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Short Communication

Do nuclear and renewable energy improve the environment? Empirical evidence from the United States

Jungho Baek*

University of Alaska at Fairbanks, Department of Economics, 213B Bunnell, Fairbanks, AK 99709 United States

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ABSTRACT

The central focus of this article is to assess the dynamic effects of nuclear and renewable energy consumption on CO_2 emissions, for a given level of income and energy consumption. We apply an autoregressive distributed lag (ARDL) approach to cointegration to U.S. data from 1960 to 2010. We find that nuclear energy consumption indeed reduces CO_2 emissions in both the short- and long-run, while renewable energy consumption does only in the short-run. We also find that income increases CO_2 emissions in the long-run after showing the environmental Kuznets curve (EKC) initially in the short-run. Finally, energy consumption is found to have a negative impact on reducing CO_2 emissions in the short- and long-run.

1. Introduction

Numerous studies published by the UN Intergovernmental Panel on Climate Change (IPCC) have claimed that, among various greenhouse gas (GHG) emissions, carbon dioxide (CO_2) emissions generated by the burning fossil fuels are the main culprit behind global warming. Accordingly, the determinants of CO_2 emissions have been studied extensively. Given the use of variables, previous studies are generally categorized into three groups. In testing the significance of factors on CO_2 emissions in different countries, the first group typically includes income and energy consumption as explanatory variables in a model, known as the *income-energy-CO_2 nexus*. Examples of the literature on this category include Liu (2005) for 24 OECD countries, Ang (2007) for France, Soytas et al. (2007) for the United States, Apergis and Payne (2009) for Central American countries, Pao and Tsai (2010) for Brazil, Russia, India and China, Lean and Smyth (2010) for ASEAN, Wang et al. (2011) for China, Pao et al. (2011) for Russia, Baek and Kim (2011) for G-20 countries, Shahbaz et al. (2012) for Pakistan, Saboori and Sulaiman (2013) for Malaysia, Ozcan (2013) for Middle East, and Yavuz (2014) for Turkey.[1] Most studies arrive at mixed results as far as the income effect is concerned.

The second group of studies views nuclear energy as a possible low-carbon energy alternative to fossil fuels and estimates an empirical model in which CO_2 emissions are related to nuclear power generation (consumption) in addition to other determinants such as income and energy consumption, known as the *income-energy-nuclear-CO_2 nexus*. The list includes Richmond and Kaufman (2006) for 20 OECD and 11 non-OECD countries, Apergis et al. (2010) for 19 developed and developing countries, Iwata et al. (2010) for France, Iwata et al. (2011, 2012) for 17 OECD and 11 non-OECD countries, Baek and Kim (2013) for Korea, Baek and Pride (2014) for the United States, France, Japan, Canada, Spain and Korea, and Baek (2015) for 12 major nuclear generating countries.[2] Iwata et al. (2012), for example, show that nuclear energy does not reduce CO_2 emissions in 11 OECD countries. Baek and Pride (2014), by contrast, provide evidence that nuclear energy reduces CO_2 emissions in major nuclear generating countries. Finally, the last group includes only a few studies that argue that like nuclear energy, renewable energy also could be a potential source of mitigating CO_2 emissions and has included renewable energy as a major determinant of CO_2 emission in addition to other variables (i.e., nuclear energy and income) in their analyses. Apergis et al. (2010),

* Tel.: +1 907 474 2754.
E-mail address: jbaek3@alaska.edu

[1] See Al-mulali et al. (2015) for a comprehensive review of the related literature.

[2] Chang (2010) and Al-mulali (2014) have examined the *income-nuclear-CO_2 nexus* for China and 30 major nuclear energy consuming countries, respectively. They show that nuclear energy has a beneficial effect on reducing CO_2 emissions in those countries.

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Menyah and Wolde-Rufael (2010) and Tiwari (2011) are studies in this group. Apergis et al. (2010), for example, find that nuclear energy reduces CO_2 emissions in 19 countries in the short-run, but renewable energy has little effect.

Up until now, however, studies in the third group have been rather sparse. In addition, the empirical emphasis of this group has mostly been on the short-run effect of renewable energy on CO_2 emissions (mainly using Granger causality tests). Furthermore, no study has controlled energy consumption in the analysis even though energy consumption is empirically found to have a significant effect on CO_2 emissions and hence could cause the omitted variable bias if not controlled (Baek, 2015). The main focus of this article is, therefore, to expand the third group of the literature by conducting the direct and simultaneous assessments of the short- and long-run determinants of CO_2 emissions within the cointegration framework. Special attention is paid to investigate the short- and long-run effects of renewable energy, nuclear energy, income and energy consumption on CO_2 emissions in the U.S. using an autoregressive distributed lag (ARDL) modeling approach to cointegration. Since the ARDL method allows the simultaneous determination of both the short- and long-run effects of an explanatory variable by one step, it is very well suited to achieve our objective.

2. The method

Since the previous studies do not rely on economic theory to derive an empirical model, they have little to say regarding the correct form of model specifications. In constructing the economic model in the paper, therefore, the so-called standard model of the *income-energy-CO_2 nexus* has been extended to include nuclear and renewable energy consumption as done in the third group as follows:

$$\ln(co_2)_t = \beta_0 + \beta_1 \ln y_t + \beta_2 \ln en_t + \beta_3 \ln nuc_t + \beta_4 \ln ren_t + u_t \tag{1}$$

where $(co_2)_t$ is the CO_2 emissions; y_t is the real income; en_t is the energy consumption; nuc_t is the nuclear energy consumption; ren_t is the renewable energy consumption; and u_t is the error term including other factors affecting CO_2 emissions. As found in the literature, income plays an important role in determining environmental quality; if growth increases (decreases) CO_2 emissions, the income is expected to be positive (negative). Since a rise in energy consumption led by income growth generally results in a rise in CO_2 emissions, the energy consumption is expected to be positive. Finally, if nuclear and renewable energy mitigate CO_2 emissions, the coefficients of these variables are expected to be negative.

In order to estimate Eq. (1) using the ARDL approach, it is recommended by Pesaran et al. (2001) that short-run dynamics be incorporated into the modeling process. This is generally achieved by reformatting Eq. (1) as an error-correction modeling (ECM) form as follows[3]:

$$\begin{aligned}\Delta \ln(co_2)_t = {} & \beta'_0 + \sum_{k=1}^{p} \beta'_{k1} \Delta \ln(co_2)_{t-k} + \sum_{k=0}^{p} \beta'_{k2} \Delta \ln y_{t-k} \\ & + \sum_{k=0}^{p} \beta'_{k3} \Delta \ln en_{t-k} + \sum_{k=0}^{p} \beta'_{k4} \Delta \ln nuc_{t-k} \\ & + \sum_{k=0}^{p} \beta'_{k5} \Delta \ln ren_{t-k} + \varphi_0 \ln(co_2)_{t-1} + \varphi_1 \ln y_{t-1} \\ & + \varphi_2 \ln en_{t-1} + \varphi_3 \ln nuc_{t-1} + \varphi_4 \ln ren_{t-1} + \nu_t \end{aligned} \tag{2}$$

where Δ represent the first differences of the variable and p is the lag lengths. Pesaran et al. (2001) recommend conducting the conventional F-test in Eq. (2) for joint significance of lagged level variables so as to establish cointegration. This test takes the nonexistence of cointegration among the lagged level variables as the null hypothesis (that is, H_0: $\varphi_0 = \varphi_1 = \varphi_2 = \varphi_3 = \varphi_4 = 0$) and tests against alternative involving the existence of cointegration (H_1: $\varphi_0 \neq 0$, $\varphi_1 \neq 0$, $\varphi_2 \neq 0$, $\varphi_3 \neq 0$, $\varphi_4 \neq 0$). Because this calculated statistic is non-standard F-distribution under the null hypothesis, regardless of whether the selected variables are $I(0)$ or $I(1)$, Pesaran et al. (2001) propose two critical value bounds (upper and lower critical values) that encompass the integrated processes of the variables. Indeed, all of the variables used in Eq. (2) are characterized as either $I(0)$ or $I(1)$ as found in the literature. Hence, the ARDL approach is not required to conduct pre-unit-root testing for the variables. Once Eq. (2) is estimated, estimated coefficients of first-differenced variables – in other words, coefficient estimates of the summation signs (Σ) – indicate the short-run dynamics. The long-run coefficients are obtained by the estimates of φ_1, φ_2, φ_3 and φ_4 that are normalized on φ_0. Hence, the ARDL approach has a main advantage over the standard cointegration analysis (i.e., Johansen, 1988) in that the short- and long-run impacts can be determined by one step through a simple linear transformation.

3. Data

The data used for estimating Eq. (2) are annual observations for the period 1960–2010. CO_2 emissions are measured as total carbon dioxide emissions in millions of metric ton. Income is measured as real GDP per capita in constant 2005 USD. Energy consumption is measured as kg of oil equivalent per capita. These three variables are taken from the World Development Indicator (WDI), a databased of the World Bank. Following Apergis et al. (2010) and Menyah and Wolde-Rufael (2010), nuclear electric power consumption (measured in quadrillion Btu) and total renewable energy consumption (measured in quadrillion Btu), which includes geothermal, solar, wind and biomass consumption, are used as proxies for nuclear and renewable energy consumption. These two variables are from the U.S. Energy Information Administration (EIA). Table 1 summarizes descriptive statistics of the level variables used in estimating Eq. (2).

Fig. 1 shows CO_2 emissions and energy consumption during the period 1960–2010. It seems clear that both CO_2 emissions and energy consumption tend to track each other closely over time. For

Table 1
Descriptive statistics.

Variable	Mean	Std. dev.	Min	Max
$(co_2)_t$	4,694,510.00	817,122.60	2,880,506.00	5,828,697.00
y_t	30,053.08	9251.02	15,469.07	45,431.03
en_t	7470.82	680.64	5612.05	8438.40
nuc_t	4.20	3.17	0.01	8.46
ren_t	5.36	1.31	2.93	8.08

[3] It is worth mentioning that energy consumption is defined as the sum of fossil fuel energy consumption (such as crude oil, coal and natural gas), nuclear energy consumption and renewable energy consumption. If we include fossil fuel energy consumption as an independent variable in Eq. (2), we then say the model suffers from the so-called *perfect collinearity* because one independent variable – that is, energy consumption – in Eq. (2) can be expressed as an exact linear combination of the other three independent variables – that is, fossil fuel, renewable and nuclear energy consumption (Wooldridge, 2013). In order to solve the perfect collinearity as well as to achieve our empirical objective, therefore, we drop fossil fuel energy consumption from Eq. (2).