Empirical Study on the Determinants of CO2 Emissions: Evidence from OECD Countries

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Abstract

This paper empirically investigates the environmental Kuznets curve (EKC) for CO_2 emissions in the cases of 11 OECD countries by taking into account the role of nuclear energy in electricity production. The autoregressive distributed lag (ARDL) approach to cointegration is employed as the estimation method. Our results indicate that energy consumption has a positive impact on CO_2 emissions in most countries in the study. However, the impact of trade is not statistically significant. The results provide evidence for a role of nuclear power in reducing CO_2 emissions only in some countries. Additionally, although the estimated long-run coefficients of income and its square satisfy the EKC hypothesis in Finland, Japan, Korea and Spain, only Finland's EKC turning point is inside the sample period of the study, providing poor evidence in support of the EKC hypothesis.

Keywords: CO_2; Environment; EKC; OECD; ARDL

JEL classifications: Q43; Q51; Q53

1 Introduction

Carbon dioxide (CO_2) is considered one of the main causes of global warming. For this reason, whether the environmental Kuznets curve (EKC) exists

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for CO_2 emissions has been a central topic in environmental economics. The EKC hypothesis claims that an inverted U-shaped relation exists between income and environmental pollutants.[1] A great number of related studies on the EKC for CO_2 emissions are available. For example, Shafik (1994) and Holtz-Eakin and Selden (1995) find that CO_2 emissions monotonically increase with per capita income. Soytas *et al.* (2007) find no causal relation running from income to CO_2 emissions, including energy consumption, in an EKC analysis in the US. On the other hand, Liu (2005) studies 24 OECD nations using the panel data and finds that the EKC exists for CO_2 emissions by considering each country's energy consumption as well as income. In more recent studies, Ang (2007), Jalil and Mahmud (2009) and Iwata *et al.* (2010) provide evidence supporting the EKC for CO_2 emissions in France and China. Based on panel data and smooth transition regression model, Aslanidis and Iranzo (2009) find no evidence of EKC in non-OECD countries.[2] However, as can be seen, there is no clear evidence for the EKC hypothesis for CO_2 emissions.

With the aim of contributing to the research on the EKC for CO_2 emissions, this study provides new evidence from 11 OECD countries by focusing on nuclear energy for electricity production. This approach is of interest because the world demand for electricity is increasing with economic growth. Electricity can be produced using various resources such as oil, coal, natural gas, hydropower and nuclear power, the latter two of which produce fewer CO_2 emissions during the production of electricity. Our paper, however, focuses on nuclear power because the ratio of hydropower to the total electricity produced is low in most countries except for a few, such as Canada, which possess abundant water resources.

Richmond and Kaufman (2006), an earlier study considering nuclear power generation, investigate the EKC for CO_2 in OECD and non-OECD countries. However, they use panel data analysis as their estimation method. Iwata *et al.* (2010) also focus on nuclear energy but analyze only the case of France because its nuclear energy share in electricity production is the largest in the world. As an extension of Iwata *et al.* (2010), we focus on the time series analysis of 11 individual OECD countries. The analysis of individual countries is of interest because it may permit the clarification of effects which could be overlooked in the panel data analysis.

[1] For early empirical studies on the EKC hypothesis, see Grossman and Krueger (1993, 1995) and Selden and Song (1994).

[2] For other recent studies on the EKC hypothesis, see, for example, Halicioglu (2009), Musolesi *et al.* (2009) and Kearsley and Riddel (2010).

The structure of this paper is as follows. Section 2 discusses the estimation methodology. Section 3 provides the empirical analysis, including data and the estimation results. Section 4 is the conclusion.

2 Estimation Methodology

In addition to the EKC hypothesis, which suggests that there is a nonlinear quadratic relationship between income and environmental pollutants, this study considers the effects of nuclear energy in electricity production, which may impact CO_2 emissions. The logarithm version for our baseline estimation model can be written as follows:

$$\ln(co_2)_t = \alpha + \beta \ln y_t + \gamma \left(\ln y_t\right)^2 + \rho \ln nuc_t + \upsilon_t \tag{1}$$

where co_2 is per capita CO_2 emissions, y is per capita real GDP, nuc is electricity production from the nuclear source (% of total) and υ is the standard error term.

As the estimation methodology, we employ the autoregressive distributed lag (ARDL) approach proposed by Pesaran *et al.* (2001).

The estimation equation (1) above can be written as an unrestricted error correction representation of the ARDL model:

$$\begin{aligned} \Delta \ln(co_2)_t \quad = \quad & \alpha_0 + \sum_{i=1}^{n} \alpha_{1i} \Delta \ln(co_2)_{t-i} + \sum_{i=1}^{n} \alpha_{2i} \Delta \ln y_{t-i} + \sum_{i=1}^{n} \alpha_{3i} \Delta \left(\ln y_{t-i}\right)^2 \\ & + \sum_{i=1}^{n} \alpha_{4i} \Delta \ln nuc_{t-i} + \delta_1 \ln(co_2)_{t-1} + \delta_2 \ln y_{t-1} \\ & + \delta_3 \left(\ln y_{t-1}\right)^2 + \delta_4 \ln nuc_{t-1} + \zeta_t, \end{aligned} \tag{2}$$

where ζ_t is the standard error term.

In the analysis, first, the existence of a long-run relation between the variables in the system is tested. The null hypothesis of no cointegration relationship, $H_0: \ \delta_1 = \delta_2 = \delta_3 = \delta_4 = 0$, is tested against its alternative, $H_1: \ \delta_1 \neq 0, \delta_2 \neq 0, \delta_3 \neq 0, \delta_4 \neq 0$. The computed F-statistics from this test are compared to the critical values of the F-statistics provided in Pesaran *et al.* (2001). If the computed F-statistic is higher than the appropriate upper bound of the critical value, the null hypothesis of no cointegration is rejected; if it is below the appropriate lower bound, the null hypothesis cannot be rejected, and if it lies between the lower and upper bounds, the result is inconclusive. Next, the lag orders of the variables are chosen using Akaike Information Criteria (AIC), and the short-run and long-run models are estimated following the selected ARDL models. The CUSUM (Cumulative Sum) and CUSUMSQ (CUSUM of Squares) of recursive residuals are also used as stability tests.

Following Ang (2007), Jalil and Mahmud (2009) and Iwata *et al.* (2010), equation (1) will be expanded to incorporate trade and energy consumption, which may also affect CO_2 emissions.

3 Data and Estimation Results

3.1 Data

Our study employs the annual data of OECD countries obtained from the World Development Indicators (WDI) CD-ROM (2007) released by the World Bank. The countries chosen for estimation are those that have introduced nuclear energy sources for electricity production. Moreover, given the number of the variables in our estimation model, countries with continuous sample sizes of less than 25 are dropped from the analysis in order to ensure that the sample size is sufficient for cointegration analysis. Accordingly, 11 OECD countries are selected: Belgium (1972-2003), Canada (1963-2003), Finland (1977-2003), Germany (1961-2003), Japan (1966-2003), the Republic of Korea (Korea, 1977-2003), Spain (1968-2003), Sweden (1965-2003), Switzerland (1969-2003), the United Kingdom (UK, 1960-2003) and the United States (US, 1960-2003). The sample periods in the parentheses are based on the availability of all data. Although the sample sizes for Italy and Netherlands are sufficient, they are not considered in this study because Italy ceased using nuclear energy for electricity production in 1988 and the sample average of the share of nuclear energy sources in total electricity production in the Netherlands is less than 5%.

CO_2 emissions (co_2) are measured as metric tons per capita. Real GDP (y) is GDP per capita in constant local currency. Electricity produced from a nuclear source (nuc) is the percentage of total electricity produced. Trade (tr) is total trade as the percentage of GDP.[3] Per capita energy use or consumption (en) is measured as kg of oil equivalent per capita.

3.2 Estimation Results

First, F-test results with 1 and 2 lag orders are reported in Table 1.[4] The results of baseline equation (2) are presented as case 1, whereas the results

[3] Trade here is defined as the sum of exports and imports.

[4] We set this lag order in order to ensure a sufficient degree of freedom for time series analysis because the sample sizes of the selected countries in our study are quite small.

of cases in which baseline equation (1) is expanded to incorporate trade and energy consumption are provided as cases 2 and 3, respectively. From the table, we can see that the computed F-statistics of Belgium (case 1), Canada (cases 1 and 3), France (cases 1 and 3) and Korea (case 1) are above the criteria bounds provided in Pesaran *et al.* (2001), indicating evidence of long-run or cointegration relationships between the variables in estimation models. For other countries, most of the computed F-statistics lie between the criteria bounds, so it is inconclusive whether there are long-run or cointegration relationships among the considered variables in these countries. In such a circumstance, we rely on the significance of the error correction term in the next step for information on the existence of cointegration relationships (Kramer *et al.*, 1992; Bahmani-Oskooee and Nasir, 2004).

Table 1: F-statistics of Bound Tests

Case	Case 1		Case 2		Case 3	
Lag order	1	2	1	2	1	2
Belgium	1.642	3.760*	2.322^a	3.104^a	1.625	2.766^a
Canada	4.299**	3.325^a	3.064^a	2.186	4.455**	5.520***
Finland	3.238^a	3.437^a	2.295^a	2.501^a	2.457^a	2.590^a
Germany	3.326^a	2.791^a	1.939	1.472	2.792^a	1.850
Japan	1.990	3.062^a	2.291^a	2.473^a	1.805	2.619^a
Korea	3.784*	2.962^a	2.595^a	2.382^a	3.214^a	1.907
Spain	2.620^a	2.304^a	2.600^a	2.827^a	2.210	2.038
Sweden	2.759^a	2.657^a	2.465^a	1.858	3.236^a	2.865^a
Switzerland	2.854^a	2.479^a	2.046	2.292^a	2.059	1.849
UK	2.475^a	2.596^a	1.884	1.991	1.927	1.805
US	1.582	2.273	1.563	1.697	2.028	2.307^a

Note: 1. ***, ** and * are respectively the 1%, 5% and 10% of the significant level.
2. 10% CV [2.425, 3.574], 5% CV [2.850, 4.049] and 1% CV [3.817, 5.122] for case 1. 10% CV [2.262, 3.367], 5% CV [2.649, 3.805] and 1% CV [3.516, 4.781] for cases 2 and 3.
3. "*a*" is the value lies between criteria value (CV) bands.

Next, baseline equation (2) and the expanded equations are estimated using the ARDL approach.[5] The maximum lag length is set to 2 for all countries except for Finland and Korea, whose maximum lag length for the ARDL estimation procedure is set to 1 because the sample sizes, which span from 1977 to 2003, are small compared to those of other countries. With this maximum lag length setting, the ARDL models are selected using AIC.

[5] We also conduct an analysis of the model in which CO_2 emissions are determined only by income and its square. However, except for Germany, the coefficients of income and its square are not statistically significant.

The selected models are reported in the third column of Table 2. In the table, we also provide the long-run estimation results of cases 1, 2 and 3 as well as the lagged error correction term (EC_{t-1}) for each country.[6]

As shown in Table 2, except for the cases of Canada (case 2), Sweden, Switzerland (cases 2 and 3) and the US (cases 1, 2 and 3), the coefficients of EC_{t-1} are significantly negative and smaller than unity in absolute values. These results provide evidence supporting the existence of a cointegration relationship among variables. We also conduct the CUSUM and CUSUMSQ stability tests for the cases of countries in which the cointegration is confirmed from the results of EC_{t-1} estimated coefficients. The results support the stability of the estimated models. Although the lagged error correction terms confirm a cointegration relation among variables with stability, some variables may not be in the cointegration vector space. As shown in Table 2, in most countries, energy consumption ($\ln en$) is positive and significant, while trade ($\ln tr$) is not significant. The results of the positive impact of energy consumption on CO_2 emissions are consistent with those of previous studies (e.g., Liu, 2005; Ang, 2007, 2009; Jalil and Mahmud, 2009). As for nuclear energy ($\ln nuc$), the results are mixed. Except for the cases of Finland, Japan, Korea and Spain, the coefficients are not statistically significant, indicating that less than half of the results for the selected countries support a role of nuclear energy in reducing CO_2 emissions. Furthermore, although the results indicate that the signs of estimated long-run coefficients of $\ln y$ and $(\ln y)^2$ satisfy the EKC hypothesis in these four countries, only the calculated turning point of the EKC in the case of Finland is inside the sample period.[7] Iwata *et al.* (2010) indicate that the EKC for CO_2 is proven for the case of France and its turning point lies inside the sample period. Given the fact that OECD countries are at mature stages of economic development, the turning points of the EKC in these countries should be within the sample period if the EKC exists. Thus, in general, our results provide poor evidence for the EKC hypothesis for CO_2 emissions.

4 Conclusion

This study examines the determinants of CO_2 emissions in 11 OECD countries by using an estimation equation that incorporates nuclear energy for

[6]The results of the short run can be provided upon request.

[7]The turning points of Finland, Japan, Korea and Spain in logarithm versions are, respectively, 10.109 (case 2), 15.555 (case 1), 16.861 (case 1) and 9.909 (case 1).

Table 2: Estimation Results Using ARDL Approach

Country		AIC-based	$\ln y$	$(\ln)^2$	$\ln nuc$	$\ln tr$	$\ln en$	EC_{t-1}	*CUSUM*	*CUSUMSQ*
Belgium	Case 1	ARDL(1,0,0,1)	-46.878	2.344	-0.018	-	-	-0.299**	S	S
	Case 2	ARDL(1,0,0,1,0)	-44.241	2.239	-0.025	-0.862**	-	-0.402***	S	S
	Case 3	ARDL(1,0,0,2,2)	6.436	-0.408	-0.040	-	2.148***	-0.457***	S	S
Canada	Case 1	ARDL(1,0,0,0)	-101.621*	4.968*	0.166	-	-	-0.177*	S	S
	Case 2	ARDL(2,0,1,0,0)	-142.014	6.961	0.196	-0.200	-	-0.130	-	-
	Case 3	ARDL(2,1,2,2,0)	-95.446***	4.636***	0.106*	-	2.422***	-0.443***	S	S
Finland	Case 1	ARDL(1,0,0,0)	45.989*	-2.285	-0.406***	-	-	-0.637***	S	S
	Case 2	ARDL(1,1,1,0,0)	55.885*	-2.764*	-0.387***	0.116	-	-0.626***	S	S
	Case 3	ARDL(1,1,1,0,1)	6.109	-0.335	-0.121	-	1.770	-0.550***	S	S
Germany	Case 1	ARDL(1,1,1,1)	-17.027	0.805	0.171	-	-	-0.354***	S	S
	Case 2	ARDL(1,1,1,1,0)	17.661	-0.939	0.039	0.239	-	-0.451***	S	S
	Case 3	ARDL(1,0,0,1,2)	-4.176	0.181	0.003	-	1.415***	-0.644***	S	S
Japan	Case 1	ARDL(2,0,1,1)	44.021**	-1.415**	-0.429**	-	-	-0.198**	S	S
	Case 2	ARDL(2,0,1,1,2)	38.004*	-1.211*	-0.440**	0.076	-	-0.182**	S	S
	Case 3	ARDL(2,1,1,0,1)	4.424	-0.150	-0.084**	-	1.044***	-0.356**	S	S
Korea	Case 1	ARDL(1,1,1,0)	15.513***	-0.460***	-0.177***	-	-	-0.655***	S	S
	Case 2	ARDL(1,1,1,0,0)	10.062*	-0.289	-0.136**	-0.209	-	-0.560***	S	S
	Case 3	ARDL(1,1,1,0,1)	12.864***	-0.385***	-0.154**	-	0.241	-0.659***	S	S
Spain	Case 1	ARDL(1,0,0,0)	21.344**	-1.077**	-0.165***	-	-	-0.487***	S	S
	Case 2	ARDL(1,0,0,0,0)	22.479**	-1.140**	-0.166***	0.053	-	-0.502***	S	S
	Case 3	ARDL(2,1,1,1,2)	-27.560	1.314	-0.054	-	3.302***	-0.420***	S	S

Table 2 (Continued): Estimation Results Using ARDL Approach

Country		AIC-based	$\ln y$	$(\ln)^2$	$\ln nuc$	$\ln tr$	$\ln en$	EC_{t-1}	*CUSUM*	*CUSUMSQ*
Sweden	Case 1	ARDL(2,1,1,0)	-250.739	10.380	0.000	-	-	-0.067	-	-
	Case 2	ARDL(2,1,1,0,2)	-29.009	1.209	-0.212	2.859	-	-0.080	-	-
	Case 3	ARDL(2,1,1,0,2)	3614.2	-148.391	-0.459	-	45.134	0.011	-	-
Switzerland	Case 1	ARDL(1,1,0,0)	9.170	-0.439	-0.022	-	-	-0.696***	S	S
	Case 2	ARDL(0,1,2,0,1)	-56.963*	2.617*	0.071*	-0.393**	-	-1.000	-	-
	Case 3	ARDL(1,0,0,2,1)	326.037	-14.837	-0.425	-	-3.538	-0.064	-	-
UK	Case 1	ARDL(1,1,2,2)	-4.394	0.228	0.004	-	-	-0.611***	S	S
	Case 2	ARDL(2,1,2,2,1)	-6.801	0.357	0.038	-0.003	-	-0.475***	S	S
	Case 3	ARDL(1,2,2,0,1)	1.450	-0.089	-0.055	-	0.743***	-0.649***	S	S
US	Case 1	ARDL(1,0,1,0)	94.755	-4.561	-0.690	-	-	-0.030	-	-
	Case 2	ARDL(1,0,1,1,1)	-17.593	1.029	0.236	-4.234	-	-0.033	-	-
	Case 3	ARDL(0,0,0,0,1)	-1.328	0.066	-0.039***	-	1.146***	-1.000	-	-

Note: 1. ***, ** and * are respectively the 1%, 5% and 10% of the significant level.

2. "S" stands for stable.

electricity production into the equation of the environmental Kuznets curve (EKC). Furthermore, we expand our estimation equation by including trade and energy consumption.

Employing the autoregressive distributed lag (ARDL) to cointegration as the estimation methodology, cointegration relationships are confirmed in most selected countries based on the results of the estimated coefficients of the lagged error correction terms. However, the significance of variables in the cointegration vector is very diverse. While our results indicate that trade is not statistically significant, energy consumption is positive and significant in most selected countries, providing evidence that energy consumption is a main factor in increasing CO_2 emissions. For nuclear energy, the results are mixed. Except for the cases of Finland, Japan, Korea and Spain, our estimation results do not provide evidence for a role of nuclear energy in reducing CO_2 emissions.[8] Furthermore, although our results indicate that the signs of estimated long-run coefficients of income and its square satisfy the EKC hypothesis in these four countries, only the calculated turning point of Finland's EKC is within the sample period. Based on these results, we have only limited evidence to support the EKC hypothesis for CO_2 emissions in selected countries.

Finally, it is worth noting that our study does not take into account the trade of electric power among selected countries. Because some countries may export electric power produced by nuclear energy to neighboring countries, the nuclear energy in electricity production in the exporting countries may also affect the CO_2 emissions of their neighbors. Thus, when considering the trade of electrical power in the study, the obtained results may change to some extent. This factor is beyond the scope of our study but will be examined in future research.

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[8]It is necessary to bear in mind that it is very costly to ensure the safety management of nuclear energy generation to prevent any accident that may be detrimental to the environment and humans.

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