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Can Nuclear Energy Contribute to the Transition Toward a Low-carbon Economy? The Japanese Case

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ABSTRACT

This paper examines the impact of nuclear energy consumption on CO_2 emissions in Japan over the period 1970–2010. Using an autoregressive distributed lag bounds testing approach, we develop bivariate and multivariate models specifying CO_2 emissions as the dependent variable. The results reveal that in the long run, there is no evidence that an increase in nuclear energy consumption leads to a decrease in CO_2 emissions other than price-induced effects from the decrease in electricity demand given the increase in electricity prices. These results suggest that whether nuclear energy is a low-carbon electricity generation option remains an open question from a long-term perspective.

Keywords: Nuclear Energy, CO_2 Emissions, Cointegration, Autoregressive Distributed Lag
JEL Classifications: Q43, Q50

1. INTRODUCTION

In Japan, nuclear energy has long been thought to play an important role in its transition toward a sustainable society. For this reason, the Japanese government has so far promoted the development of nuclear energy. However, following the disaster (NIES Level 7) at the Fukushima Daiichi nuclear power plants in March 2011, a large proportion of the Japanese population became more skeptical of the merits of nuclear energy. As a result, all 54 nuclear reactors in the country were forced offline while stress testing was conducted as a means to calm public unrest.

Despite the seriousness of the Fukushima Daiichi disaster, the Japanese government has continued its policy of dependence on nuclear energy believing, at least for the time being, that the use of nuclear energy is necessary to achieve the transition of Japan toward a low-carbon economy[1]. In fact, a few reactors have been restarted and more reactors are likely to be restarted in coming years through government pressure, even though current electricity generation from Japan's nuclear plants is still far lower than before the disaster.

Without any doubt, the current situation is one of the most significant setbacks for the Japanese government since the dawn of the nuclear age. However, this situation is also a good opportunity to reexamine the rationality of using nuclear energy to generate electricity. Japanese electricity generation has involved the use of commercial nuclear power reactors for more than half a century, which provides sufficient time-series data for an analysis of nuclear energy. Nonetheless, there have been few studies on the nuclear–CO_2 nexus in Japan using time-series analysis. In this paper, we focus on the nuclear–CO_2 nexus in Japan using the autoregressive distributed lag (ARDL) modeling approach proposed by Pesaran et al. (2001).

The remainder of this paper is organized as follows. Section 2 reviews the literature on related studies. Section 3 describes the methods and data used in this analysis. Section 4 reports the results, using which Section 5 examines the viability of nuclear energy in Japan. Section 6 concludes.

1 Ministry of Economy, Trade and Industry, (2014). Strategic Energy Plan (in Japanese). http://www.enecho.meti.go.jp/category/others/basic_plan/pdf/140411.pdf (accessed July 20, 2017).

2. LITERATURE REVIEW

One popular method of estimating CO_2 emissions from nuclear plants is the life-cycle assessment (LCA) procedure. This is important as the Japanese government's belief that nuclear power generation is an extremely low-carbon technology compared with fossil fuel-fired generation mainly relies on the results of LCA analysis conducted by researchers at the Central Research Institute of Electric Power Industry, in which life-cycle CO_2 emissions per kWh of electricity generated were estimated to be 19–28 g CO_2/kWh (Hondo, 2005; Imamura and Nagano, 2010; Imamura et al., 2016).

Worldwide, many studies have examined the average life-cycle CO_2 emissions for nuclear power plants, with estimates ranging from <2–288 g CO_2/kWh (Sovacool, 2008). This large disparity in estimates reflects the differences in these studies' assumptions concerning the boundaries, quality of uranium ore, type of mining, method of enrichment, type of reactor, operational lifetime, and type of life-cycle analysis. The disparity in assumptions in these studies necessarily produces the wide variety of estimates reported.

Apart from this approach, a cointegration framework can also be a useful tool to evaluate the actual impact of nuclear power generation on CO_2 emissions. Existing studies using a cointegration framework to examine the nuclear–CO_2 nexus can be classified into two groups in terms of methodology. The first involves single-country studies and the second panel data studies. Each method has its advantages and disadvantages. As 30–40 years of data are available for most energy-related variables, it is appropriate to use panel data in order to obtain large sample sizes (Smyth and Narayan, 2015).

Apergis et al. (2010) examined the causal relationship between nuclear energy consumption and CO_2 emissions using panel data for a group of 19 developed and developing countries within a multivariate framework, and showed that nuclear energy contributes to a reduction in CO_2 emissions (see also Destek, 2015; Balogh and Jámbor, 2017). In contrast, Alam (2013) conducted a similar analysis for 25 developed and developing countries, and demonstrated that the use of nuclear energy leads to an increase in CO_2 emissions. One of the reasons why these two studies contradict each other may be that the effects of nuclear energy consumption on CO_2 emissions vary from country to country. In fact, the results of existing studies based on the single-country approach have shown that the nuclear–CO_2 nexus varies even among developed countries (Iwata et al., 2012; Baek and Pride, 2014; Ozturk, 2017). Given this background, the importance of focusing on a single country is clear (Baek and Pride, 2014).

We now turn to the Japanese case. Existing studies based on time-series analysis are extremely rare, and with just a few exceptions have concluded that nuclear energy contributes to a reduction in CO_2 emissions (Iwata et al., 2012; Baek and Pride, 2014; Naser, 2015). These studies share a common feature in that the percentage share of nuclear power in total electricity generation is specified as the "nuclear" variable. However, an increase in the share of nuclear power results not only from an increase in the amount of electricity generated by nuclear power plants in constant total electricity generation, but also by decreases in the total amount of electricity generated at constant generation from nuclear power plants.

If the amount of electricity generated by fossil fuel power plants declines, it is unsurprising that CO_2 emissions will be reduced ceteris paribus. In this situation, although the share of nuclear power generation must be higher than before, it is not adequate to say that promoting nuclear power generation plays a substantial role in reducing CO_2 emissions. To avoid this problem, it seems reasonable to specify nuclear energy consumption as an explanatory variable.

Additionally, no studies examine the nuclear–CO_2 nexus after considering the effects of any change in electricity prices driven by nuclear energy consumption. Given the importance of such price-induced effects, as explained later, we need to develop a model that also includes the electricity price as an explanatory variable.

3. METHODOLOGY AND DATA

Compared with panel studies, single-country studies are often plagued by relatively small sample sizes because energy-related time-series data for a single country are generally available only for very short periods (30–40 years). To resolve this problem, the ARDL bounds test approach suggested by Pesaran et al. (2001) with critical values tabulated by Narayan (2005) has been frequently used in cointegration analyses with small sample data. Hence, we employ the ARDL bounds testing approach to examine the nuclear–CO_2 nexus in Japan.

Next, we consider the model specifications. To obtain robust results, we estimate four models as follows:

$$\ln CDE_t = \lambda_{10} + \lambda_{11} \ln NUC_t + \varepsilon_{1t} \quad (1)$$

$$\ln CDE_t = \lambda_{20} + \lambda_{21} \ln NUC_t + \lambda_{22} \ln Y_t + \varepsilon_{2t} \quad (2)$$

$$\ln CDE_t = \lambda_{30} + \lambda_{31} \ln NUC_t + \lambda_{32} \ln EPR_t + \varepsilon_{3t} \quad (3)$$

$$\ln CDE_t = \lambda_{40} + \lambda_{41} \ln NUC_t + \lambda_{42} \ln EPR_t + \lambda_{43} \ln Y_t + \varepsilon_{4t} \quad (4)$$

Where CDE is CO_2 emissions, NUC is nuclear energy consumption, Y is real GDP, and EPR is the real price of electricity. The process to develop these models is explained below.

The use of a bivariate model as in Equation (1) is obviously the simplest way to study the nuclear–CO_2 nexus using a time-series approach. The use of bivariate analysis has certain advantages, especially as a multivariate framework with many variables may lead to a substantial loss in degrees of freedom. Moreover, there is no need to suffer from selecting other variables to be added to the model.

However, the use of a bivariate framework, in some cases, may lead to biased results resulting from potential omitted variables (Stern, 2000; Chang et al., 2001; Narayan and Smyth, 2005).

Thus, recent studies in the field of energy economics have tended to conduct analyses within a multivariate framework. However, because the sample sizes for time-series data are invariably small, a potential problem is that the many variables in a multivariate framework may lead to a substantial loss of degrees of freedom, as noted. Therefore, as a rule of thumb, we develop models with at most four variables. How then should we choose the third (or fourth) variable to be added to the model? Unfortunately, there is no underlying theoretical framework for the choice of additional variables (Smyth and Narayan, 2015). Intuitively, if no particular rationale exists, it seems reasonable to add the most potentially influential variable that has a significant impact on CO_2 emissions. Hence, we add variable Y to the bivariate model and in doing so develop a trivariate model, as in Equation (2).

Contrary to the above two models, the remaining multivariate models, Equations (3 and 4), are developed with a particular reason as follows. Recently, Ishida (2016) examined the relationship between nuclear energy consumption and electricity prices in Japan using a cointegration framework, and found that an increase in nuclear energy consumption leads to an increase in electricity prices. Given this, it is unsurprising that an increase in nuclear energy consumption will indirectly lead to a decrease in CO_2 emissions because an increase in electricity prices will usually lead to a reduction in fossil fuel consumption through a downturn in electricity demand. Note that fossil fuel power has long been the dominant source of electricity in Japan (ANRE, 2016). We refer to this mechanism as the "price-induced effects" on CO_2 emissions.

If nuclear energy contributes to the reduction of CO_2 emissions only through these price-induced effects, it is inadequate to say that nuclear plants are a low-carbon power source as any instruments designed to raise electricity prices would be expected to lead to the same result. To explore whether nuclear energy actually contributes to the reduction of CO_2 emissions through any mechanism other than price-induced effects, we add EPR to each model as an explanatory variable. If nuclear power plays a role in the reduction of CO_2 emissions even without price-induced effects, the coefficients of NUC in Equations (3 and 4) are expected to be negative. We refer to this mechanism as the "direct effects" on CO_2 emissions.

The unrestricted error correction models corresponding to Equations (1–4) are as follows:

$$\begin{aligned}\Delta \ln CDE_t &= \alpha_{10} + \sum_{i=1}^{n11} \alpha_{11,i} \Delta \ln CDE_{t-i} \\ &+ \sum_{i=0}^{n12} \alpha_{12,i} \Delta \ln NUC_{t-i} + \alpha_{13} \ln CDE_{t-1} \\ &+ \alpha_{14} \ln NUC_{t-1} + u_{1t}\end{aligned} \quad (5)$$

$$\begin{aligned}\Delta \ln CDE_t &= \alpha_{20} + \sum_{i=1}^{n21} \alpha_{21,i} \Delta \ln CDE_{t-i} \\ &+ \sum_{i=0}^{n22} \alpha_{22,i} \Delta \ln NUC_{t-i} \\ &+ \sum_{i=0}^{n23} \alpha_{23} \Delta \ln Y_{t-i} + \alpha_{24} \ln CDE_{t-1} \\ &+ \alpha_{25} \ln NUC_{t-1} + \alpha_{26} \ln Y_{t-1} + u_{2t}\end{aligned} \quad (6)$$

$$\begin{aligned}\Delta \ln CDE_t &= \alpha_{30} + \sum_{i=1}^{n31} \alpha_{31,i} \Delta InCDE_{t-i} \\ &+ \sum_{i=0}^{n32} \alpha_{32,i} \Delta lnNUC_{t-i} \\ &+ \sum_{i=0}^{n33} \alpha_{33,i} \Delta lnEPR_{t-i} + \alpha_{34} lnCDE_{t-1} \\ &+ \alpha_{35} lnNUC_{t-1} + \alpha_{36} lnEPR_{t-1} + u_{3t}\end{aligned} \quad (7)$$

$$\begin{aligned}\Delta lnCDE_t &= \alpha_{40} + \sum_{i=1}^{n41} \alpha_{41,i} \Delta InCDE_{t-i} \\ &+ \sum_{i=0}^{n42} \alpha_{42,i} \Delta lnNUC_{t-i} \\ &+ \sum_{i=0}^{n43} \alpha_{43,i} \Delta lnEPR_{t-i} \\ &+ \sum_{i=0}^{n44} \alpha_{44,i} \Delta lnY_{t-i} + \alpha_{45} lnCDE_{t-1} \\ &+ \alpha_{46} lnNUC_{t-1} + \alpha_{47} lnEPR_{t-i} \\ &+ \alpha_{48} lnY_{t-1} + u_{4t}\end{aligned} \quad (8)$$

The null hypothesis of no cointegration between the variables in Equation (5) is H_0: $\alpha_{13}=\alpha_{14}=0$. Similarly, $\alpha_{24}=\alpha_{25}=\alpha_{26}=0$ for Equation (6), $\alpha_{34}=\alpha_{35}=\alpha_{36}=0$ for Equation (7), and $\alpha_{45}=\alpha_{46}=\alpha_{47}=\alpha_{48}=0$ for Equation (8). To determine the optimal lag structure, we employ the Akaike information criterion (Acquah, 2010; Hamdi et al., 2014; Satti et al., 2014).

The data used for the analysis covers the 41-year period from 1970 to 2010. This period has been chosen after considering not only data availability, but also the period during which nuclear power plants have played an important role in the supply of electricity in Japan. The data for CO_2 emissions in Japan are from EDMC (2015). The data for nominal GDP are from the website of the Cabinet Office, Government of Japan[2]. Electricity prices and the amount of electricity generated by nuclear plants are from ANRE (2016). GDP and electricity prices are transformed in real terms using deflators obtained from the website of the Cabinet Office, Government of Japan.

4. EMPIRICAL RESULTS

The ARDL bounds testing approach can be applied irrespective of whether the variables are I(0) or I(1). However, this procedure leads to invalid results if any variable is I(2) or beyond the second order of integration. Hence, before proceeding to ARDL bounds testing, we need to ensure that the variables are integrated of order I(0) and/or I(1). To check this, we conduct augmented Dickey–Fuller (ADF) and Phillips–Perron (PP) unit root tests and present the results in Table 1. The results indicate that all the variables are integrated of either order I(1) or I(0).

Table 2 reports the results of the ARDL bounds test for cointegration between the variables. For the models in Equations

2 The Cabinet Office, Government of Japan. (2015). Annual Report on the Japanese Economy and Public Finance 2015. http://www5.cao.go.jp/j-j/wp/wp-je15/index_pdf.html (accessed April 9, 2017).

(1 and 2), the respective estimated bounds F-statistics lie under the lower critical bounds at the 5% significance level. Hence, we conclude that there is no long-run relationship between the variables for these two models. In contrast, for the models in Equations (3 and 4), the respective estimated bounds F-statistics lie above the upper critical bounds at the 5% significance level, which implies that there is a long-run relationship between the variables in each model.

Table 3 provides the long- and short-run estimation results for those models that passed the cointegration test. For the model in Equation (3), in the long run, the coefficient for the electricity price is significantly negative at the 1% level, which means that an increase in electricity prices leads to a decrease in CO_2 emissions. Contrary to our expectation, the long-run coefficient of nuclear energy consumption is significantly positive at the 1% level, which means that an increase in nuclear energy consumption leads to an increase in CO_2 emissions rather than a decrease. A 1% increase in nuclear energy consumption increases CO_2 emissions by 0.0895%, ceteris paribus.

In the short run, the results suggest that an increase in nuclear energy consumption will lead to a reduction of CO_2 emissions without price-induced effects. However, note that the coefficient for the lagged error correction term is −0.6621, which suggests that the convergence to the long-run equilibrium following a shock to CO_2 emissions takes place within 2 years.

For the model in Equation (4), in the long run the estimated coefficient for the electricity price is significantly negative at the 1% level, while that for real GDP is significantly positive at the 10% level. Contrary to the result for the model in Equation (3), the long-run coefficient for nuclear energy consumption is negative but insignificant.

In the short run, and similar to the results for the model in Equation (3), we find that an increase in nuclear energy consumption will lead to a reduction in CO_2 emissions in the absence of price-induced effects. The estimated coefficient for the lagged error correction term is −0.3695, which suggests that the convergence to the long-run equilibrium following a shock to CO_2 emissions takes place within 3 years.

As shown at the bottom of Table 3, for both models, the estimated ARDL models pass the tests for serial correlation, misspecification of the functional form, and heteroscedasticity. In addition, we test for the stability of the coefficients in the estimated models using the cumulative sum and the cumulative sum of squares stability tests. Figures 1 and 2 indicate that the estimated parameters for both models appear stable throughout our chosen sample period.

From the results obtained, it is not easy to determine which particular model is valid. Nonetheless, it seems reasonable to prefer the model in Equation (3) to that in Equation (4) for the following reasons. First, despite the significance of the estimated bounds F-statistics, the long-run coefficient for NUC for the model in Equation (4) is statistically insignificant. Namely, the long-run relationship between the variables for the model in Equation (4) is imprecise. Second, the results of the long-run estimation for the model in Equation (3) are consistent with the results of the ARDL bounds test for cointegration for the models in Equations (1 and 2). The results of the long-run estimation for the model in Equation (3) imply that the impacts of nuclear energy consumption on CO_2 emissions can be decomposed into a (positive) direct effect and a (negative) price-induced effect, the former and the latter corresponding to the estimated coefficients for NUC and EPR, respectively. If these two effects are mixed,

Table 1: Results of unit root tests

Variables	ADF		PP	
	level	1st difference	level	1st difference
lnCDE	−2.1204 (0)	−6.1670 (1)**	−2.2326	−5.9779**
lnNUC	−0.6833 (0)	−5.5374 (1)**	−2.6833	−8.0813**
lnEPR	−1.8816 (0)	−6.2336 (0)**	−1.8816	−6.2337**
lnY	−0.9585 (1)	−5.2350 (0)**	−0.4640	−5.2119**

Lag lengths (in parenthesis) are determined by AIC, including trend and intercept. *,** indicate significance at 5% and 1% level, respectively. ADF: Augmented Dickey–Fuller, PP: Phillips–Perron, AIC: Akaike information criterion

Table 2: Bounds F-test for cointegration

Model	F-statistics	Cointegration
F (CDE|NUC)	2.3219[a]	No
F (CDE|NUC, Y)	3.1893[b]	No
F (CDE|NUC, EPR)	17.1936[b]	Yes
F (CDE|NUC, EPR, Y)	18.9811[c]	Yes

[a]5% critical value bounds: I (0)=7.1148, I (1)=7.8478. [b]5% critical value bounds: I (0)=5.4072, I (1)=6.4397. [c]5% critical value bounds: I (0)=4.4792, I (1)=5.7091

Figure 1: Plot of cumulative sum (top) and cumulative sum of squares (bottom) for the model CDE=f(NUC, EPR)

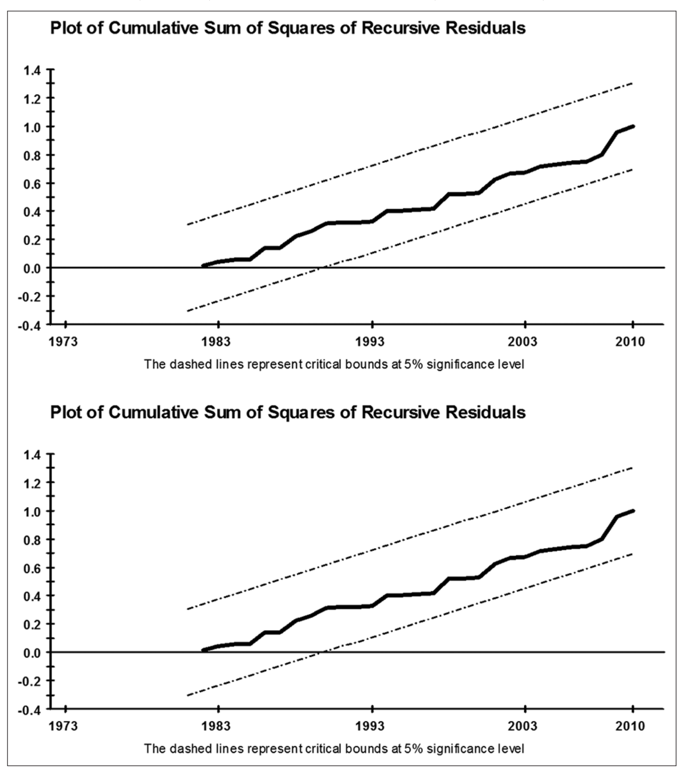
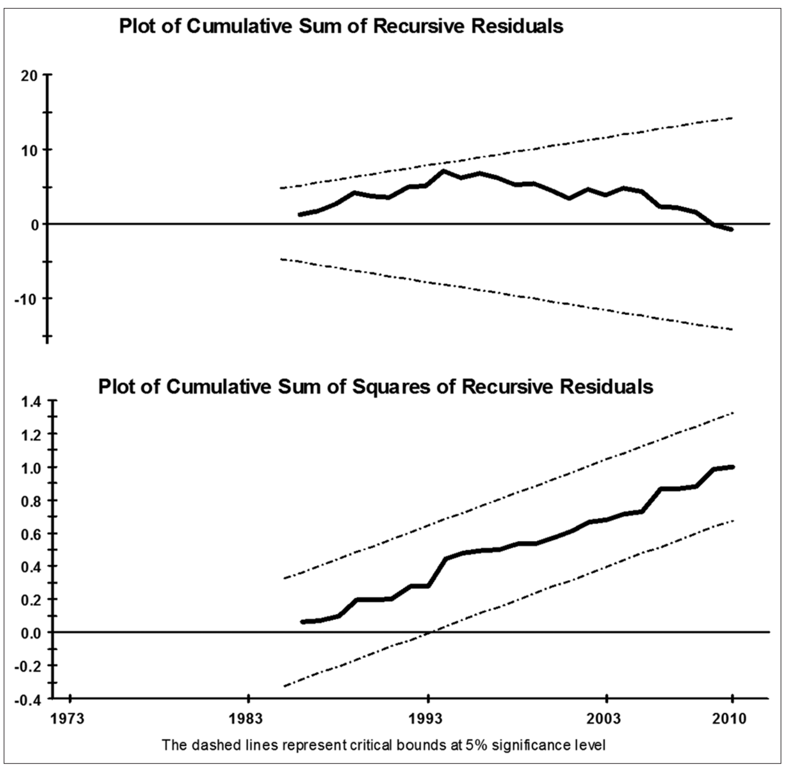


Table 3: ARDL long- and short-run results

Estimated models	CDE=f (NUC, EPR)		CDE=f (NUC, EPR, Y)	
Variables	ARDL (1,2,1)		ARDL (3,2,1,1)	
	Coefficients	T-statistics	Coefficients	T-statistics
Long-run results				
lnNUC	0.0895	5.3064 [0.000]	−0.0227	−0.3243 [0.748]
lnEPR	−0.4767	−7.7485 [0.000]	−0.6043	−3.9303 [0.001]
lnY			0.7849	1.9958 [0.057]
Short-run results				
dlnNUC	−0.0551	−1.7219 [0.095]	−0.0463	−1.6364 [0.113]
dlnNUC(−1)	−0.0589	−2.0962 [0.044]	−0.0523	−1.8817 [0.070]
dlnEPR	−0.1239	−2.3993 [0.022]	−0.0088	−0.1771 [0.861]
dlnY			0.9881	4.8919 [0.000]
ECT(−1)	−0.6621	−5.8822 [0.000]	−0.3695	−3.5153 [0.001]
R-bar squared	0.6292		0.7938	
F-statistics	13.955 [0.000]		19.180 [0.000]	
DW	1.9113		2.2028	
RSS	0.0158		0.0076	
Serial correlation	0.0548 [0.817]		0.5958 [0.447]	
RESET	1.1935 [0.284]		2.8665 [0.103]	
Heteroscedasticity	0.7992 [0.377]		0.0004 [0.984]	

The optimal lag order of lags in the model is selected based on AIC. Brackets represent probability values. ARDL: Autoregressive distributed lag

Figure 2: Plot of cumulative sum (top) and cumulative sum of squares (bottom) for the model CDE=f(NUC, Y, EPR)



it is unsurprising to find that the effects of nuclear energy consumption on CO_2 emissions are generally neutral. However, if only the price-induced effect exists, the mixed effects should also be negative.

In either case, we can conclude that, at least in the long run, there is no mechanism to ensure that the use of nuclear energy leads to a reduction of CO_2 emissions apart from the price-induced effects. This finding contradicts Iwata et al. (2012) and Baek and Pride (2014), but is consistent with Jaforullah and King's (2015) finding for the US case.

5. DISCUSSION

In Japan, nuclear energy is widely believed to be a low-carbon electricity source. Based on this belief, the Japanese government has to date aggressively promoted the use of nuclear power. However, the results of this study, at least in the long run, cast doubt over this conviction. We reveal that the contribution of nuclear energy to the reduction in CO_2 emissions merely arises from a fall in electricity demand because of the price increase, without which an increase in nuclear energy consumption would not directly induce a decrease in CO_2 emissions.

How do we explain our results? Intuitively, they seem to contradict the notion that nuclear power plants have substantially lower carbon life-cycle intensity per kWh generated than comparable fossil fuel power plants (Hondo, 2005; Imamura and Nagano, 2010; Imamura et al., 2016)[3]. Perhaps the only way to resolve this contradiction is to conclude that Japanese nuclear policy has, somehow, failed in replacing fossil fuel with nuclear energy. This idea is consistent with the empirical results in Lee and Chiu (2011), who concluded that nuclear energy consumption and oil, at least in Japan, are complements rather than substitutes. In fact, the number of fossil fuel power plants and the amount of electricity generated by these plants grew threefold and fourfold from 1970 to 2010, respectively (ANRE, 2016).

Despite the results shown, we could insist that to overcome any shortage in electricity supply the use of nuclear power plants is relatively more environmentally friendly than burning fossil fuels in thermal power plants. But this claim seems misleading as we do not necessarily have to choose either nuclear or fossil fuels. A third option exists, which is to not meet the shortage of electricity. In general, the meaning of energy shortage is not necessarily obvious. What does "shortage" mean in the context of energy issues? What happens if we do not meet the shortage?

In fact, there is no evidence that the Japanese economy would suffer following a reduction in electricity supply. Existing studies of the electricity–growth nexus for Japan have supported neither the "growth hypothesis" nor the "feedback hypothesis," which implies that electricity conservation policies do not adversely impact economic growth (Narayan and Prasad, 2008; Sami, 2011; Huang, 2012; Lin and Chen, 2013). In other words, the Japanese economy can continue to grow without increasing electricity consumption. In sum, the validity of policies that promote nuclear energy investment is doubtful from both an economic and an environmental perspective.

Energy saving should be a top priority for energy policy. Of course, there must exist a subsistence or threshold level of electricity consumption below which economic conditions will clearly start to deteriorate. What is this minimum level of electricity consumption for the Japanese economy? How should we generate this minimum amount of electricity? Indeed, do we still have to depend upon nuclear power plants in addition to more efficient fossil fuel power plants (such as natural gas-fired combined-cycle power plants) or renewable energy?

These questions have so far not been discussed sufficiently in Japan, at least partly because of the Japanese government's positive attitude toward nuclear energy, largely based on the untested belief that nuclear power plants are indispensable for achieving economic growth with lower CO_2 emissions. In addition, it is difficult to determine whether our results reflect the effect of particular Japanese institutions, or the intrinsic nature of nuclear energy. To tackle these questions, the approach used in this paper should be applied to other countries.

Note that our cointegration framework is far from perfect in estimating the CO_2 emissions from nuclear power generation because we cannot intrinsically cover those emissions arising from mining activities abroad and the future storage of radioactive wastes. The relationship between LCA and the cointegration approach is complementary, not competitive.

6. CONCLUSION

This study estimates the impact of nuclear energy consumption on CO_2 emissions in Japan using annual time-series data over the period 1970–2010. We develop four different bivariate and multivariate models, and estimate the relationships between the variables in each model using the ARDL bounds testing approach. The results reveal that in the long run there is no evidence that an increase in nuclear energy consumption leads to a decrease in CO_2 emissions except for the price-induced effects. However, in the short run, the results imply that an increase in nuclear energy consumption will lead to a decrease in CO_2 emissions. However, the magnitude of the coefficient of the lagged error correction term implies that the convergence to the long-run equilibrium following a shock to CO_2 emissions takes place within 2–3 years. Our results imply that, at least from a long-term perspective, Japan has not so far succeeded in replacing fossil fuels with nuclear energy because nuclear energy and fossil fuels are thought to be complements rather than substitutes.

One possible mechanism through which nuclear energy could contribute to a reduction in CO_2 emissions involves an increase in electricity prices, because the long-run effect of electricity prices on CO_2 emissions is found to be significantly negative. The existence of this mechanism, however, does not necessarily mean that a nuclear power plant itself is a low-carbon energy source. Plainly speaking, the mechanism for CO_2 reductions associated with generating electricity from nuclear power plants is essentially no different from the effect of levying taxes on electricity consumption. Ignoring the risk of radioactive pollution, a tax would be a better solution than the promotion of nuclear energy. Accordingly, whether an energy policy dependent on nuclear energy is green remains an open question.

7. ACKNOWLEDGMENTS

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3 Storm van Leeuwen (2012) pointed out that energy analyses of nuclear power usually underestimate the life-cycle emissions of CO_2. Considering the decreasing grade of uranium ore, Storm van Leeuwen warned about the possibility of the life-cycle CO_2 emissions of nuclear-generated electricity surpassing those of gas- and even coal-fired electricity generation. However, our analysis does not consider the life-cycle emissions of CO_2 arising from mining uranium ore abroad and the storage of radioactive wastes in the future.

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