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A panel cointegration analysis of CO_2 emissions, nuclear energy and income in major nuclear generating countries

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HIGHLIGHTS

- This study revisits the nuclear-energy-growth-CO_2 emissions nexus.
- A panel cointegration analysis is employed.
- Nuclear energy has a beneficial effect on reducing CO_2 emissions.
- CO_2 emissions decrease with economic growth.

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ABSTRACT

A number of studies have examined the effect of nuclear energy on CO_2 emissions, and a lot has been learned from these studies. Due to their weaknesses in modeling approaches and variable uses, however, properly constructed and comprehensive analyses are limited. The main objective of this study is thus to contribute to the debate over nuclear energy and the environment with an enhanced model and variables. For this, a panel cointegration analysis is applied to quantify the effects of nuclear energy, energy consumption and income on CO_2 emissions in 12 major nuclear generating countries. The results show that nuclear energy tends to reduce CO_2 emissions. It is also found that CO_2 emissions tend to decrease monotonically with income growth, providing no evidence in support of the Environmental Kuznets Curve (EKC) for CO_2 emissions.

1. Introduction

Examining the relationship between economic growth and environment quality – particularly measured by carbon dioxide (CO_2) emissions – has been an active field of empirical research in environmental economics over the past decade. Early research has typically concentrated on the effect of income growth and energy consumption on CO_2 emissions, referred to as the *growth-energy-CO_2 emissions nexus* (Table 1). Zhang and Cheng [3], for example, assess the effects of energy consumption and output on CO_2 emissions in China; they conclude that an increase in energy consumption induced by economic growth leads to an increase in CO_2 emissions. Baek and Kim [8] also examine the growth-energy-CO_2 emissions nexus in G-20 economies; they find that growth reduces (increases) CO_2 emissions in the developed (developing) member countries.

The various studies conducted by the UN Intergovernmental Panel on Climate Change (IPCC) (for example, [16,17] have recently shown that, among various Greenhouse Gas (GHG) emissions, CO_2 emissions produced from the burning fossil fuels to generate electricity are considered to be the main culprit behind global warming and climate change. It is thus believed that turning to low or no carbon sources of electricity generation – particularly nuclear power – may help reduce a country's CO_2 emissions even with economic growth. Accordingly, researchers have recently turned their attention to examine the independent effect of nuclear power generation on CO_2 emissions, referred to as the *growth-nuclear-energy-CO_2 emissions nexus* (Table 1). Apergis et al. [10], for example, analyze the dynamic effect of nuclear energy on CO_2 emissions, after controlling for renewable energy and economic growth; they find that nuclear energy tends to reduce CO_2 emissions. Iwata et al. [13], on the other hand, find little evidence for a beneficial effect of nuclear energy on CO_2 emissions for a given level of income in a sample of 11 OECD countries. More recently, Baek and Pride [15] report that nuclear energy has a significant effect on reduction in CO_2 emissions in six out of the top ten nuclear generating countries.

A potential weakness of the current literature is that the empirical emphasis has mostly been on country specific time series data

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Table 1
Summary of the selected studies on relationship between economic growth and CO_2 emissions.

Studies	Countries	Data	Methods	Results		
				Growth	Energy consumption	Nuclear energy
Growth-energy-CO_2 emissions nexus						
Liu [1]	24 OECD countries	1975–1990 (annual)	SES	EKC holds	Negative effect	–
Soytas et al. [2]	United States	1960–2004 (annual)	Time series (VAR, Granger causality)	No effect	Positive effect	–
Zhang and Cheng [3]	China	1960–2007 (annual)	Time series (VAR, Granger causality)	Positive effect	Positive effect	–
Soytas and Sari [4]	Turkey	1960–2000 (annual)	Time series (VAR, Granger causality)	No effect	No effect	–
Apergis and Payne [5]	6 Central American countries	1971–2004 (annual)	Panel VEC analysis	EKC holds	Positive effect	–
Jalil and Mahmud [6]	China	1975–2005 (annual)	Time series (ARDL)	EKC holds	Positive effect	–
Halicioglu [7]	Turkey	1960–2005 (annual)	Time series (ARDL)	EKC holds	Positive effect	–
Baek and Kim [8]	G-20 countries	1960–2006 (annual)	Time series (cointegrated VAR)	EKC holds only for developed G-20 countries	Positive effect	–
Growth-nuclear-CO_2 emissions nexus						
Richmond and Kaufman [9]	20 OECD countries, 11 non-OECD countries	1973–1997 (annual)	Panel analysis (random effect)	EKC holds for OECD countries	Positive effect	Negative effect
Apergis et al. [10]	19 developing and developed countries	1984–2007 (annual)	Panel error-correction model	Negative effect	–	Negative effect
Iwata et al. [11]	France	1960–2003 (annual)	Time series (ARDL)	EKC holds	Positive effect	Negative effect
Iwata et al. [12]	17 OECD countries, 11 non-OECD countries	1960–2003 (annual)	Panel analysis (pooled mean group)	Negative effect only in OECD countries	–	Negative effect
Iwata et al. [13]	11 OECD countries	1960–2003	Time series (ARDL)	EKC does not hold for most countries	Positive effect	Negative effect for only 4 countries
Baek and Kim [14]	Korea	1971–2007 (annual)	Time series (ARDL)	EKC holds	Positive effect	Negative effect
Baek and Pride [15]	10 countries	1965–2007 (annual)	Time series (cointegrated VAR)	Negative effect for some countries	–	Negative effect

Note: SES, VAR and ARDL mean a simultaneous equation system, a vector autoregressive model, and an autoregressive distributed lag model, respectively. Results summarize the effect of growth, energy consumption and nuclear energy on CO_2 emissions.

(mainly in a cointegrated time series framework) with a relatively small sample size (usually about 40 annual observations). Since a small sample size generally leads to large sampling variances through a decrease in the sample variation in each of the selected variables [18], this problem is likely to cause the estimated coefficients in a model to be sensitive to its specification and even inefficient, thereby raising questions about the credibility of the findings. Another shortcoming of the past studies is that no sufficient attention has been given to allow for the potential effect of energy consumption. More specifically, energy consumption is empirically found to have a significant impact on environmental outcomes (e.g., [13,14]. Thus, excluding this factor in the analysis may cause biased estimates of the nuclear energy impacts, which is known as the omitted variable bias [18].

In this short paper, therefore, we seek to contribute to the existing literature by assessing the effect of nuclear energy on the environment in a *panel cointegration* framework. Empirical attention is given to the examination of the effects of nuclear energy, energy consumption and income on CO_2 emissions using panel data of 12 major nuclear generating countries. These 12 countries include the United States, France, Japan, South Korea, Canada, Germany, UK, Sweden, Spain, Belgium, Switzerland and Finland (Table 2); they account for approximately 80% of total world nuclear generation in 2013. The panel cointegration techniques developed by Pedroni [19,20] such as group-mean fully modified ordinary least squares (FMOLS) and dynamic ordinary least squares (DOLS) are used to estimate the coefficients of the cointegrated panel data. To the best of our knowledge, this study is the first to examine the *nuclear-energy-growth-CO_2 emissions nexus* within a panel cointegration framework, which can have substantive improvements in statistical power and sample size but has been largely ignored by early studies. It should be pointed out that Richmond and Kaufman [9], Apergis et al. [10] and Iwata et al. [12] examine the nuclear energy impacts on CO_2 emissions using the panel data analysis (Table 1). However, Richmond and Kaufman [9] adopt a typical static panel analysis (i.e., random effect analysis), while Apergis et al. [10] and Iwata et al. [12] model the effect of nuclear energy on CO_2 emissions only by taking income into account. The remaining sections present empirical methodology, estimations results, and conclusions.

Table 2
Major nuclear generating countries, 2013. *Source*: Power Reactor Information System, International Atomic Energy Agency (IAEA).

Country	Megawatt capacity	Share in world's nuclear power generation (%)
United State	101,409	27.4
France	63,130	17.0
Japan	44,215	11.9
South Korea	20,671	5.6
Canada	12,604	3.4
Germany	12,003	3.2
United Kingdom	9703	2.6
Sweden	9326	2.5
Spain	7567	2.0
Belgium	5927	1.6
Switzerland	3263	0.9
Finland	2736	0.7
Others	77,907	21.0
World	370,461	100