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A panel study of nuclear energy consumption and economic growth

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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.

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[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.

Table 1
Panel unit root tests.

Variables	(France included)	(France excluded)
Y	−1.25(3)	−1.18(3)
ΔY	−4.97(2)[a]	−4.53(1)[a]
NE	−1.13(3)	−1.20(3)
ΔNE	−5.06(2)[a]	−4.84(1)[a]
K	−1.47(3)	−1.51(2)
ΔK	−4.77(1)[a]	−4.36(1)[a]
L	−1.61(4)	−1.59(3)
ΔL	−4.73(2)[a]	−4.56(2)[a]

Notes: Critical value at the 1% significance level denoted by "a" is −2.61 with trend. Numbers in parentheses are the augmented lags included in the unit root test.

Table 2
Panel cointegration tests.

Panel A: France included			
Within dimension		Between dimension	
Panel v-statistic	29.3474[a]	Group ρ-statistic	−29.4652[a]
Panel ρ-statistic	−28.5547[a]	Group PP-statistic	−28.9633[a]
Panel PP-statistic	−28.2629[a]	Group ADF-statistic	−4.3528[a]
Panel ADF-statistic	−4.5861[a]		
Panel A: France excluded			
Within dimension		Between dimension	
Panel v-statistic	34.6621[a]	Group ρ-statistic	−32.5488[a]
Panel ρ-statistic	−30.0947[a]	Group PP-statistic	−30.8050[a]
Panel PP-statistic	−30.1855[a]	Group ADF-statistic	−4.7593[a]
Panel ADF-statistic	−4.8433[a]		

Notes: Of the seven tests, the panel v-statistic is a one-sided test where large positive values reject the null hypothesis of no cointegration whereas large negative values for the remaining test statistics reject the null hypothesis of no cointegration. Critical value at the 1% significance level denoted by "a": panel v (24.56), panel ρ (−17.60), panel and group PP (−25.59), panel ADF (−2.97), group ρ (−21.12), and group ADF (−3.18).

ADF regression and ε_{it} are the stationary error terms. The null hypothesis is that each series in the panel contains a unit root (H_0 : $\rho_i = 1\ \forall_i$). The alternative hypothesis is that at least one of the individual series in the panel is stationary (H_0 : $\rho_i < 1$). Im et al. (2003) use a t-bar statistic as the average of the individual ADF statistics which is normally distributed under the null hypothesis.[9] Table 1 reports the results of the IPS panel unit root tests for both panel data sets. The panel unit root tests indicate that each variable is integrated of order one.

Next, the Pedroni (1999, 2004) heterogeneous panel cointegration test which allows for cross-section interdependence with different individual effects is estimated as follows:

$$Y_{it} = \alpha_i + \delta_i t + \gamma_{1i}NE_{it} + \gamma_{2i}L_{it} + \gamma_{3i}K_{it} + \varepsilon_{it} \quad (2)$$

where $i = 1,\ldots,N$ for each country in the panel and $t = 1,\ldots,T$ refers to the time period. The parameters α_i and δ_i allow for the possibility of country-specific fixed effects and deterministic trends, respectively. ε_{it} denote the estimated residuals which represent deviations from the long-run relationship. All variables are expressed in natural logarithms so the γ's parameters of the model can be interpreted as elasticities.

To test the null hypothesis of no cointegration, $\rho_i = 1$, the following unit root test is conducted on the residuals as follows:

$$\varepsilon_{it} = \rho_i\varepsilon_{it-1} + w_{it} \quad (3)$$

Pedroni (1999, 2004) proposes two tests for cointegration. The panel tests are based on the within dimension approach which includes four statistics: panel v, panel ρ, panel PP, and panel ADF statistics. These

[9] Im et al. (2003) provide the appropriate critical values.

Table 3
FMOLS long-run estimates.

Panel A: FMOLS estimates (France included)			
$Y = 0.558 + 0.32\text{NE} + 0.17\text{ K} + 0.76\text{ L}$			
(5.52)[a] (4.19)[a] (11.84)[a] (3.97)[a]			
Adj. $R^2 = 0.41$	LM = 0.87 [0.58]	RESET = 1.04 [0.44]	HE = 1.17 [0.39]
Panel B: FMOLS estimates (France excluded)			
$Y = 0.593 + 0.37\text{NE} + 0.21\text{ K} + 0.78\text{ L}$			
(4.90)[a] (4.63)[a] (10.05)[a] (4.25)[a]			
Adj. $R^2 = 0.46$	LM = 1.08 [0.50]	RESET = 0.96 [0.46]	HE = 1.12 [0.52]

Notes: t-statistics and probability values are reported in parentheses and brackets, respectively. LM is the Lagrange multiplier test for serial correlation. RESET is the misspecification test. HE is White's heteroscedasticity test. Significance at the 1% level denoted by "a".

statistics essentially pool the autoregressive coefficients across different countries for the unit root tests on the estimated residuals. These statistics take into account common time factors and heterogeneity across countries. The group tests are based on the between dimension approach which includes three statistics: group ρ, group PP, and group ADF statistics. These statistics are based on averages of the individual autoregressive coefficients associated with the unit root tests of the residuals for each country in the panel. All seven tests are distributed asymptotically as standard normal.[10] Panels A and B of Table 2 report both the within and between dimension panel cointegration test statistics for each panel data set. The seven test statistics for each panel data set reject the null hypothesis of no cointegration at the 1% significance level.

Given the presence of cointegration, the fully modified OLS (FMOLS) technique for heterogeneous cointegrated panels is estimated to determine the long-run equilibrium relationship (Pedroni, 2000).[11] Panels A and B of Table 3 report the FMOLS results. All the coefficients are positive and statistically significant at the 1% level where the coefficients can be interpreted as elasticity estimates. In Panel A which includes France, the results indicate that a 1% increase in nuclear energy consumption increases real GDP by 0.32%; a 1% increase in real gross fixed capital formation increases real GDP by 0.17%; and a 1% increase in the labor force increases real GDP by 0.76%. In Panel B which excludes France, the results indicate that the elasticity estimates are only slightly larger, but quite similar to those reported in Panel A. For Panel B, a 1% increase in nuclear energy consumption increases real GDP by 0.37%; a 1% increase in real gross fixed capital formation increases real GDP by 0.21%; and a 1% increase in the labor force increases real GDP by 0.78%.

To infer the causal relationship between the variables a panel vector error correction model (Pesaran et al. 1999) is estimated. The Engle and Granger (1987) two-step procedure is undertaken by first estimating the long-run model specified in Eq. (2) in order to obtain the estimated residuals. Next, defining the lagged residuals from Eq. (2) as the error correction term, the following dynamic error correction model is estimated:

$$\Delta Y_{it} = \alpha_{1j} + \textstyle\sum_{k=1}^{q}\theta_{11ik}\Delta Y_{it-k} + \sum_{k=1}^{q}\theta_{12ik}\Delta NE_{it-k} + \sum_{k=1}^{q}\theta_{13ik}\Delta K_{it-k} + \sum_{k=1}^{q}\theta_{14ik}\Delta L_{it-k} + \lambda_{1i}\varepsilon_{it-1} + u_{1it} \quad (4a)$$

$$\Delta NE_{it} = \alpha_{2j} + \textstyle\sum_{k=1}^{q}\theta_{21ik}\Delta Y_{it-k} + \sum_{k=1}^{q}\theta_{22ik}\Delta NE_{it-k} + \sum_{k=1}^{q}\theta_{23ik}\Delta K_{it-k} + \sum_{k=1}^{q}\theta_{24ik}\Delta L_{it-k} + \lambda_{2i}\varepsilon_{it-1} + u_{2it} \quad (4b)$$

[10] See Pedroni (1999) for details on the heterogeneous panel and heterogeneous group mean panel cointegration statistics.

[11] The estimates from either the FMOLS or DOLS are asymptotically equivalent for more than 60 observations (Banerjee, 1999). The panel data sets of this study contain 256 (France included) and 240 (France excluded) observations, respectively.

Table 4
Panel causality tests.

Panel A: Panel causality tests (France included)

Dependent variable	Sources of causation (independent variables)								
	Short-run								Long-run
	ΔY		ΔNE		ΔK		ΔL		*ECT*
ΔY	–		9.14	(0.437)	6.73	(0.306)	6.94	(0.364)	−0.037
			[0.00][a]	[0.00][a]	[0.00][a]	[0.01][a]	[0.00][b]	[0.00][a]	[0.00][a]
ΔNE	7.44	(0.168)	–		6.46	(0.537)	0.13	(0.007)	−0.004
	[0.00][a]	[0.01][a]			[0.00][a]	[0.00][a]	[0.85]	[0.41]	[0.41]
ΔK	5.93	(0.336)	8.72	(0.761)	–		4.27	(0.318)	−0.137
	[0.00][a]	[0.00][a]	[0.00][a]	[0.00][a]			[0.00][a]	[0.00][a]	[0.00][a]
ΔL	6.30	(0.509)	1.23	(0.164)	7.18	(0.589)	–		−0.083
	[0.00][a]	[0.00][a]	[0.58]	[0.01][a]	[0.00][a]	[0.00][a]			[0.01][a]

Panel B: Panel causality tests (France excluded)

Dependent variable	Sources of causation (independent variables)								
	Short-run								Long-run
	ΔY		ΔNE		ΔK		ΔL		*ECT*
ΔY	–		17.09	(0.484)	6.94	(0.358)	7.42	(0.378)	−0.041
			[0.00][a]	[0.00][a]	[0.00][a]	[0.00][a]	[0.00][b]	[0.00][a]	[0.00][a]
ΔNE	5.36	(0.147)	–		6.82	(0.575)	0.09	(0.053)	−0.003
	[0.00][a]	[0.02][b]			[0.00][a]	[0.00][a]	[0.91]	[0.53]	[0.48]
ΔK	6.92	(0.368)	11.50	(0.738)	–		4.39	(0.359)	−0.158
	[0.00][a]	[0.00][a]	[0.00][a]	[0.00][a]			[0.00][a]	[0.00][a]	[0.00][a]
ΔL	12.95	(0.577)	0.83	(0.121)	8.52	(0.607)	–		−0.094
	[0.00][a]	[0.00][a]	[0.72]	[0.03][b]	[0.00][a]	[0.00][a]			[0.00][a]

Notes: Partial *F*-statistics reported with respect to short-run changes in the independent variables. The sum of the lagged coefficients for the respective short-run changes is denoted in parentheses. ECT represents the coefficient of the error correction term. Probability values are in brackets and reported underneath the corresponding partial *F*-statistic and sum of the lagged coefficients, respectively. Significance at the 1 and 5% levels are denoted by "a" and "b", respectively.

$$\Delta K_{it} = \alpha_{3j} + \textstyle\sum_{k=1}^{q}\theta_{31ik}\Delta Y_{it-k} + \sum_{k=1}^{q}\theta_{32ik}\Delta NE_{it-k} + \sum_{k=1}^{q}\theta_{33ik}\Delta K_{it-k} + \sum_{k=1}^{q}\theta_{34ik}\Delta L_{it-k} + \lambda_{3i}\varepsilon_{it-1} + u_{3it} \tag{4c}$$

$$\Delta L_{it} = \alpha_{4j} + \textstyle\sum_{k=1}^{q}\theta_{41ik}\Delta Y_{it-k} + \sum_{k=1}^{q}\theta_{42ik}\Delta NE_{it-k} + \sum_{k=1}^{q}\theta_{43ik}\Delta K_{it-k} + \sum_{k=1}^{q}\theta_{44ik}\Delta L_{it-k} + \lambda_{4i}\varepsilon_{it-1} + u_{4it} \tag{4d}$$

where Δ is the first-difference operator; k is the lag length set at two (France included) and three (France excluded), respectively; and u is the serially uncorrelated error term.[12] With respect to Eqs. (4a)–(4d), short-run causality is determined by the statistical significance of the partial *F*-statistic associated with the corresponding right hand side variables. Long-run causality is revealed by the statistical significance of the respective error correction terms using a *t*-test.

Panels A and B of Table 4 report the results of the short-run and long-run Granger-causality tests for each panel data set. In Panel A which includes France, Eq. (4a) shows that nuclear energy consumption, real gross fixed capital formation, and the labor force each have a positive and statistically significant impact on economic growth in the short-run. In terms of Eq. (4b), both economic growth and real gross fixed capital formation have a positive and statistically significant influence on nuclear energy consumption while the labor force is statistically insignificant in the short-run. In the case of Eq. (4c), economic growth, nuclear energy consumption, and the labor force each have a positive and statistically significant impact on real gross fixed capital formation. In regards to Eq. (4d), economic growth and real gross fixed capital formation have a positive and statistically significant influence on the labor force whereas nuclear energy consumption is statistically insignificant. Thus, from the short-run causality results, it appears that nuclear energy consumption and real gross fixed capital formation serve as complements to each other in contributing to economic growth.

[12] The number of lags was determined via likelihood ratio tests.

The long-run dynamics displayed by the error correction terms from Eqs. (4a)–(4d) reveal that economic growth, real gross fixed capital formation, and labor force respond to deviations from long-run equilibrium given the statistical significance of their respective error correction terms. However, the statistical insignificance of the error correction term corresponding to nuclear energy consumption suggests that nuclear energy consumption is not responsive to deviations from long-run equilibrium. Overall, the results from Panel A suggest there is bidirectional causality between nuclear energy consumption and economic growth in the short-run with unidirectional causality from nuclear energy consumption to economic growth in the long-run. For Panel B with France excluded from the analysis, the results and conclusions are very similar to those reported in Panel A. In general, the results are robust to whether or not France is included in the analysis.

The presence of bidirectional causality lends support for the feedback hypothesis whereby nuclear energy consumption and economic growth are interdependent. Within the panel of countries examined, the interdependence between nuclear energy consumption and economic growth suggests that energy policies designed to increase the production and consumption of nuclear energy will have a positive impact on economic growth, ceteris paribus. Likewise, the positive influence on economic growth from the use of nuclear energy further enhances the viability of the nuclear energy sector. These results provide additional support for the assertion that nuclear energy can serve as an important energy source in the development of long-term energy and environmental strategies that meet growing global energy demands.

4. Concluding remarks

The growing concerns over greenhouse gas emissions, the recent volatility associated with oil and gas prices, the uncertainty surrounding the political stability of oil producing countries, and the dependency on foreign energy sources have revitalized interest in the role of nuclear energy as a viable energy source. Even with the benefits of reducing air pollution and greenhouse gas emissions, providing a low cost and stable supply of electricity, and decreased dependency on foreign energy sources, both policymakers and the general public still have some reservations with respect to the production and consumption of nuclear energy. These reservations about nuclear energy stem from the perceived risks which include operational safety, the disposal of radioactive waste, and the risk of proliferation of nuclear material are reasonable concerns. However, to address the growing global energy demands, long-term energy and environmental strategies must consider nuclear energy as an important energy source in the discussion of the world's energy portfolio.

The objective of this study was to provide additional information in the discussion of the role of nuclear energy in satisfying global energy needs while reducing greenhouse gas emissions through an examination of the causal relationship between nuclear energy consumption and economic growth. First, in both panel data sets (France included and excluded) heterogeneous panel cointegration tests indicate there is a long-run equilibrium relationship between real GDP, nuclear energy consumption, real gross fixed capital formation, and the labor force. The long-run elasticity estimates are positive and statistically significant with the magnitude of the estimates quite similar across both panel data sets. Second, for both panel data sets, the estimation of panel error correction models reveal there is short-run bidirectional causality between nuclear energy consumption and economic growth whereas in the long-run there is unidirectional causality from nuclear energy consumption to economic growth. Thus, the short-run bidirectional causality results lend support for the feedback hypothesis. The interdependence between nuclear energy consumption and economic growth suggests that energy policies designed to increase the production and consumption of nuclear energy will have a positive impact on economic growth. Moreover, given the reduction in the emission of air pollution and greenhouse gases associated with nuclear energy, there is also a positive spillover to the environment. Likewise, the positive influence on economic growth from the use of nuclear energy further enhances the viability of the nuclear energy sector over time.

In summary, though the results of this study indicate bidirectional causality between nuclear energy consumption and economic growth in the short-run with unidirectional causality from nuclear energy consumption to economic growth in the long-run, there are still some interesting questions to pursue in future research. First, given the use of nuclear power in the former Soviet Union, what is the relationship between nuclear energy consumption and economic growth for those countries within the Commonwealth of Independent States? Second, given that both nuclear and renewable energy sources garner environmental benefits in terms of reducing greenhouse gas emissions, is one energy source more important in its contribution to economic growth than the other? Third, in light of the results reported in this study as well as in previous studies, would the relationship between nuclear energy consumption and economic growth change with the inclusion of other energy consumption measures?

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