Causal relationship between nuclear energy consumption and economic growth in G6 countries: Evidence from panel Granger causality tests

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Abstract:

Looking at the recent nuclear accident in Fukushima, Japan, the consequences were not just environmental or economic. The accident was a big hit to the reputation and trust in nuclear power generation making a number of countries reconsider the nuclear energy as an option. The recent financial crisis might have limited even more the developed countries from the necessary capital to invest in expensive power options but this might change in the future if the positive environmental effects of the nuclear power can be proven substantial. The purpose of this paper is to analyse the causal link between nuclear energy consumption and economic growth for six developed countries over the period from 1971 to 2011.Granger causality procedure based on Meta-analysis in heterogeneous mixed panels is used to allow for cross-sectional dependency and heterogeneity across countries. The empirical findings for the overall panel support the presence of unidirectional causality running from economic growth to nuclear energy consumption across the G-6 countries. However, in the case of UK we find a bidirectional causality running from nuclear energy consumption to economic growth; while the results for Germany confirm the growth hypothesis and for the rest of the countries the neutrality hypothesis.

Keywords: Nuclear energy consumption; GDP; Granger Causality; heterogeneous mixed panels

JEL Codes : C12, C33, Q4

1. Introduction

Energy plays a crucial role in the development process of a country. It provides electricity for various industries which help with production in the economy and in turn generate economic growth. According to previous studies, energy consumption has a favourable effect on economic growth in many countries [1,2,3]. Energy has been identified as an important input in the production process and some authors have argued for its inclusion in the production function alongside other factors of production such as land, labour and capital [4,5,6], while other authors see energy as enhancing the productivity of other factors of production [7]. According to Toman and Jemelkova [8], the development of the energy sector is essential for economic development and improved quality of energy services are expected to increase economic productivity.

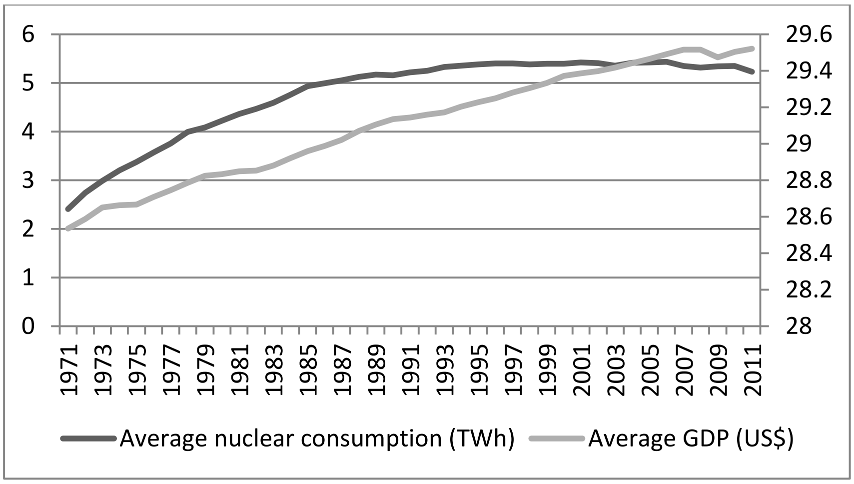
However, as an economy continuously grows and develops both the industrial and residential needs for energy rise. Both developed and developing economies have been facing the dilemma of how to increase the production of energy in order to meet the growing demands for energy [9]. However, increasing energy production presents issues such greenhouse gas emissions generated from using fossil fuels, the volatility of energy prices in world markets, especially oil prices and geopolitical issues concerning the production of fossil fuels and energy security due to the fact that there are energy sources that are concentrated in the volatile Middle East region.

Diversifying the countries' energy sources and finding stable, safe and clean energy supplies have become one of the policy makers' main priorities. The International Energy Agency [10, 11] states that current trends in the supply of energy and its use are patently unsustainable — economically, environmentally and socially. They also state that without decisive action, energy-related emissions of CO_2 will more than double by 2050 and increased oil demand will heighten concerns over the security of supplies [11]. Therefore continuing on the current energy path, without any adequate change in government policy by the main energy consuming countries would result in an increasing dependency on fossil fuels which will have disastrous consequences for climate change, and hence have an effect on economic growth.

To avoid doing so, many countries have started switching to cleaner alternatives (such as nuclear, hydropower, natural gas and wind power) that will assist in covering the increasing demand; reducing the dependence on imported oil; minimizing the effect of price volatility that is associated with importing these fossil fuels; reducing greenhouse gas emissions and increasing their supply of secure energy. The U.S. Energy Information Administration's (EIA), in their recently released International Energy Outlook 2013 [12] stated that renewable energy and nuclear power are the world's fastest-growing energy sources, each increasing 2.5% per year. Nuclear energy is considered a virtually carbon free source of energy and one of the solutions to global warming and energy security in the future [13,14]. Opposition to the use of nuclear power argues that the option is not viable or preferable due to the high costs involved in building nuclear power stations, disposal of nuclear waste, operation safety as well as the threat of nuclear terrorism. Mainly due to the high costs of construction, large scale nuclear power plants exist primarily in developed countries such as the G7, with the exception of Italy that has stopped its nuclear power generation since the 1980s.

Figure 1 presents the average GDP and the average nuclear consumption of the G6 countries (G7 minus Italy) for the period from 1970 to 2011.

Figure 1: Average GDP and nuclear energy consumption of G6 countries from 1970 to 2011



Source: IMF [15] and BP [16]

It can be observed that both variables have a positive trend through the years; however, the nuclear consumption increases at decreasing rates and stabilizes from the beginning of 1990s. It can be said that the full nuclear energy capacity of the G6 countries has been reached and the countries have stopped investing in this form of energy generation in the 2000s.

Looking at the recent nuclear accident in Fukushima, Japan, the consequences were not just environmental or economic. The accident was a big hit to the reputation and trust in nuclear power generation making a number of countries reconsider the nuclear energy as an option. For example, the German government promised that they will shut down all their nuclear plants by 2022 while eight of the seventeen reactors closed down following large anti-nuclear protests after the Fukushima disaster in 2011. In addition, substitutes such as natural gas have become more attractive for investors due to their lower costs of construction and maintenance [17].

The question here however is whether the nuclear power is a factor affecting the economic growth positively or if it comes as a “by-product” of the increase in economic growth and development of the countries. The recent financial crisis might have limited the developed countries from the necessary capital to invest in expensive power options but this might change in the future if the positive environmental effects of the nuclear power can be proven substantial.

Hence, the purpose of this paper is to examine the relationship between economic growth measured in GDP and nuclear energy generation for the G6 countries for the period from 1971 to 2011. The existence and direction of the causality have numerous policy implications that will be discussed here. As discussed before, in the recent history a shock in one country (Japan in 2011) had an impact to other countries even though they are significantly different from each other when it comes to geographical, political and socioeconomic conditions. These two issues (heterogeneity of countries as well as cross-sectional dependency) should be taken into account when proceeding with the econometric analysis. To do so in this paper, we employ the panel causality methodology as proposed by Emirmahmutoglu and Kose [18] in which they propose a bootstrap Granger causality procedure based on meta analysis in heterogeneous mixed panels. This methodology has the advantage of accounting for both heterogeneity and cross sectional dependency which has been shown to induce bias estimates [19].

The rest of the paper proceeds as follows: Section 2 provides an overview of the various energy consumption-growth hypotheses and the relevant literature. Section 3 discusses the data, methodology; while Section 4 presents the empirical results. Section 5 provides concluding remarks.

2. Brief literature review on the nexus between nuclear energy and economic growth

There are currently four testable hypotheses regarding the direction of causality between energy consumption and economic growth, as follows.

- Growth hypothesis: Unidirectional causality from energy consumption to economic growth. This is an indication that the economy is energy dependent although energy conservation policies may have an adverse impact on economic growth.
- Conservation hypothesis: Unidirectional causality running from economic growth to energy consumption. This implies that economic growth is the dynamic which causes the consumption of energy sources and suggests that energy conservation policies do not adversely impact economic growth.
- Feedback hypothesis: Bidirectional causality between energy consumption and economic growth which indicates interdependence and possible complementarities between energy consumption and economic growth. This complementary relationship means that fluctuations in economic growth may be transmitted back to energy consumption and vice versa.
- Neutrality hypothesis: Absence of causality in any direction between energy consumption and economic growth, implying that energy policies will have an insignificant impact on economic growth.

The current literature on the relationship between nuclear energy consumption and economic growth is vast but there is currently no consensus with regard to the direction of causality between nuclear energy consumption and economic growth. Yoo and Jung [20] in the case of Korea provide support for unidirectional causality from nuclear energy consumption to economic growth. Payne and Taylor [21] for the United States, Yoo and Ku [22] for Argentina and Germany in contrast found no causality between energy consumption and economic growth; bidirectional causality in the case of Switzerland and unidirectional causality running from economic growth to nuclear energy consumption when studying France and Pakistan. Wolde-Rufael [23] found that for India there is unidirectional causality running from nuclear energy consumption to economic growth. Apergis and Payne [24] use a panel cointegration and panel causality study, found bidirectional causality running between nuclear energy consumption and economic growth supporting the feedback hypothesis associated with the relationship between nuclear energy consumption and economic growth. Lee and Chiu [25] considered six industrialised countries and found bidirectional causality for Canada, Germany, and United Kingdom ; an absence of causality for France and the U.S.

and unidirectional causality running from economic growth to nuclear energy consumption for Japan. Wolde-Rufael and Menyah [26] analyzed the direction of causality in nine industrialised countries and supported a unidirectional causality running from nuclear energy consumption to economic growth in Japan, Netherlands and Switzerland; the opposite unidirectional causality running from economic growth to nuclear energy consumption in Canada and Sweden; and a bidirectional causality running between economic growth and nuclear energy consumption in France, Spain, the United Kingdom and the United States. In contrast to the findings of Lee and Chiu [25], they found unidirectional causality running from nuclear energy to economic growth for Japan, Netherlands, and Switzerland; unidirectional causality from economic growth to nuclear energy for Canada and Sweden; bidirectional causality between nuclear energy and economic growth for France, Spain, the UK, and the USA. Apergis et al. [27] found evidence in support of the growth hypothesis in the short-run and on the feedback relationship in the long run for nineteen industrialized and newly developing countries.

Wolde-Rufael and Menyah [26] argued that nuclear energy consumption alone is not enough to spur economic growth. Consequently the null hypothesis of non-causality in the bivariate system might be rejected when relevant variables are omitted from the estimations[1]. To overcome this problem they included capital and labour as additional variables. However, including other variables might alter the pure causality and its existence between the two variables in question. Hence, in this paper at first stage we identify the relationship in a bivariate context firstly.

3. Methodology and Data

3.1 Empirical Methodology

One important issue in a panel causality analysis is to take into account possible cross-sectional dependency amongst countries. This is because a high degree of economic and financial integration makes a country sensitive to economic shocks in another country. Cross-sectional dependency may play an important role in detecting causal linkages between nuclear energy consumption and economic growth.

[1] Many studies have suffered from the omitted variable bias since inputs such as labour and investment are important determinants of economic growth in the Solow growth model [28].

The second issue before carrying out causality tests is to find out whether the slope coefficients are treated as homogenous or heterogeneous to impose causality restrictions on the estimated parameters. As pointed out by Granger [29], the causality from one variable to another variable by imposing the joint restriction for the panel is a strong null hypothesis. Furthermore, as Breitung [30] contends the homogeneity assumption for the parameters is not able to capture heterogeneity due to region specific characteristics. In the nuclear energy consumption and economic growth nexus – as in many economic relationships – while there may be a significant relationship in some countries, vice versa may also be true in some other countries.

Given the above consideration before we conduct tests for causality, we start with testing for cross-sectional dependency, followed by slope homogeneity across countries. Then, we decide to which panel causality method should be employed to appropriately determine the direction of causality between nuclear energy consumption and economic growth in the six countries. In what follows, we outline the essentials of econometric methods used in this study.

3.1.1 Testing for cross-sectional dependency

To test for cross-sectional dependency (CD), we employ the Lagrange multiplier (LM) test of Breusch and Pagan [31]. The procedure to compute the LM test requires the estimation of the following panel data model:

$$y_{it} = \alpha_i + \delta_i t + \beta_i' x_{it} + u_{it} \qquad (1)$$

Where i=1,…, N for each country in the panel and t=1,…,T refers to the time period, x_{it} is $k\times 1$vector of explanatory variables which includes nuclear energy consumption. Parameters α_i and $\delta_i t$ allow for country specific fixed effects and deterministic trends. β_i represents the slope coefficients which are allowed to vary across states and u_{it}represents the estimated residuals which indicate deviations from the long-run relationship

The null hypothesis in the LM test is of no cross-section dependence- $H_o : Cov(u_{it}, u_{jt}) = 0$ for all t and i≠j-is tested against the alternative hypothesis of cross-section dependence H_A: Cov (u_{it}, u_{jt})≠0, for at least one pair of i≠j.

$H_1 : Cov(u_{it}, u_{jt}) \neq 0$, for at least one pair of $i \neq j$. To test the hull hypothesis, Breusch and Pagan (1980) developed the LM test statistic as:

$$LM = T\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{p}_{ij}^2 \qquad (2)$$

where $\hat{\rho}_{ij}$ is the sample estimate of the pair-wise correlation of the residuals from Ordinary Least Squares (OLS) estimation of equation (1) for each i . Under the null hypothesis of no cross-section dependency the statistic has chi-square asymptotic distribution with $N(N-1)/2$ degrees of freedom. This is valid for N relatively small and T sufficiently large.

However, the CD test is subject to decreasing power in certain situations population average pair-wise correlations are zero, although the underlying individual population pair-wise correlations are non-zero [32]. In addition, for stationary dynamic panel data models the CD test fails to reject the null hypothesis when the factor loadings have zero mean in the cross-sectional dimension. In order to deal with these problems, Pesaran et al. (2008) proposes a bias-adjusted test which is a modified version of the LM test by using the exact mean and variance of the LM statistic. The bias-adjusted LM test is:

$$LM_{adj} = \sqrt{\left(\frac{2T}{N(N-1)}\right)}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{p}_{ij}\frac{(T-k)\hat{p}_{ij}^2 - \mu_{Tij}}{\sqrt{v_{Tij}^2}} \qquad (3)$$

Where μ_{Tij} and v_{Tij}^2 represent the mean and variance of$(T-k)\hat{p}_{ij}^2$, that are provided in Pesaran et al. [32]. Under the null hypothesis with first T→∞ and then N→∞, LM_{adj} test is asymptotically distributed as standard normal.

3.1.2 Testing slope homogeneity

Second issue in a panel data analysis is to decide whether or not the slope coefficients are homogenous. The causality from one variable to another variable by imposing the joint restriction for whole panel is the strong null hypothesis [29]. Moreover, the homogeneity assumption for the parameters is not able to capture heterogeneity due to region specific characteristics [30].

We test the null hypothesis of slope homogeneity -H_0: $\beta_i = \beta$ for all i- against the alternative hypothesis of no homogeneity (heterogeneity) - H_1 : $\beta_i \neq \beta_j$ for a non-zero fraction of pair-wise slopes i≠j- by applying the standard F test. This test is valid when the cross-section dimension (N) is relatively small and the time dimension (T) is large, the explanatory variables are strictly exogenous, and the error variances are homoscedastic. By relaxing homoscedasticity assumption in the *F* test, Swamy [33] developed the slope homogeneity test on the dispersion of individual slope estimates from a suitable pooled estimator. However, both the *F* and Swamy's test require panel data models where *N* is small relative to *T* [24]. Pesaran and Yamagata [34] proposed a standardized version of Swamy's test (the so-called $\tilde{\Delta}$ test) for testing slope homogeneity in large panels. The $\tilde{\Delta}$ test is valid as $(N,T)\rightarrow\infty$ without any restrictions on the relative expansion rates of N and T when the error terms are normally distributed. In the $\tilde{\Delta}$ test approach, first step is to compute the following modified version of the Swamy's test:

$$\tilde{S}=\sum_{i=1}^{N}\left(\hat{\beta}_i-\tilde{\beta}_{WFE}\right)'\frac{x_i'M_\tau x_i}{\tilde{\sigma}_i^2}\left(\hat{\beta}_i-\tilde{\beta}_{WFE}\right) \tag{4}$$

where $\hat{\beta}_i$ is the pooled OLS estimator, $\tilde{\beta}_{WFE}$ is the weighted fixed effect pooled estimator, M_τ is an identity matrix, the $\tilde{\sigma}_i^2$ is the estimator of σ_i^2.[2] Then the standardized dispersion statistic is developed as:

$$\tilde{\Delta}=\sqrt{N}\left(\frac{N^{-1}\tilde{S}-k}{\sqrt{2k}}\right) \tag{5}$$

Under the null hypothesis with the condition of $(N,T)\rightarrow\infty$ so long as $\sqrt{N}/T\rightarrow\infty$ and the error terms are normally distributed, the $\tilde{\Delta}$ test has asymptotic standard normal distribution. The small sample properties of $\tilde{\Delta}$ test can be improved under the normally distributed errors by using the following bias adjusted version:

$$\tilde{\Delta}_{adj}=\sqrt{N}\left(\frac{N^{-1}\tilde{S}-E(\tilde{z}_{it})}{\sqrt{\mathrm{var}(\tilde{z}_{it})}}\right) \tag{6}$$

where the mean $E(\tilde{z}_{it})=k$ and the variance $\mathrm{var}(\tilde{z}_{it})=2k(T-k-1)/T+1$.

[2] In order to save space, we refer to Pesaran and Yamagata [34] for the details of estimators and for Swamy's test

3.1.3 Panel Granger causality analysis

Emirmahmutoglu and Kose [18] propose a causality test in heterogenous mixed panels based on the meta analysis of Fisher [35]. They extended the lag augmented VAR (LA-VAR) approach by Toda and Yamamoto [36], which uses the level VAR model with extra *dmax* lags to test Granger causality between variables in heterogeneous mixed panels. Consider a level VAR model with $k_i + dmax_i$ lags in heterogeneous mixed panels:

$$x_{i,t} = \mu_i^x + \sum_{j=1}^{k_i + d\max_i} A_{11,ij} x_{i,t-j} + \sum_{j=1}^{k_i + d\max_i} A_{12,ij} y_{i,t-j} + \mu_{i,t}^x \tag{7}$$

$$y_{i,t} = \mu_i^y + \sum_{j=1}^{k_i + d\max_i} A_{21,ij} x_{i,t-j} + \sum_{j=1}^{k_i + d\max_i} A_{22,ij} y_{i,t-j} + \mu_{i,t}^y \tag{8}$$

where i $(i = 1, \ldots., N)$ denotes individual cross-sectional units and t $(t = 1, \ldots., T)$ denotes time periods,μ_i^x and μ_i^y are two vectors of fixed effects, $u_{i,t}^x$, $u_{i,t}^y$ are column vectors of error terms, k_i is the lag structure which is assumed to be known and may differ across cross-sectional units, and $dmax_i$ is the maximal order of integration in the system for each *i.* Following the bootstrap procedure by Emirmahmutoglu and Kose [18], testing causality from x to y_i's summarized as follows:

1. Determine the maximal order $dmax_i$ of integration of variables in the system for each cross-section unit based on the Augmented Dickey Fuller (ADF) unit root test and select the lag orders k_is via information criteria (AIC or SBC) by esteeming the regression (2) using the OLS method.

2. Re-estimate equation (8) using the $\boldsymbol{dmax_i}$ and k_i under the non-causality hypothesis and calculate the residuals for each individual.

$$\hat{u}_{i,t}^y = y_{i,t} - \hat{u}_i^y + \sum_{j=1}^{k_i + d\max_i} \hat{A}_{21,ij} x_{i,t-j} + \sum_{j=1}^{k_i + d\max_i} \hat{A}_{22,ij} y_{i,t-j} \tag{9}$$

3. Residuals are centered using Stine's (1987) suggestion, i.e.,

$$\tilde{u}_t = \hat{u}_t - (T - k - l - 2)^{-1} \sum_{t=k+l+2}^{T} \hat{u}_t \tag{10}$$

where $\boldsymbol{\hat{u}_t} = (\boldsymbol{\hat{u}_{1t}}, \boldsymbol{\hat{u}_{2t}}, \ldots, \boldsymbol{\hat{u}_{Nt}})'$, $\boldsymbol{k} = \mathbf{max}(\boldsymbol{k_i})$ and $\boldsymbol{l} = \mathbf{max}(\boldsymbol{dmax_i})$. Next, we develop the $[\boldsymbol{\tilde{u}_{i,t}}]_{\boldsymbol{N \times T}}$from these residuals.We select randomly a full column with replacement from the matrix at a time to preserve the cross covariance structure of the errors. We denote the bootstrap residuals as $\tilde{\boldsymbol{u}}_t^*$where $(\boldsymbol{t} = \mathbf{1}, \ldots, \boldsymbol{T})$.

4. A bootstrap sample of $\boldsymbol{y_i}$'s generated under the null hypothesis, i.e

$$y_{i,t}^* = \hat{\mu}_i^y + \sum_{j=1}^{k_i + d\max_i} \hat{A}_{21,ij} x_{i,t-j} + \sum_{j=1}^{k_i + d\max_i} \hat{A}_{22,ij} y_{i,t-j}^* + u_{i,t}^* \tag{11}$$

where $\hat{\boldsymbol{\mu}}_i^y$, $\hat{\boldsymbol{A}}_{21,ij}$ and $\hat{\boldsymbol{A}}_{22,ij}$ are the estimations from step 3.

5. For each individual, Wald statistics are calculated to test for the non-causality null hypothesis by substituting$\boldsymbol{y}_{i,t}^*$ for $\boldsymbol{y}_{i,t}$ and estimating equation (8) without imposing any parameter restrictions.

6. Using individual p-values (p_i) that correspondto the Wald statistic of the i^{th} individual cross-section, the Fisher test statistic ($\boldsymbol{\lambda}$) is obtained as follows:

$$\lambda = -2\sum_{i=1}^{N} \ln(p_i) \qquad \mathrm{i} = 1,\ldots\ldots, \mathrm{N} \tag{12}$$

7. The bootstrap empirical distribution of the Fisher test statistics are generated by repeating steps 3 to 5 10000 times and specifying the bootstrap critical values by selecting the appropriate percentiles of these sampling distributions.

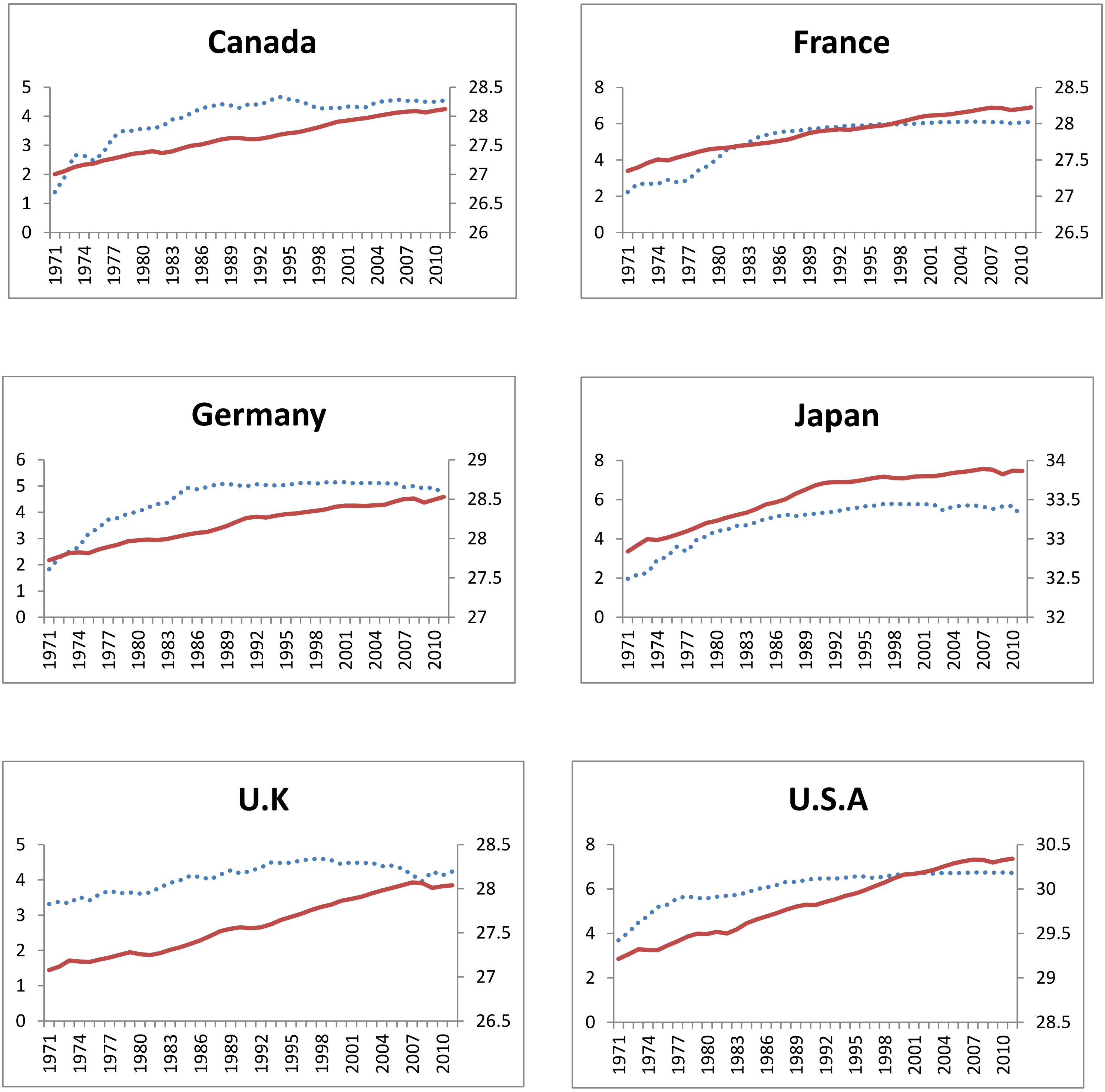
Using simulation studies, Emirmahmutoglu and Kose [18] demonstrate that the performance of LA-VAR approach under both the cross-section independency and the cross-section dependency seem to be satisfactory for the entire values of T and N.

3.2 Data

In order to examine the causality between nuclear energy consumption and economic growth we use annual data for the period from 1971 to 2011 for six countries: Canada, France, Germany, Japan, United Kingdom (U.K), and the United States of America (U.S.A). These countries represent the world's largest economies and nuclear energy consumers. Economic growth is proxied by the growth rate of the real Gross Domestic Product (GDP) obtained from the IMF's International Financial Statistics [15]. The use of GDP instead of gross national product is more appropriate due to the fact that the nuclear energy consumption depends on goods and services produced within the country, not outside the country [22]. Nuclear energy consumption measured in Terawatt-hours (TWh) is obtained from BP Statistical Review of World Energy June 2013 [16]. Both variables are expressed in their natural logarithms.

Figure 2 shows the trend between nuclear energy consumption and real GDP for the six countries over the period 1971-2011. Different patterns emerge from these figures, confirming the unclear relationship between the two variables. Although in all of them a positive trend is observed in both variables, in some of them such as in Canada, the increase in nuclear energy consumption kept rising much longer before it stabilized than in for example Germany, where the nuclear energy consumption was more or less stable for more than half of the sample period.

Figure 2 : Nuclear Energy Consumption and Economic Growth : 1971-2011



Note : Nuclear Energy Consumption (dotted line, left axis) and real GDP (solid line, right axis)

4. Empirical results

To investigate the existence of cross-sectional dependency we used four different tests (CD_{BP} ,CD_{LM} , CD, LM_{adj}). The results for testing for cross section dependency and homogeneity are reported in Table 1. From these results we can conclude that the null hypothesis of no cross-sectional dependency is rejected in favour of the alternative of cross-sectional dependency at 5% and 10% levels of significance, depending on the specific test. This implies that a shock that occurs in one of these countries spills over onto other countries hence we should take into account this information when examining the causal links between nuclear energy consumption and economic growth.

Table 1 Cross-sectional Dependence and Homogeneous Tests results

Cross-sectional dependency tests	
CD_{BP}	188.324***
CD_{LM}	31.644**
CD	13.332***
LM_{adj}	95.8056***
Slope homogeneity tests	
$\tilde{\Delta}$	23.0689***
$\tilde{\Delta}_{adj}$	0.5977
Swamy Shat	53.6612***

Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

The test for slope homogeneity rejects the null hypothesis of no heterogeneity in favour of the alternative hypothesis; therefore country specific characteristics should be taken into account. Furthermore this implies that the panel causality analysis that imposes the homogeneity restriction on the variables of interest will result in misleading inferences.

Having determined that there is cross-sectional dependency and slope heterogeneity we can now test for Granger causality between nuclear energy consumption and economic growth. Using the approach by Emirmahmutoglu and Kose [18] based on meta-analysis of Fisher [35] in heterogeneous mixed panels

We begin by examining the stationary properties of the variables for each cross-section employing the Augmented Dickey Fuller (ADF) unit root test and determining the maximum order of integration of the variables ($dmax_i$). The results[3] confirm that the maximum order of integration is one for all countries except France.

The results from the panel Granger causality analysis are reported in Tables 2 and 3 along with the bootstrap critical values.

Table 2: Causality analysis (Schwartz-Bayesian Criterion)

GDP does not Granger cause Nuclear energy Consumption (Schwartz-Bayesian Criterion)			
Country	***Lag length***	***Wald Statistics***	***p-value***
Canada	1	0.598	0.439
France	4	3.221	0.521
Germany	1	5.885**	0.015
Japan	3	5.257	0.154
UK	3	10.205**	0.017
US	1	1.019	0.396
Fisher test value		**Bootstrap Critical value**	
25.538*	10%	5%	1%
	21.754	25.039	32.451

Nuclear Energy Consumption does not Granger cause GDP (Schwartz-Bayesian Criterion)			
Country	***Lag length***	***Wald Statistics***	***p-value***
Canada	1	0.471	0.493
France	4	1.584	0.812
Germany	1	0.218	0.640
Japan	3	2.123	0.547
UK	3	10.154**	0.017
US	1	0.670	0.413
Fisher test value		**Bootstrap Critical value**	
13.814	10%	5%	1%
	21.380	24.268	32.061

Notes: 1. ***, **and * indicate significance at the 1%, 5% and 10% respectively.
2. Bootstrap critical values are obtained from 10,000 replications.

[3] The results of the ADF tests can be provided by the authors upon request.

Table 3: Akaike Information Criterion

GDP does not Granger cause Nuclear energy Consumption (Akaike Information Criterion)			
Country	*Lag length*	*Wald Statistics*	*p-value*
Canada	4	5.161	0.271
France	4	3.221	0.521
Germany	4	8.674**	0.070
Japan	3	5.257	0.154
UK	3	10.205**	0.017
US	3	2.970	0.396
Fisher test value	**Bootstrap Critical value**		
22.991*	10%	5%	1%
	22.562	26.111	34.501

Nuclear Energy Consumption does not Granger cause GDP (Akaike Information Criterion)			
Country	*Lag length*	*Wald Statistics*	*p-value*
Canada	4	1.723	0.787
France	4	1.584	0.812
Germany	4	3.036	0.552
Japan	3	2.123	0.547
UK	3	10.154**	0.017
US	3	3.833	0.280
Fisher test value	**Bootstrap Critical value**		
13.951	10%	5%	1%
	22.863	26.317	35.464

Notes: 1. ***, **and * indicate significance at the 1%, 5% and 10% respectively.
2. Bootstrap critical values are obtained from 10,000 replications.

The overall panel results confirm that there is a unidirectional causality running from GDP to nuclear energy growth under both AIC and SIC while the opposite direction causality does not hold.

The individual country results remain contradictory to each other. The neutrality hypothesis seems to be confirmed for the majority of the G6 countries (Canada, France, Japan and US) with two exceptions. These results come in line with Yoo and Ku [22]. For the UK, the feedback hypothesis is confirmed showing that there is a bidirectional causality between the two variables while for Germany the overall panel result is confirmed: causality running from

GDP to nuclear energy consumption. The results for UK are consistent with the findings by Lee and Chiu [25] who found bidirectional causality between nuclear energy consumption and economic growth.

5. Conclusion

Over the years, alternative sources of energy to fossil fuels have emerged as a solution to alleviate the growing concerns over greenhouse gas emissions, the volatility of energy prices in world markets, and energy security issues. Among them, the nuclear energy power had been considered a more environmentally-friendly alternative until the recent Fukushima accident in 2011. Since then, nuclear energy became a less popular option. Still, due to its high plant construction and maintenance costs, it seems that nuclear energy is preferred by more advanced economies.

In this paper the causal relationship between nuclear energy consumption and economic growth was examined for six countries (G7 with the exception of Italy that does not use nuclear power since the 1980s) using panel Granger causality analysis, taking into account cross-sectional dependency and heterogeneity across the countries for the period 1971-2011.

The panel result is favourable to the unidirectional causality running from economic growth to nuclear energy consumption which supports the conservation hypothesis. This implies that economic growth is the dynamic which causes the consumption of nuclear energy sources and suggests that energy conservation policies do not adversely impact economic growth. This finding is also in support of the argument that wealthier economies can afford the construction and maintenance cost of nuclear power generation and hence, the higher the economic growth the higher the nuclear energy consumption. This finding was also supported for Germany when looking at the cross-sections individually.

The individual country results provided support for the neutrality hypothesis indicating that for the majority of the countries (Canada, France, US and Japan), nuclear energy does not get affected by the economic growth level. Looking at the sample period, the nuclear energy consumption has been stabilised during the last decade regardless of the growth –minor – fluctuations. Hence, policies for nuclear power generation or reducing it due to safety concerns will not affect the countries' economic growth.

In the case of UK, the feedback hypothesis was confirmed showing possible complementarities between nuclear energy consumption and economic growth. This is supported by the fact that the government of the UK recently announced that its first new nuclear power station in over a generation will be under construction to provide electricity and lower the country's dependence on fossil fuels [37].

The safety of nuclear energy is however a concern for the environment and hence many countries are diversifying into other more stable, clean and reliable forms of renewable energy and changing their energy polices in order to achieve their goals. Further research should examine the substitutes to nuclear energy chosen by countries internationally and how they may affect the economic growth and development apart from the expected environmental effects.

References

[1] Belke, A., Dobnik, F., Dreger, C. Energy Consumption and Economic Growth: New Insights Into The Cointegration Relationship. *Energy Economics* **2011; 33(5)**, pp. 782–789.

[2] Francis, B. M., Moseley, L., Iyare, S. O. Energy Consumption And Projected Growth In Selected Caribbean Countries. *Energy Economics* **2010; 29(6)**, pp. 1224–1232.

[3] Squali, J. Electricity Consumption And Economic Growth: Bounds And Causality Analysis Of OPEC Members. *Energy Economics* **2006; 29(6)**, 1192–1205.

[4] Ebohon, O. J. Energy, Economic Growth and causality in Developing Countries: A Case Study of Tanzania and Nigeria, *Energy Policy* **1996; 24 (5)**, pp. 447-453.

[5] Chontanawat, J. , Hunt, L. C. and Pierse, R.. Causality between Energy Consumption and GDP: Evidence from 30 OECD and 78 Non-OECD Countries, **2006.** Discussion Paper no. 113, Surrey Energy Economics Centre, Department of Economics, University of Surrey.

[6] Alam, M. S. Economic Growth with Energy. **2006.** MPRA paper 1260, University Library of Munich, Germany.

[7] Cheng, B. S. and Lai, T. W.. An Investigation of Co-integration and Causality between Energy Consumption and Economic Activity in Taiwan. *Energy Economics* **1997; 19,** pp. 435-444.

[8] Toman, M. and Jemelkova, B. Energy and Economic Development: An Assessment of the State of Knowledge. **2003.** Discussion Paper no. 03-13, Washington D. C. : Resources for the Future.

[9] Balat, M. Energy consumption and economic growth in Turkey during the past two decades. *Energy policy* **2008;** pp 118-127.

[10] International Energy Agency (IEA). *Renewables for Power Generation.* **2003** OECD/IEA, Paris.

[11] International Energy Agency (IEA). *Transport, Energy and CO2. Moving towards mobility.* **2009.** OECD/IEA, Paris.

[12] US Energy Information Administration (EIA). *International Energy Outlook.* **2013** US EIA, Washington.

[13] Elliot, D., Nuclear or Not? Does nuclear power have a place in sustainable energy future? **2007.** Palgrave Macmillan, Houndmills, Basingstoke

[14] Ferguson, C.D., Nuclear Energy: Balancing benefits and risks. **2007.** Council of Foreign Relations, CRS No. 28.

[15] International Monetary Fund (IMF). International Financial Statistics. **2013.** IMF, Paris.

[16] BP. Statistical review of world energy. **2012.** Available at: http://www.bp.com/liveassets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2011/STAGING/local_assets/pdf/statistical_review_of_world_energy_full_report_2012.pdf

[17] Broder, J.M. The Year of Peril and Promise in Energy Production. **2011.** Available at: http://www.nytimes.com/2011/10/11/business/energy-environment/the-year-of-peril-and-promise-in-energy-production.html?src=un&feedurl=http%3A%2F%2Fjson8.nytimes.com%2Fpages%2Fbusiness%2Fglobal%2Findex.jsonp&_r=2&

[18] Emirmahmutoglu, F. and Kose, N., Testing for Granger causality in heterogeneous mixed panels. *Economic Modelling* **2011; 28**, pp. 870-876.

[19] Pesaran, M. H. Estimation and Inference in Large Heterogeneous Panels with Multifactor Error Structure. *Econometrica* **2006; 74 (4)**, pp. 967-1012.

[20] Yoo, S.H., Jung, K.O. Nuclear energy consumption and economic growth in Korea. *Progress in Nuclear Energy* **2005; 46 (2)**, pp. 101–109.

[21] Payne, J.E., Taylor, J.P. Nuclear energy consumption and economic growth in the US: an empirical note. *Energy Sources, Part B: Economics, Planning, and Policy* **2010; 5 (3),** pp. 301–307.

[22] Yoo, S.H., Ku, S.J., Causal relationship between nuclear energy consumption and economic growth: a multi-country analysis. *Energy Policy* **2009; 37**, pp. 1905–1913.

[23] Wolde-Rufael, Y. Bounds test approach to cointegration and causality between nuclear energy consumption and economic growth in India. *Energy Policy* **2010; 38,** pp. 52–58.

[24] Apergis , N., Payne, J.E.. A panel study of nuclear energy consumption and economic growth. *Energy Economics* **2010; 32,** pp. 545–549.

[25] Lee, C.C., Chiu, Y.B. Nuclear energy consumption, oil prices, and economic growth: evidence from highly industrialized countries. *Energy Economics* **2011; 33 (2)**, pp. 236–248

[26] Wolde-Rufael, Y., Menyah, K. Nuclear energy consumption and economic growth in nine developed countries. *Energy Economics* **2010; 32**, pp. 550–556.

[27] Apergis, N., Payne, J.E., Menyah, K., Wolde-Rufael, Y. On the causal dynamics between emissions, nuclear energy, renewable energy and economic growth. *Ecological Economics* **2010; 69 (11)**, pp. 2255–2260.

[28] Aslan, A ,Yildirim,E. Energy consumption and economic growth nexus for 17 highly developed OECD countries: Further evidence based on bootstrap-corrected causality tests. *Energy Policy* **2011; 51,** pp. 985–993.

[29] Granger, C.W.J. Some aspects of causal relationships. *Journal of Econometrics,* **2003; 112**, pp. 69-71.

[30] Breitung, J. A parametric approach to the estimation of cointegration vectors in panel data. *Econometric Reviews* **2005; 24,** pp. 151-173.

[31] Breusch, T. S., and Pagan, A. R. The Lagrange Multiplier test and its applications to model specification in econometrics. *The Review of Economic Studies* **1980; 47(1)**, pp. 239-253.

[32] Pesaran, M. H., Ullah, A. and Yamagata, T. A bias-adjusted LM test of error cross-section independence. *Econometrics Journal* **2008; 11,** pp. 105–127.

[33] Swamy, P.A.V.B.Efficient inference in a random coefficient regression model. *Econometrica* **2007; 38**, pp. 311–323.

[34] Pesaran, M. H. and Yamagata, T. Testing slope homogeneity in large panels. *Journal of Econometrics* **2008; 142,** pp. 50–93.

[35] Fisher, R.A., Statistical Methods for Research Workers, 4th edition. **1932**. Oliver and Boyd, Edinburgh.

[36] Toda, H.Y., Yamamoto, T. Statistical inference in vector autoregressions with possibly integrated processes. *Journal of Econometrics* **1995; 66,** pp. 225-250.

[37] BBC. UK nuclear power plant gets go ahead. **2013**. Available: http://www.bbc.co.uk/news/business-24604218. Last accessed 08 November 2013.