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RESEARCH ARTICLE

Evaluating the efficiency of nuclear energy policies: an empirical examination for 26 countries

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Abstract The decarbonization of the global economy is an urgent concern. As a potential solution, it can be important to understand the efficiency of nuclear energy policies. For this purpose, the paper analyzes whether there is a unit root in nuclear energy consumption in 26 countries and it uses the unit root tests with two endogenous (unknown) structural breaks. The paper finds that nuclear energy consumption is stationary around a level and the time trend in 25 of 26 countries and nuclear energy consumption contains a unit root only in France. The paper also discusses the potential implications of the findings.

Keywords Energy demand · Energy policies · Nuclear energy · Decarbonization · Unit root tests · Structural breaks

Introduction

Nuclear energy is still at the core of discussions of the greenhouse gas emissions produced from fossil fuel energy sources and the rising global energy demand (Apergis and Payne 2010b). Nuclear energy provides sustainable energy production but also controversial for its safety (Zhu and Guo 2016). Nuclear power plants provided 10.9% of the world's electricity production in 2015 (Nuclear Energy Institute 2016). The share of nuclear power in total electricity production is 76.3% in France in 2015 (Nuclear Energy Institute 2016). As of April 2016, there are 444 nuclear units with a total capacity of 386,276 MW, and according to the British Petroleum Global (2016), nuclear power accounted for 4.4% of global primary energy consumption. Figure 1 shows the nuclear energy consumption in the World, the USA, Japan, Russia, and France. China also became the fourth largest supplier of nuclear power after the USA, France, and Russia. In the case of Japan, there has been a dramatic decrease since 2012, due to the Fukushima-Daiichi incident, and nuclear energy consumption was almost zero in 2014. From 1965 to 1990, there was a sharp increase in nuclear energy consumption; however, since then the growth rate has decreased.

Nuclear energy has three advantages. First, nuclear energy decreases the dependence on imports, and other fossil fuels, especially for imported energy-dependent countries. As a result of decreased dependency on foreign energy sources, the current account deficits of those countries will decline.[1] Second, nuclear energy is almost carbon-free reducing the greenhouse gas emissions.[2] Indeed, nuclear energy facilities avoided 564 million metric tons of carbon dioxide in 2015 across the USA, which is equal to carbon dioxide released from nearly 128 million cars (Nuclear Energy Institute 2016). Third, nuclear energy is a stable and safe energy supply promoting the economic growth in countries by decreasing the energy supply problems (Zhu and Guo 2016). Nuclear energy will also provide a clean energy for sustainable economic development. Especially, imported energy-dependent countries are always prone to energy crises, such as energy price

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[1] This concern only applies to countries with currency controls. For instance, in Europe and the USA it has not been a concern since the 1980s and for the countries with freely traded currencies and with market exchange rates there is little or no problem here.

[2] Nuclear new build reduces carbon emissions only if it displaces existing carbon emitting generation. If it merely meets growing demand growth, then there will be no emissions benefit.

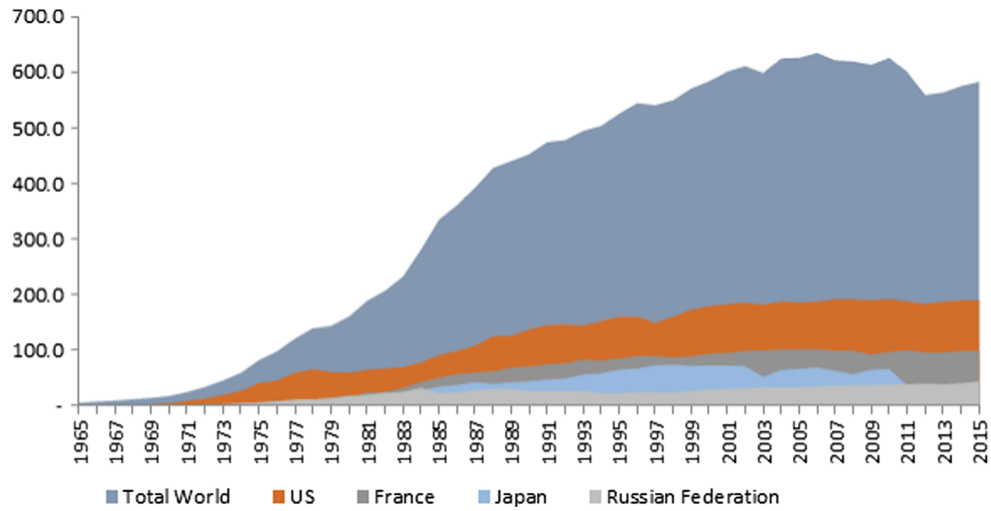


Fig. 1 Nuclear energy consumption (million tons oil equivalent). Data source: British Petroleum Global (2016)

fluctuations and instability of oil supply, which may depress the economic growth. In addition, nuclear power can be a part of a zero-carbon energy system to avert catastrophic climate change (Budnitz 2016; Cameron and Taylor 2011).

However, it is important to note that high relative costs and substantial economic risks for investors put nuclear power at a disadvantage even before the Fukushima-Daiichi incident (Akhmat et al. 2014; Kargari and Mastouri 2011). The failure of global carbon pricing has further led to an erosion of confidence in the nuclear sector. Plus, severe nuclear accidents have had only minor safety direct implications (the policy response usually kills more people), but the socio-political consequences of major accidents are real and substantial (violation of trust, etc.).

As nuclear energy is at the center of the debate and during the last four decades and its consumption has increased more than 37% (Zhu and Guo 2016), it is crucial to understand whether nuclear energy consumption is stationary or not. If nuclear energy consumption is a stationary process, shocks will not be permanent and nuclear energy consumption will fluctuate around the mean. Therefore, the long-term objectives of energy policies will be ineffective. Moreover, the historical data on nuclear energy consumption can be used for forecasts. However, if nuclear energy consumption contains a unit root, shocks will be permanent, and past behavior of nuclear energy consumption will provide little or no use in forecasting. Depending on the integration of the nuclear energy sector of the economy, shocks to nuclear energy consumption that are permanent may be transmitted to other sectors (Barros et al. 2013). Therefore, the goal of this paper is to analyze the unit root and stationary (stochastic) properties of nuclear energy consumption in 26 countries. For this purpose, the unit root tests of Lee and Strazicich (2003) and Narayan and Popp (2010) with two structural breaks were implemented.

However, a unit root test with one structural break will be inadequate to model stochastic properties of nuclear energy consumption for the period from the 1960s to 2014, due to the evidence that there are various incidents to provide structural breaks in energy consumption: the Energy Crises in the 1970s, the Chernobyl Disaster in 1986, the Great Global Recession of 2008–2009, and the Fukushima-Daiichi incident in 2011. Plus, if more than two structural breaks in nuclear energy consumption are considered in the unit root test methodology, this can lead to biased findings, due to the fact that the sample size is small for energy consumption series (Omri 2014). To the best of our knowledge, this is the first paper in the literature that analyzes the stochastic properties of nuclear energy consumption by using the unit root tests with two structural breaks.[3]

The remainder of this paper is organized as follows: section "Literature review" reviews the previous literature. Section "Data and econometric methodology" explains the data set and the econometric methodology of unit root tests. Section "Empirical results" argues the results and discusses the policy implications, and section "Conclusion" concludes.

Literature review

Starting with Narayan and Smyth (2007), the number of studies examining stochastic properties of energy consumption has been dramatically increased.[4] However, the majority of studies focus on the aggregate energy consumption. A typical problem with focusing on total energy consumption is that some types of energy consumption are more likely to be a mean-reverting process than other types (Lean and Smyth 2013b). Plus, focusing on the aggregate energy might be one reason for inconclusive findings achieved in those studies (Lean and Smyth 2013a).

[3] At this stage, Zhu and Guo (2016) use the panel unit root test with structural breaks over the period 1993–2013 across 27 countries, while we consider the individual (time series) unit root tests with two structural breaks for the period from the 1970s to 2014 in 26 countries.

[4] See Smyth (2013) for a literature review in detail.

As seen from Table 1, while the number of studies analyzing the unit root behavior of disaggregated energy has recently increased, most of them have focused on fossil fuels (coal, natural gas, and oil). Barros et al. (2012) perform several fractional integration methodologies, which consider the seasonality in order to examine the degrees of the persistence in renewable energy consumption for the period from 1981 to 2010 in the USA. According to their results, random shocks may shift the renewable energy consumption from the targeted levels. By using a similar methodology, Barros et al. (2013) examine whether shocks to the various components of renewable energy consumption have permanent or temporary effects. The findings show the non-stationarity, but the mean-reverting process in the case of hydropower, solar, wind, and biofuels. Recently, Tiwari and Albulescu (2016) test for the unit root in the renewable-to-total electricity consumption ratio of 90 countries for the period of 1980 and 2011 by proposing a new ADF Fourier test. Their results document the presence of stationary in most of the countries. The papers of Lean and Smyth (2013a, b) also focus on the production of renewable energy. To the best of our knowledge, the paper of Zhu and Guo (2016) is the only study for examining the stochastic properties of nuclear energy consumption across 27 countries. The panel unit root test with structural breaks show that nuclear energy consumption is stationary for the whole sample; however, two sub-samples follow a unit root process over the period 1993–2013.

Another branch of the literature looks at the effects of nuclear energy consumption on economic growth. For instance, Menyah and Wolde-Rufuael (2010) observe that nuclear energy consumption can help to reduce CO_2 emissions. Lee and Chiu (2011) argue that energy-imported (energy-dependent) countries should set up long-term income and energy policies for stimulating their nuclear energy development. Heo et al. (2011) and Lin et al. (2015) also document a unidirectional causality from nuclear energy consumption to economic growth in Taiwan and India, respectively. Plus, Heo et al. (2011) and Lin et al. (2015) suggest energy policy formulators for encouraging nuclear energy consumption.

Data and econometric methodology

Data

This paper uses nuclear energy consumption (million tons oil equivalent) in 26 countries[5] over the period 1965–2014.[6] The frequency of the data is annual, and therefore, there is no seasonality problem. Nuclear energy consumption data are obtained from the Statistical Review of World Energy of the British Petroleum in 2015. A summary of the descriptive statistics is reported in Table 2. Time series plots for nuclear energy consumption from 1965 to 2014 in 26 countries are also provided in Appendix.

According to Table 2, the leading nuclear energy consumers are the USA, France, and Japan. When the means of nuclear energy consumption are analyzed, they are observed as 101.3, 50.11, and 34.55 in the USA, France, and Japan, respectively. In other words, the USA, France, and Japan are the prominent nuclear energy consumers in the world. In addition, nuclear energy consumption is growing in South Korea over the period under concern.

Econometric methodology

Unit root test of Lee and Strazicich (2003)

In this paper, we apply the unit root tests of Lee and Strazicich (2003) and Narayan and Popp (2010) with two structural breaks into the nuclear energy consumption. Indeed, various energy economics papers have applied the unit root test of Lee and Strazicich (2003) with two structural breaks (see Table 1). The unit root test of Lee and Strazicich (2003) can be written as follows:

Consider an unobserved components model for the data generation process (DGP):

$$y_t = \delta Z_t + X_t, X_t = \beta X_{t-1} + \varepsilon_{t\sim i.i.d.N(0,\sigma^2)} \qquad (1)$$

In Eq. (1), Z_t indicates the exogenous variables and $\varepsilon_{t\sim i.i.d.N(0,\sigma^2)}$ is the error term. The null hypothesis, which is the significant unit root, is described by $\beta = 1$, and it means that there is no structural break in the Lagrange multiplier (LM) unit root test. According to the LM principle, unit root test statistics can be written from the following regression:

$$\Delta y_t = \delta' \Delta Z_t + \varphi \tilde{S}_{t-1} + \mathrm{DU_i} + \mathrm{DT_i} + \varepsilon_{t\sim i.i.d.N(0,\sigma^2)} \qquad (2)$$

In Eq. (2), $\tilde{S}_t = y_t - \varphi_x - Z_t\delta, t = 2, \ldots, T;$ δ is the coefficient in the regression of Δy_t on ΔZ_t and φ_x is the restricted maximum likelihood estimation of φ_x (φ+X_0); $\varepsilon_{t\sim i.i.d.N(0,\sigma^2)}$ is the error term. $\mathrm{DU_i}$ and $\mathrm{DT_i}$ denote the structural breaks. The unit root null hypothesis is described by $\varphi = 0$, and the location of the break is obtained by searching all possible breakpoints for the minimum (i.e., the most negative). However, the usage of two structural breaks in their unit root test of Lee and Strazicich (2003) can provide a "substantial

[5] Argentina, Belgium, Brazil, Bulgaria, Canada, the Czech Republic, Finland, France, Germany, Hungary, India, Japan, Mexico, the Netherlands, Pakistan, Russia, Slovakia, South Africa, South Korea, Spain, Sweden, Switzerland, Taiwan, Ukraine, the UK, and the USA

[6] China is excluded from the empirical analysis due to the fact that the GAUSS codes could not run for such a small sample case (1993–2014).

Table 1 Survey of literature for stationarity properties of energy consumption at disaggregated level

Authors	Country	Time period	Energy type	Methodology	Findings
Apergis et al. (2010a)	USA	1982–2007	Coal consumption	Carrion-i-Silvestre et al. (2005), Im et al. (2005), and Westerlund (2005) panel unit root/stationarity tests with structural breaks	Stationarity
Apergis et al. (2010b)	USA	1980–2007	Natural gas consumption	Carrion-i-Silvestre et al. (2005), Im et al. (2005), and Westerlund (2005) panel unit root tests with structural break	Stationarity
Apergis and Payne (2010a)	USA	1960–2007	Petroleum consumption	Lee and Strazicich (2003) and Narayan and Popp (2010) univariate unit root tests with two structural breaks	Evidence of stationarity in majority of cases
Apergis and Tsoumas (2011)	USA	1989–2009	Solar, geothermal, and biomass energy consumption	Fractional integration	Stationary
Aslan (2011)	USA	1960–2008	Natural gas consumption	Lee and Strazicich (2003) univariate unit root tests with up to two structural breaks and Kruse (2011) non-linear unit root test.	Mixed (Non-stationary in 27 of 50 States)
Kula et al. (2012)	23 OECD countries	1960–2005	Electricity consumption per capita	Lee and Strazicich (2003) unit root test with up to two structural breaks	Stationary for 21 countries
Barros et al. (2012)	USA	1981–2010	Renewable energy consumption	Fractional integration and autoregressive models	Evidence of non-stationarity
Barros et al. (2013)	USA	1994:2–2011:10	Disaggregated renewable energy consumption	Fractional integration and autoregressive models	Non-stationary
Lean and Smyth (2013a)	USA	Different time periods	Production of renewable energy, biofuels, and biomass	Lagrange multiplier (LM) univariate unit root tests with up to two structural breaks	Non-stationarity
Lean and Smyth (2013b)	115 countries	1980–2008	Renewable electricity generation	Carrion-i-Silvestre et al. (2005) panel unit root test with multiple structural breaks	Non-stationary
Shahbaz et al. (2013)	67 countries	1971–2007	Electricity consumption per capita	Lee and Strazicich (2003) univariate unit root tests with up to two structural breaks	65 of 67 countries are stationary
Shahbaz et al. (2014)	47 countries	1965–2010	Coal consumption per capita	LM unit root test of Lee and Strazicich (2003) with one break and two breaks	45 of 47 countries are stationary
Lean and Smyth (2014)	55 countries	1965–2011	Hydroelectricity consumption	Lee and Strazicich (2003) unit root test with two structural breaks	Stationarity
Zhu and Guo (2016)	27 countries	1993–2013	Nuclear energy consumption per capita	Carrion-i-Silvestre et al. (2005) panel unit root test with structural breaks	Stationarity
Tiwari and Albulescu (2016)	90 countries	1980–2011	Renewable-to-total electricity consumption	Becker et al.'s (2006) Fourier stationarity test as a benchmark and propose a new ADF Fourier test	Stationarity
Solarin and Lean (2016)	57 countries	1965–2012	Oil consumption	Kruse (2011) non-linear unit root test	Mixed

Table 2 Descriptive summary statistics for nuclear energy (million tons oil equivalent)

Countries	Data coverage	Mean	Standard deviation	Minimum	Maximum
Argentina	1974–2014	1.259	0.512	0.232	1.864
Belgium	1966–2014	6.366	4.401	0.001	11.09
Brazil	1984–2014	1.257	1.209	0.012	3.232
Bulgaria	1974–2014	3.013	1.188	0.210	4.576
Canada	1971–2014	14.03	6.855	0.905	24.23
The Czech Republic	1985–2014	3.515	1.533	0.542	5.997
Finland	1977–2014	4.194	1.292	0.602	5.359
France	1965–2014	50.11	40.37	0.239	102.4
Germany	1965–2014	22.60	15.19	0.031	38.76
Hungary	1982–2014	2.681	0.923	0.001	3.353
India	1969–2014	1.669	1.400	0.164	4.379
Japan	1965–2014	35.55	27.38	0.006	74.04
Mexico	1989–2014	1.754	0.707	0.084	2.458
The Netherlands	1968–2014	0.729	0.278	0.005	0.954
Pakistan	1971–2014	0.170	0.186	0.011	0.622
Russia	1985–2014	28.71	4.547	22.14	36.90
Slovakia	1972–2014	2.201	1.376	0.001	4.075
South Africa	1984–2014	2.469	0.618	0.935	3.240
South Korea	1977–2014	14.79	11.49	0.016	34.16
Spain	1968–2014	7.934	5.682	0.018	14.42
Sweden	1965–2014	9.963	6.686	0.004	17.37
Switzerland	1969–2014	4.159	1.994	0.120	6.284
Taiwan	1977–2014	6.655	2.765	0.023	9.238
Ukraine	1985–2014	16.90	2.774	9.664	20.94
The UK	1965–2014	13.09	5.857	3.425	22.51
The USA	1965–2014	101.3	67.94	0.871	192.1

deviations in size and power” in the case of small samples (Lee and Strazicich 2003).[7]

Unit root test of Narayan and Popp (2010)

Narayan and Popp (2013) indicate that the unit root test of Narayan and Popp (2010) is more powerful than the unit root test of Lee and Strazicich (2003) with two structural breaks in general and in the case of the small sample in particular. Furthermore, the unit root test of Narayan and Popp (2010) accurately sets the structural breaks than the unit root test of Lee and Strazicich (2003) (Narayan and Popp 2013). At this point, the unit root test of Narayan and Popp (2010) can be expressed as follows:

An unobserved components model is defined as the DGP. DGP (y_t) has two components, the deterministic component (d_t) and the stochastic component (μ_t), and they can represent as such:

$$y_t = d_t + \mu_t \tag{3}$$

$$\mu_t = \rho\mu_{t-1} + \varepsilon_t \tag{4}$$

$$\varepsilon_t = \psi^*(L)e_t = A^*(L)^{-1}B(L)e_t \tag{5}$$

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

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

$$d_t^{M1} = \alpha + \beta t + \psi^*(L)\left(\theta_1 DU'_{1,t} + \theta_2 DU'_{2,t}\right) \tag{6}$$

[7] Another issue in the unit root test methodology for (nuclear) energy consumption is to consider structural breaks both in the constant and the time-trend terms (Gozgor 2016; Smyth and Narayan 2015).

Table 3 Results of the unit root test of Lee and Strazicich (2003)

Countries	LM	Lag	Breaks	LM	Lag	Breaks
Argentina	−3.104**	0	1982, 1989	−5.101***	0	1982, 1995
Belgium	−2.096	2	1976, 2007	−4.991***	2	1984, 2006
Brazil	−3.160**	0	1993, 2000	−8.999***	0	1999, 2005
Bulgaria	−3.121**	0	1980, 2006	−6.831***	0	1980, 2005
Canada	−2.135	0	1990, 1994	−6.209***	0	1989, 2000
The Czech Republic	−3.492**	0	2001, 2006	−5.246***	0	1990, 1999
Finland	−2.114	2	1982, 1990	−9.073***	2	1987, 1996
France	−2.361	3	1981, 2009	−3.837	3	1971, 1988
Germany	−1.604	0	1987, 1991	−4.125*	0	1983,2007
Hungary	−1.952	1	2002, 2005	−4.631**	1	1991, 2005
India	−2.669	0	1988, 1990	−5.631***	0	1996, 2005
Japan	−1.782	1	2002, 2007	−4.807**	0	1994, 2007
Mexico	−2.743*	2	1996, 2003	−7.344***	0	1999, 2008
The Netherlands	−4.458***	0	1973, 1975	−7.454***	0	1972, 1975
Pakistan	−2.751*	3	2008, 2010	−6.558***	0	1998, 2005
Russia	−3.113**	2	1993, 1999	−5.964***	2	1991, 1998
Slovakia	−2.774*	1	2006, 2008	−4.142*	1	1982, 2007
South Africa	−2.755*	3	2000, 2010	−5.534***	0	1990, 2003
South Korea	−2.650	0	2002, 2006	−4.884***	0	1990, 2002
Spain	−2.259	2	1982, 1991	−5.447***	2	1982, 1993
Sweden	−1.768	0	1980, 1985	−5.553***	0	1979, 1990
Switzerland	−1.962	0	1979, 1984	−5.935***	0	1983, 2005
Taiwan	−1.881	0	1986, 2000	−6.998***	0	1983, 1989
Ukraine	−2.993*	3	1997, 2008	−6.119***	3	1992, 2003
The UK	−1.800	0	2003, 2006	−4.427**	0	1980, 1998
The USA	−2.143	1	1989, 1999	−4.797**	1	1980, 1996

Notes: The results both include (i) the break on the level (left column) and (ii) the break on the level and the trend terms (right column). Null hypothesis: series have unit root. The optimal number of lags is selected by the Akaike criteria (AIC). The maximum number of lags is 3. The Trimmer rate is defined as 0.20. CV for the break on the level: 1%, 3.610; 5%, 3.047; 10%, 2.673. CV for the break on the level and the trend terms: 1%, 4.82; 5%, 4.19; 10%, 3.89

CV critical values

*Rejection of the null hypothesis at the 10% significance level; **rejection of the null hypothesis at the 5% significance level; ***rejection of the null hypothesis at the 1% significance level

$$d_t^{M2} = \alpha + \beta t + \psi^*(L)\left(\theta_1 DU'_{1,t} + \theta_2 DU'_{2,t} + \gamma_1 DT'_{1,t} + \gamma_2 DT'_{2,t}\right) \quad (7)$$

$DU'_{i,t} = 1\left(t > TB'_{B,i}\right) DT'_{i,t} = 1\left(t > TB'_{B,i}\right)\ \left(t - TB'_{B,i}\right), i = 1, 2.$ $TB'_{B,i}, i = 1, 2.$ is the true structural break dates. θ and γ represent the magnitude of the level and slope of the structural 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). This process is known as the *IO model*, and the IO-type models can be used in the unit root hypothesis for M1 and M2. The unit root null hypothesis of $\rho = 1$ against the alternative hypothesis. Narayan and Popp (2010) use the t statistics, and the IO-type models are derived by combining the structural models in Eqs. (3) to (7).[8]

[8] See 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 CVs both in small and finite sample sizes.

Empirical results

Results of the unit root test of Lee and Strazicich (2003)

The unit root test of Lee and Strazicich (2003) with two unknown structural breaks is applied for nuclear energy consumption series in 26 countries, and the results are reported in Table 3.

The results in Table 3 show that nuclear energy consumption series are stationary in 11 of 26 countries when two structural breaks in the level are modeled. In other words, nuclear energy consumption contains a unit root in 15 countries when the structural breaks in the level are considered.

The results in Table 3 also illustrate that nuclear energy consumptions are stationary in 25 of 26 countries when the structural breaks both in the level and in the time trend terms are modeled. In other words, nuclear energy consumption contains a unit root only in France when the structural breaks both in the level and in the trend terms are considered. The results of the structural breaks in the level as well as both in the level and in the trend terms should be considered as the "benchmark results" (Smyth and Narayan 2015).

Results of the unit root test of Narayan and Popp (2010)

We also check the robustness of the results of the unit root test of Lee and Strazicich (2003) since the unit root test of Lee and Strazicich (2003) can provide a "substantial deviations in size and power" in the case of the small samples (Lee and Strazicich 2003). Therefore, the unit root test of Narayan and Popp (2010) with two unknown structural breaks is implemented for nuclear energy consumption in 26 countries, and the results are reported in Table 4.

The results in Table 4 illustrate that nuclear energy consumption series are stationary in 19 of 26 countries when two structural breaks in the level are modeled. In other words, nuclear energy consumption contains a unit root in seven countries when the structural breaks in the level are considered.

The results in Table 4 also indicate that nuclear energy consumptions are stationary in 25 of 26 countries when the structural breaks both in the level and the time trend terms are modeled. In other words, nuclear energy consumption still contains a unit root only in France when the structural breaks both in the level and in the trend terms are considered. Again, the results of the structural breaks in the level as well as both in the level and in the trend terms should be considered as the "benchmark results" (Smyth and Narayan 2015).

Policy implications

It is observed that nuclear energy consumption contains a unit root only in France. The results in France are in line with the previous findings of Zhu and Guo (2016). In other words, our empirical analysis shows that energy policy only works for nuclear power in France and a robust conclusion is intended. The main conclusion is that only in France is it possible to observe the impact of energy policies and hence to judge their effectiveness.

The empirical findings also provide some policy implications. First, policy changes have transitory effects on nuclear energy consumption in 25 countries, but they will persistently affect the level of nuclear energy consumption only in France. In other words, permanent policy implications (e.g., guarantee provided by the government for stable nuclear energy demand) will be a more effective tool than temporary policy stances (e.g., investment incentives) in France. Temporary policy stances will be more successful in other 25 countries.

Table 4 Results of the unit root test of Narayan and Popp (2010)

Country	ADF	Lag	Breaks	ADF	Lag	Breaks
Argentina	−5.904***	0	1982, 1988	−5.399**	0	1982, 1988
Belgium	−3.823	2	1973, 1981	−5.558**	2	1981, 2008
Brazil	−9.272***	0	1989, 1999	−9.942***	0	1992, 1999
Bulgaria	−6.044***	0	1979, 2005	−7.485***	0	1987, 2005
Canada	5.075**	0	1981, 1995	8.413***	0	1992, 2002
The Czech Republic	−7.129***	1	1993, 2001	−10.78***	1	1998, 2001
Finland	−19.74***	3	1987, 1995	−18.48***	3	1995, 2008
France	−5.268***	3	1981, 2005	−3.501	3	1972, 1991
Germany	−3.130	0	1982, 2005	−5.814**	0	1982, 2002
Hungary	−9.431***	3	2001, 2003	−10.43***	3	2001, 2005
India	−6.164***	0	1995, 2008	−6.423***	0	1997, 2006
Japan	−3.531	0	2001, 2008	−5.077*	1	2003, 2007
Mexico	−5.503***	2	1994, 2007	−6.247***	2	1998, 2007
The Netherlands	−5.266***	3	1995, 2008	−6.610***	3	1976, 2007
Pakistan	−4.625**	0	1998, 2007	−7.446***	0	1999, 2006
Russia	−7.936***	3	1992, 1998	−6.543***	3	1992, 2008
Slovakia	3.796	0	1982, 2007	−6.075***	0	1984, 1998
South Africa	5.375***	3	1994, 2003	−5.287**	3	1995, 2004
South Korea	−4.142	0	1996, 2007	−5.824**	0	1991, 2003
Spain	−6.620***	2	1982, 2003	−6.085***	2	1979, 1982
Sweden	4.307*	0	1973, 1982	−5.836**	0	1973, 1984
Switzerland	−6.456***	0	1978, 1983	−7.141***	0	1978, 1983
Taiwan	−5.774***	0	1982, 1989	−7.909***	3	1985, 1995
Ukraine	−6.581***	2	2001, 2007	−6.914***	3	1999, 2006
The UK	−3.835	0	1998, 2004	−4.878*	0	1991, 2005
The USA	−3.030	1	1973, 1983	−4.813*	1	1988, 2002

Notes: The results both include (i) the break on the level (left column) and (ii) the break in the level and the trend terms (right column). Null hypothesis: the series have a unit root. The optimal number of lags is selected by the AIC. The maximum number of lags is 3. The Trimmer rate is defined as 0.10. CV for the break on the level: 1%, 5.259; 5%, 4.514; 10%, 4.143. CV for the break on the level and the trend terms: 1%, 5.949; 5%, 5.181; 10%, 4.789

CV critical values

*Rejection of the null hypothesis at the 10% significance level; **rejection of the null hypothesis at the 5% significance level; ***rejection of the null hypothesis at the 1% significance level

Second, there is the possibility of shock spillover from the level of nuclear energy consumption to macroeconomic indicators (e.g., economic growth, external balance, inflation, and real exchange rate) in France, and a possible relationship between nuclear energy consumption and macroeconomic indicators should be analyzed by co-integration techniques in France. In other words, the Autoregressive Distributed Lag (ARDL) model estimations will be useful for analyzing the relationship between nuclear energy consumption and macroeconomic indicators in another 25 developing and developed countries.

Third, since its nuclear energy consumption contains a statistically significant unit root, it is impossible to forecast the future path of nuclear energy consumption in France. However, this issue can be successfully done in 25 countries, in which the nuclear energy consumption is found as stationary in the empirical analysis.

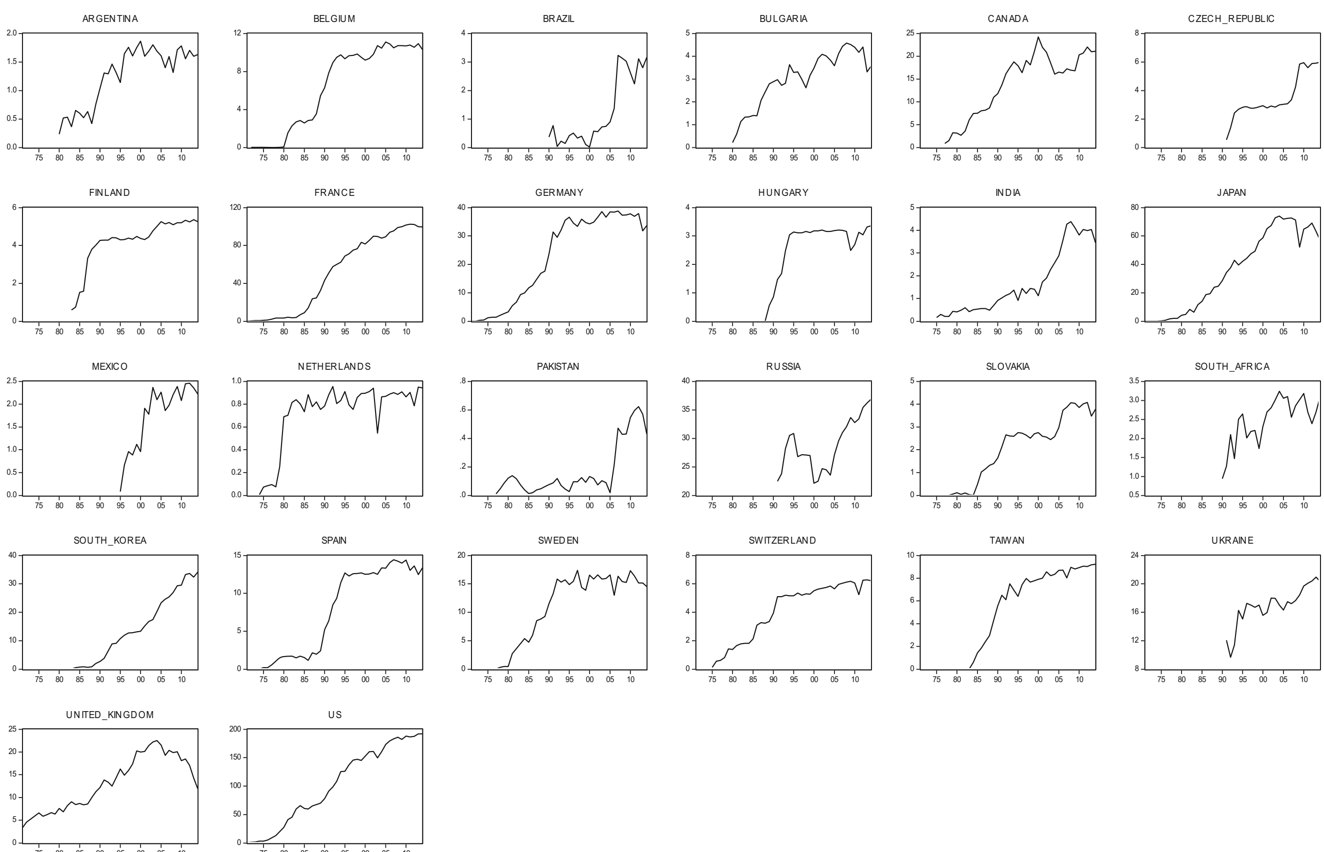
In short, our findings basically indicate that nuclear energy production does not respond quickly to investments and money used to subsidize nuclear plant would be better spent on renewable energy from a CO_2 emissions perspective. The only exception is the case of France over the period 1965–2014.

Conclusion

In this paper, we analyzed whether there is a unit root in nuclear energy consumption in 26 countries over the period 1960s–2014. For this purpose, the unit root tests of Lee and Strazicich (2003) and Narayan and Popp (2010) with two structural breaks were implemented. It was found that nuclear energy consumption series were stationary around the level and the time trend in 25 of 26 countries when two structural breaks were considered.

Future papers on the topic can also analyze the relationship between macroeconomic indicators and nuclear energy consumption in France, where there is a statistically significant unit root in the time-series of nuclear energy consumption. However, it is important to note that our paper (and all its analysis) is essentially based on the pre-Fukushima-Daiichi period. The Fukushima-Daiichi incident seems to be arguably changed the global situation.

Appendix. Time series plots for nuclear energy consumption in 26 countries



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