An econometric investigation of Dynamic Linkages between CO2 emissions, energy consumption, economic growth: A Case of India and China

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Abstract

The paper investigates the co-integrating relationship between economic growth, energy and environment for India and China for the period 1970-2014 (using log transformed yearly data). Whereas GDP per capita is taken as the growth proxy , CO_2 emissions per capita represents environmental degradation & fossil fuel consumption is the proxy for energy consumption. The methodology adapted is ARDL Partial 'F' Bounds Test with single structural break. The results of the study showed that Co-integrating relation was established amongst all the variables except when CO_2 (China) is taken as dependent variable. The ECM term was negative and significant in all the cases (except for CO_2 China again) Further the speed of adjustment towards equilibrium was highest @16 % per annum for CO_2 of India while it was between 3% - 8 % p.a for rest of the variables. Chow Break even confirmed that India CO_2 emissions had a break in 1996.

Keywords : Co-integration, ARDL, Serial Correlation, Structural Break, Chow Breakpoint test, error correction, CUSUM

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1. Introduction

The emerging economies of today are drawing up ambitious plans to catch up their counterparts i.e. economies from the developed world, however in their attempt to move rapidly towards their targets, these economies too end up consuming significant quantum of resources which eventually impacts the environmental degradation. This is true for every emerging economy including both China & India. (Govindaraju, V. C., & Tang, C. F. (2013)

Speaking of China and India, although both the economies have shown their ability to achieve higher economic growth , this however has been achieved at a cost, the cost being substantial energy consumption levels. The share of the two economies in the total world energy consumption has reached an astonishingly high levels at 23.6 % for China and 5.8% for India in 2018, with an annual growth rate of energy consumption being 5.6 % (China) and 7.8 % (India) respectively which was substantially higher than the average world growth rate of world energy consumption of 2.9 % p.a. (Dudley, B. (2019). If we examine different components of energy consumption; the three prominent fuels viz. oil, coal and natural gas account for a combined share of 84 % of the world's energy consumption. During 2018, the consumption of these three fossil fuels also rose for both India and China, while many countries including Japan, Germany & France did manage to reduce the consumption of these fuels from the previous year 2017.Clearly both India and China must think out strategies to reduce the consumption of energy and prominent fuels ; one most obvious and viable option here would be to cut back on economic growth, however this is something which most countries in the developing world are not willing to indulge.

Economists have traditionally attempted to link economic growth ,energy & environment using economic models and the most popular of these models is the Environmental Kuznets Curve*(EKC) which was proposed by Grossman and Krueger in 1991. According to EKC Model, economic growth need not always be bad for environment & this is so because once a country achieves a particular level of income called threshold income (see Fig.1 below), people resist further economic growth as it impacts the environment adversely and hence over a period of time this effort actually leads to the reversal of environmental degradation. Sometimes people also tend to compel the government to substitute fossil fuels consumption with renewable energy fuels with the intention of making further growth which is sustainable. Thus according to this theory, after reaching the threshold level, there is an auto-generating process of reversal of environmental degradation.

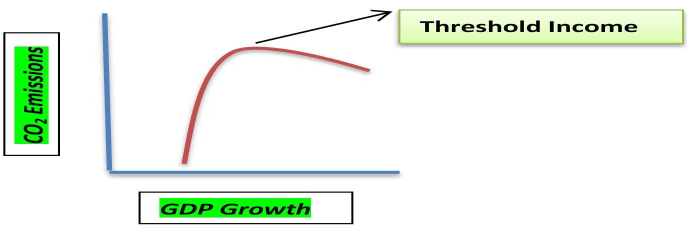

Fig.1 : The Environmental Kuznets Curve

*** The original Kuznets curve showing a relation between & income inequality & economic growth was modified by Grossman, G. M., & Krueger, A. B. (1991) by adding the dimension of environment*

Many researchers however do not agree to the EKC hypothesis in its entirety or agree to the same only partially, especially the aspect pertaining to the reversal of environmental degradation (i.e. many feel that relation is monotonous rather than somewhat inverted 'U' shaped at higher income levels as given by their EKC) According to some researchers like Coondoo and Dinda (2002) every economy on growth path , be it developing or developed must be ready to sacrifice some part of economic growth. The quantum of this sacrifice would depend upon the nature of the long run relation between the three pillars namely income, emissions & energy consumption.

This sacrifice can be in terms of redefining the goals & priorities of different sectors of the economy, implementation of pollution tax or command and control based regime and so on. One of the popular strategies to meet the fine tuned goals is to switch to renewable energy from primary (coal) based energy to meet the well defined sustainable development targets. This was proved in a study by Nathaniel, S., Nwodo, O., Sharma, G., & Shah, M. (2020) whereby they showed that whereby non-renewable energy were the real culprits in deterioration of environmental quality , renewable energy actually improved this quality in CIVETS countries. A study by Sikdar and Mukhopadhyay (2018) showed that for India , economic growth along with trade openness could lower emissions by exporting more of labour intensive environment friendly goods. Some authors including Lotfalipour, M. R. et.al. (2010) who too do not consent to EKC are of the opinion that economic growth and energy consumption must be determined jointly using economic tools. This they say because according to them for an economy, efficient use of energy could be due to economic growth , while economic growth which is sustainable in turn may sometimes lead to an overall fall in energy consumption for that economy.

On the other hand a study by Bratt, L. (2012) points out that the relation between GDP and environment can also be sometimes 'U' shaped as against inverse 'U' shaped as given by the EKC Model. This hypothesis was developed after analysing the report of the World Commission on Environment and Development 1987(Our Common Future), however this model has failed to achieve the desired attention.

It is important to mention that EKC was actually not the starting point for the researchers for linking growth and environment. This is because before the hypothesis of EKC was proposed by Grossman and Krueger in 1991, the researchers were focusing on another related model ; relation between energy and economic growth which was pioneered by *Kraft, J., & Kraft, A. (1978)*. On the other hand it has been found that most studies which focus on relation between environment and economic growth also include other variables like FDI, financial development, trade openness etc. but these are usually brought in as control variables. It is interesting to note that a no. of researchers have also found that environmental degradation also impacts economic growth. Research Studies by *Sbia, R., Shahbaz, M., & Hamdi, H. (2014), Sebri, M., & Ben-Salha, O. (2014*) found the two way causality between growth and environmental degradation.

Some research studies have also gone ahead and have tried to explain the entire process or flowchart whereby growth leads to environmental degradation and the popular route for most studies has been the energy route. Thus when the income rises this invariably is accompanied by increase in fossil fuel consumption which in turn has an impact on the environment. Research studies in few developed economies have shown that replacement of fossil fuels with renewable energy does help in improving the environment, however research in this area is extremely limited.

Speaking in terms of techniques used to study the relation, a lot of researchers have used popular econometric tools of co-integration and causality , another group of researchers have tried to build a dynamic relation between economic growth, energy and environment under a multivariate environment using newer tools & techniques like Dynamic OLS , ARDL etc. The present study too revolves around building a dynamic relation between the three variables; growth, emissions & energy for two emerging markets of Asia viz. India and China. The motivation behind the study is to make a comparison between India and China when it comes to GDP and CO_2 emissions. Both China's GDP and CO_2 emissions started an upward trend from 2001 onwards till 2013 for which data is available (see Appendix I (A) Fig 1 & 2). Although for India too both GDP and CO_2 emissions were also rising during the same period, however still this increase was of nowhere in comparison to that of China. Therefore the main motivation for this paper was to find out whether or not there exists a long term relation between these two variables GDP and CO_2 emissions for both economies and whether or not the same could be translated to long run equilibrium .

The structuring of the entire paper is as follows: Section 1, the Introduction or the Current Section provides an overview of the research topic ; linkages between CO_2 emissions, energy consumption, & economic growth. Section 2, reviews the similar studies in the area of establishing relation between the CO_2 emissions , energy and economic growth. Section 3, discusses the data and describes the variables used while Section 4, discusses the research objectives of the study. Section 5, provides the methodology employed in detail along with stating of various hypothesis to be tested followed by Section 6 which provides empirical results of the study & its interpretation. Section 7 is developed to provide the conclusions of the study & give some policy recommendations followed by references as Section 8 and appendices as Section 9.

2. ***Review of Literature***

Under literature review we discuss those studies which are similar to the present study in terms of selection of variables or pertaining to the building of the relation. We have used the tabular format as it is not only easy to compare the research undertaken by researchers with respect to the sample, period and methodology but also to find out consistency of the results from these studies.

Author(s)	Variables	Country	Period	Methodology	Results
Awosusi,A ; & D, Kalmaz (2020)	CO2 emissions , Economic growth, Financial Development, energy consumption, trade openness, FDI	Nigeria	1971 to 2015	FMOLS and DOLS, Bounds , wavelet causality test	Short and long economic growth impacts CO2 emissions but positively
Nathaniel, S., Nwodo, O., Adediran, A., Sharma, G., Shah, M., & Adeleye, N. (2019)	Ecological Footprint, Urbanization and Energy consumption	South Africa	1965–2014	ARDL,DOLS, FMOLS	Economic Growth hampers environment in both short and long run
Sbia, R., Shahbaz, M., & Hamdi, H. (2014)	Co_2 Emissions, Energy, GDP & FDI	UAE	1975-2012	ARDL	Bi-Directional Causality between CO_2 emissions & GDP , Energy & CO_2 emissions & also between Energy & GDP.
Sari, R., & Soytas, U. (2009)	GDP , Energy Consumption & Co_2 (all variables in per capita basis)	Algeria, Indonesia, Nigeria, Saudi Arabia, and Venezuela	1971–2002	ARDL	GDP growth results in fall in CO_2 in Nigeria & Venezuela. Energy use causing CO_2 emissions in Nigeria & Indonesia while not in S Arabia
Bozkurt, C., & Akan, Y. (2014)	GDP, Energy & Co_2	Turkey	1960-2010	Johansen Co-integration,	CO_2 emissions is negatively related to growth
Antonakakis, N., Chatziantoniou, I., & Filis, G. (2017)	Economic Growth, Energy & CO_2 emissions *(five sub-categories of energy considered include coal, gas, electricity oil and renewable energy consumption)*	106 countries	1976-2011	Panel VAR, Impulse & Causality	Bi-Directional Causality between growth & energy, Individual segments of energy consumption including renewable energy could not be individually be linked to growth
Narayan, P. K., & Narayan, S. (2010)	GDP, Energy Consumption and Co_2 emissions (all variables at per capita)	43 Developing countries	1980-2004	Long run and short run Elasticity Models	Results of Middle East Countries showed long run elasticity < short run elasticity, confirming the assumptions that wise rise in income ,there is a fall in CO_2 Levels
Akbostancı, E., Türüt-Aşık, S., & Tunç, G. İ. (2009)	So_2 , Co_2 , PM10 emissions, Economic Growth, Energy Consumption	Turkey	1968-2003	Co-integration	As income rises, CO_2 level also rises monotonously in the long run
Sebri, M., & Ben-Salha, O. (2014)	GDP, trade, renewable energy, Co_2 emissions	BRICS	1971-2010	ARDL	Bi-Directional Causality between energy & GDP
Begum, R. A., Sohag, K., Abdullah, S. M. S., & Jaafar, M. (2015)	GDP, energy , population growth & CO_2 emissions	Malaysia	1970-2009	ARDL, Dynamic OLS & SLM 'U' test	Period :1970-80; CO_2 emissions decreased with increase in GDP Period: 1980-2009: Results were completely reversed .

Author(s)	Variables	Country	Period	Methodology	Results
Govindaraju, V. C., & Tang, C. F. (2013)	Coal consumption , CO_2 & economic growth	China and India	1965–2009	Causality, Co-integration	China : (a) Long-run relation between the variables established (b) Long & Short run Bi-directional causality between coal and economic growth & also between coal & CO_2. India Only Short run bi-directional causality between (i) CO_2 & growth and (ii) CO_2 and coal (iii)Unilateral causality from growth to coal.
Tiwari, A. K. (2011)	Renewable Energy Consumption, CO_2 & GDP	India	1960-2009	Structural VAR , Impulse, Variance Decomposition	A shock on the renewable energy consumption impacted GDP positively while the impact on CO_2 emissions was negative. A shock on GDP impacted CO_2 strongly. Variance Decomposition of GDP: Renewable energy could explain a significant part of error variance. No evidence of co-integration amongst the variables.
Tiwari, A. K. (2011 A)	GDP, Energy & Environmental Degradation	India	1971-2007	Granger causality (with VECM & DL approaches)	No causality between energy & economic growth. Environmental degradation was seen impacting growth adversely
Lotfalipour, M. R., Falahi, M. A., & Ashena, M. (2010)	GDP, Energy & Co_2	Iran	1967-2007	Toda Yamamoto Causality	Causality seen moving from fossil fuels to CO_2 and also from GDP to energy No long run relation could be established.
Halicioglu, F. (2009)	income, CO2 emissions, foreign trade & commercial Energy Consumption	Turkey,	1960-2005	ARDL	Long-run elasticity of CO_2 w.r.t energy was 0.78. & w.r.t income 12.31 ,Granger causality was bi-lateral between CO_2 emissions & income,
Soytas, U., & Sari, R. (2009)	GDP, Energy & Co_2	Turkey	1960-2000	Toda Yamamoto Causality, VAR	Uni-directional CO_2 emissions causing energy consumption. No causal relation between income and CO_2 emissions implying that any reduction in CO_2 emissions could be achieved without impacting economic growth

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Research Gap

The literature review given above points out that most of the empirical studies do support the fact that economic growth does impact environment via energy consumption, however there is no consensus amongst the researchers about speed and intensity of exact relation between the variables .This implies that final outcome of the relation is likely to differ from economy to economy and there is a high probability that this would depend upon the stage of development of a particular economy.

Taking clues from above, that the dynamics of inter-linkages between energy, environment and economic growth is also a function of stage of growth of an economy , we have developed our study on two emerging economies of Asia viz. India and China. Both India and China have shown potential for growth and this could be seen by examining the march of the GDP Curve which started an upward trend from 2001 onwards till 2013 for which data is available (see Appendix I (A) Fig 1). However the two economies have managed to achieve this feast by following altogether different models of growth , the growth model of China is manufacturing while that of India is Services. Further growth in GDP is also accompanied by a similar rise in CO_2 emissions in both the economies (see Appendix I (A) Fig 2). Therefore through this paper our attempt would be to examine whether the dynamics of inter-linkages between energy, environment and economic growth also depends upon the type of growth model adapted by the economy in addition to the stage of growth of an economy. Further the linkages between the three variables; energy, environment and economic growth have been studied under the ARDL framework with the addition of structural break in time series , a concept ignored by most of the empirical studies. With the incorporation of break in time series ARDL Model would help us to study the linkages in a more appropriate manner resulting in better and more accurate outcomes.

3. ***About the Sample & Description of Variables***

As already stated, the sample of the study includes two emerging economies of China and India. Both India and China have successfully recorded a reasonable growth during the past two decades , however the approaches to growth have been altogether different in these two economies; whereas growth of China has been mainly driven by their manufacturing sector, India's growth is mainly a service led growth which picked up pace post 90s and could be one of the reasons for higher incremental rise in CO_2 emissions especially after 1999.

The time period of study is 43 year period 1970-2014 (yearly data). The data has been obtained from website of the World Bank ((data.worldbank.org). The study takes Gross Domestic Product or GDP (current level in US$ per capita) as the proxy for Economic Growth , CO_2 emissions (metric tonnes per capita) as the level of environmental degradation & fossil fuel consumption as the proxy for energy consumption. Before applying econometric tests on these variables, all the three variables have been log transformed.

4. Research Objectives

The following are the Research Objectives of the Study :-

(i) To identify whether there exists a structural break in time series of variables; GDP, Fossil Fuel Consumption and CO_2 emissions for two countries , India and China using CUSUM & CUSUMSq. Plots with confirmation of the same given by Chow-F Breakpoint test.

(ii) To establish three ARDL Co-integrating equations for India and China (after incorporating structural break, if any) by including all the three variables viz. GDP, CO_2 emissions & fossil fuel consumption.

(iii) To identify long run co-integration amongst variables by applying Partial 'F' test for each of the ARDL equations subject to the optimal lag selection.

(iv) To identify the error correcting mechanism which acts as a binding factor between long run and short run amongst the co-integrated variables.

(v) To carry out pre-requisite diagnostics for our ARDL Models in terms of (a) Variable Stationarity (b) Heteroscedasticity & (c) Serial Correlation

5. Methodology Adopted

Before we develop an ARDL Co-integration Model, we under this section would first discuss the pre-requisites that are required for development and working of the ARDL Model.

5.1 ARDL Pre-requisites

5.1.1 Model Pre-requisite I: Stationarity of Variables

The ARDL Co-integration model is becoming popular as a novel co-integration process since it does not require same level of integration amongst all the variables. Thus the model gives correct results if the variables are integrated either at level or first difference (but not second level which is however rarely the case). In order to test the variables for stationarity , we use the popular ADF unit root test (with intercept and trend) and the following equations have been developed for the same.

$$\Delta FFC_t = \beta_1 + (\beta_2 - 1)\ FFC_{t-1} + \sum_{i=1}^{m} \beta_{3i}\ \Delta FFC_{t-i} + \beta_4 t + u_{2t} \quad \text{.............eq. (i)}$$

$$\Delta\ GDP_t = \alpha_1 + (\alpha_2 - 1)\ GDP_{t-1} + \sum_{i=1}^{m} \alpha_{3i} \Delta\ GDP_{t-i} + \alpha_4 t + u_{1t} \quad \text{.............eq. (ii)}$$

$$\Delta\ CO_{2\,t} = \lambda_1 + (\lambda_2 - 1)\ CO_{2(t-1)} + \sum_{i=1}^{m} \lambda_{3i} \Delta\ CO_{2(t-i)} + \lambda_4 t + u_{3t} \quad \text{.............eq. (iii)}$$

(where FFC is the Fossil Fuel Consumption, GDP is Gross Domestic Product & CO_2 is the Carbon Dioxide Emissions. Consider equation (i) the variable for which we are testing stationarity is FFC . In this equation; $\Delta\ FFC_t$ is change in FFC in period t, β_1 is the intercept , $(\beta_2 - 1)$ is the coefficient

which tests for the variable stationarity ,$\sum_{i=1}^{m} \beta_{3i} \Delta$ FFC $_{t-i}$ is the change in FFC in period t-i & takes care of serial correlation in the equation. The summation of the term shows that the variable ΔFFC_{t-i} is added 'm' times in equation (i) till the serial-correlation is removed. The next term $\beta_4 t$ is for the trend variable and takes care of deterministic trend in equation .This term is included in the equation so that only stochastic trend can be detected, Finally we have u_{1t} which is random error term.)

The testable hypothesis for Stationarity test of our Variable *FFC* (eq (i)) would be

(H_0) : $\beta_2 - 1 = 0$ *0r* $\beta_2 = 1$ *(the FFC is not stationary)*
(H_a)*:* $\beta_2 - 1 \neq 0$*, (FFC is stationary)*

Working out on similar lines, we carry out stationarity tests for our two other variables namely GDP & CO_2(eq.(ii)& (iii))

5.1.2 Model Pre-requisite II : Absence of Serial Correlation

Absence of Serial Correlation is the second ARDL Pre-requisite and the model is expected to satisfy the following assumption ; Covariance(u_t , u_{t-1}) = 0 . To test for serial correlation the study has applied BG-LM test for serial correlation. Under this test, we first run an AR equation for the variable under consideration say $\mathbf{Y_t = \theta_1 + \theta_2 Y_{t-1} + \theta_3 Y_{t-2} + \ldots + \theta_p Y_{t-p} + e_t}$ and obtain the residuals. In the next step we run another regression where the dependent variable is the current residuals while independent variables shall include all AR terms and all lags of the current residuals

$$\mathbf{e_t = \pi_1 + \pi_2 Y_{t-1} + \pi_3 Y_{t-2} + \ldots + \pi_p Y_{t-p} + \rho_1 e_{t-1} + \rho_2 e_{t-2} + \rho_3 e_{t-3} + \ldots\ldots + \rho_m e_{t-m} + v_t \ldots\ldots\ldots\ldots\ldots(iv)}$$

Null Hyp : No Serial Correlation amongst the residuals (residuals are jointly equal to zero)

(H_0) : $\rho_1 = \rho_2 = \rho_3 = \rho_m = 0$ against alternate hypothesis
(H_a) : $\rho_1 = \rho_2 = \rho_3 = \rho_m \neq 0$

The computed R square of above equation (iv) follows $\chi 2$ and if R^2 (n-p) > χ^2_m, the Null Hypothesis of No Serial Correlation gets rejected.

5.1.3 Model Pre-requisite III : No Heteroscedasticity

Absence of heteroscedasticity (also called unequal variance of the error term) is another important pre-requisite for most time series models and to test its presence we follow B-P-G technique under which we run a regression say $Y_t = \beta_1 + \beta_2 X_{2t} + \beta_3 X_{3t} + \ldots\ldots + \beta_k X_{kt} + u_t$ & Obtain the residuals u_t and its variance $\widehat{\sigma^2} u_t = \Sigma u^2_t / n$.
Next defining a variable $p_t = u^2_t / \widehat{\sigma^2} u$ we run another regression such that
$p_t = \alpha_1 + \alpha_2 X_{2t} + \alpha_3 X_{3t} + \ldots. + e_t$ ……(v)
Next we obtain the explained sum of the squares (ESS) of eq.(v) which follows χ^2 distribution.

The Null shall be No Heteroscedasticity which can only exist if $\alpha_2 = \alpha_3 = \ldots = 0$ *(from eq. v)*

5.2 ARDL Model specification with structural breaks

ARDL Co-integration Model was originally developed by *(Pesaran & Shin 1999)*& was later modified by *(Perasan et.al 2001)* reveals not only long term relation amongst the variables but also dynamic interaction amongst them .The Model enjoys certain advantages over tradtional co-integration models as it does not require stationary pre-testing of variables as both I(0) & I(1) types can be incorporated in the model & the model has the ability to give efficient results even for small samples. Further long run information is not lost while establishing the dynamic relation & the co-integration test can be applied even if some of the regressors are endogenous *(Srinivasan & Prakasam (2014), Sehrawat & Giri(2015))*

Next, we proceed towards developing our ARDL Co-integration Model. However before formulating our model, we would be testing our variables for likely structural breaks. This is important as the study period of forty five years is quite long and therefore the chances of a break in time series are quite high. To achieve this we have used stability plots called CUSUM & CUSUMSQ plots. Further the to re-confirm the actual year of break, we have used Chow Breakpoint test . Chow Breakpoint test breaks the time series data into two parts and runs three separate regression, one each for two parts and one for combined data. The three regressions gives three residual sum of the squares; RSS_1 , RSS_2 & RSS_C; The following formula is used to obtain 'F' Statistics for Chow test.

$$F_{computed}' = \frac{\dfrac{RSS_C-(RSS_1+RSS_2)}{k}}{\dfrac{(RSS_1+RSS_2)}{[(n_1+n_2)-2k]}},$$ 'k' = no. of regressors, 'C' = Combined Model

Null : Hypothesis : No Break in time series
Alternate Hypothesis : Time Series has a break at stated time period

Once a satisfactory break date is known for any variable , we incorporated the same in our ARDL model using a Dummy Variable (which takes the value '0' for period before the break and takes value '1' for break period and after period the break) . Thus our final ARDL Model takes the following shape :

ARDL Model Without Break

(a) $$\Delta\, LGDP_t = \beta_1 + \beta_2 LGDP_{t-1} + \beta_3\, LFFC_{t-1} + \beta_4 LCO_{2(t-1)} + \sum_{i=0}^{n}\left(\beta_{5,i}\Delta LCO_{2(t-i)}\right) + \sum_{i=1}^{n}\left(\beta_{6,i}\Delta LGDP_{t-i}\right) + \sum_{i=0}^{n}\left(\beta_{7i,}\Delta LFFC_{t-i}\right) + u_t \quad \ldots\ldots(vi)$$

$$\text{(b)}\quad \Delta LFFC_t = \pi_1 + \pi_2 LGDP_{t-1} + \pi_3 LFFC_{t-1} + \pi_4 LCO_{2(t-1)} + \sum_{i=0}^{n}(\pi_{5,i}\Delta LCO_{2(t-i)}) + \sum_{i=0}^{n}(\pi_{6,i}\Delta LGDP_{t-i}) + \sum_{i=1}^{n}(\pi_{7,i}\Delta LFFC_{.t-i}) + v_t \;......(vii)$$

<u>**ARDL Model With Break**</u>

$$\text{(a)}\quad \Delta LCO_{2t} = \delta_1 + \delta_2 LGDP_{t-1} + \delta_3 LFFC_{t-1} + \delta_4 LCO_{2(t-1)} + \sum_{i=1}^{n}(\delta_{5,i}\Delta LCO_{2(t-i)}) + \sum_{i=0}^{n}(\delta_{6,i}\Delta LGDP_{t-i}) + \sum_{i=0}^{n}(\delta_{7i,}\Delta LFFC_{.t-i}) + \delta_8 Dummy_t + w_t \;......(viii)$$

(Note : Break could be identified in only one of the three variables viz. CO_2 under study)

5.3 ARDL Model Error Correction and short run parameters

Next we run a regression to obtain short term parameters & coefficient of the lagged error term as under :-

$$\Delta LGDP_t = \alpha_1 + \alpha_2 u_{t-1} + \sum_{i=1}^{n}(\psi_{3i}\Delta LGDP_{t-i}) + + \sum_{i=0}^{n}(\gamma_{4i,}\Delta LFFC_{t-i}) + \sum_{i=0}^{n}(\theta_{5,i}\Delta LCO_{2,t-i}) + e_{1,t} ....(ix)$$

$$\Delta LFFC_t = \alpha_6 + \alpha_7 v_{t-1} + \sum_{i=0}^{n}(\psi_{8i}\Delta LGDP_{t-i}) + \sum_{i=1}^{n}(\gamma_{9i,}\Delta LFFC_{t-i}) + \sum_{i=0}^{n}(\theta_{10,i}\Delta LCO_{2,t-i}) + e_{2,t} \quad ....(x)$$

$$\Delta CO_{2,t} = \alpha_{11} + \alpha_{12} w_{t-1} + \sum_{i=0}^{n}(\psi_{13i}\Delta LGDP_{t-i}) + + \sum_{i=0}^{n}(\gamma_{14i,}\Delta FFC_{t-i}) + \sum_{i=1}^{n}(\theta_{15,i}\Delta CO_{2,t-i}) + e_{3,t} ....(xi)$$

(*Where ψ, γ & θ are the short run parameters to be estimated, α_2, α_7 & α_{12} are the parameters of error correction term(ECM) terms u_{t-1}, v_{t-1}, w_{t-1} obtained from the running OLS on contemporaneous variables (see eq. xii, xiii & xiv) It is to be noted that 'n' for the short term co-integration has be defined by the best model given by AIC.)*

5.4 OLS Model showing contemporaneous relation

To test for the contemporaneous relation amongst the variables which was also required to obtain the error correction term , we carried out three OLS regressions for the three variables under study for both India and China , however it was ensured that the variables included were Stationary . Thus we obtained the following regressions :-

$$\Delta\ LGDP_t = \lambda_1 + \lambda_2\ \Delta LFFC_t + \lambda_3\ \Delta LCO_{(2)t} + e_{1t}\ \ldots\ldots(xii)$$

$$\Delta LFFC_t = \beta_1 + \beta_2\ \Delta\ LGDP_t + \beta_3 \Delta LCO_{(2)t} + e_{2t}\ \ldots\ldots(xiii)$$

$$\Delta LCO_{(2)t} = \alpha_1 + \alpha_2\ \Delta\ LGDP_t + \alpha_3\ \Delta LFFC_t + e_{3t}\ \ldots\ldots(xiv)$$

6 Empirical Results of the Study

The empirical results of our study are given in Appendices. To begin with we discuss the pattern of the GDP per capita and CO_2 per capita in the two countries, India & China ; followed by Descriptive Statistics on the three variables used in our study. If we observe the pattern of GDP and CO_2 emissions over the years(See **Appendix I (A) : (Figure I & II))** as the figure clearly shows that till 1992 , GDP Per Capita was almost the same for both the countries, however post 1992, China's GDP per capita showed an upward trend and thereafter never looked back. On the other hand , GDP Per capita of India also started growing after 1992 but at a much slower pace than that of China. On the other hand , if we examine the CO_2 emissions per capita of both the countries, we find that Co_2 emissions of China have been growing at a much higher rate than that of India since early 1970s with the gap between the two countries being nearly stable till 2001 (see Figure II, Appendix IA) . The pace of CO_2 emissions for China however gained momentum from 2001 thereby widening the gap between the two countries to a great extend.

Next we compare the two countries with respect to different parameters ; Mean, Median, Standard Deviation, Skewness & Kurtosis . **Appendix I(B)** gives the Statistical Description of variables LGDP, LFFC & LCO_2 for the two countries India and China. The table shows that average GDP levels, CO_2 Levels & FFC of India are much lower than that of its counterpart viz. China . Further, India has a lower variability of CO_2 and GDP while China has a lower variability when it comes to FFC. In terms of the distribution of returns, all the three variables in two countries were found to be normally distributed (Normal JB <5.99).

The next appendix; **Appendix II** gives the results of the stationarity of our variables GDP , & CO_2 & FFC for both India and China using ADF Unit root test (with intercept and trend) . The table gives the 'p' values of obtained statistics both at levels and first difference for all the three variables viz. LGDP, LFFC & LCO_2. The results reveal that all the variables except LFFC of China are stationary at 1^{st} difference while LFFC of China is stationary at level. Now with this kind of mixture of variables, one variable being I(0) while all others being I(1), ARDL co-integration was the obvious choice of the study.

Appendix III(a) gives the results of Long term Co-integration between the variables using ARDL Partial 'F' Bounds approach. The results reveal that Long term Co-integrating relation is established amongst all the variables except for China when CO_2 is taken as dependent variable. The test statistic applied is given in **Appendix III(b).** In all the cases except CO_2 (China), the computed 'F' Statistic value is greater than the critical values of both Pesaran et.al. (2011) & Narayan, P.K (2004) tables suggesting that the long run co-integration is established. A**ppendix III(c)** gives the results of the Optimal Lag Selection for our ARDL Model & Lag Criteria approach followed in our paper is AIC. Here again we see that for each ARDL co-integration model, unlike a typical VAR Model, all the variables need not be of same lag length reflecting the superiority of model. The same lag structure is also applied for constructing an error correcting equation which also includes short run variables.

Appendix IV (a to c) gives the ARDL long run results. It is to be noted that only in case of India CO_2 we could find additional variables in the form of a Dummy . This is so because only for India CO_2 we could detect a structural break in time series, while rest of the variables had no break.

Appendix V gives error correction mechanism from short run disequilibrium to long run equilibrium. To achieve a significant movement towards equilibrium in the long run, it is important that the coefficient of the lagged error term (ECM_{t-1}) should be both negative and significant. As seen in the Appendix V, the ECM term is negative and significant in all the cases (for CO_2 of China, this is not required as co-integration is not established) Further the coefficient of this term may also be interpreted as speed of adjustment towards equilibrium which is 16 % per annum for CO_2 of India i.e. the equilibrium is achieved in 6.3 years. Further speed of adjustment for all other variables is much shorter and lies anywhere between 3% to 8 % p.a.

Appendix VI , VII & VIII give the results of the model pre-requisites i.e. the results for the test of serial correlation, heteroscedasticity & stability for all the variables . Whereas results of serial correlation and heteroscedasticity as shown in Appendix VI(a& b), stability results are shown as CUSUM and CUSUMSQ stability plots (Appendix VII). The results clearly show that all the variables *(except FFC for India)* are free from serial correlation as well as heteroscedasticity , however the same was not the case with the results of the Model Stability parameters which revealed a different story. The Stability Plots i.e. CUSUM and CUSUMSQ plots revealed a likely break in 1996 for India CO_2 . Further assuming that this break in the Model Stability plot for India CO_2 was due to the structural break in time series , we carried out another test , the Chow Break Point Test to confirm the same. The Chow Break - Point test rejected the Null of No Break in time series as the computed ‘F’ Statistics has a ‘p’ value as highly significant thereby confirming the existence of a break as was detected in Stability Plot for India Co_2 (See Appendix VIII). Further , no other variable showed any signs of break as the CUSUM & CUSUMSQ Plots showed that the model for other variables was stable *(these plots have been ignored for convenience)*

7 *Conclusion & Policy Recommendations*

To conclude, the present study empirically investigated the co-integrating relation between economic growth, energy and environment for two countries namely India and China for the 44 year period 1970-2014 (yearly data obtained from data.worldbank.org). . The study takes Gross Domestic Product per capita as the proxy for Economic Growth , CO_2 emissions per capita as the level of environmental degradation & fossil fuel consumption as the proxy for energy consumption. The methodology adapted was Autoregressive Distributed Lag (ARDL) Partial ‘F’ Bounds Co-integration Approach. The Structural Break was incorporated in the ARDL model using a Dummy variable (in case the break was detected in time series by Chow Break even test). The results showed that India CO_2 emissions had a break in 1996. The ARDL Model was chosen for the study as variables were mixed in nature, some were I(0) while others were I(1) integrated. For model optimality AIC optimal lag criteria was preferred. The model results showed that long term co-integrating relation was established amongst all the variables except for CO_2 (China). It was found that ‘F’ Statistics from Partial F Bounds test of all the variables (except China CO_2) was greater than the upper bound limit as given in both Pesaran, M. H., Shin, Y., & Smith, R. J. (2001)) & also Narayan(2004) tables. The error correction term (lagged error term) was negative and significant in all the cases *(for CO_2 of China this was not required)* Further the speed of adjustment towards equilibrium was fastest @16 % per annum for CO_2 of India while it was much slower between 3% to 8 % for rest of the variables. The Serial Correlation and Heteroscedasticity was not found in any of the variables (except India FFC), ADF Unit root test showed that the variables were either I(0) or I(1) Integrated.

The energy–environment–income nexus which was proved in the study to have a two way or bi-lateral long run co-integration relation in case of India throws a lot of challenges to policy makers in India. For India, this would mean that all long run growth targets must be sustainable e.g. replacing coal powered plants with plants that consume renewable energy. However this may not be easy as it requires huge amount of resources which may not be presently feasible for developing countries like India, so attempt can be made to shift to renewable energy plants in a phased manner. It is also very much possible that a complete overhaul may not possible/feasible, here the plants may be allowed to shift to alternative less environment impacting fuels e.g. natural gas based power which are proven to reduce the CO_2 emissions by approximately 50 %.

Apart from this, acquiring technology that captures and stores carbon must be encouraged; however this too must be achieved in a gradual manner. Further long term objective of both the countries should be in line with EU norms which has set a target of reduction in Green House Gases emissions to 20-40 % by 2050 from what these were in 1990 and for this the policy makers have to carefully employ all the measures at their disposal i.e. a combination of sustainable development coupled with stringent pollution regulations and market based solutions. As far as China is concerned, it was seen that GDP was having a long run relation with Fossil Fuel Consumption, however this was not being seen to impact CO_2 emissions. This may be due to sustainable policy decisions of the government whereby it has been successful in restricting most of the emissions and hence achieved substantial reduction in GHG emissions. Since China's growth revolves around manufacturing sector with a lot of export focus, this reduction in GHG emissions could be attributed to stricter international environmental norms. Thus for China, it is important that such sustainable policies are continued and maintained in future.

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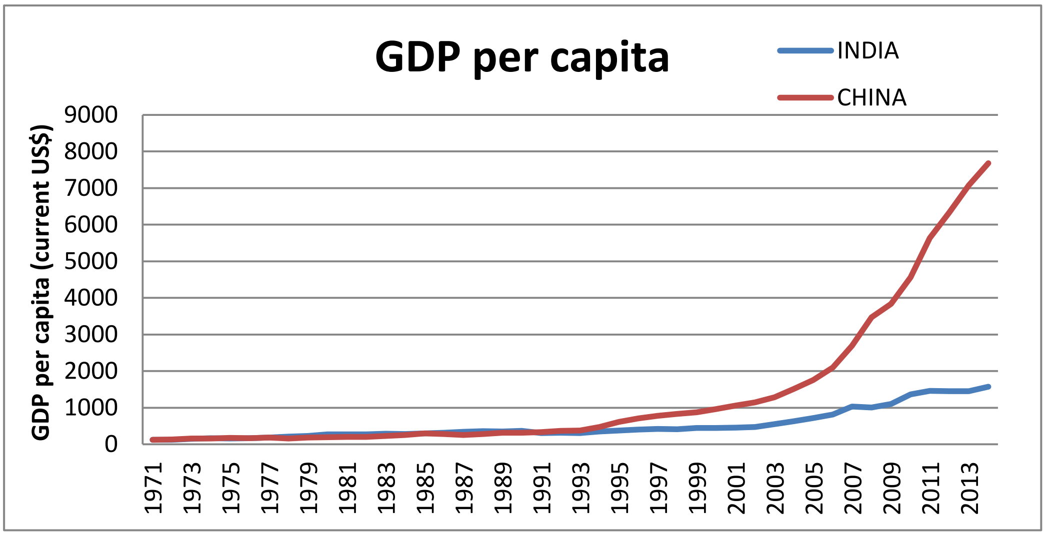
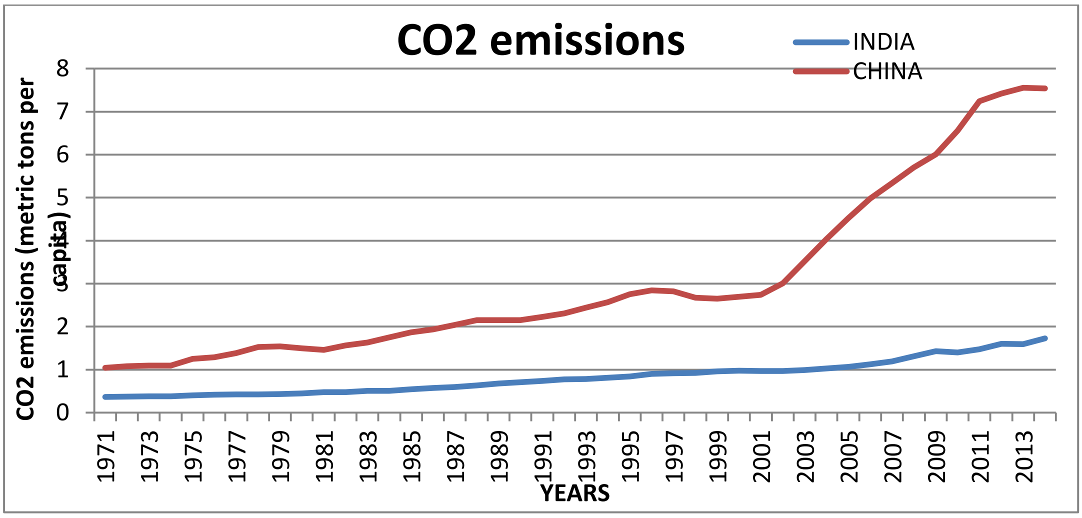
9 Appendices

Appendix I (A) : Fig I : GDP per capita of India and China (1971-2014)



Appendix I(A) : Fig II :CO_2 emissions per capita of India and China (1971-2014)



Appendix I (B) Statistical Description of the Variables

	INDIA				CHINA		
Parameter	***LCO_2***	***LGDP***	***LFFC***		***LCO_2***	***LGDP***	***LFFC***
Mean	0.297565	5.990908	3.972423		0.933242	6.402939	4.326862
Median	0.251844	5.861819	4.034450		0.865080	5.918585	4.331891
Standard Deviation	0.465408	0.702327	0.246708		0.588647	1.249913	0.115116
Kurtosis	1.824594	2.453067	1.703128		2.176956	2.157054	2.164392
Skewness	0.063850	0.423707	0.385324		0.425506	0.635727	-0.319730
Minimum	-1.011751	4.778682	3.558765		0.041372	4.776217	4.092666
Maximum	0.548122	7.362648	4.298332		2.022502	8.946831	4.487494
No. of Observations	44	44	44		44	44	44
JB Statistics	2.562794	1.864955	4.172253		2.569638	4.266451	2.029772

Appendix II : ADF (Unit Root) test (with intercept and trend) of all the variables under study for India and China

	India		China	
Variable	**'P' value at Level**	**'p' value at 1st Diff**	**'P' value at Level**	**'p' value at 1st Diff**
GDP	0.9260	0.0001*	0.9670	0.0000*
CO_2	0.6804	0.0000*	0.9444	0.0146*
FFC	0.9925	0.0001*	0.0457*	0.0004*

*** Significant at 5 % level**

Appendix III(a) :ARDL Co-integration Partial 'F' test Results (both the countries have model with Lag 2 as optimal)

	INDIA	
Type of Relation	***'F' Bounds Value (Computed)***	***Inference***
GDP as a f(CO_2 , FFC)	*6.410217*	*Co-integration Established*
CO_2 as a f(GDP , FFC)	*8.634891*	*Co-integration Established*
FFC as a f(GDP,CO_2)	*6.046821*	*Co-integration Established*
	CHINA	
Type of Relation	***'F' Bounds Value (Computed)***	***Inference***
GDP as a f(CO_2 , FFC)	*7.426997*	*Co-integration Established*
CO_2 as a f(GDP , FFC)	*2.281425*	*Co-integration Not Established*
FFC as a f(GDP,CO_2)	*5.734211*	*Co-integration Established*

Appendix III(b) Critical Tables for ARDL F Bounds test

	Pesaran Critical Values	Narayan Critical Values
Lower Bound	3.79	3.116
Upper Bound	4.85	4.094
No Inference	Between 3.79 & 4.85	Between 3.116 & 4.094

Appendix III(c): AIC Optimal Lag Determination for our ARDL Model

Model (AIC) with Optimal Lags	*INDIA*	*CHINA*
Dependent: CO_2	(2,0,3)	(2,0,3)
Dependent: GDP	(1,0,0)	(1,1,4)
Dependent FFC	(1,1,2)	(1,1,0)

(figures in parenthesis are no. of lags of dependent variable followed by lags of regressor)

Appendix IV (a): Long Run Results of ARDL Model : Dep Variable CO_2

	INDIA		CHINA	
Independent Variable	Coefficient	'p' value	Coefficient	'p' value
CO2(-1)	**0.618832**	**0.0006***	**1.449606**	**0.0000***
CO2(-2)	**0.219556**	**0.1368**	**-0.559012**	**0.0014***
FC	**0.248103**	**0.0102***	**2.607556**	**0.0000***
FC(-1)			**-3.020765**	**0.0001***
FC(-2)			**-0.036124**	**0.9563**
FC(-3)			**0.736710**	**0.0655****
GDP	**-0.000836**	**0.9866**	**0.030459**	**0.1323**
GDP(-1)	**0.072141**	**0.3061**		
GDP(-2)	**0.135183**	**0.0612****		
GDP (-3)	**0.152515**	**0.0148***		
Dummy	**-0.032033**	**0.0963****		
C	**-1 .314280**	**0.0090**		

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* SIGNIFICANT AT 5 % LEVEL , ** SIGNIFICANT AT 10 % LEVEL

Appendix IV (b): Long Run Results of ARDL Model : Dep Variable GDP

	INDIA		CHINA	
Independent Variable	Coefficient	'p' value	Coefficient	'p' value
CO2	0.271146	0.2268	0.691765	0.0805**
CO2(-1)			-0.523852	0.2081
FC	-0.349478	0.2416		
FC(-1)			-1.2194S8	0.4607
FC(-2)			0.666988	0.7029
FC(-3)			3.292064	0.0394*
FC(-4)			-5.588625	0.0007*
GDP(-1)	0.942201	0.0000*	3.174014	0.0026*
C	1.872332	0.2146	-0.980879	0.6254

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* SIGNIFICANT AT 5 % LEVEL , ** SIGNIFICANT AT 10 % LEVEL

Appendix IV (c): Long Run Results of ARDL Model : Dep Variable FFC

	INDIA		CHINA	
Independent Variable	Coefficient	'p' value	Coefficient	'p' value
CO2	0.171457	0.0349*	0.182645	0.0000*
CO2(-1)	-0.239374	0.0018*	-0.187186	0.0000*
FC(-1)	1.056023	0.0000*	0.960831	0.0000*
GDP	-0.014110	0.5667	0.001336	0.8021
GDP(-1)	0.003387	0.9237		
GDP(-2)	0.029205	0.2589		
C	-0.339841	0.2208	0.165317	0.3773

** SIGNIFICANT AT 5 % LEVEL , ** SIGNIFICANT AT 10 % LEVELS*

Appendix V : ARDL Model Error Correction Results

Error Correcting Variable	Coefficient	'p' value
ECM(-1) CO_2 India	-0.161612	0.0000
ECM(-1) CO_2 China	NO COINTEGRATION	NO COINTEGRATION
ECM(-1) FFC India	-0.056023	0.0000
ECM(-1) FFC China	-0.039169	0.0000
ECM(-1) GDP India	-0.057799	0.0000
ECM(-1) GDP China	-0.077722	0.0000

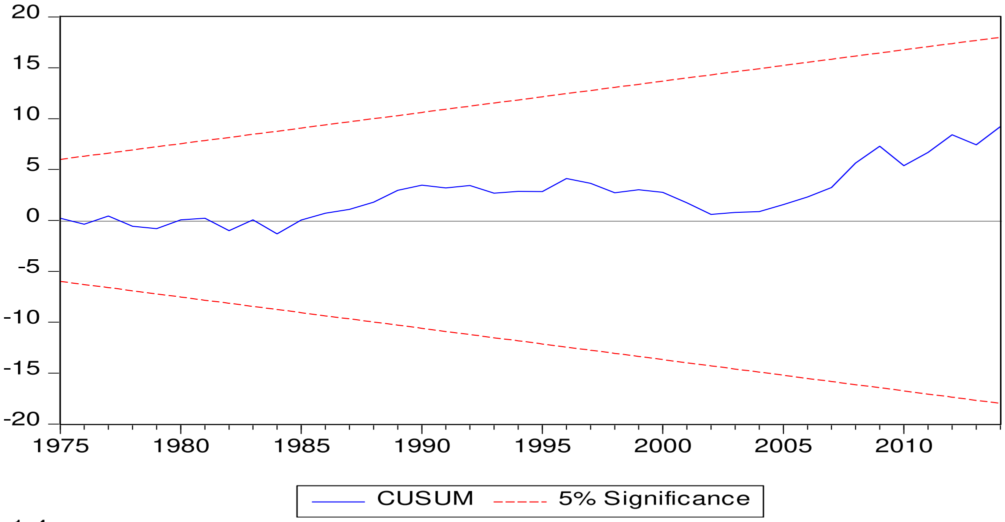
Appendix VI (a) : Serial Correlation using BG-LM test Statistic

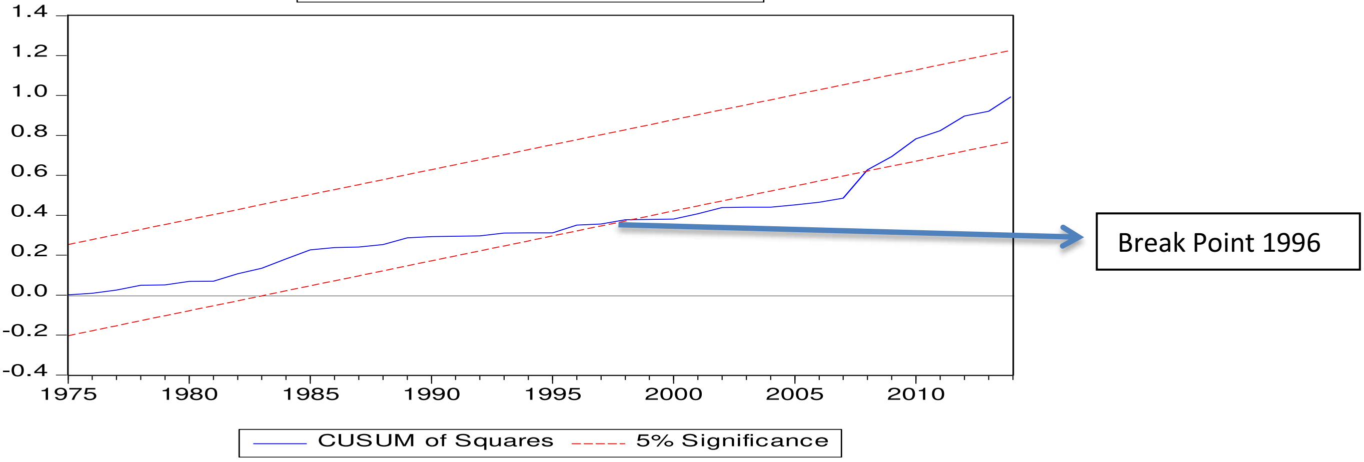
Variable	'F' Statistics	Prob F(,)	Observed R Square	Prob Chi Sq
India CO_2	0.413541	0.7974 (4,28)	2.287054	0.6831
India GDP	0.124272	0.9728 (4,35)	0.602158	0.9628
India FFC	2.552002	0.0587 (4,31)	10.40420	0.0341
China CO2	0.794472	0.5385 (4,29)	4.049161	0.3994
China GDP	0.959748	0.4454(4,27)	4.979399	0.2894
China FFC	0.793158	0.5379 (4,34)	3.669990	0.4525

Appendix VI (b) Heteroscedasticity Results using B-P-G test Statistic

Variable	**'F' Statistics**	**Prob F(,)**	**Observed R Square**	**Prob Chi Sq ( )**
India CO_2	1.531805	0.1854 (8,32)	11.35326	0.1825
India GDP	0.274640	0.8433 (3,39)	0.889629	0.8279
India FC	3.166832	0.0138 (6,35)	14.77828	0.0221
China CO2	1.842307	0.1119 (7,33)	11.52040	0.1175
China GDP	1.321428	0.2697 (8,31)	10.17182	0.2532
China FC	1.214215	0.3208 (4,38)	4.873083	0.3006

APPENDIX VII : CUSUM & CUSUMSQ Plots for CO2 Emissions (India)





Appendix VIII : Chow Break Even Test for CO_2 Emissions India

Chow Breakpoint Test: 1996
Null Hypothesis: No breaks at specified breakpoints
Varying regressors: All equation variables
Equation Sample: 1972 2014

F-statistic	4.321290	Prob. F(3,37)	0.0104
Log likelihood ratio	12.91644	Prob. Chi-Square(3)	0.0048
Wald Statistic	12.96387	Prob. Chi-Square(3)	0.0047