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# CO2 emissions, renewable and non-renewable energy consumption, and economic growth: evidence from panel data for developed countries

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## Abstract

In this paper, using panel data of 31 developed countries over the period 1996-2011 we attempt to empirically investigate the relationship between CO2 emissions, renewable and non-renewable energy consumption, and economic growth. Our results suggest that energy conservation policy leads to a negative impact on economic growth for developed countries. Additionally, we find that renewable energy consumption contributes to reductions in emissions.

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## 1. Introduction

Since the Kyoto Protocol was signed in 1997 there has been growing concern regarding environmental problems related to fossil fuel energy in the world. Given that most of the countries with binding targets under the Kyoto Protocol are developed countries, the question of whether or not a reduction in carbon dioxide (CO2) emissions through reduced fossil fuel usage has a positive effect on economic growth is a crucial issue for those countries. Although a number of empirical studies have been conducted on the relationship between (total) energy consumption and economic growth, relatively little attention has been given to the nexus between CO2 emissions, renewable energy consumption and the growth. Moreover, the findings of these studies are mixed. For instance, Huang *et al.* (2008) state using panel data for the period 1972-2002 that there is a unidirectional causality from economic growth to energy consumption for high income countries. Narayan and Smyth (2008) use panel data of 7 developed countries over the period 1972-2002 and conclude that Granger causality runs from energy consumption to real GDP, but only weakly significant. Salim *et al.* (2014) address using panel data for 1980-2011 that there is a bidirectional relationship between GDP and non-renewable energy consumption, whereas a unidirectional causality runs from renewable energy consumption to GDP for 29 OECD countries. Apergis and Payne (2010) find using panel data during the period 1985-2005 from 20 OECD countries that there exists bidirectional causality between economic growth and renewable energy consumption. Similarly, Kula (2014) uses panel data of 19 OECD countries for 1980-2008 and states that a unidirectional causality runs from GDP to renewable electricity consumption. By contrast, Menegaki (2011) argues using panel data for 27 European countries over the period 1997-2007 that there is no causal relationship between consumption of renewable energy and GDP. By using panel data for 28 high income countries from 1985 to 2005 Sharma (2011) stresses that GDP and energy consumption are positively associated with emissions of CO2, but the CO2-GDP nexus is not statistically significant. On the other hand, Dinda and Coondoo (2006) address using panel data covering the period 1960-1990 that there is a bidirectional causal relationship between CO2 emissions and GDP for Western Europe (16 countries). Using panel data of 19 developed and developing countries covering 1984-2007 Apergis *et al.* (2010) argue the existence of bidirectional causality between each pair of CO2 emissions, economic growth, nuclear energy consumption and renewable energy consumption, except a weak unidirectional causality running from nuclear energy consumption to economic growth.

The purpose of this paper is to empirically investigate the link between CO2 emissions, economic growth, non-renewable and renewable energy consumptions for the developed countries. Different from previous studies, we employ not only traditional panel OLS and GMM methodologies but also Granger causality test within a lag augmented vector autoregressive (LA-VAR) model proposed by Toda and Yamamoto (1995).

The rest of the paper is organized as follows. Section 2 describes the data and methodology, while section 3 provides the results of the estimates. Section 4 concludes.

## 2. Data and Methodology

### 2.1 Data

In our model we use an annual balanced panel data for 31 developed countries.[1] The data cover the period 1996-2011, giving 496 observations. The variables used are as follows: carbon dioxide emissions (CO2; metric tons per capita); consumption of fossil fuel energy such as coal, oil, petroleum and natural gas products (FEC; as % of total) as a proxy of non-renewable energy consumption; GDP per capita based on purchasing power parity (GDP) as a proxy of economic growth; and renewable energy consumption (REC; as % of total final energy use). The emissions of CO2, which are used as an indicator for the level of environmental degradation, have a technical measurement problem that emission data are not directly measured, but calculated from estimates of the burning of fossil fuels and the manufacture of cement. They include carbon dioxide produced during consumption of solid, liquid, and gas fuels and gas flaring. Uncertainties in CO2 emissions, therefore, are unavoidable due not only to the discrepancies in interpretation of the process generating emissions, but also to the inaccuracies of data collection systems. Nevertheless, CO2 emissions are common and the only available data for time series analysis. All time series are taken from the World Bank, *World Development Indicator database* (http://data.worldbank.org/indicator) and expressed in natural logarithms. The descriptive statistics of variables are presented in Table 1.

Table 1 Summary of descriptive statistics

| | Mean | Median | Maximum | Minimum | Std. Dev. | Skewness | Kurtosis |
|---|---|---|---|---|---|---|---|
| CO2 | 2.1613 | 2.1517 | 3.2108 | 0.9555 | 0.4080 | 0.0606 | 3.4053 |

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[1] Australia, Austria, Belgium, Canada, Cyprus, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Israel, Italy, Japan, Latvia, Lithuania, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Spain, Slovak Republic, Slovenia, South Korea, Sweden, Switzerland, United Kingdom, United States.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| FEC | 4.2785 | 4.3863 | 4.5900 | 2.7850 | 0.3151 | -2.0389 | 7.8282 |
| GDP | 10.2292 | 10.2665 | 11.4194 | 7.7547 | 0.4258 | -0.9574 | 6.2858 |
| REC | 2.2321 | 2.1758 | 6.4583 | -0.4942 | 1.1269 | -0.1352 | 2.6928 |

*Notes*: All variables are expressed in their logarithms.

## 2.2 Methodology

We first use the traditional panel OLS, *i.e.* the fixed or random effects model as a benchmark for our comparison. The fixed effects model takes the following form:

$$Y_{it} = \alpha_i + \beta_1 X_{1it} + \beta_2 X_{2it} + \cdots + \beta_k X_{kit} + \varepsilon_{it} \qquad (1)$$

where $Y$ is the dependent variable, $X$ is the explanatory variable, $\varepsilon$ is the error term and the subscripts $i$ and $t$ represent country and time period, respectively. Given that $\alpha_i = \alpha + v_i$, the random effects model can be written as:

$$Y_{it} = (\alpha + v_i) + \beta_1 X_{1it} + \beta_2 X_{2it} + \cdots + \beta_k X_{kit} + \varepsilon_{it} \qquad (2)$$

$$Y_{it} = \alpha + \beta_1 X_{1it} + \beta_2 X_{2it} + \cdots + \beta_k X_{kit} + (v_i + \varepsilon_{it}) \qquad (3)$$

where $v_i$ is a zero mean standard random variable. As a robustness check, we apply the first-difference GMM estimator, proposed by Arellano and Bond (1991), for a dynamic panel model with lagged dependent variables. The GMM model is given by:

$$Y_{it} - Y_{it-1} = \alpha(Y_{it-1} - Y_{it-2}) + \beta'(X_{it} - X_{it-1}) + (\varepsilon_{it} - \varepsilon_{it-1}) \qquad (4)$$

with the following moment conditions:

$$E[Y_{it-s}(\varepsilon_{it} - \varepsilon_{it-1})] = 0 \quad \text{for} \quad s \geq 2; t = 3, \ldots, T, \qquad (5)$$

$$E[X_{it-s}(\varepsilon_{it} - \varepsilon_{it-1})] = 0 \quad \text{for} \quad s \geq 2; t = 3, \ldots, T. \qquad (6)$$

## 3. Empirical Results

Before conducting panel regressions, the null hypothesis of non-stationary are tested for common unit root process by the LLC test (Levin *et al.*, 2002) and for individual unit root process by the IPS test (Im *et al.*, 1997). Table 2 reports the results of the panel unit root tests. It is observed that the null hypothesis of a unit root in log levels cannot be rejected (except for GDP using the LLC), but all variables are stationary in first differences at the 1 percent level of significance. Overall, the results suggest that all variables are stationary $I(1)$.

Table 2 Results for panel unit root tests

| | LLC | | IPS | |
|---|---|---|---|---|
| | Log Levels | First differences | Log Levels | First differences |
| CO2 | 1.972(0.975) | -14.049(0.000)* | 1.944(0.974) | -12.747(0.000)* |
| FEC | 4.520(1.000) | -13.078(0.000)* | 5.814(1.000) | -12.374(0.000)* |

|  |  |  |  |  |
|---|---|---|---|---|
| GDP | -4.966(0.000)* | -11.026(0.000)* | 1.615(0.946) | -10.019(0.000)* |
| REC | 1.312(0.905) | -14.495(0.000)* | 3.329(0.999) | -12.830(0.000)* |

*Notes*: Probabilities for the tests assume asymptotic normality. * indicates significance at the 1% level. Selection of lags is based on SIC. Newey-West bandwidth selection using Bartlett kernel is applied for the test. Panel unit root test includes intercept and trend.

Next, the Hausman test (Hausman, 1978) is employed in order to choose between fixed and random effects as an appropriate model in panel data estimation. The null hypothesis is that the coefficients of the fixed effects are equal to those of the random effects. As for the regression model for CO2 emissions, the Hausman test yields a chi-square value of 31.591 with *p*-value of 0.000, thus suggesting the fixed effects model. The results of the estimation are reported in Table 3. We observe that all estimated coefficients in columns (1) to (5) are statistically significant at the 1 percent level. It is observed that all *p*-values of the Sargan test exceed the conventional significance level of 0.05, thereby indicating the validity of the instruments. As expected, the coefficients from both OLS fixed-effects and GMM models show that an increase in FEC and GDP, respectively, leads to an increase in CO2, whereas a rise in REC contributes to a reduction in CO2, ranging from 0.02 to 0.11 percent. This last result is not in line with the finding of Apergis *et al.* (2010) that there is a positive relationship between emissions and renewable energy consumption. Overall, it should be noted that the effect of FEC on CO2 is much larger than that of REC.

Table 3 Regression results of panel OLS (fixed effects) and GMM

| Dependent variable: CO2 |  |  |  |  |  |
|---|---|---|---|---|---|
| Variables | OLS | First-differenced GMM |  |  |  |
|  | (1) | (2) | (3) | (4) | (5) |
| CO2(-1) |  | 0.419** | 0.445** | 0.539** | 0.538** |
|  |  | (0.003) | (0.021) | (0.016) | (0.014) |
| FEC | 0.792** | 0.700** | 0.532** | 0.862** | 0.853** |
|  | (0.057) | (0.088) | (0.057) | (0.054) | (0.054) |
| GDP | 0.055** | 0.079** | 0.048** | 0.026** | 0.017* |
|  | (0.011) | (0.013) | (0.011) | (0.008) | (0.008) |
| REC | -0.078** | -0.109** | -0.102** | -0.023** | -0.020** |
|  | (0.008) | (0.008) | (0.010) | (0.008) | (0.007) |
| Intercept | -1.625** |  |  |  |  |
|  | (0.294) |  |  |  |  |
| Observations | 496 | 434 | 434 | 434 | 434 |

| | | | | | |
|---|---|---|---|---|---|
| R-squared | 0.978 | | | | |
| J-statistic | | 29.412 | 29.627 | 29.325 | 29.104 |
| Sargan test (*p*-value) | | 0.341 | 0.331 | 0.345 | 0.355 |

*Notes*: ** and * denote significance at the 1% and 5% level, respectively. All variables are expressed in their logarithms. Standard errors are reported in parentheses. The selection of the fixed effects model is based on the Hausman test: Chi-square=31.591; p=0.000. Instrument variables are as follows: CO2(lagged) and FEC in model (2); CO2(lagged) and GDP in model (3); CO2(lagged) and REC in model (4); and CO2(lagged), FEC, GDP and REC in model (5). The null hypothesis of the Sargan test is that the over-identifying restrictions are valid.

As a robustness check, we also use a long-run Granger causality test in a LA-VAR model, which is the ordinary least-squares (OLS) estimation of an unrestricted level VAR $(h)$ model with an artificially augmented lag $d$. It is well-known that the VAR $(h+d)$ makes it possible to avoid the pretest biases. In particular, the merit of this method is not to require the attention to cointegration properties of the data-generating process. Since the optimal lag length ($h=2$) was selected by the Schwarz information criterion, the causality test based on the level VAR (2+1) was conducted. The null hypothesis of Granger non-causality is tested using the Wald test for zero restrictions on the parameters of the model. As can be seen in table 4, the results suggest the existence of unidirectional Granger causality running from CO2 and FEC to GDP, respectively, with no feedback. Given that emissions occur in the process of production, these results imply that consumption of non-renewable energy can induce economic growth, but not vice versa. Likewise, it is observed that there exists unidirectional causality running from CO2 to FEC. This can be interpreted that production process influences consumption of non-renewable energy. At the same time, it is found that there is bidirectional causality between CO2 and REC, thus suggesting the presence of a feedback effect. This implies that renewable energy consumption can play a crucial role in reducing CO2 emissions. On the other hand, we observe that there is no causality between GDP and REC, confirming the finding of Menegaki (2011). In addition, it is found that there exists no causality between FEC and REC. The no-causality results may be attributed to the fact that the share of renewable energy relative to non-renewable energy resources is remarkably low.

Table 4 Granger causality test

| Hypothesis | Chi-square | *p*-values |
|---|---|---|
| CO2 does not cause FEC | 9.582 | 0.022* |
| FEC does not cause CO2 | 2.262 | 0.519 |
| CO2 does not cause GDP | 13.634 | 0.003** |
| GDP does not cause CO2 | 6.176 | 0.103 |

| | | |
|---|---|---|
| CO2 does not cause REC | 8.251 | 0.041* |
| REC does not cause CO2 | 9.972 | 0.018* |
| FEC does not cause GDP | 9.260 | 0.026* |
| GDP does not cause FEC | 1.257 | 0.739 |
| FEC does not cause REC | 0.811 | 0.846 |
| REC does not cause FEC | 3.800 | 0.283 |
| GDP does not cause REC | 1.357 | 0.715 |
| REC does not cause GDP | 2.701 | 0.440 |

*Notes*: ** and * denote statistical significance at the 1% and 5% level, respectively.

## 4. Conclusion

In this paper, based on panel OLS, difference GMM and the Granger causality test within LA-VAR framework using annual balanced panel data for 31 developed countries over the period 1996-2011, we have attempted to examine the relationship between CO2 emissions, economic growth, fossil fuel energy consumption and renewable energy consumption. This study has led to the following main findings: (i) energy conservation policy leads to a negative impact on economic growth for developed countries; (ii) renewable energy consumption contributes to reductions in emissions; (iii) there exists no causality between economic growth and renewable energy consumption; and (iv) no causality exits between renewable and non-renewable energy consumption.

Overall, it seems reasonable to conclude that developed countries are energy dependent countries. In order to mitigate emissions of CO2 and meet sustainable development it is necessary not only to decrease energy intensity but also to increase energy efficiency and renewable energy use, although, as Marques *et al.* (2010) note, the lobby of fossil fuels may limit the development of renewable energy policy.

Notwithstanding its limitations, we believe that this study contributes to existing literatures on the linkage between emissions, energy and growth.

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