literature survey on energy–economic growth nexus: evidence from country-specific studies. *Renew Sust Energ Rev* 38:951–959. <https://doi.org/10.1016/j.rser.2014.07.084>
- Ozcan B (2013) Are shocks to energy consumption permanent or temporary? The case of 17 Middle East countries. *Energy Explor Exploit* 31(4):589–605. <https://doi.org/10.1260/0144-5987.31.4.589>
- Ozturk I, Aslan A (2011) Are fluctuations in energy consumption per capita transitory? Evidence from Turkey. *Energy Explor Exploit* 29(2):161–167. <https://doi.org/10.1260/0144-5987.29.2.161>
- Ozturk I, Aslan A (2015) Are fluctuations in electricity consumption permanent or transitory? Evidence from a nonlinear unit root test in high-income OECD countries. *Energy Sources, Part B: Economics, Planning, and Policy* 10(3):257–262
- Pesaran, MH.(2004) General diagnostic tests for cross section dependence in panels. IZA (Institute of Labor Economics) Discussion Paper Series no. 1240, Bonn: IZA
- Pesaran MHA (2007) Simple panel unit root test in the presence of cross-section dependence. *J Appl Econ* 22(2):265–312. <https://doi.org/10.1002/jae.951>
- Salisu AA, Adeleke AI (2016) Further application of Narayan and Liu (2015) unit root model for trending time series. *Econ Model* 55:305–314. <https://doi.org/10.1016/j.econmod.2016.02.026>
- Shahbaz M, Tiwari AK, Jam FA, Ozturk I (2014) Are fluctuations in coal consumption per capita temporary? Evidence from developed and

- developing economies. *Renew Sust Energ Rev* 33:96–101. <https://doi.org/10.1016/j.rser.2014.01.086>
- Smyth R (2013) Are fluctuations in energy variables permanent or transitory? A survey of the literature on the integration properties of energy consumption and production. *Appl Energy* 104:371–378. <https://doi.org/10.1016/j.apenergy.2012.10.069>
- Smyth R, Narayan PK (2015) Applied econometrics and implications for energy economics research. *Energy Econ* 50:351–358. <https://doi.org/10.1016/j.eneco.2014.07.023>
- Tiwari AK, Albulescu CT (2016) Renewable-to-total electricity consumption ratio: estimating the permanent or transitory fluctuations based on flexible Fourier stationarity and unit root tests. *Renew Sust Energ Rev* 57:1409–1427. <https://doi.org/10.1016/j.rser.2015.12.098>
- Zhang YJ, Yao T (2016) Interpreting the movement of oil prices: driven by fundamentals or bubbles? *Econ Model* 55:226–240. <https://doi.org/10.1016/j.econmod.2016.02.016>
- Zhu H, Guo P (2016) Are shocks to nuclear energy consumption per capita permanent or temporary? A global perspective. *Prog Nucl Energy* 88:156–164. <https://doi.org/10.1016/j.pnucene.2015.12.013>