# An Empirical Test of the Environmental Kuznets Curve for CO2 in G7: A Panel Cointegration Approach

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## ABSTRACT

This paper examines the relationship among $CO_2$ emissions, energy consumption and GDP for G7 countries over the period 1980–2010. The variables which are used in this paper are energy use, $CO_2$ emissions and GDP per capita. We test the presence of the environmental Kuznets curve in the G7. To test the relationship panel data approach is used. Kao and Pedroni approaches are used to test the cointegration of the variables. The findings indicate that there is a long-run cointegrated relationship among the variables. The results of the causality tests show that GDP strongly Granger-causes $CO_2$ emissions and energy consumption.


## INTRODUCTION

The relationship between energy consumption and GDP has long been investigated. Energy consumption for production is obtained by burning fossil fuels, and leads to carbon emissions. The environmental Kuznets curve (EKC) is a hypothesized relationship between various indicators of environmental degradation and income and, since the work of Grossmann and Krueger (1991, 1993, 1995), there has been a large amount of both theoretical and empirical work studying this relationship. The EKC hypothesis states that the environmental degradation first increases with per capita national income during the early stages of economic growth, and then declines with per capita GDP after arriving at a threshold, called "turning point". This relationship is named as the EKC because it follows a similar pattern to the income inequality, which was identified by Kuznets (1955). Whereas majority of the previous literature found an inverse U-shaped relationship between economic activity many researchers found different types of functional forms between these variables.

The model may have seven types of functional forms which are defined and drawn as follows:

1. $\beta_1 > 0, \beta_2 < 0 \; and \; \beta_3 > 0$ reveals a cubic polynomial that is called N shaped curve (Fig. a)
2. $\beta_1 < 0, \beta_2 > 0 \; and \; \beta_3 < 0$ reveals an inverse N shaped curve (Fig. b)
3. $\beta_1 < 0, \beta_2 > 0 \; and \; \beta_3 = 0$ reveals a U-shaped relationship (Fig. c) and this equation the turning point level of income is calculated by $\tau = \exp(\frac{-\beta_1}{2\beta_2})$
4. $\beta_1 > 0, \beta_2 < 0 \; and \; \beta_3 = 0$ reveals an inverse U-shaped relationship (Fig. d)

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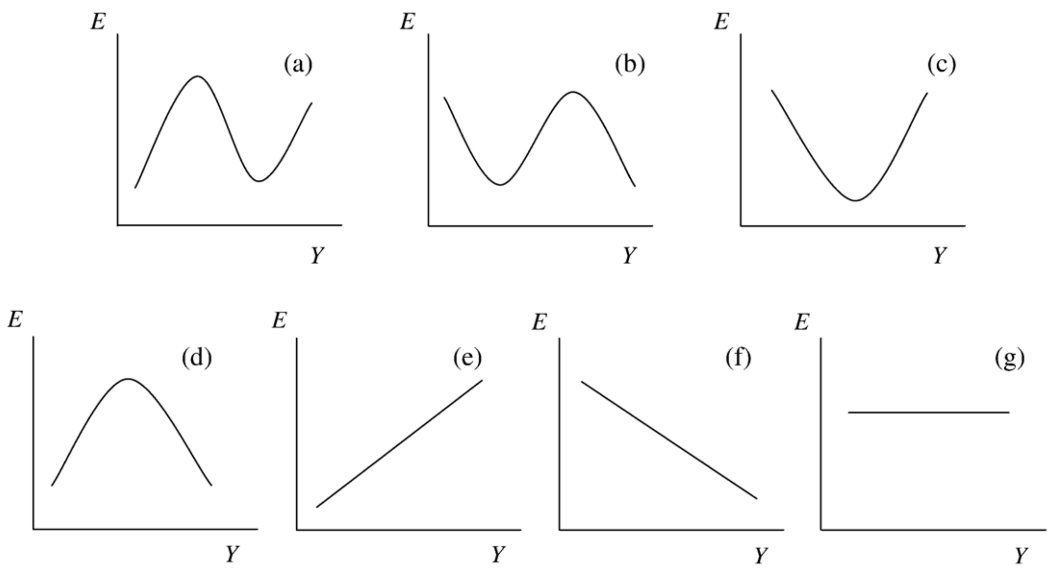
5. $\beta_1 > 0, \beta_2 = \beta_3 = 0$ reveals a monotonically increasing linear curve (Fig. e)
6. $\beta_1 > 0, \beta_2 = \beta_3 = 0$ reveals a monotonically increasing linear relationship (Fig. e)
7. $\beta_1 < 0, \beta_2 = \beta_3 = 0$ reveals a monotonically decreasing linear relationship (Fig. f)




Stern and Common (2001) investigate the EKC relationship for sulfur emissions from 1960 to 1990 for 73 countries and estimate the relationship for the OECD and non-OECD countries. They show that sulfur emissions in fact rise with increasing income at all levels of income.

Stern (1998) provides a critique of the EKC. In that study he identifies seven major problems based on Stern et. al. (1996) which are (a) simultaneity and irreversibility, (b) trade and the EKC, (c) econometric problems, (d) ambient concentrations versus emissions, (e) asymptotic behavior, (f) mean versus median income, (g) aggravation of other environmental problems. Stern (2004) states four main categories of the problem of EKC which are heteroskedasticity, simultaneity and omitted variables bias and cointegration issues. Heteroskedasticity is also discussed in Stern et al. (1996), Schmalensee et al. (1998) and Stern (2002) , simultaneity is addressed in Cole et al. (1997) and Holtz-Eakin and Selden (1995), omitted variables are discussed in Stern and Common (2001).

Wagner (2008) argues several major econometric problems and the spurious relationship of the papers which has found an inverted U-shape type of functional form. The author discusses the problems due to the presence of cross-sectional dependencies that invalidate the use of so called first generation panel unit root and cointegration tests that are designed for cross-sectionally independent panels. Wagner concludes that although first generation methods lead to seemingly strong support for the prevalence of an EKC, this evidence is entirely spurious.

Also Shafik and Bandyopadhyay (1992) estimate three different functional forms which are log-linear, log-quadratic and logarithmic cubic polynomial to test EKC and the findings support the presence of an inverted-U shaped relationship. Shafik (1994) shows that the relation between emissions of sulfur dioxide and income per capita is characterized by EKC. Grossman and Krueger (1995) use many different pollutants and point out that economic growth itself does not guarantee the cure for problems related to the environment.

Pao and Tsai (2010) use panel cointegration method for the BRIC countries and find a strong unidirectional causality from carbon dioxide emissions and energy consumption to real output in the short-run. In this paper three different causality tests are used i.e., short-run Granger non-causality test, weak exogeneity (long-run non-causality test) and strong exogeneity tests.

This paper investigates the relationship among $CO_2$ emissions, energy consumption and income level in the G7 countries over the period of 1980-2010. The long run relationship and the causal relationship of the series are investigated. In detecting causal relationship the panel causality approach which is used in Pao and Tsai (2010) is applied.

The remainder of this paper is organized as follows. Section 2 discusses the method used. Section 3 outlines the model and presents the empirical findings. Section 4 is summarizing and concluding the paper.

## METHODOLOGY

We investigate the long run relationship of the $CO_2$ emission, the GDP and the energy consumption of the selected countries. In the analysis of the long run relationship, at first the order of integration for the variables must be determined. If the variables have the same order of integration, cointegration tests will be able to be used. When all series are integrated into the same order different type of cointegration tests can be used such as Kao (1999) and Pedroni (1999, 2004).

The Pedroni and the Kao tests are based on the Engle-Granger (1987) two-step (residual-based) cointegration tests. Whereas the Pedroni and the Kao tests follow the same basic approach, the Kao test specifies cross-section specific intercepts and homogeneous coefficients during the first-stage. As mentioned below, after the Pedroni and the Kao tests find the long run relationship, the fully modified OLS estimator (FMOLS), which is proposed by Pedroni (1996, 2001), is used to show long-run relationship. Kao and Chiang (2000) use feasible pooled FMOLS estimators for heterogeneous cointegrated panels where the long-run variances differ across cross-sections. Based on the existence of the long run relationship short-run dynamics can be investigated using the vector error correction model (VECM) approach suggested by Engle and Granger (1987). In this approach, cointegrated variables must have an error correction mechanism which is contained in VECM by an error correction term (ECT). The VECM is used for correcting disequilibrium in the cointegration relationship, captured by the ECT, as well as to test for the causality among cointegrated variables, both for long-run causality by the error correction terms and short-run causality by the lagged dynamic terms.

We use three types of causality tests based on Ang (2008), Masih and Masih (1996) and Pao and Tsai (2010); which are short-run Granger non-causality test, weak exogeneity (long-run non-causality test) and strong exogeneity tests respectively.

In the short run Granger non-causality test, the statistical significance of the lagged dynamic terms are tested by the joint null hypothesis. In this test null hypothesis implies that the variables which coefficients are tested do not Granger-cause of the dependent variable of the investigated model. Second type of test is the weak exogeneity test, which is a notion of long-run non-causality test. The null hypothesis of is the weak exogeneity test implies that non-causality from long-run equilibrium deviation in the previous period to dependent variable of the investigated model. Thus this means the testing of the significance of the ECT parameter of the variable. The last type is strong exogeneity test examines the joint significance of both the lagged dynamic terms and ECT parameter.

## EMPIRICAL ANALYSIS

In our empirical analysis, we use annual data for G7 countries for the period of 1980 to 2010, except for Germany data which covers 1991-2010 period. This study investigates the relationship among $CO_2$ emissions, energy use and GDP per capita. The data are collected from the World Bank World Development Indicators. $CO_2$ emissions are measured in metric tons per capita, per capita real GDP is measured in US dollars at current prices and the per capita energy use is measured in kg of oil equivalent.

**Table 1:** Results of the Panel Unit Root Tests for G7 countries

| Variables | LLC | | Breitung | | IPS | | ADF-Fisher | | PP-Fisher | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Level | 1st diff. | Level | 1st diff. | Level | 1st diff. | Level | 1st diff. | Level | 1st diff. |
| **LCO**2 | 1.5761 | -10.0617*** | 1.2694 | -3.0481*** | 0.2383 | -10.7677*** | 18.1994 | 105.9736*** | 21.0574 | 109.4035*** |
| **LEN** | 3.1531 | -5.0784*** | 1.9350 | -2.2887** | 2.1762 | -9.4517*** | 12.8236 | 95.5348*** | 9.8340 | 136.7371*** |
| **LGDP** | 0.3166 | -6.6943*** | 1.6082 | -3.5599*** | -0.1569 | -4.9346*** | 17.2453 | 47.6786*** | 5.0167 | 57.6370*** |
| **$LGDP^2$** | 0.3821 | -6.7094*** | 1.3892 | -3.4872*** | -0.2340 | -5.0022*** | 17.6633 | 48.3158*** | 4.4309 | 55.0247*** |
| **$LGDP^3$** | 0.4645 | -6.6687*** | 1.1575 | -3.4136*** | -0.3777 | -5.0676*** | 18.1829 | 48.9367*** | 5.0531 | 52.9638*** |

Note: The lag lengths are selected using SIC. *** denotes the rejection of the null hypothesis at 1% level of significance.

**Table 2:** Results of the Panel Unit Root Tests for G7 except Germany countries

| Variables | LLC | | Breitung | | IPS | | ADF-Fisher | | PP-Fisher | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Level | 1st diff. | Level | 1st diff. | Level | 1st diff. | Level | 1st diff. | Level | 1st diff. |
| **LCO**2 | 1.9664 | -9.8858*** | 1.4694 | -2.7764*** | 1.0418 | -9.8771*** | 11.8995 | 91.4298*** | 14.7486 | 92.0480*** |
| **LEN** | 3.5763 | -8.6382*** | 2.0422 | -2.1635** | 3.3999 | -9.3425*** | 4.5353 | 86.0264*** | 1.5458 | 113.7884*** |
| **LGDP** | 0.2755 | -6.7951*** | 1.7834 | -3.1570*** | 0.1055 | -4.9677*** | 14.7758 | 43.5319*** | 4.6324 | 53.4180*** |
| **$LGDP^2$** | 0.3348 | -6.8066*** | 1.5595 | -3.0786*** | 0.0073 | -5.0330*** | 15.2572 | 44.1078*** | 4.0515 | 50.8286*** |
| **$LGDP^3$** | 0.4155 | -6.8295*** | 1.3240 | -2.9996*** | -0.1663 | -5.0953*** | 15.8432 | 44.6643*** | 4.6780 | 48.7859*** |

Note: The lag lengths are selected using SIC. *** denotes the rejection of the null hypothesis at 1% level of significance.

Table 1 and Table 2 show the results of the panel unit root tests used that are LLC, Breitung, IPS, ADF-F and PP-F panel unit root tests. Whereas LLC and Breitung tests assume that there is a common unit root process across cross-sections, IPS and F-ADF tests assume individual unit root processes across cross-sections. The null hypotheses of these tests are each series in the panel contains a unit root. The results of Table 1 and Table 2 show that the null hypothesis is rejected in first difference thus all series are stationary in their first differences, in other words they are integrated at order one, I(1) .

As it is stated in the methodology section, after it is found that the series are integrated at same level, cointegration tests can be used. Table 3 and Table 4 show the results of the panel cointegration tests.

**Table 3:** Results of the Panel Cointegration Tests for G7

| **Pedroni Cointegration Tests** | | |
|---|---|---|
| **Test Statistics** | **Statistics** | **Weighted Statistics** |
| Panel v-Statistic | 3.8093*** | -0.7040 |
| Panel rho-Statistic | 1.5962 | 0.9276 |
| Panel PP-Statistic | -2.1786** | -2.6302*** |
| Panel ADF-Statistic | -2.2462** | -3.1719*** |
| Group rho-Statistic | 2.4609 | |
| Group PP-Statistic | -1.5863* | |
| Group ADF-Statistic | -2.1198** | |
| **Kao cointegration tests** | | |
| **Test Statistics** | **Statistics** | |
| ADF | -4.5831*** | |

Note: The lag lengths are selected using SIC. ***, ** and * denote the rejection of the null hypothesis at 1%, 5% and 10 % level of significance.

**Table 4:** Results of the Panel Cointegration Tests for G7 except Germany

| **Pedroni Cointegration Tests** | | |
|---|---|---|
| **Test Statistics** | **Statistics** | **Weighted Statistics** |
| Panel v-Statistic | 3.3265*** | 3.3265*** |
| Panel rho-Statistic | 1.4698 | 1.4698 |
| Panel PP-Statistic | -2.1702** | -2.1702** |
| Panel ADF-Statistic | -2.1998** | -2.1998** |
| Group rho-Statistic | 2.1232 | |
| Group PP-Statistic | -2.2712** | |
| Group ADF-Statistic | -2.8538*** | |
| **Kao cointegration tests** | | |
| **Test Statistics** | **Statistics** | |
| ADF | -4.4425*** | |

Note: The lag lengths are selected using SIC. ***, ** and * denote the rejection of the null hypothesis at 1%, 5% and 10 % level of significance.

Pedroni test values are divided into two parts; statistics and weighted statistics. The test provides seven statistics and three weighted statistics. Four of the seven statistics reject the null hypothesis of no cointegration and two of the four weighted statistics reject the null hypothesis of no cointegration then the result of the Pedroni test reveals cointegration. Also Kao test indicates cointegration. Hen ce we find that $CO_2$ emission, energy consumption and GDP are cointegrated within the G7 countries. Given that the cointegration tests indicate cointegration the log-run panel model can be estimated.

We use FMOLS model to estimate long run relationship for the selected countries. FMOLS can provide us more accurate results due to its advantages such as eliminating the long run correlation problem. The long-run relationship model using panel data framework is as follows:

$$LCO2_{it} = \alpha_{0i} + \alpha_{1i}LEN_{it} + \alpha_{2i}LGDP_{it} + \alpha_{3i}LGDP^2_{it} + \alpha_{4i}LGDP^3_{it} + u_{it}$$

**Table 5:** Results of the FMOLS Model

| **Dependent Variable: LCO2** | | |
|---|---|---|
| **Variables** | **G7** | **G7 except Germany** |
| **LEN** | 0.8754*** | 0.8572*** |
| **LGDP** | 42.0873** | 45.7746** |
| **LGDP$^2$** | -4.2974** | -4.6792** |
| **LGDP$^3$** | 0.1456** | 0.1587** |

Note: ***, ** denote the rejection of the null hypothesis at 1%, 5% level of significance.

The results of the FMOLS model show that all variables are statistically significant at 1% level. The sign on energy consumption is positive because a higher level of energy consumption should create economic activity and stimulate $CO_2$ emissions. The sign of the coefficient of the LGDP is positive, whereas LGDP$^2$ is negative. Lastly the LGDP$^3$ has positive sign. Therefore the results provide an N-shaped relationship between GDP and emissions and thus emissions appear to rise again at high-income levels.

The process continues with the error correction model which is as follows:

$$\Delta LCO2_{it} = \alpha_{1i} + \sum_{j=1}^{p_{11}} \beta_{11ij}\Delta LCO2_{it-j} + \sum_{j=1}^{p_{12}} \beta_{12ij}\Delta LEN_{it-j} + \sum_{j=1}^{p_{13}} \beta_{13ij}\Delta LGDP_{it-j} + \sum_{j=1}^{p_{14}} \beta_{14ij}\Delta LGDP^2_{it-j} + \sum_{j=1}^{p_{15}} \beta_{15ij}\Delta LGDP^3_{it-j} + \theta_{1i}ECT_{it-1} + \varepsilon_{1it}$$

$$\Delta LEN_{it} = \alpha_{2i} + \sum_{j=1}^{p_{21}} \beta_{21ij}\Delta LCO2_{it-j} + \sum_{j=1}^{p_{22}} \beta_{22ij}\Delta LEN_{it-j} + \sum_{j=1}^{p_{23}} \beta_{23ij}\Delta LGDP_{it-j} + \sum_{j=1}^{p_{24}} \beta_{24ij}\Delta LGDP^2_{it-j} + \sum_{j=1}^{p_{25}} \beta_{25ij}\Delta LGDP^3_{it-j} + \theta_{2i}ECT_{it-1} + \varepsilon_{2it}$$

$$\Delta LGDP_{it} = \alpha_{3i} + \sum_{j=1}^{p_{31}} \beta_{31ij}\Delta LCO2_{it-j} + \sum_{j=1}^{p_{32}} \beta_{32ij}\Delta LEN_{it-j} + \sum_{j=1}^{p_{33}} \beta_{33ij}\Delta LGDP_{it-j} + \sum_{j=1}^{p_{34}} \beta_{34ij}\Delta LGDP^2_{it-j} + \sum_{j=1}^{p_{35}} \beta_{35ij}\Delta LGDP^3_{it-j} + \theta_{3i}ECT_{it-1} + \varepsilon_{3it}$$

$$\Delta LGDP^2_{it} = \alpha_{4i} + \sum_{j=1}^{p_{41}} \beta_{41ij}\Delta LCO2_{it-j} + \sum_{j=1}^{p_{42}} \beta_{42ij}\Delta LEN_{it-j} + \sum_{j=1}^{p_{43}} \beta_{43ij}\Delta LGDP_{it-j} + \sum_{j=1}^{p_{44}} \beta_{44ij}\Delta LGDP^2_{it-j} + \sum_{j=1}^{p_{45}} \beta_{45ij}\Delta LGDP^3_{it-j} + \theta_{4i}ECT_{it-1} + \varepsilon_{4it}$$

$$\Delta LGDP^3_{it} = \alpha_{5i} + \sum_{j=1}^{p_{51}} \beta_{51ij}\Delta LCO2_{it-j} + \sum_{j=1}^{p_{52}} \beta_{52ij}\Delta LEN_{it-j} + \sum_{j=1}^{p_{53}} \beta_{53ij}\Delta LGDP_{it-j} + \sum_{j=1}^{p_{54}} \beta_{54ij}\Delta LGDP^2_{it-j} + \sum_{j=1}^{p_{55}} \beta_{55ij}\Delta LGDP^3_{it-j} + \theta_{5i}ECT_{it-1} + \varepsilon_{5it}$$

where, i=1,…,N denotes country, t=1,…,T denotes the time period, $p_{ij}$ is the optimal lag length determined by the AIC, $\varepsilon_{it}$ is assumed to be independent and identically distributed with zero mean and constant variance.

$ECT_{it} = LCO2_{it} - \alpha_{0i} - \alpha_{1i}LEN_{it} - \alpha_{2i}LGDP_{it} - \alpha_{3i}LGDP^2_{it} - \alpha_{4i}LGDP^3_{it}$ and the coefficient of the ECT shows that the adjustment velocity for any shock is leading to a deviation from the long-run equilibrium.

The VECM model is used to test causality tests based on Ang (2008) and Pao and Tsai (2010). Table 6 shows the short-run Granger non-causality test, weak exogeneity (long-run non-causality test) and strong exogeneity tests respectively.

In the first column dependent variables of the model which are investigated is given. The next three columns show the name of the variables of the lagged dynamic terms which are tested by the joint null hypothesis. The null hypotheses which are tested in second column are; $\beta_{r1ip} = 0 \; \forall ip$ r= 2,3,4,5 for each row, where r shows row number. In third column, $\beta_{r2ip} = 0 \; \forall ip$ are tested for each row where r= 1,3,4,5 and shows row number. In the fourth column different form of GDP variables are tested by $\beta_{r3ip} = \beta_{r4ip} = \beta_{r5ip} = 0 \; \forall ip$ where r= 1,2 and shows row number.

The fifth column, which is named ECT, shows the t statistics of the significance of the error correction term of the models investigated. The last three columns represent the joint significance of both the lagged dynamic terms and the ECT parameter. The null hypotheses which are tested in sixth column are; $\beta_{r1ip} = \theta_{1i} = 0 \; \forall ip$ r= 2,3,4,5 for each row, where r shows row number. In seventh column, $\beta_{r2ip} = \theta_{2i} = 0 \; \forall ip$ are tested for each row where r= 1,3,4,5 and shows row number. In the eighth column different form of GDP variables are tested by $\beta_{r3ip} = \beta_{r4ip} = \beta_{r5ip} = \theta_{2i} = 0 \; \forall ip$ where r= 1, 2 and shows row number.

Table 6 shows the results of the panel causality test results for G7. For the short run the null hypothesis of no existence of Granger causality is rejected only for GDP in 1% level and implies that GDP Granger causes $CO_2$ emissions and energy consumption.

The coefficients of the ECT are significant in $CO_2$ emission, GDP, $GDP^2$ and $GDP^3$ models in 1%, 5%, 5% and, 10% significance level respectively. This result shows the existence of long run relationship.

The joint (short run/long run) results show that the null hypothesis of energy consumption does not cause CO2 emissions is rejected thus energy consumption strongly Granger- causes emissions. Meanwhile for emission and energy consumption models null hypotheses are rejected for GDP. Therefore, GDP strongly Granger-causes $CO_2$ emissions and energy consumption.

**Table 6:** Results of the Panel Causality Tests for G7

| Dependent variables of the models | Independent variables | | | | | | |
|---|---|---|---|---|---|---|---|
| | Short run | | | Long run | Joint (Short run / Long run) | | |
| | $\Delta LCO2$ | $\Delta LEN$ | $\Delta LGDP$, $\Delta LGDP^2$, $\Delta LGDP^3$ | ECT | $\Delta LCO2$, ECT | $\Delta LEN$, ECT | $\Delta LGDP$, $\Delta LGDP^2$, $\Delta LGDP^3$, ECT |
| | F-statistics | | | t-statistics | F-statistics | | |
| $\Delta LCO2$ | - | 0.2852 | 2.8759** | -0.1389*** | - | 2.7102** | 3.8786*** |
| $\Delta LEN$ | 1.8237 | - | 4.2710*** | -0.0072 | 1.2719 | - | 3.6998*** |
| $\Delta LGDP$ | 0.9257 | 0.4609 | - | -0.2849** | 2.2773* | 1.9443 | - |
| $\Delta LGDP^2$ | 0.8731 | 0.3669 | - | -5.3680** | 2.0508 | 1.6934 | - |
| $\Delta LGDP^3$ | 0.8204 | 0.3004 | - | -75.7469* | 1.8292 | 1.4654 | - |

Note: The lag lengths are selected using SIC. ***, ** and * denote the rejection of the null hypothesis at 1%, 5% and 10 %level of significance.

If balanced (except for Germany) model is considered approximately same results are obtained as seen from the Table 7, short run F-statistics GDP Granger causes energy consumption. The joint F statistics show that the GDP, $GDP^2$ and $GDP^3$ are rejected in 1% level of significance for the first model and 5% level of the second model. Thus the existence of a panel long-run cointegration relationship among the variables suggests that there must be Granger causality in only one direction which is from income to other variables. Additionally energy consumption strongly Granger causes $CO_2$ emissions, the GDP, $GDP^2$ and $GDP^3$ in 5%, 10%, 10% and 10% respectively.

**Table 7:** Results of the Panel Causality Tests for G7 except Germany

| Dependent variables of the models | Panel causality tests | | | | | | |
|---|---|---|---|---|---|---|---|
| | Independent variables | | | | | | |
| | Short run | | | Long run | Joint (Short run / Long run) | | |
| | $\Delta LCO2$ | $\Delta LEN$ | $\Delta LGDP$, $\Delta LGDP^2$, $\Delta LGDP^3$ | ECT | $\Delta LCO2$, ECT | $\Delta LEN$, ECT | $\Delta LGDP$, $\Delta LGDP^2$, $\Delta LGDP^3$, ECT |
| | F-statistics | | | t-statistics | F-statistics | | |
| $\Delta LCO2$ | - | 0.5342 | 1.8770 | -2.4523** | - | 3.2076** | 3.4681*** |
| $\Delta LEN$ | 2.4765 | - | 3.6249** | -0.1359 | 1.2517 | - | 2.8635** |
| $\Delta LGDP$ | 0.0003 | 1.5221 | - | -2.0462** | 2.0938 | 2.7582* | - |
| $\Delta LGDP^2$ | 0.3303 | 2.0696 | - | -1.8910* | 1.3232 | 2.3920* | - |
| $\Delta LGDP^3$ | 0.2767 | 1.9745 | - | -1.8106* | 1.1861 | 2.2363* | - |

Note: The lag lengths are selected using SIC. ***, ** and * denote the rejection of the null hypothesis at 1%, 5% and 10 %level of significance.

The coefficients of the ECT are significant in all models except for the energy consumption model. Beside that the ECT term must be negative to work and all significant coefficients are negative. This implies that there is a long run relationship in the VECM equations which have $\Delta LCO$, $\Delta LGDP$, $\Delta LGDP^2$, $\Delta LGDP^3$ dependent variables.

The joint (short run/long run) results show that GDP strongly Granger-causes both emissions and energy consumption, also energy consumption strongly Granger-causes all other variables (except itself).

Summary of the results indicates that there is a bi-directional short-run causal relationship from GDP to $CO_2$ emission and energy consumption. Error correction term shows that except for the energy consumption model, all models return to equilibrium in other words which all the three variables dynamically interact to restore long-run equilibrium whenever there is a deviation from the cointegrating relationship. Results of the significances of interactive terms of the investigated variables, along with the ECT on both, emissions equation suggests that, in the joint (short run/long run), energy consumption and GDP strongly Granger-causes $CO_2$ emission. Afterwards the joint test results show that GDP strongly Granger-causes energy consumption and emission strongly Granger-causes $CO_2$ emission.

## CONCLUSION

This paper investigates the relationship between $CO_2$ emissions and GDP of the G7 countries over the period 1980–2010, except for Germany data which covers the 1991–2005 period. That is why we use two panel data sets one of which is named as a balanced data (for six countries which are G7 without Germany) and the other one is unbalanced (G7) data. Panel cointegration techniques are applied to estimate the relationship of the $CO_2$ emission GDP and energy consumption. This relationship is widely investigated in literature as an environmental Kuznets Curve and inverse U-shaped functional form. By using panel cointegration techniques both long-and short-run relationship are investigated and also an error-correction model was used to capture the short-run dynamics for both balanced and unbalanced data set.

At first order of integration level of the $CO_2$ emission, energy consumption and different functional forms of GDP (GDP, $GDP^2$ and $GDP^3$) are tested. After it is found that the series same order integrated Pedrioni and Kao cointegration test were used to decide whether the series are cointegrated. Pedrioni and Kao tests conclude that the series are cointegrated. The long run cointegration model shows N-shaped relationship for the variables. After the cointegrated regression models are estimated to see the short run and the long run relationships, VECM models are estimated using ECT term of the cointegrated regression model are interpreted.

The results show that energy consumption and GDP strongly Granger-causes $CO_2$ emission, GDP strongly Granger-causes energy consumption and emission strongly Granger-causes $CO_2$ emission.

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