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A panel study of nuclear energy consumption and economic growth

Nicholas Apergis [a], James E. Payne [b,*]

[a] Department of Banking and Financial Management, University of Piraeus, Karaoli and Dimitriou 80, Piraeus, ATTIKI 18534, Greece
[b] Interim Dean and Professor of Economics, College of Arts and Sciences, Illinois State University, Normal, IL 61790-4100, United States

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ABSTRACT

This study examines the relationship between nuclear energy consumption and economic growth for sixteen countries within a multivariate panel framework over the period 1980–2005. Pedroni's (1999, 2004) heterogeneous panel cointegration test reveals there is a long-run equilibrium relationship between real GDP, nuclear energy consumption, real gross fixed capital formation, and the labor force with the respective coefficients positive and statistically significant. The results of the panel vector error correction model finds bidirectional causality between nuclear energy consumption and economic growth in the short-run while unidirectional causality from nuclear energy consumption to economic growth in the long-run. Thus, the results provide support for the feedback hypothesis associated with the relationship between nuclear energy consumption and economic growth.

1. Introduction

In light of the recent concerns over greenhouse gas emissions produced from fossil fuel energy sources, the high volatility of oil and gas prices on international markets, and the geopolitical landscape faced by countries dependent on foreign energy sources, the discussion of nuclear energy is a timely one. According to the *Energy Information Administration*, electricity generation from nuclear power is projected to increase from roughly 2.7 trillion kilowatt hours in 2006 to 3.8 trillion kilowatt hours in 2030 in response to the concerns mentioned. More specifically, as stated in the *International Energy Outlook 2009*, "higher fossil fuel prices allow nuclear power to become economically competitive with the generation from coal, natural gas, and liquids despite the relatively high capital and maintenance costs associated with nuclear power plants. Moreover, higher capacity utilization rates have been reported for many existing nuclear facilities".[1] As noted by Vaillancourt et al. (2008), long-term energy and environmental strategies to meet growing global energy demands have embraced the transition from fossil fuels to renewable or other non-greenhouse gas emitting energy sources.

Nuclear energy is an important energy source in the development of such long-term energy and environmental strategies. Nuclear energy can address global energy needs in regions of the world where energy demand growth is rapid, known gas and oil reserves are likely to be exhausted in a few generations, alternative resources are scarce, energy supply security is a priority, and the reduction in air pollution and greenhouse gas emissions is critical (Fiore, 2006; Toth and Rogner, 2006).[2] However, the prospects for growth in nuclear energy are faced with ongoing controversies, namely, operational safety, radioactive waste disposal, proliferation risk of nuclear material along with the public perception and acceptance of nuclear power (Toth and Rogner, 2006).

An important component in the discussion on nuclear energy as an option for sustainable development is its impact on economic growth. Though the literature on the causal relationship between energy consumption and economic growth is relatively well established, the empirical studies related to nuclear energy consumption and economic growth are rather limited.[3] According to Vaillancourt et al. (2008, p. 2297), there are 441 nuclear power reactors in operation in thirty-one countries around the globe. Given the availability of data and consistency with respect to the time horizon of the study, sixteen of the thirty-one countries are included in this study.[4] Twelve of the sixteen countries which include Belgium, Canada, Finland, France, Japan, Korea, Netherlands, Spain, Sweden, Switzerland, U.K., and the U.S. are categorized as high income by the World Bank. The remaining four countries are categorized as upper middle income (Argentina), lower middle income (Bulgaria), and low income (India and Pakistan). Of these countries, the percentage of total electricity production from nuclear energy varies considerably from a high of 79.13% in France to a low of 6.5% in Argentina.

* Corresponding author. Tel.: +1 309 438 5669.
E-mail addresses: napergis@unipi.gr (N. Apergis), jepayne@ilstu.edu (J.E. Payne).

[1] *International Energy Outlook 2009* (www.eia.doe.gov/oial/ieo/highlights.html).

[2] The International Thermonuclear Experimental Reactor (ITER) project involves the development of a fusion reactor that will emit no carbon gas and overheating along with the quantity of radioactive waste being close to zero (Fiore, 2006).

[3] See Payne (forthcoming) for a survey of the empirical studies on the causal relationship between energy consumption and economic growth across countries.

[4] The following countries that currently produce nuclear energy were excluded from this study given the desire to have a balanced panel with availability and consistency in the data: Armenia, Brazil, China, Czech Republic, Germany, Hungary, Lithuania, Mexico, Romania, Russia, Slovakia, Slovenia, South Africa, Taiwan, and Ukraine.

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Specifically, this study extends the existing literature with the inclusion of more countries than in previous studies as well as examining the causal relationship within a multivariate panel cointegration/error correction framework which combines the cross-section and time series data while allowing for heterogeneity across countries. Indeed, consideration of the implications of nuclear energy for economic growth is relevant in the discussion of the global energy portfolio that can address the current and future economic and environmental concerns about the world's energy supply.

Section 2 briefly overviews the hypotheses related to the causal relationship between energy consumption and economic growth along with a summary of the previous studies on the causal relationship between nuclear energy consumption and economic growth. Section 3 discusses the data, methodology, and empirical results. Concluding remarks are given in Section 4.

2. Energy consumption-growth hypotheses and nuclear energy-growth literature

Four hypotheses have been associated with the causal relationship between energy consumption and economic growth. First, the growth hypothesis postulates that energy consumption can directly impact economic growth and indirectly as a complement to labor and capital in the production process. The presence of unidirectional causality from energy consumption to economic growth confirms the growth hypothesis. Second, the conservation hypothesis suggests that energy conservation policies which reduce energy consumption and waste will not have an adverse impact economic growth. The conservation hypothesis is supported if there is unidirectional causality from economic growth to energy consumption. Third, the feedback hypothesis asserts that energy consumption and economic growth are interrelated and may very well serve as complements to each other. The feedback hypothesis suggests there is a bidirectional causal relationship between energy consumption and economic growth. Fourth, the neutrality hypothesis considers energy consumption to be a relatively small component of overall output and thus will have little or no impact on economic growth. As in case of the conservation hypothesis, energy conservation policies would not adversely impact economic growth. The absence of a causal relationship between energy consumption and economic growth lends support for the neutrality hypothesis.

In light of the aforementioned hypotheses, there have been only a few studies that examine the causal relationship between nuclear energy consumption and economic growth. Yoo and Jung (2005) find support for unidirectional causality from nuclear energy consumption to economic growth for Korea. In an examination of the causal relationship between nuclear energy consumption and economic growth for a sample of six countries, Yoo and Ku (2009) provide evidence of unidirectional causality from nuclear energy consumption to economic growth for Korea; unidirectional causality from economic growth to nuclear energy consumption for France and Pakistan; bidirectional causality between nuclear energy consumption and economic growth for Switzerland; and the absence of a causal relationship between nuclear energy consumption and economic growth for Argentina and Germany. However, these two studies examined the causal relationship between nuclear energy consumption and economic growth within a bivariate framework.

A common problem of a bivariate analysis is the possibility of omitted variable bias (Lutkepohl, 1982). The remaining three studies rectify the omitted variable problem by analyzing the causal relationship between nuclear energy consumption and economic growth within a multivariate framework with the inclusion of measures of labor and capital. The results for the U.S. by Payne and Taylor (forthcoming) indicate the absence of a causal relationship between nuclear energy consumption and economic growth. Wolde-Rufael (2009a) provides similar findings to those of Payne and Taylor (forthcoming) in the case of Taiwan. In a nine country study, Wolde-Rufael (2009b) finds unidirectional causality from nuclear energy consumption to economic growth for Japan, the Netherlands, and Switzerland; unidirectional causality from economic growth to nuclear energy consumption for Canada and Sweden; and bidirectional causality between nuclear energy consumption and economic growth for France, Spain, U.K., and the U.S.

The next section describes the data, the panel cointegration/error correction methodology, and the panel causality results associated with nuclear energy consumption and economic growth within a multivariate framework.[5]

3. Data, methodology, and results

Annual data from 1980 to 2005 were obtained from the *World Bank Development Indicators*, CD-ROM and the *Energy Information Administration* for Argentina, Belgium, Bulgaria, Canada, Finland, France, India, Japan, Netherlands, Pakistan, South Korea, Spain, Sweden, Switzerland, U.K., and the U.S. The multivariate framework includes real GDP (Y) in billions of constant 2000 U.S. dollars, real gross fixed capital formation (K) in billions of constant 2000 U.S. dollars, total labor force (L) in millions, and nuclear energy consumption (NE) defined as net nuclear electric power consumption in millions of kilowatts. The data is compiled within a panel data framework in light of the relatively short time span of the data.[6] Given that France is heavily dependent on nuclear energy for electricity consumption, the analysis will proceed with and without France included in the panel data set in order to infer the sensitivity of the results.

First, the dynamic heterogeneity (i.e. variation of the intercept over countries and time) of the relevant variables in the model is examined following the methodology of Holtz-Eakin et al. (1985) and Holtz-Eakin (1986). The results indicate that the relationships exhibit heterogeneity in both the dynamics and error variances across countries.[7] The existence of parameter heterogeneity suggests the use of the Im et al. (IPS, 2003) panel unit root test to determine the stationarity properties of the respective variables before testing for cointegration.[8] The Im et al. (2003) panel unit root test allows for heterogeneous autoregressive coefficients. Specifically, the Im et al. (2003) panel unit root test averages the augmented Dickey-Fuller (ADF) unit root tests while allowing for different orders of serial correlation, $\varepsilon_{it} = \sum_{j=1}^{p_i} \phi_{ij}\varepsilon_{it-j} + u_{it}$, yielding the following expression:

$$y_{it} = \rho_i y_{it-1} + \sum_{j=1}^{p_i} \phi_{ij}\varepsilon_{it-j} + \delta_i X_{it} + \varepsilon_{it} \quad (1)$$

where $i=1,\ldots,N$ for each country in the panel; $t=1,\ldots T$ refers to the time period; X_{it} represents the exogenous variables in the model including fixed effects or individual time trend; ρ_i are the autoregressive coefficients. ρ_i represents the number of lags in the

[5] See recent studies by Apergis and Payne (2009a,b) and citations therein for additional studies on the use of panel cointegration and error correction modeling within the context of the energy consumption-growth nexus.

[6] The use of real gross fixed capital formation as a proxy for capital parallels the work by Soytas and Sari (2006, 2007, 2009) and Soytas et al. (2007). Specifically, changes in investment closely follow changes in the capital stock under the assumption of a constant depreciation rate within the perpetual inventory method.

[7] Three tests of dynamic heterogeneity were undertaken. First, the ADF(3) test examines the null hypothesis that the regression parameters are equal across equations using an *F*-test. The ADF(3) test statistics (27.36 France included and 34.50 France excluded) for parameter equality reject the null hypothesis at the 1 percent significance level. Second, a Chow-type *F*-test on a 3rd order autoregressive model, AR(3), for each of the relationships is estimated to test the null hypothesis of parameter equality. The AR(3) test statistics (32.45 France included and 39.58 France excluded) reject the null hypothesis which indicate heterogeneity in the cross-sectional parameters at the 1 percent significance level. Third, the White test for group-wise heteroskedasticity is used to test the null hypothesis of homogeneity error variance across countries. White's chi-square test statistics (64.93 France included and 71.27 France excluded) reject the null hypothesis of homogeneity error variance across countries at the 1 percent significance level.

[8] The Breitung (2000), Hadri (2000), Choi (2001), Levin et al. (2002), and Carrion-i-Silvestre et al. (2005) tests were also performed and available upon request.