# Nexus between $CO_2$ emission and GDP in USA, China, India and Japan: Panel Cointegration and Vector Error Correction Model.

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***Abstract-*** In this paper author tried to show the relationship between $CO_2$ emission and GDP in panel data during 1960-2016 for four economies namely, USA, China, India and Japan through the methodology of fixed effect panel regression, Fisher-Johansen cointegration and vector error correction model with hypothesis of decoupling to justify EKC. The paper found that one per cent increase in GDP of USA, China, India and Japan led to 0.445 per cent increase in $CO_2$ emission per year significantly during 1960-2016 in the fixed effect model of panel regression. In the decoupling model under panel regression during the same period it was found that the elasticities of $CO_2$ emission with respect to GDP, $GDP^2$, $GDP^3$ and $GDP^4$ were -8.94, 2.45, -0.262 and 0.0098 respectively all of which are significant at 5% level. It indicates that EKC is inverted N shaped. Panel cointegration among log value of $CO_2$ emission and log values of GDP, $GDP^2$, and $GDP^3$ showed three cointegrating equations where VECM is stable, nonstationary, non-normal and having serial correlation problems. There is no short run causality running from GDP, $GDP^2$, $GDP^3$ respectively on $CO_2$ emission but there is long run causality running from GDP and $GDP^3$ on $CO_2$ emission in which one of three error correction is converging significantly towards equilibrium with the speed of adjustment at the rate of 9.98% per annum.

***Index Terms***- $CO_2$ emissions, GDP, time-varying coefficient cointegration, VECM, short run causality, long run causality, EKC hypothesis, decoupling

**JEL Classification Codes** C14; C32; Q01; Q43; Q52; Q53; Q56

## I. INTRODUCTION

The relationship between $CO_2$ emissions- the main gas responsible for global warming, and economic growth is among the most studied themes of environmental economics. Reducing overall emissions while keeping a high pace of economic development is at the heart of the notion of sustainable development. The relationship between economic growth and $CO_2$ emissions has been the subject of intense research over the past few decades. Many countries have been facing a major challenge, namely, to ensure stable economic growth and to protect the environment. The increase of $CO_2$ emissions is the major factor in the climate change threat. Economic growth of countries impels an intensive use of energy which results in growing

$CO_2$ emissions, so pollution is directly linked with economic growth and development. On the other hand, economic growth and development result in introduction of new energy-saving and low-carbon technologies that displace the old, energy- and carbon-intensive ones.

There's a debate about whether growth can drive or even coexist with climate stabilization. On the other side of the coin, it's also a discussion of whether climate stabilization can drive growth. While the relationship between growth and resource is a complex one. When emissions cease to increase or even decline while the economy grows it is referred to as decoupling. More precisely, if emissions grow less rapidly than economic growth, it is a situation of relative decoupling. When they instead decline while the economy grows, that can be said of absolute decoupling. This is ultimately the goal of any climate agreement. The environmental and energy economics literature has long been interested in the empirical study of decoupling of emissions from GDP and in the strictly related concept of the Environmental Kuznets Curve (EKC)(1955), whereby as income grows relative decoupling turns into absolute after some income turning point. The empirical evidences of decoupling vary from country to country, region to region with respect to time. If the period of studies is taken for long years then there is possibility of acceptance of EKC.

## II. REVIEW OF LITERATURE

Several economic literatures are available on the relation between emission and GDP or growth but a few literatures are available on decoupling analysis under panel cointegration and VECM perspectives. Author studied some important researches which are related to this paper. Martinez-Zarzoso and Bengochea-Morancho (2004) extended the functional form to cubic specification in addressing the relationship between $CO_2$ and GDP for 22 OECD (Organisation for Economic Co-operation and Development) countries for the period 1975–1998. The cubic function indicated that a decline in $CO_2$ emissions when income is rising can be expected, but only up to a certain level, and then an increase of pollution can be expected again at higher incomes. Kristrom and Lundgren (2005) studied $CO_2$ emissions in Sweden since 1900. They single out the use of long time series as the "key contribution" of their paper and discussed the advantages of studying emissions "through several phases of development" instead of relying solely on "short panel data sets". They estimated the trend in emissions over long windows (1900-99) and shorter ones (1970-99) to see how the trend behavior has changed over time. Mehrara (2007) studied the causality issue between energy consumption and economic growth for Iran, Kuwait, and Saudi Arabia. The results show a unidirectional long-run causality from economic growth to energy consumption for Iran and Kuwait, and unidirectional strong causality from energy consumption to economic growth for Saudi Arabia. Lean and Smyth's (2010) Vector Error-Correction Model analysis for five ASEAN (Association of Southeast Asian Nations) countries over the period of 1980–2006 was based on quadratic specification. They concluded, among other, that there is a statistically significant non-linear relationship between emissions and economic growth in support of EKC. Kumar (2011) examined the causality in both static and dynamic framework between energy consumption, $CO_2$ emissions and economic growth in India using Granger approach in VAR framework. He found from the VAR analysis that energy consumption, capital and population Granger-cause economic growth not the vice versa. Impulse Response Functions and Variance Decomposition analysis results indicate that $CO_2$ emissions has positive impact on energy use and capital but negative impact on population and GDP. Energy consumption has positive impact on $CO_2$ emissions and GDP but its impact is negative on capital and population.

Ru, Chen and Dong (2012) divided target research stage (1960-2008) into 5 sub-time periods, that is 1960-1969, 1970-1979, 1980-1989, 1990-1999, 2000-2008, then inspected the relationship among GDP per capita, carbon emissions and intensity of carbon emissions in China. Based on Daly's dematerialization theory (1990) and income elasticity theory, authors analyzed relationship between China's economic development and environmental pressures which are presented by carbon emissions from 1960 to 2008.The major findings are:

[i] On the terms of 5 sub-time periods, absolute dematerialization occurred in 1960-1969, materialization occurred in 1970-1979, relative dematerialization occurred in 1980-1989, 1990-1999 and 2000-2008.[ii] On the terms of the whole period, relative dematerialization is occurred in 1960-2008.[iii]From 1960 to 2008, income elasticity of carbon emissions is 0.59 and income elasticity of carbon emissions' intensity is -0.34, income elasticity of environmental pressures is 0.84, which means that when economic growth changes 1%, carbon emissions, carbon emissions' intensity and environmental pressures changes 0.59%, -0.34% and 0.84% respectively, which shows that the relationship of environmental pressures and economic development, carbon emissions and economic development are relative decoupling.

Arouri et al (2012) provided similar analysis and results for 12 MENA (Middle East and North Africa region) countries over the period 1981–2005. However, having found that single EKC turning points considerably vary across the countries, they expressed concerns regarding the validity of conclusions stemming from the panel analysis. Mert and Bozdag (2013) found that the relationship between GDP and $CO_2$ emission was inverted N shaped for Bosnia and Herzegovina during 1992-2009.The relation between per capita GDP and per capita $CO_2$ emission was found as monotonically increasing linear function. Kapusuzoglu (2014) used variance decomposition within cointegration analysis to provide similar evidence on the causality from $CO_2$ emissions to GDP in developing economies, but not in OECD and European countries. Alshehry and Belloumi (2015) investigated the dynamic causal relationships among energy consumption, energy price, and economic activity in Saudi Arabia, using a Johansen multivariate cointegration approach. The results indicate that there exists at least a long-run relationship between energy consumption, energy price, carbon dioxide emissions, and economic growth. Kasperowicz (2015) used the panel data approach to investigate the relationship between $CO_2$ emissions and economic growth for 18 EU Member Countries from 1995 to 2012. Using basic ECM estimation the paper verified that the long-run relationship between GDP and $CO_2$ emissions is negative, because the development of new low-carbon technologies enables in the long-run reaching the same production level at lower $CO_2$ emissions and that the short-run relationship between GDP and $CO_2$ emissions is positive, because the fast increase in production can be reached due to more intensive energy use by the existing technologies, then the capacity increases as well $CO_2$ emissions.
Liddle and Messinis (2016) using the linear cointegration method with endogenous breaks investigated the $CO_2$ emissions-GDP relationship for 21 OECD countries over a very long period 1870-2010 utilizing panel FMOLS and DOLS methods. An inverted-U pattern is found for Denmark, France, Switzerland and UK; a positive, less than unity income elasticity for Italy and Norway (termed "saturation"), a near zero elasticity for Belgium, and a unitary elasticity ("no transition") for Spain. Cederborg and Suobohm (2016) conducted 69 industrial countries and 45 poor countries in cross section data in 2012 to find the relationship between per capita GDP and per capita emission which is positive but had no turning point to decline. Mir and Storm (2016) studied 40 countries and 35 industries during 1995-2007 to estimate per capita $CO_2$ emission and per capita GDP. It supports EKC pattern for production- based $CO_2$ emission but not support consumption-based $CO_2$ emission. There is no automatic decoupling between growth and emission which implies to give up EKC hypothesis. To fix 2ºC, it needs to check consumption and production patterns. The study of Cederborg and Snöbohm (2016) conducted on 69 industrial countries as well as 45 poor countries using cross-sectional data. The empirical result of the cross-sectional study implies that there is in fact a relationship between per capita GDP and per capita carbon dioxide emissions. $CO_2$ emissions increase as a result of economic growth. The negative correlation between $CO_2$ emissions and GDP per capita squared suggests a possible polynomial form similar to the inverse U-shape of the EKC. The coefficient is significant in all models although the level of significance varies. The size of the coefficient however is very small, which suggest the impact of the negative correlation after the possible turning point is fractional. A 1-dollar increase in per capita GDP after the turning point would, according to the results, cause a decrease in $CO_2$ emissions by 1.44965e-09 tons (1.44965 mg) per capita. The results provided for GDP per capita suggest $CO_2$ emissions increase by approximately 0.0002 tons (0.2 kg) per capita when GDP per capita increase by 1 dollar, holding all other variables constant. Magazzino and Elliott (2016) examined the relationship among real GDP, $CO_2$ emissions, and energy use in the six Gulf Cooperation Council (GCC) countries using annual data for the years 1960–2013. The results significantly reject the

assumption that energy is neutral for growth. A decrease in energy consumption causes a decrease in real GDP. In this case, the economy is called "energy dependent," and energy conservation policies may be implemented with adverse effects on real GDP. Therefore, if energy uses Granger-causes economic growth, then energy conservation policies aiming at protecting the environment are expected to deteriorate the current stage of economic growth.
Beser and Beser (2017) studied the relationship between total energy consumption and carbon dioxide ($CO_2$) emissions under the Environmental Kuznets Curve (EKC) framework based on the data in Turkey during 1960-2015. The overall results indicate that EKC is valid, besides, energy conservation policies and controlling $CO_2$ emissions are likely to have adverse effect on the real output growth of Turkey. According to the results combined both long run and short run, authors see that $CO_2$ emissions and national income has positive and significant role energy consumption for Turkey. The significant lagged error-correction terms obtained from Models also support the long run relation among relevant variables. Thus, authors conclude that $CO_2$ emissions and national income have a significant and positive impact on energy consumption which makes the feedback hypothesis valid for Turkey. Lise (2006) concluded that the relation between $CO_2$ emissions and income in Turkey is linear rather than quadratic and does not support the EKC hypothesis. In contrast, Ang (2008) found a long-run positive dependence between pollution and energy consumption using a VAR approach for EKC model for Turkey. Furthermore, Soytas and Sari (2009) investigated the long-run Granger causality relationship between economic growth, $CO_2$ emissions and energy consumption in Turkey. The empirical findings suggest the existence of Granger causality running from carbon emissions to energy consumption, but only one way and in this direction.

Miti'c, Ivanovi'c and Zdravkovi'c (2017) analyzed the relationship between real GDP and $CO_2$ emissions for 17 transitional economies based on a series of annual data from 1997 to 2014. They conducted Dynamic Ordinary Least Squares (DOLS) and Fully Modified OLS (FMOLS) approaches. The results clearly suggest the existence of a statistically significant long-run cointegrating relationship between $CO_2$ emissions and real GDP. A 1% change in GDP leads to around a 0.35% change of $CO_2$ emission on average for the considered group of countries. Close values of long-run coefficients for all estimations confirm the robustness of the estimated results. The authors state that transitional economies need to follow global policy incentives, and try to implement new mechanisms and instruments for the purpose of reducing $CO_2$ emissions, such as environmental taxes, emissions-trading schemes, and carbon capture and storage, if they want to achieve future $CO_2$ emission reductions, while attaining economic growth. Long-run cointegrating relationship between $CO_2$ emissions and real GDP that is statistically significant. For all four versions of estimations the observed calculated coefficient was approximately 0.35, which means that, on average, a 1% change in GDP leads to a 0.35% change in $CO_2$ emission for the considered group of countries. Close values of long-run coefficients for all estimations confirm the robustness of the estimated results. Furthermore, it is necessary to state that this result does not explain the factors behind the observed $CO_2$–GDP relationship.

Mikayilov, Hasanov and Galeotti (2018) allow the income elasticity of emissions – a critical metrics for the study of decoupling – to vary over time. The reason is that the elasticity might change through the time due to the factors affecting the drivers of the $CO_2$ emissions. Authors use a time-varying coefficients cointegration approach to investigate the $CO_2$ emissions-GDP relationship for 12 Western European countries over a long period ranging from 1861 to 2015. The main finding is that the income elasticities of $CO_2$ emissions are found to be positive in all investigated countries. In addition, authors find evidence in favor of relative decoupling – emissions increasing more slowly than GDP – in 8 out of the 12 European countries. The remaining 4 cases the income elasticities of $CO_2$ emissions are in excess of unity. In nearly half of cases the analysis confirms a statistically significant time-varying pattern for the income elasticities. Cohen, Jalles, Loungani and Marto (2018) studied 20 countries during 1990-2014 to investigate the decoupling of emissions and growth and found the average trend elasticity, viz. the response of trend emissions to a 1 percent change in trend GDP, is 0.4. For the advanced economies within this group, the elasticity averages zero. Some countries have negative elasticities, suggesting that they had made progress in decoupling their trend emissions from trend GDP. Consumption-based emissions weakens the case for progress but does not overturn it. Encouragingly, authors found suggestive evidence that trend elasticities could be lowered through policy efforts on the part of countries. Moreover, the investigation of the historical relationships between emissions and GDP showed that elasticities in recent decades were considerably lower than in previous decades.

## III.Objective of the paper

In this paper author tried to show the relationship between $CO_2$ emission and GDP among four countries e.g. USA, China, India and Japan through fixed effect panel regression, panel cointegration and vector error correction models during 1960-2016 with the hypothesis of decoupling to justify the Environment Kuznets Curve in the form of inverted U or N shaped. The short and long run association between $CO_2$ emission and GDP with higher order were also the aim of analysis of the paper.

## I. Methodology and source of data

To find the relationship between $CO_2$ emission in Kilo ton and GDP in billion US$ in current prices during 1990-2016, author used fixed effect panel regression model after verifying the Hausman Test (1978). Fisher (1932)-Johansen cointegration test (1991) was used to show cointegration. Johansen (1991) Panel VECM was also used to show long and short run association between $CO_2$ emission and GDP where Wald test (1943) was verified in the short run causality.
Data of $CO_2$ emission in kilo ton and GDP in billion US$ in current prices for USA, China, India and Japan from 1960 to 2016 were taken from the World Bank.

## II. Findings of the econometric models

Regression analysis of Panel data of $CO_2$ emission in Kilo ton and GDP in current US$ of USA, China ,India and Japan during 1960-2016 in the random effect model showed that one per cent increase in GDP per annum led to 0.445 per cent increase in the $CO_2$ emission per annum significantly in which Hausman test was accepted for regression due to $\chi^2(4)=0.168208$ whose prob=0.6817.

$Log(x_1) = 11.16289+0.445532 log(y_1)+u_i$
(88.27)* (24.47)*

$R^2=0.88$, F=430.52*, AIC=0.93, SC=1.008, DW=0.349 where $x_1$=$CO_2$ emission in kilo ton, $y_1$=GDP in current prices in billion US$, *=significant at 5% level.

Most of the researchers, now-a-days agreed that $CO_2$-GDP relation is polynomial which is given below.

$Log(x_1)=a_0+a_1(logy_1)+a_2(logy_1)^2+a_3(logy_1)^3+ a_4(logy_1)^4$

Here, random effect model for regression is rejected because Hausman test (1978) is rejected since $\chi^2(4)=17.856518$ whose prob=0.0013 so that fixed effect model for regression was applied where the estimated equation is shown below.

$Log(x_1)=23.40711-8.942610(logy_1)+2.452342(logy_1)^2-0.262413(logy_1)^3+0.009849(logy_1)^4$

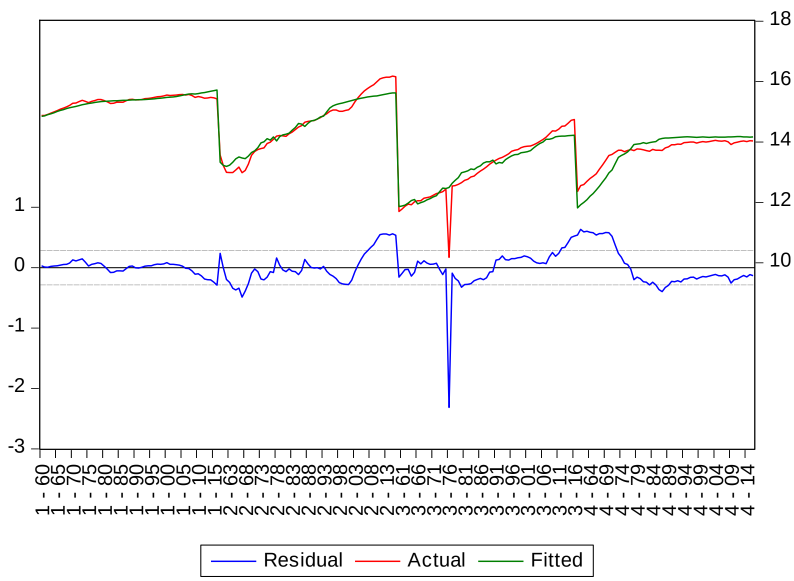
(4.66)* (-2.75)* (3.22)* (-3.404)* (3.45)*

$R^2=0.936$, F=465.77*, AIC= 0.36, SC=0.48, DW=0.62, where it was assumed that $\Delta logx_1/\Delta logy_1>0$ in relative decoupling and $\Delta logx_1/\Delta logy_1<0$ in absolute decoupling when Environment Kuznets Curve is inverted U or N shaped.

In the above fitted model all the coefficients are significant at 5% level with high $R^2$ and F but with low DW.

In Figure 1, the inverted N shaped curve in four cross section data have been partially visible.

**Figure 1: Inverted N shaped Kuznet curve**




Source-Plotted by author

Panel causality between $CO_2$ emission and GDP in four countries during 1960-2016 in Granger Causality test with lags-2 confirmed that GDP does Granger cause $CO_2$ emission but not vice versa. In Table 1, it is shown clearly.

**Table 1: Causality test**

| Null Hypothesis | Observations | F statistic | Probability |
|---|---|---|---|
| $Logy_1$ does not Granger cause $logx_1$ | 220 | 3.51730 | 0.0314 |
| $Logx_1$ does not Granger cause $logy_1$ | | 2.76842 | 0.0650 |

Source-Calculated by author.

Johansen-Fisher Panel unrestricted rank cointegration test between $CO_2$ emission and GDP in cubic form of 4 top emitter countries (USA, China, India, Japan) during 1960-2016 taking linear deterministic trend with lag1 assured that both Trace statistic and Max Eigen statistic contain three significant cointegration equations.

**Table 2: Panel cointegration**

| Hypothesized No. of CE(s) | Fisher Stat.* (from trace test) | Prob. | Fisher Stat.* (from max-eigen test) | Prob |
|---|---|---|---|---|
| None | 105.6 | 0.0000 | 95.08 | 0.0000 |
| At most 1 | 40.35 | 0.0000 | 26.60 | 0.0008 |
| At most 2 | 19.95 | 0.0105 | 16.64 | 0.0341 |
| At most 3 | 10.55 | 0.2288 | 10.55 | 0.2288 |

* Probabilities are computed using asymptotic Chi-square distribution, Source-Calculated by author

The three cointegrating equations are given below.

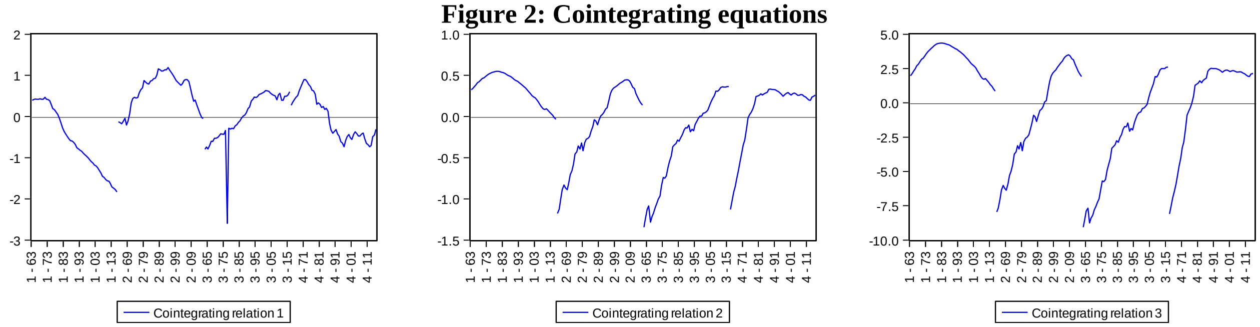
[1] $EC_{1t-1}=logx_{1t-1}-0.004671logy_{1t-1}^3+0.00756t-13.309$
(-5.81)* (3.52)*

[2]$EC_{2t-1}=logy_{1t-1}-0.005435logy_{1t-1}^3-0.001197t-4.6498$
(22.14)* (-1.82)*

[3]$EC_{3t-1}=logy_{1t-1}^2-0.081894logy_{1t-1}^3-0.010339t-17.498$
(-42.28)* (-1.99)*

In Figure 2, the cointegrating equations have been plotted clearly where first cointegrating equation is stationary and others are nonstationary.

**Figure 2: Cointegrating equations**

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The estimated equations of the VECM are given below.

[1]$\Delta logx_{1t}=-0.02722EC_1+0.760049EC_2-0.105244EC_3-0.58954\Delta logx_{1t-1}-0.02315\Delta logx_{1t-2}$
(-0.84) (2.03)* (-2.10)* (-8.24)* (-3.37)*
$+5.0579\Delta logy_{1t-1}-1.1626\Delta logy_{1t-2}-0.6806\Delta logy_{1t-1}^2+0.0906\Delta logy_{1t-2}^2+0.03103\Delta logy_{1t-1}^3$
(1.66) (-60.42)* (-1.37) (0.19) (1.20)
$-0.00032\Delta logy_{1t-2}^3+0.040266$
(-0.013) (1.93)*

$R^2$=0.319, F=8.71, AIC=-0.39, SC=-0.204, *=significant at 5% level
Therefore, $\Delta logx_{1t}$ is significantly negatively related with $\Delta logx_{1t-1}$ , $\Delta logx_{1t-2}$ ,and $\Delta logy_{1t-2}$.
$EC_3$ is significantly moving towards equilibrium correcting error at the rate of 10.52 per cent per year. (visible in first diagram in Figure 2).

[2] ]$\Delta logy_{1t}=0.0425EC_1-0.1943EC_2+0.0225EC_3-0.0374\Delta logx_{1t-1}-0.0138\Delta logx_{1t-2}$
(3.14)* (-1.27) (1.105) (-1.28) (-0.49)
$+0.8258\Delta logy_{1t-1}-1.7009\Delta logy_{1t-2}-0.1314\Delta logy_{1t-1}^2+0.3040\Delta logy_{1t-2}^2+0.00857\Delta logy_{1t-1}^3$
(0.66) (-1.50) (-0.64) (1.62) (0.81)
$-0.0165\Delta logy_{1t-2}^3+0.05797$
(-1.67) (6.83)*

$R^2$=0.19, F=4.60, AIC=-2.18, SC=-1.99
Therefore, $\Delta logy_{1t}$ is insignificantly related with all and the $EC_2$ is insignificantly approaching equilibrium correcting error at the rate of 19.43 % per year.

[3]$\Delta logy_{1t}^2 = 0.55699EC_1 - 2.5879EC_2 + 0.3515EC_3 - 0.4341\Delta logx_{1t-1} - 0.1675\Delta logx_{1t-2}$
(3.11)* (-1.28) (1.29) (-1.12) (-0.45)
$+9.4121\Delta logy_{1t-1} - 17.4825\Delta logy_{1t-2} - 1.7553\Delta logy_{1t-1}^2 + 3.2127\Delta logy_{1t-2}^2 + 0.1294\Delta logy_{1t-1}^3$
(0.57) (-1.17) (-0.65) (1.29) (0.92)
$-0.1783\Delta logy_{1t-2}^3 + 0.7296$
(-0.1.36) (6.49)*

$R^2$=0.226, F=5.44, AIC=2.98, SC=3.17
Therefore, $\Delta logy_{1t}^2$ is insignificantly related with all and the $EC_1$ is significant but positive and divergent.

[4]$\Delta logy_{1t}^3 = 5.8391EC_1 - 32.6097EC_2 + 4.810EC_3 - 3.994\Delta logx_{1t-1} - 1.5619\Delta logx_{1t-2}$
(2.99)* (-1.48) (1.62) (0.94) (-0.387)
$+116.506\Delta logy_{1t-1} - 144.4299\Delta logy_{1t-2} - 23.8644\Delta logy_{1t-1}^2 + 27.1459\Delta logy_{1t-2}^2 + 1.7839\Delta logy_{1t-1}^3$
(0.065) (-0.88) (-0.81) (1.004) (1.17)
$-1.5302\Delta logy_{1t-2}^3 + 7.2977$
(-1.07) (5.95)*

$R^2$=0.279, F=7.18, AIC=7.76, SC=7.94

Therefore, $\Delta logy_{1t}^3$ is also insignificantly related with all but $EC_1$ is significant but positive and is divergent.

Thus, all the equations in VECM are poorly fit because $R^2$, F, are low and AIC and SC are inappropriate. So, VECM is nonstationary which is shown by Impulse Response Functions in Figure 4 but the VECM is stable since all roots lie inside or on the unit circle (in which there is one unit root) shown in Figure 3.Even,it suffers from autocorrelation problems which is shown by residual test for correllogram (Figure 5) .Also the residuals of the VECM are not normally distributed as observed by Hansen-Doornik test (1994) and the values have been arranged in Table 3.

Figure 3: Unit circle

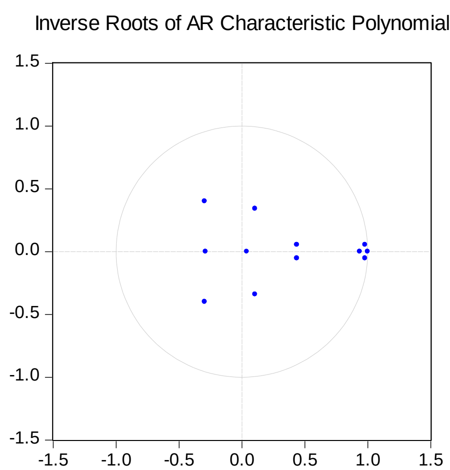


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Figure 4: Impulse Response Functions

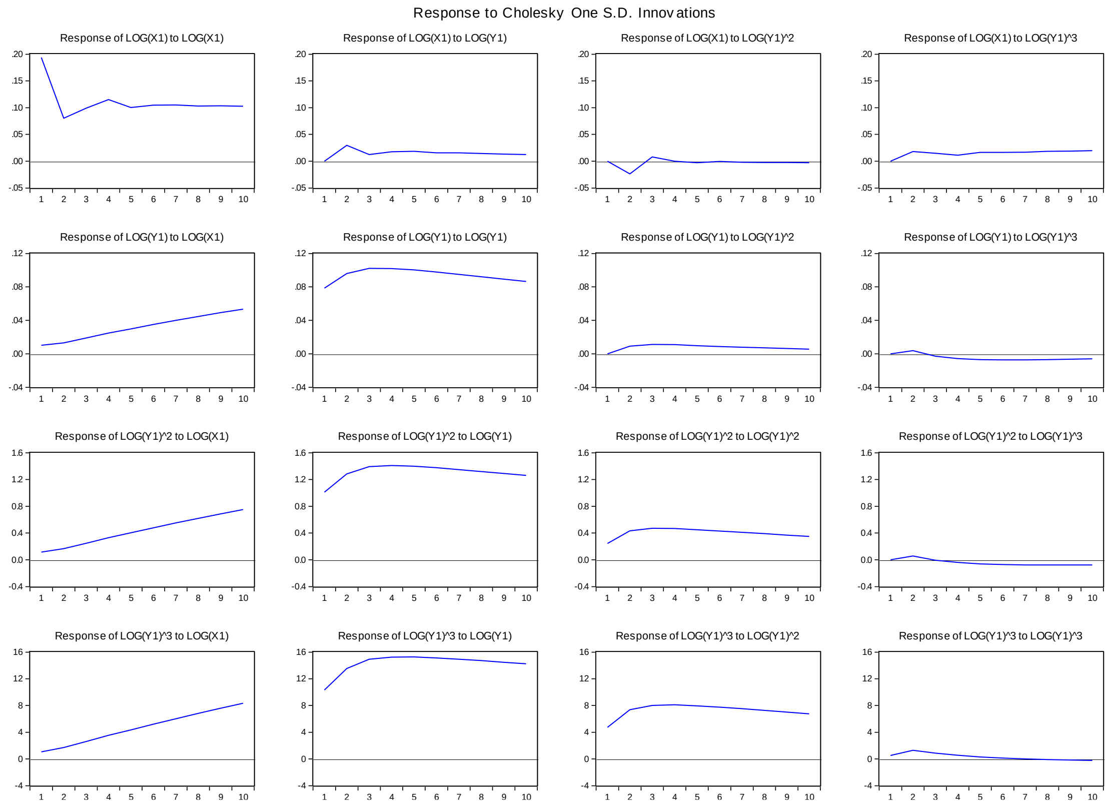


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Figure 5: Problem of autocorrelation

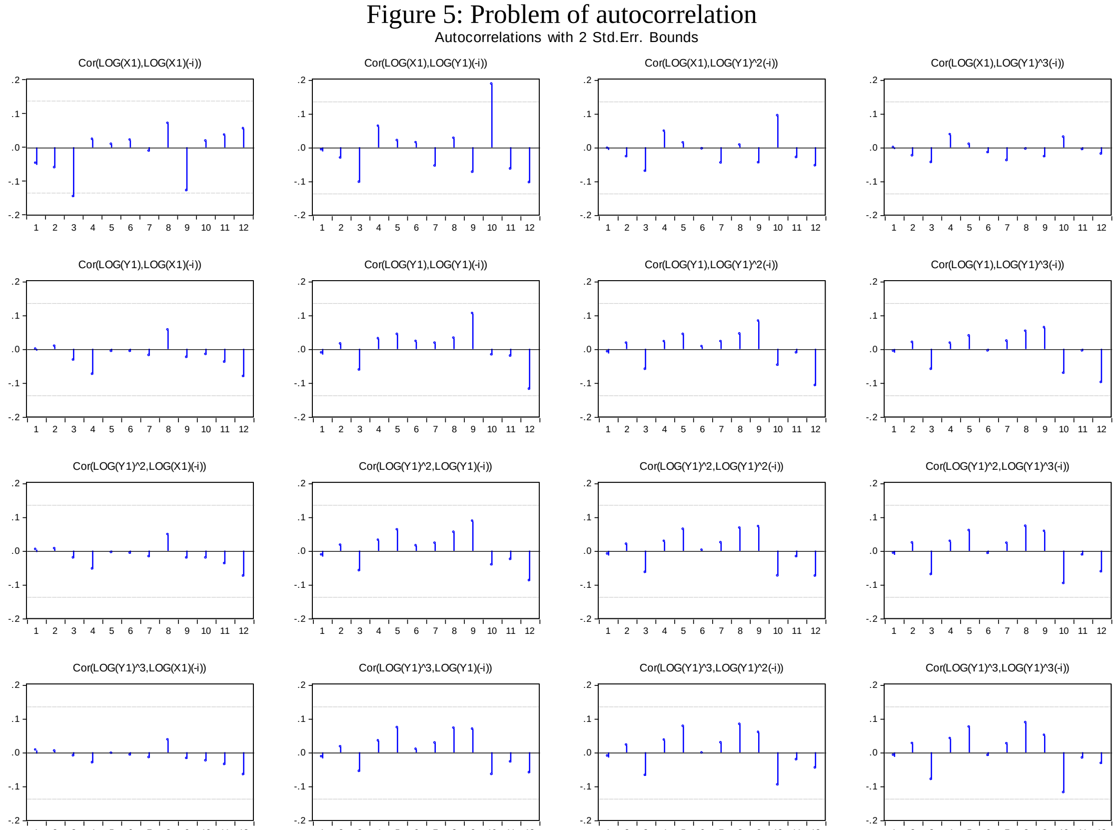


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**Table 3: Normality test (H0=residuals are multivariate normal)**

| Component | Skewness | Chi-square | df | Prob. |
|---|---|---|---|---|
| 1 | -6.832333 | 1680.508 | 1 | 0.0000 |
| 2 | -0.435875 | 6.839525 | 1 | 0.0089 |
| 3 | 1.522227 | 83.41833 | 1 | 0.0000 |
| 4 | -2.087027 | 156.8046 | 1 | 0.0000 |
| Joint | | 1927.570 | 4 | 0.0000 |
| Component | Kurtosis | Chi-square | df | Prob. |
| 1 | 93.15778 | 73155.83 | 1 | 0.0000 |
| 2 | 6.438081 | 106.3836 | 1 | 0.0000 |
| 3 | 15.05436 | 1307.769 | 1 | 0.0000 |
| 4 | 16.68261 | 1684.924 | 1 | 0.0000 |
| Joint | | 76254.90 | 4 | 0.0000 |
| Component | Jarque-Bera | df | Prob. | |
| 1 | 74836.33 | 2 | 0.0000 | |
| 2 | 113.2231 | 2 | 0.0000 | |
| 3 | 1391.187 | 2 | 0.0000 | |
| 4 | 1841.728 | 2 | 0.0000 | |
| Joint | 78182.47 | 8 | 0.0000 | |

Source-Calculated by author

[A]From the system equation of VECM-1, the observations of the short run and long run causality or associations among variables are as follows.
[i]Short run causality on $logx_{1t}$ is shown in Table 4 which were found from Wald test.

**Table 4: Short run causality**

| H0=no causality | Value of $\chi^2(2)$ | prob | Reject/Accept | Causality(yes/no) |
|---|---|---|---|---|
| From $logy_{1t-1}$,$logy_{1t-2}$, to $logx_{1t}$ | 2.86 | 0.23 | Accept | no |
| From $logy_{1t-1}^2$,$logy_{1t-2}^2$ to $logx_{1t}$ | 2.076 | 0.35 | Accept | No |
| From $logy_{1t-1}^3$ ,$logy_{1t-2}^3$to $logx_{1t}$ | 1.77 | 0.41 | Accept | No |

Source-Calculated by author

Therefore, it is noted that there are no short run causalities running from $logy_1$,$logy_1^2$,$logy_1^3$ to $logx_{1t}$ .
[ii] Long run causality
The estimated cointegrated equations from the system equation of VECM-1 are given below:
[1]$EC_{1t-1}$=-0.0179$logx_{1t-1}$-0.004671$logy_{1t-1}^3$+0.00756t-13.309
(0.79) (-5.81)* (3.52)*
[2]$EC_{2t-1}$=0.7172$logy_{1t-1}$-0.005435$log_{1t-1}^3$-0.001197t-4.6498
(2.11)* (22.14)* (-1.82)*
[3]$EC_{3t-1}$=-0.0998$logy_{1t-1}^2$-0.081894$logy_{1t-1}^3$-0.010339t-17.498
(-2.18)* (-42.28)* (-1.99)*
Thus,[i] there is insignificant long run causality running from $logy_{1t-1}^3$ to $\Delta logx_{1t-1}$ [ii] there is no long run causality running from $logy_{1t-1}^3$ and $\Delta logy_{1t-1}$ to $\Delta logx_{1t-1}$ [iii] there is significant long run causality running from $logy_{1t-1}^3$ and $logy_{1t-1}^2$ to $\Delta logx_{1t}$.(visible in first figure in Figure 2 and the figures of the first row in Figure 4).
[B]From the system equation of VECM-2, the observations of the short run and long run causality are as follows.
[i]Short run causality on $logy_{1t}$ is given below in Table 5 which was found from Wald test.

**Table 5: Short run causality**

| H0=no causality | Value of $\chi^2(2)$ | Reject/Accept | prob | Causality(yes/no) |
|---|---|---|---|---|
| From $logx_{1t-1}$,$logx_{1t-2}$ to $logy_{1t}$ | 0.565 | Accept | 0.75 | No |

Source-Calculated by author
Therefore, there is no short run causality.
[ii] Long run causality
The estimated cointegrated equations from the system equation of VECM-2 are given below:

[1]$EC_{1t-1}$=0.01819$logx_{1t-1}$-0.004671$logy_{1t-1}^3$+0.00756t-13.309
(1.95)* (-5.81)* (3.52)*
[2]$EC_{2t-1}$=-0.015433$logy_{1t-1}$-0.005435$log_{1t-1}^3$-0.001197t-4.6498
(-0.11) (22.14)* (-1.82)*
[3]$EC_{3t-1}$=-0.00153$logy_{1t-1}^2$-0.081894$logy_{1t-1}^3$-0.010339t-17.498
(-0.08) (-42.28)* (-1.99)*

Thus, [i] there is no long run causality running from $logy_{1t-1}^3$ and $logx_{1t-1}$ to $\Delta logy_{1t}$ [ii] there is insignificant long run causality running from $logy_{1t-1}^3$ and $logy_{1t-1}$ to $\Delta logy_{1t}$ [iii] there is insignificant long run causality running from $logy_{1t-1}^3$ and $logy_{1t-1}^2$ to $\Delta logy_{1t}$

[C] From the system equation of VECM-3, the observations of the short run and long run causality are as follows.

[i]Short run causality on $logy_{1t}^2$ is given below in Table 6 which were found from Wald test.

**Table 6:Short run causality**

| H0=no causality | Value of $\chi^2(2)$ | Reject/Accept | prob | Causality(yes/no) |
|---|---|---|---|---|
| From $logx_{1t-1}$,$logx_{1t-2}$ to $logy_{1t}^2$ | 0.449 | Accept | 0.449 | No |

Source-Calculated by author

Therefore, there are short run causalities running from $logx_{1t-1}$, $logx_{1t-2}$ to $logy_{1t}^2$.

[ii] Long run causality

The estimated cointegrated equations from the system equation of VECM-3 are given below:

[1]$EC_{1t-1}$=0.283578$logx_{1t-1}$-0.004671$logy_{1t-1}^3$+0.00756t-13.309
(2.31)* (-5.81)* (3.52)*
[2]$EC_{2t-1}$=-0.556019$logy_{1t-1}$-0.005435$log_{1t-1}^3$-0.001197t-4.6498
(-0.30) (22.14)* (-1.82)*
[3]$EC_{3t-1}$=0.077293$logy_{1t-1}^2$-0.081894$logy_{1t-1}^3$-0.010339t-17.498
(0.31) (-42.28)* (-1.99)*

Thus,[i] there are no long run causalities running from $logy_{1t-1}^3$ and $logx_{1t-1}$to $\Delta logy_{1t-1}^2$ [ii] there are insignificant long run causalities running from $logy_{1t-1}^3$ and $logy_{1t-1}$ to $\Delta logy_{1t-1}^2$ [iii] there are no long run causalities running from $logy_{1t-1}^3$ and $logy_{1t-1}^2$ to $\Delta logy_{1t-1}^2$

[D] From the system equation of VECM-4, the observations of the short run and long run causality are as follows.

[i]Short run causality on $logy_{1t}^3$ is shown in Table 7 which were found from Wald test.

**Table 7: Short run causality**

| H0=no causality | Value of $\chi^2(2)$ | Reject/Accept | prob | Causality(yes/no) |
|---|---|---|---|---|
| From $logx_{1t-1}$,$logx_{1t-2}$ to $logy_1^3$ | 0.338 | Accept | 0.84 | No |

Source-Calculated by author

Therefore, there is no short run causality.

[ii] Long run causality

The estimated cointegrated equations from the system equation of VECM-4 are given below:

[1]$EC_{1t-1}$=3.412851$logx_{1t-1}$-0.004671$logy_{1t-1}^3$+0.00756t-13.309
(2.56)* (-5.81)* (3.52)*
[2]$EC_{2t-1}$=-14.3236$logy_{1t-1}$-0.005435$log_{1t-1}^3$-0.001197t-4.6498
(-0.71) (22.14)* (-1.82)*
[3]$EC_{3t-1}$=2.33729$logy_{1t-1}^2$-0.081894$logy_{1t-1}^3$-0.010339t-17.498
(-2.18)* (-42.28)* (-1.99)*

Thus,[i] there are no long run causalities running from $logy_{1t-1}^3$ and $logx_{1t-1}$ to $\Delta logy_{1t}^3$ [ii] there are insignificant long run causalities running from $logy_{1t-1}^3$ and $logy_{1t-1}$ to $\Delta logy_{1t}^3$ [iii] there are no long run causalities running from $logy_{1t-1}^3$ and $logy_{1t-1}^2$ to $\Delta logy_{1t}^3$

## III. LIMITATIONS AND FUTURE SCOPE OF RESEARCH

Author has taken only four top emitter countries like USA, China, India and Japan for analysis of panel cointegration and VECM to relate $CO_2$ emission and GDP. This cross-section data can be extended in various fashions like, [i] adding more countries, [ii] adding countries with regional groupings, [iii] adding countries as poor and rich countries, [iv] adding countries as high, medium and low emitter countries. Author could include the relationship between per capita $CO_2$ emission and per capita GDP to justify the validity of EKC hypothesis or curve. This relation can be analyzed in the group of countries in above fashions. All these researches are left for future research. [v] More-longer period of study can be taken for analysis.

## IV. POLICY SUGGESTIONS

The first and foremost duties of the studied countries are to cut $CO_2$ emission for which some general policies should be adopted.

[i] Countries need environment free industries,[ii]Deforestation is strictly controlled,[iii]Kyoto protocol and Paris agreements and other vital climate negotiations should be implemented quickly(Bhowmik,2015),[iv]REDD and conservation of forest policies should be reformed, [v]Coordination and integration are needed among UNFCCC,IPCC,WMO,COP,WTO.,[vi] World Climate Fund must be revamped,[vii]US veto should be stopped,[viii] destruction of nuclear weapons and discourage of nuclear power could be encouraged,[ix] Consumption and production patterns of energy must be changed,[x]Alternative energy sources should be encouraged,[xi]Education and public awareness programme should be needed for good understanding of green earth,[xii] Use of other GHG like $CH_4$,CO,$SO_2$ etc should be less,[xiii] Ecological balance is the prime importance of climate policy ,[xiv] An international institution is needed where all emitter members should have compulsion to implement climate policy negotiations which had taken from the UNFCCC(Bhowmik,2012),[xv] It is urgent to constitute common rules for carbon trading in UNFCCC.

## V. VIII. Conclusions

The paper concludes that one per cent increase in GDP of USA, China, India and Japan led to 0.445 per cent increase in $CO_2$ emission per year significantly during 1960-2016 in the random effect model of panel regression. In the decoupling model under panel regression during the same period it was found that the elasticities of $CO_2$ emission with respect to GDP, $GDP^2$, $GDP^3$ and $GDP^4$ were -8.94, 2.45, -0.262 and 0.0098 respectively all of which are significant at 5% level under fixed effect model of panel regression. It indicates that EKC is inverted N shaped. Panel cointegration among log value of $CO_2$ emission and log values of GDP, $GDP^2$, $GDP^3$ and $GDP^4$ showed three cointegrating equations where VECM is stable, nonstationary, non-normal and having serial correlation problems. There is no short run causality running from GDP, $GDP^2$, $GDP^3$ respectively on $CO_2$ emission but there is long run causality running from GDP and $GDP^3$ on $CO_2$ emission in which one of three error correction is converging significantly towards equilibrium with the speed of adjustment at the rate of 9.98% per annum.

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