The Relationship between Renewable and Nonrenewable Energy Consumption and Economic growth in G7 countries:

Evidence from Bootstrap Panel Causality Test

Uğur Korkut Pata[1], Harun Terzi[2]

Abstract: In this study, both renewable and nonrenewable energy consumption and economic growth relations were examined by the bootstrap panel Granger causality method covering the period 1996-2014 for G7 countries. The findings show a unidirectional causality moving from renewable energy consumption to economic growth in Germany and Japan, and a bidirectional causality between these two variables in France, Italy and the United Kingdom. Regarding nonrenewable energy consumption, unidirectional causality moving from nonrenewable energy consumption to economic growth in Canada and the United States, and the causality in the opposite direction is valid in the United Kingdom and Germany. Also in Japan, there is a bidirectional causality relationship between these two variables. As a result, energy consumption is an important factor for G7 countries' economic growth.

Keywords: G7 Countries; Nonrenewable Energy Consumption; Renewable Energy Consumption; Panel Bootstrap Causality.

JEL Classification: C23; Q20; Q43

1. Introduction

The 1973 oil crisis that led to increased inflation, high unemployment rates and decreasing growth rates revealed that energy consumption had a considerable influence on economic growth. Countries trying to reduce their oil dependency began to seek new energy sources. Due to global warming and increased air pollution since the 20th century, sustainable economic growth and development became economically important. Due to both reasons, today, developed countries encourage the use of renewable sources of energy such as solar, wind, biomass and hydropower to reduce greenhouse gas emissions (GHG) instead of the use of non-renewable energy sources that pollute the air such as oil and coal.

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[1] Res. Assist., Department of Economics, Karadeniz Technical University, Turkey, Address: KTU Rektorlugu Trabzon 61080, Turkey, Corresponding author: korkutpata@ktu.edu.tr.

[2] Professor, PhD, Department of Economics, Karadeniz Technical University, Turkey, Address: KTU Rektorlugu Trabzon 61080, Turkey, E-mail: hterzi@ktu.edu.tr.

Renewable energy is not only directly included in production as an input, but it also indirectly affects economic growth. In 2014, the renewable energy sector employed 9.2 million people. The number of people employed is expected to rise to 24.4 million by 2030 (IRENA, 2016a). In addition, the global GDP is expected to rise from 0.6% to 1.1%, and global welfare is expected to rise between 2.7% to 3.7% by 2030 due to the increased consumption of renewable energy (IRENA, 2016b). According to International Energy Outlook (2016), the consumption of renewable energy, the most rapidly increasing source of energy, will increase by an average of 2.6% per year between 2012 and 2040. In cases where the countries around the world sustain their energy plans and policies, the share of renewable

energy consumption in total energy consumption, which amounted to 18.4% in 2014 will rise to 21% in 2030 (IRENA, 2016a).

The Group of Seven (G7) refers mostly to advanced industrial countries: Canada, France, Germany, Italy, Japan, the United Kingdom (UK) and the United States (US). These countries constituted 46% of the global GDP and 10% of the population in 2015 (World Bank, 2017). In line with the Kyoto Protocol signed in 2005, G7 countries support increasing renewable energy consumption to reduce GHG emissions. The G7 countries account for about 47% of the renewable energy consumption and about 30% of the primary energy consumption around the world (BP, 2016). New technologies in these countries have reduced GHG emissions and the high costs of renewable energy consumption.

There are four basic hypotheses depending on the direction of the causality relationship between energy consumption (EC) and economic growth (GDP): (a) According to the conservation hypothesis which assumes the presence of a unidirectional causality from GDP to EC, energy conservation policies can be implemented without causing any harm to the economy; (b) According to the growth hypothesis which assumes the presence of a unidirectional causality from EC to GDP, energy conservation policies damage economic growth. Therefore, energy consumption should be encouraged to achieve economic growth; (c) The feedback hypothesis assumes that bidirectional causality exists between EC and GDP. Therefore, energy conservation policies damage economic growth; (d) The neutral hypothesis assumes that there is no causality relationship between the two variables. Therefore, energy conservation policies have no adverse effect on economic growth.

2. Literature Review

The first empirical analysis of the relationship between energy consumption and economic growth was performed by Kraft and Kraft (1978) for the United States. Since the first quarter of the 21st century, the relationship between renewable energy consumption and economic growth has begun to be tested empirically. Narayan and Smyth (2008) reported that energy consumption and capital stock affected economic growth positively for the G7 countries both in the short and long run. Tugcu et al. (2012) used the ARDL bounds testing and Hatemi-J causality test and found that the growth hypothesis was valid only in Japan in terms of nonrenewable energy consumption. They also confirmed the validity of the conservation hypothesis for Germany and the feedback hypothesis for the UK and Japan in terms of renewable energy consumption. Chang et al. (2015) examined the causality relationship between renewable energy consumption and economic growth and confirmed the validity of the conservation hypothesis for France and the UK, and the growth hypothesis for Germany and Japan. Mutascu (2016) also examined the causality relationship between energy consumption and economic growth and found that the feedback hypothesis was valid in Canada, Japan, and the United States while the conservation hypothesis was valid in France and Germany. Destek and Okumus (2017) divided energy consumption into the consumption of oil, coal and natural gas and examined their relationship with economic growth. Their findings revealed that the growth hypothesis was valid in Italy, Japan and the United States for oil consumption, the conservation hypothesis was valid in the UK, and the feedback hypothesis was valid in Germany. The growth hypothesis was valid in Italy, Japan, the UK and the United States, and the feedback hypothesis was valid in Germany in terms of natural gas consumption. Finally, the validity of the growth hypothesis was confirmed for Canada, and the conservation hypothesis was confirmed in the United States for the relationship between coal consumption and economic growth.

There is no consensus in the literature for the G7 countries due to the different methods and periods. There are various studies on the relationship between energy consumption and economic growth; however, the number of those examining the relationship between renewable and nonrenewable energy consumption and economic growth in G7 countries is limited. To the best of the authors knowledge, this is the first study to investigate the relationship between both renewable and nonrenewable energy consumption and economic growth in G7 countries using the panel bootstrap Granger causality test. This study aims to investigate the energy-growth nexus in G7 countries using the panel bootstrap Granger causality test.

3. Data and Methodology

In this study conducted using annual data covering the period 1996-2014 for G7 countries, nonrenewable energy (primary) consumption (PEC), renewable energy consumption (REC), and gross domestic product (GDP) were used as variables. REC was obtained from the International Energy Agency (IEA, 2016), and GDP and PEC were obtained from the World Development Indicators (WDI, 2017). The data regarding the real GDP is expressed in millions of dollars in constant 2010. PEC and REC were expressed in terms of kilograms of equivalent petrol (kgoe) and million tonnes of oil equivalent (mtoe), respectively. All variables are included in the analysis in the logarithmic form.

3.1. Cross-Sectional Dependence Test

Due to globalization and financial integration, an economic event taking place in a country can affect the whole world. This situation is called cross-sectional dependence. The Lagrange multiplier (LM) test introduced by Breusch and Pagan (1980) tests the existence of cross-sectional dependence among countries. The following panel data is used for the LM test:

$$y_{it}=\alpha_i+\beta_i^{'}x_{it}+u_{it} \text{ for } i=1,2\ldots,N;\ t=1,2,\ldots,T \qquad \textbf{(1)}$$

In Equation. (1), i represents cross-section, t represents time, α_i is the constant term, β_i is the slope coefficient and x_{it} is the (kx1) vector of explanatory variables. In the LM test, the null hypothesis H_0: $\mathrm{Cov}(u_{it},u_{jt})=0$ states that there is no cross-sectional dependence, while the alternative hypothesis $H_{alternative}$: $\mathrm{Cov}(u_{it},u_{jt})\neq 0$ states the existence of cross-sectional dependence. The LM test statistics are calculated using the following equation:

$$LM=T\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{ij}^{2},\ \chi^2_{N(N-1)/2} \qquad \textbf{(2)}$$

In Equation (2), $\hat{\rho}$ represents the pair-wise correlation of the ordinary least squares (OLS) residuals obtained from Equation (1) for each cross-section. The LM test is valid when the cross-section (N) is relatively small and time (T) is large enough. Pesaran (2004) developed the CD_{LM} test, which is valid when N and T are sufficiently large. As a scaled version of the LM test, the CD_{LM} test is shown in Equation (3):

$$CD_{LM}=\left(\frac{1}{N(N-1)}\right)^{0.5}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}(T\hat{\rho}_{ij}^{2}-1),\ N(0,1) \qquad \textbf{(3)}$$

Because Pesaran’s (2004) CDLM test is valid with a large N and a small T, a more general CD test was developed which is valid when T→∞, and N→∞. Equation (4) shows the cross-sectional dependence (CD) test.

$$CD=\sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{ij}\right),\ N(0,1) \qquad \textbf{(4)}$$

Pesaran et al. (2008) modified the LM test using the exact mean and variance of the LM statistics. Equation (5) shows this test called bias-adjusted LM.

$$LM_{adj}=\sqrt{\frac{2}{N(N-1)}}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\frac{(T-k)\hat{\rho}_{ij}^{2}-\mu_{Tij}}{\upsilon_{Tij}^{2}},\ N(0,1) \qquad \textbf{(5)}$$

In Equation (5), k is the regressor; μ_{Tij} and υ^2_{Tij} are the exact mean and variance of the $(T\text{-}k)\hat{\rho}^2_{ij}$ respectively. The LM_{adj} test yields reliable results when the CD test is insufficient in certain cases when the population average pair-wise correlations are zero, although the underlying individual population pair-wise correlations are nonzero (Pesaran et al., 2008). For each of the four cross-sectional dependence tests, the null hypothesis states that there is no cross-dependence among countries, while the alternative hypothesis states otherwise.

3.2. Slope Homogeneity Test

When the parameters are considered homogeneous without regarding the heterogeneity, differences of the countries included in the analysis are neglected and the estimations become inconsistent. Regarding homogeneity, $\tilde{S}$ statistics was first developed by Swamy (1970) to analyze whether slope coefficients are homogenous or not. Pesaran and Yamagata (2008) improved the $\tilde{S}$ statistics and implemented the delta ($\hat{\Delta}$) homogeneity test, which is valid for large samples, and delta-adj ($\hat{\Delta}_{adj}$) homogeneity test valid for small samples. Swamy's (1970) $\tilde{S}$ statistics is estimated using the following equation:

$$\tilde{S}=\sum_{i=1}^{N}\left(\widehat{\beta}_i\text{-}\tilde{\beta}_{WFE}\right)'\frac{x_i'M_\tau x_i}{\tilde{\sigma}_i^2}\left(\widehat{\beta}_i\text{-}\tilde{\beta}_{WFE}\right) \qquad \textbf{(6)}$$

In Equation (6), M_τ is the identity matrix, $\tilde{\sigma}_i^2$ is the estimator of σ_i^2, and β_i and $\tilde{\beta}_{WFE}$ are pooled OLS and the weighted, fixed-effect pooled estimation obtained from Equation (1), respectively. Equation (7) shows the delta test using $\tilde{S}$ statistics.

$$\tilde{\Delta}=\sqrt{N}\left(\frac{N^{-1}\tilde{S}\text{-}k}{\sqrt{2k}}\right) \qquad \textbf{(7)}$$

As long as (N, T) → ∞, $\sqrt{N/T}\rightarrow\infty$ under the null hypothesis, error terms have normal distribution and the $\tilde{\Delta}$ test, which has asymptotic standard normal distribution is valid.

$$\tilde{\Delta}_{adj}=\sqrt{N}\left(\frac{N^{-1}\tilde{S}\text{-}E(\tilde{z}_{\dot{I}T})}{\sqrt{var(\tilde{z}_{\dot{I}T})}}\right) \qquad \textbf{(8)}$$

In Equation (8), in the $\tilde{\Delta}_{adj}$ test, $E(\tilde{z}_{\dot{I}T})$ is equal to k and $var(\tilde{z}_{\dot{I}T})$ is equal to 2k(T-k-1)/T+1. When N is larger than T, the results of the $\tilde{\Delta}_{adj}$ test become less reliable (Pesaran and Yamagata, 2008). In homogeneity tests, the null hypothesis states that slope coefficients are homogenous (H_0: $\beta=\beta_i$), whereas the alternative hypothesis states that slope coefficients are heterogeneous (H_0: $\beta\neq\beta_i$).

3.3. Kónya bootstrap panel Granger causality test

In Kónya’s (2006) bootstrap panel Granger causality test, the series are included in the analysis at their level without taking account of their stationarity and cointegration characteristics. In this causality test, the panel is assumed heterogeneous, i.e., countries are assumed to have different characteristics. Therefore, the Granger causality test can be performed for each country. When there is cross dependence between countries, the OLS estimators are not effective and reliable. In this causality test, this problem is resolved by using Zelner’s (1962) seemingly unrelated regression (SUR) equation. The following equations show the VAR system solved using the SUR method:

$$y_{1,t}=\delta_{1,1}+\sum_{l=1}^{mly_1}\beta_{1,1,l}y_{1,t-l}+\sum_{l=1}^{mlx_1}\mu_{1,1,l}x_{1,t-l}+u_{1,1,t},$$

$$y_{N,t}=\delta_{1,N}+\sum_{l=1}^{mly_1}\beta_{1,N,l}y_{N,t-l}+\sum_{l=1}^{mlx_1}\mu_{1,N,l}x_{i,t-l}+u_{1,N,t} \qquad \textbf{(9)}$$

$$x_{1,t}=\delta_{2,1}+\sum_{l=1}^{mly_2}\beta_{2,1,l}y_{1,t-l}+\sum_{l=1}^{mlx_2}\mu_{2,1,l}x_{1,t-l}+u_{2,1,t},$$

$$x_{N,t}=\delta_{2,N}+\sum_{l=1}^{mly_2}\beta_{2,N,l}y_{N,t-l}+\sum_{l=1}^{mlx_2}\mu_{2,N,l}x_{N,t-l}+u_{2,N,t} \qquad \textbf{(10)}$$

In Equation (9) and Equation (10), N represents the cross section, t represent time, δ represents constant terms and β and μ are coefficients. The lag length is l, and u represents the error terms. When all $\mu_{1,i}$ values are not equal to zero, but all $\beta_{2,i}$ values are equal to zero, there is unidirectional Granger causality running from X to Y. Similarly, when all $\beta_{2,i}$ values are not equal to zero, but all $\mu_{1,i}$ values are equal to zero, Y is the Granger cause of X. When all of them are equal to zero, there is no causality between the variables (Kónya, 2006). Using Akaike and Schwarz information criteria (ACI and SCI), one can determine the optimal lag lengths, which represent mly_1, mly_2 and mlx_1, and mlx_2. In Kónya’s (2006) causality test, a country-specific bootstrap table of critical values is used instead of asymptotic table critical values.

4. Empirical Results

4.1. Results of Cross-Sectional Dependence and Homogenous Tests

Before analyzing the relationships between the variables, cross-sectional dependence and homogeneity have to be tested, and the causality and cointegration tests should be performed based on the results of the cross-sectional dependence and heterogeneity. Table 1 shows the results of the cross-sectional dependence and homogeneity tests.

Table 1. Results of Cross-Sectional Dependence and Homogeneous Tests

Test	Statistic	P-value
LM	51.10***	0.00
CD_{LM}	4.64***	0.00
CD	5.22***	0.00
LM_{adj}	6.66***	0.00
$\widehat{\Delta}$	8.95***	0.00
$\widehat{\Delta}_{adj}$	10.00***	0.00

*** significant at 1% level.

According to the statistics of the LM, $CD_{LM,}$ CD and LM_{adj} tests, there is cross-dependence among the countries at a 1% significance level. The presence of cross-sectional dependence is expected between these seven countries which are the most industrially developed countries of the world. In this sense, any energy or growth shock in one of the G7 countries affects the other countries, too. The statistics of the $\widehat{\Delta}$ and $\widehat{\Delta}_{adj}$ tests show that there is heterogeneity at a 1% significance level. Therefore, we used Kónya's (2006) bootstrap panel Granger causality test which takes account of the cross-dependence and heterogeneity while examining the relationship between energy consumption and economic growth.

4.2. Results of Kónya Bootstrap Panel Granger Causality Test

Kónya's (2006) bootstrap panel Granger causality test was performed to test the relationships between renewable and nonrenewable energy consumption and economic growth with T=19 for each G7 country. The optimal lag length was found by using the SIC information criteria taking a maximum lag of 3.

Table 2. Results of Kónya Bootstrap Panel Granger Causality Test

Country	REC→GDP				GDP→REC			
	Statistic	Critical Values			Statistic	Critical Values		
		1%	5%	10%		1%	5%	10%
Canada	0.04	50.29	30.44	21.83	3.90	28.49	18.56	14.67
France	**6.75***	16.86	9.20	6.30	**3.72****	4.27	2.48	1.79
Germany	**53.17****	53.69	35.27	27.57	0.23	16.02	8.88	6.22
Italy	**11.73****	16.93	10.23	7.24	**19.12****	21.91	15.08	12.06
Japan	**15.63****	22.77	10.55	6.81	0.17	9.94	4.98	3.30
UK	**7.67***	14.96	8.30	6.19	**15.80*****	8.27	6.19	5.33
US	5.00	40.71	24.94	18.27	12.48	53.20	35.48	24.32

***Significant at 1% level; **significant at 5% and * significant at 10% level. k is the optimal lag length selected by Schwarz information criteria (SIC). Bootstrap critical values are based on 10.000 replications.

Table 2 shows the causality relationships between renewable energy consumption and economic growth. According to Table 2, there is a bidirectional causality in France, Italy and the UK, which confirms the validity of the feedback hypothesis for these countries. We also found a unidirectional causality running from renewable energy consumption to economic growth for Japan and Germany which supports the growth hypothesis. Implementation of energy conservation policies will damage economic growth in France, Italy, the UK, Japan and Germany.

Table 3. Results of Kónya Bootstrap Panel Granger Causality Test

Country	PEC→GDP				GDP→PEC			
	Statistic	Critical values			Statistic	Critical Values		
		1%	5%	10%		1%	5%	10%
Canada	**15.73*****	7.23	3.67	2.45	0.44	35.52	24.41	19.80
France	0.67	22.15	13.58	10.47	0.00	25.37	17.96	14.55
Germany	4.41	20.05	10.02	6.03	**14.25****	23.48	12.83	9.22
Italy	13.92	59.62	38.17	30.92	11.77	56.73	32.59	23.51
Japan	**3.79****	6.93	3.70	2.59	**12.23*****	9.67	5.48	3.83
UK	0.97	12.60	7.76	5.73	**8.77***	15.55	10.43	8.57
US	**7.39*****	5.59	2.99	2.02	0.01	26.02	16.71	13.22

***Significant at 1% level; **significant at 5% and * significant at 10% level. k is the optimal lag length selected by Schwarz information criteria (SIC). Bootstrap critical values are based on 10.000 replications.

Table 3 shows the causality relationships between non-renewable energy consumption and economic growth. According to the table, there is a bidirectional causality for Japan which confirms the validity of the feedback hypothesis for this country. We also found a unidirectional causality running from economic growth to nonrenewable energy consumption for Germany and the UK which supports the conservation hypothesis for these countries. There is also a unidirectional causality from nonrenewable energy consumption to economic growth in Canada and the US. This finding confirms the validity of the growth hypothesis for these countries. The neutral hypothesis which states there is no causality between two variables is valid in Canada and the US for renewable energy consumption and in Italy and France for nonrenewable energy consumption. Policies encouraging nonrenewable energy consumption may support economic growth in Canada, Japan and the US. In terms of the relationship between renewable energy consumption and economic growth, the validity of the growth hypothesis was confirmed for two of the seven countries, while the validity of the feedback hypothesis was confirmed for two countries. In terms of the causality relationship between nonrenewable energy consumption and economic growth, the growth hypothesis was found to be valid for two of the seven countries, while the conservation hypothesis was valid for two countries, and the feedback hypothesis was valid for one country. In terms of the causality relationship between both types of energy consumption and economic growth, the validity of the growth hypothesis was confirmed for four countries, and the validity of the feedback hypothesis was confirmed for four countries.

5. Conclusion

This study examined the relationships between renewable and nonrenewable energy consumption and economic growth for G7 countries using Kónya's (2006) bootstrap panel Granger causality test that takes account of cross-sectional dependence and heterogeneity. First, cross-sectional dependence and heterogeneity tests were performed. Their results indicated that the countries have different structures and any energy and economic growth shock in any of the countries could affect other G7 countries. The results of the causality test confirmed the validity of the feedback hypothesis for Japan. This validation was that, the conservation hypothesis for the UK and Germany and the growth hypothesis for Canada and the US reflect a relationship between nonrenewable energy consumption and economic growth. In terms of the relationship between renewable energy consumption and economic growth, the feedback hypothesis was found to be valid in France, Italy and the United Kingdom, while the growth hypothesis was valid in Japan and Germany. The findings also confirmed the validity of the neutral hypothesis for France and Italy for nonrenewable energy consumption and for Canada and the US for renewable energy consumption.

In each of the G7 countries, renewable or nonrenewable sources of energy interact with economic growth. The findings show that energy conservation policies affect economic growth of these countries adversely. Therefore, energy policies made in the G7 countries are of high importance for their economic growth. For these countries trying to reduce their greenhouse gas emissions, encouraging the use of renewable energy sources is important for increasing the environmental quality.

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