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Research article

Are fluctuations in coal, oil and natural gas consumption permanent or transitory? Evidence from OECD countries

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ABSTRACT

Economic development is characterised by natural resource extraction and consumption. However, due to the finite nature of fossil fuel energy sources and its price shocks, an investigation into its historical fluctuations is essential for energy policy formulation. Against the backdrop, this paper examines the stationary properties of coal, oil and natural gas consumption per capita of 16 Organisation for Economic Co-operation and Development (OECD) countries for the period 1970–2018. The study employs Fourier ADF and Fourier KSS unit root tests for linear and nonlinear series to assess the permanent or transitory shocks in coal, oil, and natural gas consumption. Empirical findings show that coal consumption is stationary for 6 of 16 countries. In contrast, oil consumption is found stationary for 4 of 16 countries while natural gas consumption is found stationary for 5 of 16 countries. These results demonstrate that any shock in oil, coal, and natural gas consumption will be permanent in most of the OECD countries. Thus, finding fossil fuel alternatives like renewable energy sources which are localized rather than internationally tradable, lessens the reliance on fossil fuel imports and the negative impacts of price shocks.

1. Introduction

Fossil fuel energy sources namely coal, oil and gas dominate the global energy mix — due to its convenience to consumers and attractive cost in terms of product and services (fuels for transportation, electricity generation, household consumption and energy for industrial production) (Tester et al., 2012). However, fossil fuel energy sources are finite and face a trade-off between economic development and environmental pollution. Because of the close connection between energy consumption and macroeconomic variables, investigating the stationary property of energy consumption is crucial for policymakers. If energy consumption is stationary, any shock to energy consumption will be transitory. However, if energy consumption is nonstationary, any shock from demand-side management and energy conservation namely, inter alia, transport-related carbon taxes on fuel consumption, imported vehicle and fuel tariffs to decline fossil fuel consumption will be permanent on economic activities (Apergis and Payne, 2010). Meaning that a permanent shock will lead to a long-term or destabilized economic growth, especially in industrialized economies dependent on energy-intensive production. Moreover, when energy consumption is stationary, the energy demand management policies designed to shrink the demand for energy will have temporary effects on energy consumption (Ozcan and Ozturk). In addition, the past behaviour of energy consumption will be used in the generation of forecasts in such situations where energy consumption is stationary. On the other hand, if energy consumption is nonstationary, utilizing the past behaviour of energy consumption may lead to incorrect forecasts (Khraief et al., 2016; Zhu and Guo, 2016).

Examining the stationarity of energy consumption is also important in terms of the sustainable development goals. Because many countries have implemented policies to increase renewable energy investments and to reduce dependence on fossil energy sources in order to mitigate carbon emissions (Owusu and Sarkodie, 2020). However, the success of these policies depends on the stationarity of fossil energy consumption. As a matter of fact, policies aimed at improving the quality of the environment will only be successful if fossil energy consumption is nonstationary and the policy shocks to be implemented have permanent effects. On the other hand, if fossil energy consumption is stationary, the policy shocks to be implemented will lose their influence in a short time.

Based on the above premise, the aim of this paper is to investigate the stationarity of coal, oil and natural gas consumption for the period 1970 to 2018. The stationary properties of coal, oil and natural gas consumption are examined in 16 OECD countries, because these countries

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presented a complete set of data. The contributions of this study are threefold: i) this is the first study to compare the stationary processes of consumption of three energy types (i.e. coal, oil, and gas) while previous studies focused only on one energy type. ii) Unlike the previous studies that assume all energy types follow a linear or nonlinear path, we determine the linearity processes of the series and use the appropriate unit root test to obtain more reliable results. iii) this study uses unit root tests with Fourier transformations to capture both large structural breaks and smooth shifts.

2. Literature review

The non-stationary properties of energy consumption and electricity consumption were confirmed in some studies namely Narayan and Smyth (2005); Narayan and Smyth (2007); Narayan and Popp (2012); Barros et al. (2012); Demir and Gozgor (2018) and Magazzino (2017a). The stationary property of energy consumption was confirmed by Ozturk and Aslan (2011); Kum (2012); Meng et al. (2012); Ozcan (2013); Bolat et al. (2013); Kula et al. (2012); Shahbaz et al. (2013); Lean and Smyth (2014); Khraief et al. (2016). Moreover, mixed results were found by Chen and Lee (2007); Hsu et al. (2008); Mishra et al. (2009); Narayan et al. (2010); Aslan and Kum (2011); Ozturk and Aslan (2015); Fallahi and Voia (2015); Ozcan and Ozturk (2016); Wang et al. (2016); and Magazzino (2017b). On the other hand, the studies examining the stationary properties of oil, coal and natural gas consumption are less.

In case of the stationary properties of oil consumption, Narayan et al. (2008) utilized Im et al. (2003), Levin et al. (2002), Breitung (2000), Hadri (2000) unit root tests to examine the stationary process of oil production for the period 1971–2003 in 60 countries. Mixed results were confirmed in this study. Apergis and Payne (2010) assessed the stationarity of oil consumption in the United States spanning the period 1960 to 2007 with the unit root tests of Lee and Strazicich (2003) and Narayan and Popp (2010) and found that oil consumption is stationary for a majority of states. Solarin and Lean (2016) probed the stationary properties of oil consumption in 57 countries for the period 1965–2012 and the study concluded that oil consumption is non-stationary in 38 countries while it is stationary in 19 countries. Burakov (2019) investigated the stationary process of oil consumption in 15 countries for the period 1990 to 2017 using the panel LM unit root test and concluded that oil consumption is stationary in the observed country.

Similar to oil consumption, a limited number of studies examined the stationary process of coal consumption. Apergis et al. (2010a) used Carrion-i-Silvestre et al., (2005) and Westerlund (2005) unit root tests to investigate the stationary properties of coal consumption for the years 1982 to 2007 in 50 U.S states and the stationary hypothesis was supported. Similarly, the persistence of evidence was found, as Congregado et al. (2012) examined the stationary properties of coal consumption utilizing the non-linear specification for the period of 1973–2010 in the United States. In addition, Shahbaz et al. (2014a) considered the stationary properties of coal consumption benefited from Lee and Strazicich (2003) LM test for the period 1965–2010. The results show that coal consumption is stationary in 47 developed and developing countries.

Moreover, Apergis et al. (2010b) investigated the stationary properties of the natural gas consumption in 50 U.S states for the years from 1980 to 2007. The results confirmed that natural gas consumption was stationary. Shahbaz et al. (2014b) examined the stationary properties of the natural gas consumption utilizing with LM unit root test and Kruse (2011) nonlinear unit root test in 48 countries for the period, 1971–2010. The non-stationarity of natural gas consumption was confirmed for more than 60% of countries. Moreover, Aslan (2011) considered the stationarity of natural gas consumption in U.S states for the period 1960–2008 and concluded that natural gas consumption is stationary for 23 states. Cai and Magazzino (2019) probed the stationarity process of natural gas consumption for the period from 1965 to 2016 in G-7 countries using a Fourier transformed unit root test and found that the stationary process is valid for the majority of G-7 countries.

As observed in previous studies that investigated the stationary properties of both total energy usage and disaggregated energy consumption found mixed findings. Most of these studies either ignored possible non-linearity or structural breaks. Despite some studies accounted for both non-linearity and structural breaks, they ignored the possible smooth-shifts which can be detected with Fourier transformed unit root tests. Based on this reason, instead of pre-assumption that linearity or non-linearity, first the non-linearity should be observed and then the suitable tests should be employed with unit root tests which observe the smooth-shifts.

3. Data and methodology

Data for each OECD country on coal consumption, oil consumption, and natural gas consumption were obtained from the British Petroleum Statistical Review. The coal, oil and natural gas consumption data were collected for 16 OECD countries namely Austria, Belgium, Canada, Chile, Czech Republic, France, Germany, Hungary, Italy, Japan, Mexico, the Netherlands, Poland, Slovakia, the United Kingdom and the United States for the period 1970–2018. Coal consumption and natural gas consumption are defined in million tons of oil equivalent, and oil consumption is defined in million tons. All variables are separated by population and expressed in per-capita terms. In addition, all variables are converted into logarithmic forms.

In this study, we utilize Fourier function with ADF and Fourier function with Kapetanios et al. (2003) unit root tests which are the expansion of the periodic y_t functions as the sum form of trigonometric terms. Fourier form unit root tests developed by Christopoulos and Leon-Ledesma (2010) allow for temporary smooth breaks by employing trigonometric variables to capture large changes in the deterministic trend (Yılancı and Eris, 2013). The initial model of the Fourier test is as follows:

$$y_t = \gamma_0 + \gamma_1 \sin\left(\frac{2\pi kt}{T}\right) + \gamma_2 \cos\left(\frac{2\pi kt}{T}\right) + v_t \tag{1}$$

where t indicates trend term, T indicates sample size, $\pi = 3.1416$ and k indicates the used frequency value obtained with an estimation of Eq. (1) which minimizes the sum of squared residuals (SSR). After determined appropriate k value, the OLS residuals are obtained with the OLS estimation of Eq. (1):

$$v_t = y_t - \left[\gamma_0 + \gamma_1 \sin\left(\frac{2\pi kt}{T}\right) + \gamma_2 \cos\left(\frac{2\pi kt}{T}\right)\right] \tag{2}$$

The obtained residuals are used in these functions:

$$\Delta v_t = a_1 v_{t-1} + \sum_{j=1}^{p} \beta_j \Delta v_{t-j} + u_t \tag{3}$$

$$\Delta v_t = \delta_1 v_{t-1}^3 + \sum_{j=1}^{p} \beta_j \Delta v_{t-j} + u_t \tag{4}$$

where u_t represents the white noise term. Model 3 indicates the Fourier ADF (FADF) test while Model 4 indicates the Fourier KSS (FKSS) test. The null hypothesis of both tests ($a_1 = 0$ and $\delta_1 = 0$) indicates a unit root process. The alternative hypothesis of FADF test ($a_1 < 0$) shows linear stationary while the alternative hypothesis of FKSS test ($\delta_1 < 0$) indicates the nonlinear stationary. Finally, the F-statistics $F(\widehat{k})$ with appropriate k is tested to determine the significance of trigonometric terms. The rejection of the null hypothesis shows the stationary around a breaking deterministic trend.

In the testing procedure, since it is a crucial issue in obtaining robust results, we first check the linearity of energy consumption series with the linearity test of Harvey et al., (2008) and use a more suitable method for each series. In addition, considering the possible structural breaks is also crucial because it is a well-known fact that energy consumption series are usually affected by energy crisis (oil shocks in the 1970s and 1985 crash in oil prices) or the wars between oil producer countries (Iraq's invasion of Kuwait). However, the unit root tests which allow the structural breaks only capture the large breaks in series so the smooth-shifts are generally ignored. Based on these pieces of information, we use the FADF unit root test for indicators that appear in linear form while FKSS unit root test is employed for the series that appears in a non-linear form. Employing the Fourier transformation gives us a chance to detect the smooth-shifts as well as large structural breaks.

4. Empirical findings

In the first step of our analysis, to decide the appropriate Fourier test, the linearity of the series is determined with Harvey et al., (2008) linearity test for each model. These linearity test results are shown in Tables 1, 2 and 3. As a result of the linearity of coal consumption series, the null of linearity is rejected for 6 OECD countries, and linearity is accepted for 10 OECD countries. When the linearity of oil consumption series is analysed, the null hypothesis of linearity is rejected for 4 OECD countries. The linearity is accepted for 12 OECD countries. Finally, the linearity of natural gas consumption is accepted for 11 OECD countries and nonlinearity is accepted for 5 OECD countries. Accordingly, the FADF unit root test is used for determined linear series, and the FKSS unit root test is utilized for determined nonlinear series.

The Fourier ADF and Fourier KSS unit root tests for coal consumption of OECD countries are reported in Table 4. The null hypothesis of a unit root in linear form is rejected in Austria, Czech Republic, Italy, and the United States, as depicted in Table 4. Therefore, energy price shocks and any shock to energy demand will be transitory in terms of coal consumption in these countries. In contrast, coal consumption in Canada, Japan, Mexico, Netherlands, Poland, and the UK seems nonstationary. This means that any shock to coal consumption will be permanent in these countries. In addition, we investigate the coal consumption of the other 6 OECD countries that follows a nonlinear path with the Fourier KSS test. According to FKSS test results, the coal consumption of

Table 1. Linearity test results for coal consumption.

Countries	W-lam	Critical Values			Results
		%10	%5	%1	
Austria	1.070	4.070	4.100	4.160	Linear
Belgium	3.490	2.140	2.450	3.110	Nonlinear
Canada	3.340	7.410	7.550	7.800	Linear
Chile	5.190	2.520	2.580	2.700	Nonlinear
Czech Rep.	1.480	2.310	2.430	2.670	Linear
France	3.180	2.360	2.600	3.090	Nonlinear
Germany	0.530	0.470	0.510	0.570	Nonlinear
Hungary	10.950	5.800	6.110	6.710	Nonlinear
Italy	6.870	11.520	11.590	11.720	Linear
Japan	7.000	7.130	7.270	7.500	Linear
Mexico	10.060	29.170	29.830	31.030	Linear
Netherlands	13.480	19.690	19.770	19.930	Linear
Poland	0.610	2.700	2.850	3.130	Linear
Slovakia	2.280	0.130	0.150	0.210	Nonlinear
United Kingdom	1.710	7.360	7.430	7.550	Linear
United States	0.370	0.420	0.440	0.470	Linear

Table 2. Linearity test results for oil consumption.

Countries	W-lam	Critical Values			Results
		%10	%5	%1	
Austria	0.710	1.240	1.250	1.260	Linear
Belgium	2.500	5.780	5.830	5.920	Linear
Canada	2.250	2.580	2.600	2.630	Linear
Chile	11.020	15.490	15.930	16.730	Linear
Czech Rep.	0.850	4.370	4.390	4.430	Linear
France	6.000	2.900	2.930	3.000	Nonlinear
Germany	4.420	5.000	5.240	5.700	Linear
Hungary	3.160	6.250	6.290	6.360	Linear
Italy	2.490	5.590	6.140	7.240	Linear
Japan	1.460	4.380	4.430	4.520	Linear
Mexico	2.310	2.200	2.220	2.250	Nonlinear
Netherlands	4.350	9.500	9.560	9.670	Linear
Poland	4.680	3.980	4.050	4.190	Nonlinear
Slovakia	9.390	28.530	28.730	29.090	Linear
United Kingdom	10.740	8.960	9.010	9.100	Nonlinear
United States	4.420	10.160	10.240	10.390	Linear

Table 3. Linearity test results for gas consumption.

Countries	W-lam	Critical Values			Results
		%10	%5	%1	
Austria	1.190	9.220	9.270	9.370	Linear
Belgium	11.000	9.500	9.620	9.840	Nonlinear
Canada	8.010	4.240	4.330	4.490	Nonlinear
Chile	9.090	14.470	14.660	15.010	Linear
Czech Rep.	3.880	6.580	6.590	6.630	Linear
France	1.030	2.770	2.780	2.790	Linear
Germany	4.880	4.640	4.660	4.680	Nonlinear
Hungary	3.680	7.290	7.320	7.380	Linear
Italy	10.920	11.110	11.160	11.240	Linear
Japan	6.480	11.450	11.480	11.540	Linear
Mexico	3.050	4.210	4.280	4.400	Linear
Netherlands	11.260	10.220	10.280	10.380	Nonlinear
Poland	1.790	1.280	1.400	1.650	Nonlinear
Slovakia	0.750	1.140	1.150	1.160	Linear
United Kingdom	1.530	6.600	6.660	6.770	Linear
United States	3.330	9.050	9.110	9.220	Linear

Table 4. Stationary properties of coal consumption.

Country	MinSSR	$\hat{k}$	FADF	FKSS	$F(\hat{k})$
Austria	0.863	3	-3.097** (0)	-	8.243
Belgium	5.142	1	-	-1.438 (15)	34.342
Canada	0.977	1	-1.758 (7)	-	38.158
Chile	6.093	1	-	-1.179 (1)	34.094
Czech Rep.	1.563	1	-4.088** (1)	-	64.227
France	4.569	1	-	-1.150 (0)	37.646
Germany	0.869	1	-	-4.036** (1)	83.338
Hungary	3.012	1	-	-3.888** (12)	56.967
Italy	0.682	2	-3.659** (16)	-	29.396
Japan	0.744	1	-1.202 (0)	-	68.049
Mexico	4.055	1	-0.765 (14)	-	53.667
Netherlands	2.437	1	-3.264 (14)	-	29.526
Poland	0.476	1	-1.874 (9)	-	56.083
Slovakia	1.244	1	-	-1.952 (2)	93.451
United Kingdom	9.969	1	-0.878 (2)	-	15.484
United States	0.392	1	-3.871** (12)	-	57.727

Notes: *, ** and *** indicate the significance at 10, 5 and 1 percent level respectively. Numbers in the parentheses show the optimal lag length.

Germany and Hungary is stationary by allowing structural breaks and nonlinearity in the data. Therefore, it can be said that energy demand management policies will have a temporary impact on coal consumption in Germany and Hungary. However, any shock to energy prices will have a permanent impact on coal consumption in Belgium, Chile, France, and Slovakia. Furthermore, as $F(\hat{k})$ statistics are larger than the critical values obtained from Becker et al. (2006), the trigonometric terms should be included in the estimated models.

The Fourier ADF and Fourier KSS unit root test results for oil consumption are shown in Table 5. The FADF test results confirm that the null of a unit root can be rejected in Canada, Germany, and the United States. Similarly, according to FKSS unit root test results, the oil consumption of Mexico is stationary by allowing structural breaks and nonlinearity in the data. It can be said that any shock to oil consumption is likely to be transitory in Canada, Germany, Mexico, and the United States. On the other hand, energy demand management policies designed to shrink oil consumption will have permanent effects in the other 12 OECD countries. In analogy with coal consumption, the trigonometric terms should be included in the estimated models.

The natural gas consumption of Chile, Mexico, and the United States is linear stationary, as shown in Table 6. It also shows that the natural gas consumption in Canada and the Netherlands is stationary by allowing structural breaks and nonlinearity in the data. It means a price shock in natural gas will be transitory in these countries. In contrary, the null of a unit root is accepted for the other 11 OECD countries, therefore, energy demand management designed to shrink natural gas consumption will have a permanent impact on the other 11 OECD countries.

Overall, the obtained results show that coal consumption has unit root in 10 OECD countries while coal consumption of Austria, Czech Republic, Italy, Germany, Hungary, and the United States is stationary. This means that a price shock or a policy shock to reduce coal consumption will be transitory in these 6 OECD countries. In the case of oil consumption, the policy shocks will be transitory in Canada, Germany, Mexico, and the United States because the oil consumption of these countries is stationary. Finally, our empirical finding reveals that a policy implementation to reduce the usage of natural gas may be successful in OECD countries excluding Canada, Chile, Mexico, Netherlands, and the United States.

Table 5. Stationary properties of oil consumption.

Country	MinSSR	$\hat{k}$	FADF	FKSS	$F(\hat{k})$
Austria	0.199	1	-2.906 (15)	-	11.595
Belgium	0.271	1	-1.946 (10)	-	49.066
Canada	0.265	2	-3.347** (1)	-	14.608
Chile	0.868	1	-1.627 (6)	-	25.576
Czech Rep.	0.577	2	-2.317 (16)	-	19.038
France	0.985	2	-	-0.021 (14)	17.492
Germany	0.371	1	-3.614* (7)	-	17.639
Hungary	0.519	1	-1.987 (3)	-	36.357
Italy	1.051	1	-1.757 (16)	-	14.520
Japan	0.413	2	-0.103 (11)	-	22.621
Mexico	0.727	1	-	-3.711** (7)	42.761
Netherlands	0.372	1	-2.497 (7)	-	8.618
Poland	2.075	1	-	-2.049 (8)	16.097
Slovakia	0.646	1	-2.717 (11)	-	27.811
United Kingdom	0.712	2	-	-0.931 (6)	10.662
United States	0.328	2	-3.908** (1)	-	20.389

Notes: *, ** and *** indicate the significance at 10, 5 and 1 percent level respectively. Numbers in the parentheses show the optimal lag length.

Table 6. Stationary properties of gas consumption.

Country	MinSSR	$\hat{k}$	FADF	FKSS	$F(\hat{k})$
Austria	1.156	1	-1.637 (5)	-	54.031
Belgium	1.932	1	-	-1.817 (10)	32.690
Canada	0.560	1	-	-4.089** (1)	34.895
Chile	6.063	1	-3.789* (8)	-	17.172
Czech Rep.	7.862	1	-0.959 (3)	-	44.385
France	2.325	1	-0.829 (11)	-	29.930
Germany	3.623	1	-	-1.162 (13)	15.981
Hungary	2.368	1	-2.722 (5)	-	27.757
Italy	3.866	1	-0.633 (13)	-	56.424
Japan	2.451	1	-0.356 (8)	-	21.391
Mexico	4.001	1	-3.658* (1)	-	15.407
Netherlands	0.610	1	-	-4.363*** (1)	9.351
Poland	1.859	1	-	-0.531 (7)	16.138
Slovakia	1.928	1	-0.563 (15)	-	64.182
United Kingdom	3.370	1	-0.998 (3)	-	38.787
United States	0.272	2	-3.717** (11)	-	21.086

Notes: *, ** and *** indicate the significance at 10, 5 and 1 percent level respectively. Numbers in the parentheses show the optimal lag length.

5. Conclusions

In this study, the stationarity of coal, oil and natural gas consumption per capita is investigated for 16 OECD countries namely Austria, Belgium, Canada, Chile, Czech Republic, France, Germany, Hungary, Italy, Japan, Mexico, the Netherlands, Poland, Slovakia, the United Kingdom and the United States for the period of 1970–2018. For this purpose, first, the linearity of the series is examined with Harvey et al., (2008) linearity test. Accordingly, the Fourier ADF unit root test and Fourier KSS unit root test are utilized in order to determine the stationarity for both linear and nonlinear series.

It is concluded that coal consumption for Austria, Czech Republic, Italy, and the United States seems stationary. In addition, the coal consumption of Germany and Hungary is stationary by allowing structural breaks and nonlinearity in the data. Therefore, energy demand management policies on coal consumption will be transitory in these countries. In the other 10 OECD countries, any policy shock for reducing the coal consumption will have a permanent impact on coal consumption. Moreover, oil consumption for Canada, Germany and the United States seem stationary. In Mexico, oil consumption is stationary by allowing nonlinearity in the data, so utilizing the past behaviour of energy consumption may be used in formulating forecasts in this country. Furthermore, the natural gas consumption series are nonstationary for 11 of 16 OECD countries. In Canada, Chile, Mexico, Netherlands and the United States, any shock to energy prices will have a transitory effect on natural gas consumption.

In the case of sustainable development targets of OECD countries, the results show that policy implementation to reduce fossil fuel energy consumption will have different effects on each country. Namely, a policy shock to reduce coal consumption will have a permanent effect on 10 OECD countries while the shocks on coal consumption will be transitory in Austria, Czech Republic, Italy, Germany, Hungary, and the United States. In the case of oil consumption, a policy shock will be transitory in Canada, Germany, Mexico, and the United States because the oil consumption of these countries is stationary. We found that a policy implementation to reduce the usage of natural gas may be successful in OECD countries excluding Canada, Chile, Mexico, the Netherlands, and the United States. Based on these findings, especially in countries where shocks to energy types are temporary, policy-makers need to consider this finding and avoid long-term energy design policies.

Future studies should aim at investigating whether the series follow a linear or nonlinear path to avoid wrong policy implications. In addition, large structural breaks and smooth shifts should be considered in the model estimation.

Declarations

Author contribution statement

Mehmet Akif DESTEK: Conceived and designed the analysis; Analyzed and interpreted the data; Wrote the paper.

Samuel Asumadu SARKODIE: Analyzed and interpreted the data; Wrote the paper.

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The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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