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The Environmental Kuznets Curve and the Role of Coal Consumption in India: Cointegration and Causality Analysis in an Open Economy

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Abstract: This study investigates the dynamic relationship between coal consumption, economic growth, trade openness and CO₂ emissions for Indian economy. In doing so, Narayan and Pop structural break unit test is applied to test the order of integration of the variables. Long run relationship between the variables is tested by applying ARDL bounds testing approach to cointegration developed by Pesaran et al. (2001).

The results confirm the existence of cointegration for long run between coal consumption, economic growth, trade openness and CO₂ emissions. Our empirical exercise indicates the presence of Environmental Kuznets Curve (EKC) long run as well as short run. Coal consumption as well as trade openness contributes to CO₂ emissions. The causality results report the feedback hypothesis between economic growth and CO₂ emissions and same inference is drawn between coal consumption and CO₂ emissions. Moreover, trade openness Granger causes economic growth, coal consumption and CO₂ emissions.

Keywords: Energy, Growth, Emissions, EKC

1. Introduction

Theoretically, the Environmental Kuznets Curve (EKC) hypothesis postulates the existence of an inverted-U shape relationship between real GDP per capita and measures of environmental degradation such as SO₂ and/or CO₂ emissions. However, the empirical evidences, either using time series and/or pooled data of a group of countries, on the EKC hypothesis vary from country to country, instead. Further, the results are not uniform across pollutants. This has created two problems being faced by environmental policy makers: to ensure that useful knowledge informs policy (without being misused and/or distorted) and to understand how to respond to this knowledge (Boehmer-Christiansen, [1]). However, in the present context we have limited ourselves to provide evidence of the EKC hypothesis for India. Our contribution lies, particularly in two directions. Firstly, we employed the ARDL method which is amenable for short time series data as in this paper and secondly, we provide empirical evidence of the EKC by incorporating coal consumption and trade as additional determinant of CO₂ emissions in case of India.

The rationale for selecting India for our analysis is that it has implemented a variety of programs and policy initiatives since the introduction of the National Forest Policy in 1988. India has become one of the fast growing countries next to China. However, in the same time consumption of coal has increased rapidly which was 35.55 mte in 1965 has reached the height of 249.86 mte in 2009. The close relationship between coal consumption and economic growth of India is evident from following Figure-1. Further if we see the relationship between percentage growth rates of GDP and coal consumption, we find that recently percentage growth rate in the coal consumption is more than twice of the percentage GDP growth rate. This situation is evident in Figure-2.

Figure-1: Coal consumption and GDP per capita

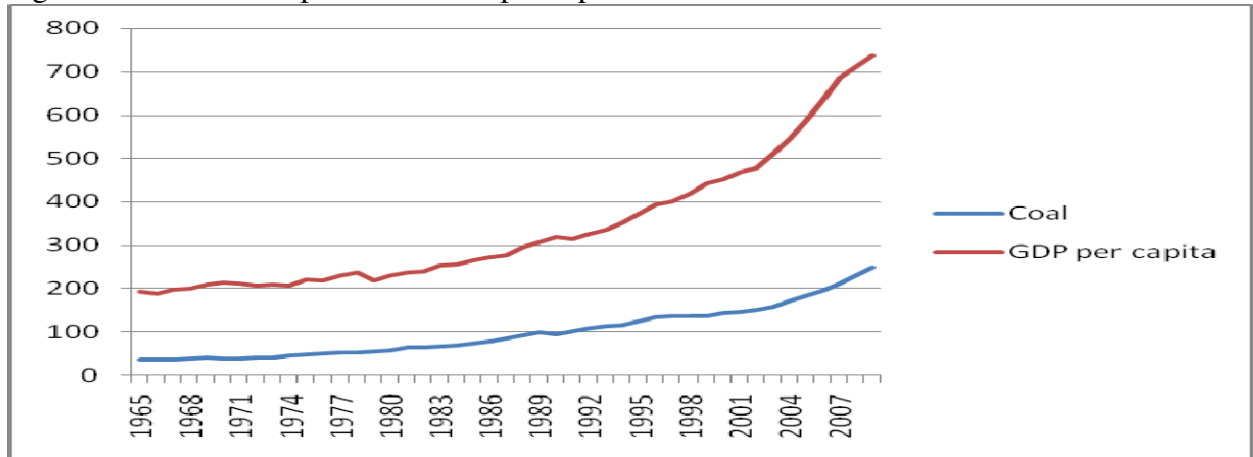
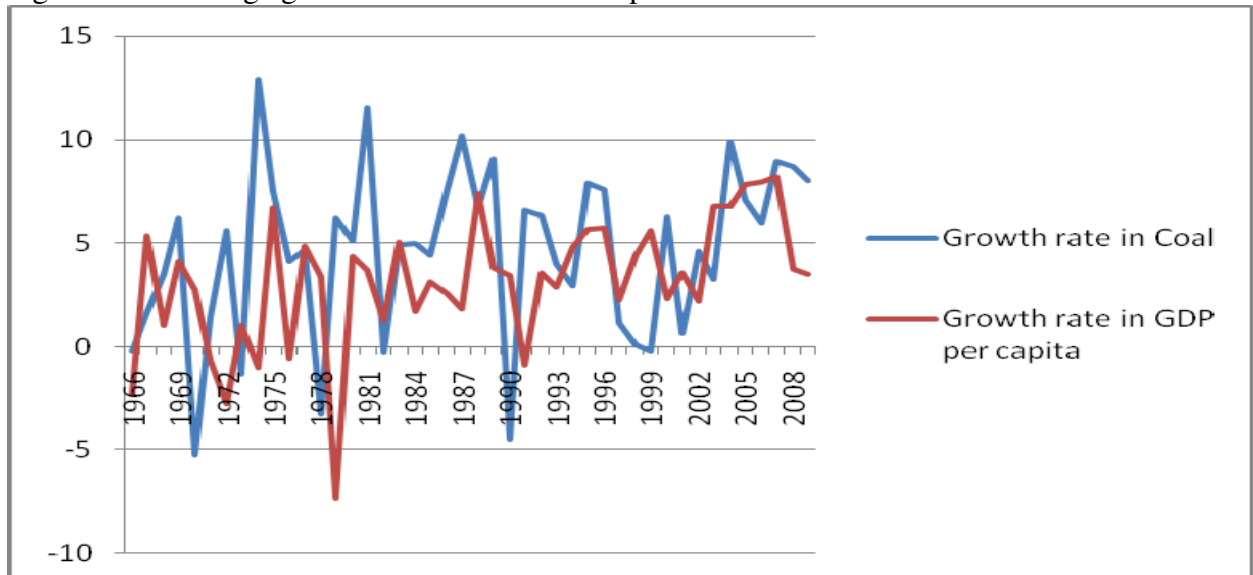


Figure-2: Percentage growth rate in coal consumption and GDP



With this background we set objective to test the Environmental Kuznets Curve hypothesis (EKC) in augmented equation framework. According to the EKC hypothesis environmental degradation increases at initial level of economic growth and then starts to decrease at a higher level of economic growth. Hence, the relationship between measure of environmental degradation, (in our case it is CO₂ emissions) and measures of economic growth (in our case it is measured by real GDP per capita) is the inverted-U

shaped curve. The objective of present study is to investigate the EKC for the Indian economy over the period of 1966-2009. In addition, we also include coal consumption and trade openness.

The rest of the paper consists of: Section II reviews a selected literature encompassing the EKC and the variables listed above, Section III has the theoretical and the econometric model including the ARDL estimation strategy. The empirical results are reported in section IV followed by the conclusion and policy implications.

II. Literature Review

There has been increasing attention on the impact of economic growth on environment since the last few decades of the previous century. The pioneering attempt in this area was made in the early 1990s by a paper of Grossmann and Krueger [2, 3] which investigated the environmental impacts of the North American Free Trade Agreement. The study postulated, estimated and ascertained an inverted-U shaped relationship between measures of several pollutants and per capita GDP which was, contemporaneously, confirmed by Shafik and Bandyopadhyay [4] and Panayotou [5]. Theoretically, the EKC does not only depend on levels of per capita GDP, but a series of factors causing changes in economic growth that can affect environment. In general, economists analyze mechanisms behind the EKC by examining scale effect, structural effect and technique effect (Song et al. [6]). However, few scholars (for example, Panayotou [5]) believe that EKC is caused by up-gradation from the adjustment of economic structure. According to the structural effect hypothesis (Stern, [7]) economic

development passes through the various states starting from preliminary, rapid-development and high-grade, industrial structure first upgrades from agriculture to a high-pollution industry, finally turns to information concentrated industry, which leads to the improvements in environmental quality. However, as Stokey [8] pointed out, due to the technique effect economic growth can break through one threshold point after arriving at a certain stage of economic development. Hence, at a low income level, only the high pollution technique can be used, but once leaping over the threshold point of economic development, cleaner technologies can be adopted which lowers the degradation in the environmental quality. Further, some scholars attribute the demand factors to the cause of EKC (for example, Lopez, [9]), which asserts that demand for a clean environment will be increased over the per capita income. Giving the importance of scale effect, Andreoni and Levinson [10] suggested that in the static model of single department, the EKC can be derived technically, only if pollution control is increasing in scale.

Further, Suri and Chapman [11] bring the contribution of industrial products of the imports and exports to industrial products of national production into the analytical framework of the EKC. That is to say, the low emissions correspond to the growth of industrial products of the imports, while the high emissions correspond to that of the exports. This implies that there is a strong relationship between trade and environmental quality, so the evolution of environmental quality can be predicted effectively. The empirical studies of EKC started by Grossman and Krueger [2] and followed by Lucas et al. [12], Wyckoff and Roop [13], Suri and Chapman [11], Heil and Selden [14](1999),

Friedl and Getzner [15], Stern [7], Nohman and Antrobus [16], Dinda and Coondoo [17] and Coondoo and Dinda [18] but presented mixed empirical evidence on the validity of EKC. Song et al. [6], Dhakal [19], Jalil and Mahmud [20] and, Zhang and Cheng [21] supported the existence of EKC in China. The findings of Fodha and Zaghoud [22] revealed the existence of EKC between the SO₂ emissions and economic growth but not for the CO₂ emissions in Tunisia. In contrast, Akbostanci et al. [23] did not support the existence of EKC in Turkey. They argued that CO₂ emissions are automatically reduced due to the rapid pace of economic growth.

Recent literature documented alliance of economic growth with energy consumption and environmental pollution to investigate the validity of EKC. The relationship between economic growth, energy consumption and CO₂ emissions have also been researched extensively both in the country case and panel studies. For example, Ang [24] found stable long run relationship between economic growth, energy consumption and CO₂ emissions for French economy while Ang [25] also got similar result for Malaysia. Ang [24] showed that causality is running from economic growth to energy consumption and CO₂ emissions in the long run but energy consumption Granger-causes economic growth in short run. In the case of Malaysia, Ang [25] reported that output increases CO₂ emissions and energy consumption. Ghosh [26] documented that no long run causality between economic growth and CO₂ emissions and in short run bidirectional causality exists in India.

For the panel studies, Apergis and Payne [27] investigated this relationship for six Central American economies using panel VECM. It is evident that energy consumption is positively linked with CO₂ emissions and EKC hypothesis has been confirmed. Lean and Smyth [28] and Apergis and Payne [29] reached the same conclusion for the case of ASEAN countries and Commonwealth of Independent States respectively. Narayan and Narayan's [30] empirical evidence also validates the EKC hypothesis for 43 low income countries. In addition, Lean and Smyth [28] noted a long run causality running from energy consumption and CO₂ emissions to economic growth but in the short span of time, energy consumption Granger causes CO₂ emissions. On the other hand, Apergis and Payne [29] found that energy consumption and economic growth Granger causes CO₂ emissions while bidirectional causality is found between energy consumption and economic growth; and between energy consumption and CO₂ emissions. Chen [31] explored this issue to Chinese provinces and documented that industrial sector's development is linked with increase of CO₂ emissions due to energy consumption. Similarly, Shiyi [32] investigated the relationship between industrial sector's development and CO₂ emissions using Chinese provincial data and concluded that industrial development increases CO₂ emissions. Pao and Tsai [33], Ozturk and Acaravci [34] and, Acaravci and Ozturk [35] also validated the existence of the EKC in case of BRIC, Turkey and Demark and Italy respectively. In case of Pakistan, Nasir and Rehman [36] and, Shahbaz et al. [37] reported that the EKC exists while a rise in economic growth and energy consumption is linked with an increase in energy pollutants. Iwata [38] investigated the empirical existence of the EKC in 28 countries adding Pakistan.

They corroborated the existence of the EKC by nuclear energy consumption taking into account.

The relationship between trade openness and environmental degradation has also been investigated empirically. Grossman and Krueger [2]) argued that environmental effect of international trade depends on the policies of an economy. There are two schools of thought about the impact of international trade on CO₂ emissions. One argued that trade openness provides an offer to each country to have access to international market which enhances the market share among countries. This leads the competition among the countries and increases the efficiency of using scarce resources and encourages importing cleaner technologies to decline CO₂ emissions (e.g. Runge, [39] and Helpman, [40]). Other group probed that natural resources are depleted due to international trade. This depletion of natural resources raises CO₂ emissions and causes environment quality worsened (e.g. Schmalensee et al. [41]; Copeland and Taylor, [42]; Chaudhuri and Pfaff, [43]). In country case studies, Machado [44] indicated positive link between foreign trade and CO₂ emissions in Brazil. Mongelli et al. [45] concluded that pollution haven hypothesis is existed in Italy. Halicioglu [46] added trade openness to explore the relationship between economic growth, CO₂ emissions and energy consumption for Turkey. The result showed that trade openness is one of main contributor to economic growth while income raises the levels of CO₂ emissions. Finally, Jayanthakumaran et al. [47] probed the relationship between economic growth, energy consumption, trade openness and CO₂ emissions in case of India and China. Their empirical evidence confirmed the validation of EKC in both countries.

III. Modeling, Empirical Strategy and Data Collection

The dynamic relationship between income, coal consumption and CO₂ emissions is investigated by including trade openness as potential determinant to CO₂ emissions. For this purpose, we followed the empirical model applied by Ang, [25, 26] for France and Malaysia, Soytas et al. [48] for United States, Jalil and Mahmud, [20] for China, Halicioglu, [46] for Turkey, and Shahbaz et al. [37] for Pakistan. We use coal consumption as an indicator of energy rather than energy consumption. More than 50 per cent energy demand in India is fulfilled from coal consumption. Following Shahbaz et al. [37], we converted all the series into natural logarithms to obtain efficient and consistent results. The relation is specified as follows:

$$CO_{2,t} = f(Y_t, Y_t^2, C_t, TR_t) \quad (1)$$

In the log-linear form the specification is written as:

$$\ln CO_{2,t} = \phi_1 + \phi_2 \ln Y_t + \phi_3 \ln Y_t^2 + \phi_4 \ln C_t + \phi_5 \ln TR_t + \mu_t \quad (2)$$

where, CO₂ denotes carbon emissions per capita (in kt); C is coal consumption per capita; Y and (Y²) mentions real GDP per capita and its square respectively. TR is trade openness [(exports + imports)/ GDP] per capita μ is a random error term. Following the EKC hypothesis we expect that $\phi_2 > 0$ and $\phi_3 < 0$. The use of coal is detrimental for environment and it is expected that $\phi_4 > 0$. The impact of trade openness on CO₂

emissions can be positive or negative. This implies that $\phi_3 < 0$ if government enforces environmental laws, and makes possibility to import of environment friendly capital and technology to be used in production process. But Grossman and Krueger [2, 3] argued that if emissions might be generated due to relocation of polluting industries from developed economies, a practice known in the literature as the ‘safe-haven hypotheses’ the $\phi_3 > 0$.

We applied more recent unit root test developed Narayan and Poop’s [49] to attain efficient and consistent empirical evidence about the integrating order of the variables. This test allows to information about two structural breaks stemming in the series which is based on two regression equations of the form as follows:

$$y_t^{M1} = \rho y_{t-1} + \alpha_1 + \beta^* t + \theta_1 D(T'_B)_{1,t} + \theta_2 D(T'_B)_{2,t} + \delta_1 DU'_{1,t-1} + \delta_2 DU'_{2,t-1} + \sum_{j=1}^k \beta_j \Delta y_{t-j} + e_t \quad (3)$$

$$y_t^{M2} = \rho y_{t-1} + \alpha^* + \beta^* t + \kappa_1 D(T'_B)_{1,t} + \kappa_2 D(T'_B)_{2,t} + \delta_1^* DU'_{1,t-1} + \delta_2^* DU'_{2,t-1} + \gamma_1^* DT'_{1,t-1} + \gamma_2^* DT'_{2,t-1} + \sum_{j=1}^k \beta_j \Delta y_{t-j} + e_t \quad (4)$$

where e_t is a white noise process, such that $e_t \sim NIID(0, \sigma^2)$,

$D(T'_B)_{i,t} = 1(t = T'_{B,i} + 1), i = 1, 2$, $DU'_{i,t} = 1(t > T'_{B,i})$, $DT'_{i,t} = 1(t > T'_{B,i})(t - DT'_{B,i})$, $T'_{B,i}$, $i = 1, 2$,

denote the true break dates. Equation (3) and (4) are IO-type test regression for M1 and M2 respectively. The unit root null hypothesis of $\rho = 1$ is tested against the alternative

hypothesis of $\rho < 1$ by using we use the t -statistics of $\hat{\rho}$. Since it is assumed that true break dates are unknown, $T'_{B,i}$ in equations (3) and (4) has to be substituted by their estimates $\hat{T}_{B,i}$, $i = 1, 2$, in order to conduct the unit root test. We used a sequential procedure following Narayan and Poop [49] to attain $\hat{T}_{B,i}$, $i = 1, 2$.

We apply autoregressive distributed lag model or ARDL bounds testing approach to cointegration. The ARDL bounds testing approach to cointegration is preferred due to its certain advantages. For example, the ARDL bounds testing is flexible regarding the integrating order of the variables whether variables are found to be stationary at I(1) or I(0) or I(1) / I(0)¹. The Monte Carlo investigation shows that this approach is superior and provides consistent results for small sample (Pesaran and Shin, [50]). Moreover, a dynamic unrestricted error correction model (UECM) can be derived from the ARDL bounds testing through a simple linear transformation. The UECM integrates the short run dynamics with the long run equilibrium without losing any information for long run. The empirical formulation of ARDL bounds testing approach to cointegration is given below:

$$\begin{aligned} \Delta \ln CO_t^2 = & \alpha_1 + \alpha_T T + \alpha_{CO^2} \ln CO_{t-1}^2 + \alpha_Y \ln Y_{t-1} + \alpha_{Y^2} \ln Y_{t-1}^2 + \alpha_C \ln C_{t-1} + \alpha_{TR} \ln TR_{t-1} + \sum_{i=1}^p \alpha_i \Delta \ln CO_{t-1}^2 \\ & + \sum_{j=0}^q \alpha_j \Delta \ln Y_{t-j} + \sum_{k=0}^r \alpha_k \Delta \ln Y_{t-1}^2 + \sum_{l=0}^s \alpha_l \Delta \ln C_{t-l} + \sum_{m=0}^t \alpha_m \Delta \ln TR_{t-m} + \mu_t \end{aligned} \quad (5)$$

¹ The ARDL approach to cointegration is applicable if variables are integrated at I(1) or I(0) or I(1) / I(0).

$$\begin{aligned} \Delta \ln Y_t = & \alpha_1 + \alpha_T T + \alpha_{CO^2} \ln CO_{t-1}^2 + \alpha_Y \ln Y_{t-1} + \alpha_{Y^2} \ln Y_{t-1}^2 + \alpha_C \ln C_{t-1} + \alpha_{TR} \ln TR_{t-1} + \sum_{i=1}^p \beta_i \Delta \ln Y_{t-i} \\ & + \sum_{j=0}^q \beta_j \Delta \ln CO_{t-1}^2 + \sum_{k=0}^r \beta_k \Delta \ln Y_{t-k} + \sum_{l=0}^s \beta_l \Delta \ln C_{t-l} + \sum_{m=0}^t \beta_m \Delta \ln TR_{t-m} + \mu_t \end{aligned} \quad (6)$$

$$\begin{aligned} \Delta \ln Y_t^2 = & \alpha_1 + \alpha_T T + \alpha_{CO^2} \ln CO_{t-1}^2 + \alpha_Y \ln Y_{t-1} + \alpha_{Y^2} \ln Y_{t-1}^2 + \alpha_C \ln C_{t-1} + \alpha_{TR} \ln TR_{t-1} + \sum_{i=1}^p \beta_i \Delta \ln Y_{t-1}^2 \\ & + \sum_{j=0}^q \beta_j \Delta \ln CO_{t-1}^2 + \sum_{k=0}^r \beta_k \Delta \ln Y_{t-k} + \sum_{l=0}^s \beta_l \Delta \ln C_{t-l} + \sum_{m=0}^t \beta_m \Delta \ln TR_{t-m} + \mu_t \end{aligned} \quad (7)$$

$$\begin{aligned} \Delta \ln C_t = & \alpha_1 + \alpha_T T + \alpha_{CO^2} \ln CO_{t-1}^2 + \alpha_Y \ln Y_{t-1} + \alpha_{Y^2} \ln Y_{t-1}^2 + \alpha_C \ln C_{t-1} + \alpha_{TR} \ln TR_{t-1} + \sum_{i=1}^p \mathcal{G}_i \Delta \ln C_{t-i} \\ & + \sum_{j=0}^q \mathcal{G}_j \Delta \ln CO_{t-1}^2 + \sum_{k=0}^r \mathcal{G}_k \Delta \ln Y_{t-k} + \sum_{l=0}^s \mathcal{G}_l \Delta \ln Y_{t-1}^2 + \sum_{m=0}^t \mathcal{G}_m \Delta \ln TR_{t-m} + \mu_t \end{aligned} \quad (8)$$

$$\begin{aligned} \Delta \ln TR_t = & \alpha_1 + \alpha_T T + \alpha_{CO^2} \ln CO_{t-1}^2 + \alpha_Y \ln Y_{t-1} + \alpha_{Y^2} \ln Y_{t-1}^2 + \alpha_C \ln C_{t-1} + \alpha_{TR} \ln TR_{t-1} + \sum_{i=1}^p \rho_i \Delta \ln TR_{t-i} \\ & + \sum_{j=0}^q \rho_j \Delta \ln CO_{t-1}^2 + \sum_{k=0}^r \rho_k \Delta \ln Y_{t-k} + \sum_{l=0}^s \rho_l \Delta \ln Y_{t-1}^2 + \sum_{m=0}^t \rho_m \Delta \ln C_{t-m} + \mu_t \end{aligned} \quad (9)$$

Here, to test for the existence of cointegration calculated F-statistic is used to compare with critical bounds generated by Pesaran et al. [51]. Two critical bounds namely upper critical bound (UCB) and lower critical bound (LCB) have been developed by Pesaran et al. [51]. In our specification of equations 5-9, the null hypothesis which is tested is

$$H_0 : \alpha_{CO^2} = \alpha_Y = \alpha_{Y^2} = \alpha_C = \alpha_{TR} = 0 \quad \text{against} \quad \text{alternate} \quad \text{hypothesis}$$

$H_0 : \alpha_{CO^2} \neq \alpha_Y \neq \alpha_{Y^2} \neq \alpha_C \neq \alpha_{TR} \neq 0$ to test for cointegration. The F-test is non-standard and we may use the LCB and UCB developed by Pesaran et al. [51]². If computed F-statistic is more than upper critical bound (UCB), there is cointegration between the variables. If computed F-statistic does not exceed the lower critical bound (LCB), there is

² Pesaran et al. [51] have computed two asymptotic critical values - one when the variables are assumed to be $I(0)$ and the other when the variables are assumed to be $I(1)$.

no cointegration relationship and if computed F-statistic falls between lower and upper critical bounds then decision regarding cointegration between the variables remains uncertain³. However, the critical bounds generated by Pesaran et al. [51] may not be appropriate for small sample like ours case with 45 observations hence, we used critical bounds developed by Narayan [52]. Further, we have conducted the stability tests to examine the stability of ARDL bounds testing estimates by utilizing CUSUM and CUSUMSQ test of (Brown et al., [53]).

After confirming the evidence of cointegration and cointegration is stable we moved ahead for testing the causal relationship between the test variables in the framework of vector error correction method (VECM). The VECM in five variables case can be written as follows:

$$\Delta \ln CO_t^2 = \alpha_{01} + \sum_{i=1}^l \alpha_{11i} \Delta \ln CO_{t-1}^2 + \sum_{j=1}^m \alpha_{22j} \Delta \ln Y_{t-j} + \sum_{k=1}^n \alpha_{33k} \Delta \ln Y_{t-1}^2 + \sum_{r=1}^o \alpha_{44r} \Delta \ln C_{t-r} + \sum_{s=1}^p \alpha_{55s} \Delta \ln TR_{t-s} \quad (10)$$

$$+ \eta_1 ECT_{t-1} + \mu_{1i}$$

$$\Delta \ln Y = \beta_{01} + \sum_{i=1}^l \beta_{11i} \Delta \ln Y_{t-i} + \sum_{j=1}^m \beta_{22j} \Delta \ln CO_{t-1}^2 + \sum_{k=1}^n \beta_{33k} \Delta \ln Y_{t-1}^2 + \sum_{r=1}^o \beta_{44r} \Delta \ln C_{t-r} + \sum_{s=1}^p \beta_{55s} \Delta \ln TR_{t-1} \quad (11)$$

$$+ \eta_2 ECT_{t-1} + \mu_{2i}$$

$$\Delta \ln Y_t^2 = \phi_{01} + \sum_{i=1}^l \phi_{11i} \Delta \ln Y_{t-1}^2 + \sum_{j=1}^m \phi_{22j} \Delta \ln CO_{t-1}^2 + \sum_{k=1}^n \phi_{33k} \Delta \ln Y_{t-k} + \sum_{r=1}^o \phi_{44r} \Delta \ln C_{t-1} + \sum_{s=1}^p \phi_{55s} \Delta \ln TR_{t-1} \quad (12)$$

$$+ \eta_3 ECT_{t-1} + \mu_{3i}$$

³ In such case, error correction method is appropriate method to investigate the cointegration (Bannerjee et al. [54]). This indicates that error correction term will be a useful way of establishing cointegration between the variables.

$$\Delta \ln C_t = \varphi_{01} + \sum_{i=1}^l \varphi_{11} \Delta \ln C_{t-i} + \sum_{j=1}^m \varphi_{22} \Delta \ln CO_{t-1}^2 + \sum_{k=1}^n \varphi_{33} \Delta \ln Y_t + \sum_{r=1}^o \varphi_{44} \Delta \ln Y_{t-1}^2 + \sum_{s=1}^p \varphi_{55} \Delta \ln TR_{t-1} + \eta_4 ECT_{t-1} + \mu_{4i} \quad (13)$$

$$\Delta \ln TR_t = \delta_{01} + \sum_{i=1}^l \delta_{11} \Delta \ln TR_{t-i} + \sum_{j=1}^m \delta_{22} \Delta \ln CO_{t-1}^2 + \sum_{k=1}^n \delta_{33} \Delta \ln Y_{t-k} + \sum_{r=1}^o \delta_{44} \Delta \ln Y_{t-1}^2 + \sum_{s=1}^p \delta_{55} \Delta \ln C_{t-1} + \eta_4 ECT_{t-1} + \mu_{4i} \quad (14)$$

where u_{it} are white noise residual terms. The estimates of ECT_{t-1} also shows the speed of convergence from short run towards long run equilibrium path in all models depending upon the sign of the coefficient of ECT_{t-1} term. The usefulness of VECM lies in distinguishing between short-and-long runs causal relationships in one hand and detecting causality in long-run, short-run and joint i.e. short-and-long runs on the other. The significance of ECT_{t-1} can be tested using t-statistic which confirms the long-run causal relationship whereas the short run causality is detected by the joint χ^2 statistical significance of the estimates of first difference lagged independent variables. In the final step we used Wald-test to test the joint significance of estimates of the lagged terms of independent variables and error correction term which confirms the existence of short-and-long run causality relations (Shahbaz et al. [55]) and known as measure of strong Granger-causality (Oh and Lee, [56]).

The data on these variables has been collected from world development indicators (CD-ROM, 2011). Further, world development indicators has been used to collect data on real GDP per capita, coal consumption per capita, real trade (real imports per capita + real

exports per capita) per capita and CO₂ emissions per capita. The study covers the period of 1966-2009.

IV. Empirical Results and Discussions

We have applied ARDL bounds testing approach to cointegration to find long run relationship between economic growth, coal consumption, trade openness and CO₂ emissions in case of India. Although bounds testing approach is flexible regarding the integrating order of the variables. We can apply it, if the variables are integrated at I(0), I(1) or I(0)/I(1). We cannot compute ARDL F-statistics for long run relationship if any variable is found to be stationary at I(2). To ensure that none of the variables is stationary at I(2) or beyond that order of integration, we applied Ng-Perron [57] unit root test. The results are reported in Table-1. This empirical evidence indicates that all the series have unit root problem at their level form but found to be stationary at 1st difference. This shows that all the variables have I(1) order of integration. The empirical evidence provided by Ng-Perron may be biased because it does not have information about structural break stemming in the series.

To solve this issue, we applied unit root test with two structural breaks developed by Narayan and Popp [49]. The inappropriate chose of structural breaks may reject null hypothesis and provide inconclusive results. The technique used in N-P unit root test allows in determining two structural breaks in the level and trend of the series endogenously. The unit root test developed by Narayan and Popp [49] indicates two structural breaks efficiently as compared to other structural break unit root tests. Table-2

reported the results by Narayan and Popp [49] unit root test. Our empirical exercise reveals that all the variables are found to be non-stationary at level but integrated at 1st difference. This confirms that all the variables are integrated at I(1) and robust⁴.

Table-1: Ng-Perron Unit Root Test

Level				
Variables	MZa	MZt	MSB	MPT
$\ln CO_{2t}$	-9.8577	-2.2095	0.2241	9.2910
$\ln Y_t$	-8.9336	-1.8632	0.2085	11.0896
$\ln Y_t^2$	1.2003	0.6869	0.5722	85.0399
$\ln C_t$	-4.1594	-1.1484	0.2761	19.0857
$\ln TR_t$	-4.8699	-1.4368	0.2950	18.0242
1st Difference				
$\ln CO_{2t}$	-24.7353*	-3.5163	0.1421	3.6862
$\ln Y_t$	-19.2482**	-3.1020	0.1611	4.7358
$\ln Y_t^2$	-23.9443*	-3.4600	0.1445	3.8058
$\ln C_t$	-21.5425**	-3.2815	0.1523	4.2324
$\ln TR_t$	-22.4313*	-3.3472	0.1492	4.0729
Note: * and ** indicate the significance at the 1% and 5% levels.				

⁴ The results of N-P at 1st difference are not provided here due lack of space and are available from authors upon request.

Table-2: Narayan and Popp [49] Structural Break Unit Root Test

Variable	Model 1(M1)			Model 2(M2)		
	T-statistic	TB1	TB2	T-statistic	TB1	TB2
$\ln CO_{2t}$	-4.0378	1976	2000	-4.3381	1976	2000
$\ln Y_t$	0.7720	1974	1978	0.4483	1974	1978
$\ln Y_t^2$	1.0668	1974	1978	0.7999	1974	1978
$\ln C_t$	-1.1955	1973	1989	-1.6512	1977	1989
$\ln TR_t$	-3.0225	1974	1981	-5.3848	1984	1994
Note: Model-1 assumes two breaks in level and Model-2 assumes two breaks in level as well as slope.						

Our empirical evidence confirms that all the variables are stationary at 1st difference form that intends to apply ARDL bounds approach in examining the long run relationship between the series. It is prerequisite to choose appropriate lag length of the variables to capture the dynamic relationship between the variables. The statistics of F-test are very much elusive with the selection of lag order of the variables. Inappropriate lag length selection provides biased results and in resulting, decision about cointegration is worthless (Lütkepohl, [58]). We have used AIC and SBC criterion to choose lag order but our decision is based minimum value of AIC. Lütkepohl, [58] suggested that lag order selected by AIC provides efficient and consistent results. The reason is that AIC has superior properties and high explaining power as compared to SBC. Our empirical

evidence shows that we cannot take lag more than 2 because data sample consists of 45 years. We have used yearly data over the period of 1966-2009 of Indian economy⁵.

After choosing lag order, next step is to compare our computed F-statistics with lower and upper critical bounds generated by Narayan [52]. The results show that our calculated F-statistics exceed upper critical bounds at 5 per cent and 10 per cent levels respectively, once, CO₂ emissions per capita, real GDP per capita (squared of real GDP per capita) and coal consumption per capita treated as respond variables. The results are reported in Table-4.

Table-4: Results of ARDL Cointegration Test

Variable	$\ln CO_{2t}$	$\ln Y_t$	$\ln Y_t^2$	$\ln C_t$	$\ln TR_t$
F-statistics	8.9129**	7.1597***	7.1578***	7.4063***	5.3858
Critical values [#]	1 per cent level	5 per cent level	10 percent level ⁶		
Lower bounds	10.150	7.135	5.950		
Upper bounds	11.130	7.980	6.680		
Diagnostic tests					
R^2	0.8325	0.9994	0.9995	0.6249	0.8018
$Adj - R^2$	0.6802	0.9990	0.9991	0.3796	0.6037
Durbin-Watson	1.6951	2.2267	2.2155	2.0707	2.3233
Note: ** and *** show the significance at 5% and 10% level respectively.					

⁵ Results of lag length selection are available from authors upon request

⁶ Critical values bounds are from Narayan [52] with unrestricted intercept and unrestricted trend.

This implies that three cointegrating vectors are found recommending the long run relationship between coal consumption, economic growth, trade openness and CO₂ emissions in case of India over the study period of 1966-2009.

The robustness of long run results established by ARDL bounds testing approach to cointegration is tested by applying Johansen multivariate cointegration approach. The results reported in Table-5 confirm that there are two cointegrating vectors at 1 per cent level of significance indicated both by Trace statistic and Maximum Eigen values. This corroborates the long run relationship between coal consumption, economic growth, trade openness and CO₂ emissions in case of India over the study period of 1966-2009.

Table-5: Results of Johansen Cointegration Test

Hypothesis	Trace Statistic	Maximum Eigen Value
$R = 0$	105.8022*	46.7978*
$R \leq 1$	59.0044*	32.3417**
$R \leq 2$	26.6626	17.6688
$R \leq 3$	8.9938	8.6642
$R \leq 4$	0.3295	0.3295
Note: * and ** show significant at 1% & 5% level respectively.		

After investigating the robustness of long run relationship between these variables, the long run marginal impacts of coal consumption, economic growth, trade openness on CO₂ emissions in case of India is investigated by applying OLS approach. The results reported in Table-6 postulated that coal consumption is major contributor to energy pollutants and it is statistically significant at 1 per cent level of significance. A 1 per cent rise in CO₂ emissions is associated with 0.8436 per cent consumption of coal. These findings support to the view by Wolde-Rufael [59] that coal consumption highly contributes to energy pollutants as compared to other indicators of energy. Jayanthakumaran et al. [47] also nominated that India meets 55 per cent of energy demand through coal consumption and produces 5 per cent of CO₂ emissions of the world⁷. Furthermore, Jayanthakumaran et al. [47] reported that in total energy emissions 86 per cent is contributed by coal consumption in case of India and same inference drawn by Alam et al. [60]⁸.

The impact of trade openness on energy emissions is positive and significant at 5 per cent level. All else is same, a 1 per cent expansion in trade openness leads to upsurge in energy emissions by 0.0862 per cent. This finding is consistent with Jayanthakumaran et al. [47] also reported positive effect of international trade on CO₂ emissions but it is statistically insignificant. In regional studies, Halicioglu [46] reported that international trade increases energy emissions by raising economic growth and same inference is drawn by Nasir and Rehman [36] in case of Turkey and Pakistan respectively. On contrary, Shahbaz et al. [37] noted that trade openness improves the environmental

⁷ Other sources of energy such as crude oil, natural gas and petroleum products are used to meet the rest 45 per cent energy demand.

⁸ Alam et al. [60] used total primary consumption as an indicator of energy.

quality by enhancing the capacity of country to implement advanced technology to increase domestic production.

Table-6: Long-and-Short Run Analysis

Dependent Variable = $\ln CO_{2t}$			
Long Run Results			
Variable	Coefficient	Std. Error	T-Statistic
Constant	-50.2450	4.7539	-10.5692*
$\ln Y_t$	10.0674	0.8740	11.5182*
$\ln Y_t^2$	-0.4942	0.0410	-12.0467*
$\ln C_t$	0.8436	0.0999	8.43771*
$\ln T_t$	0.0862	0.0415	2.07734**
Short Run Results			
Constant	0.0282	0.0055	5.0598*
$\ln Y_t$	4.9768	1.6149	3.0816*
$\ln Y_t^2$	-0.2392	0.0807	-2.9622*
$\ln C_t$	0.4481	0.0948	4.7244*
$\ln T_t$	-0.1090	0.0453	-2.4035**
ECM_{t-1}	-0.2994	0.0948	-3.1574*
Diagnostic Tests			
Test	F-statistic	Prob. value	

χ^2 <i>NORMAL</i>	0.8323	0.6595	
χ^2 <i>SERIAL</i>	1.9906	0.1548	
χ^2 <i>ARCH</i>	0.0150	0.9030	
χ^2 <i>WHITE</i>	0.7055	0.7110	
χ^2 <i>REMSAY</i>	2.3963	0.1321	

Note: * and ** denote the significant at 1% and 5% level respectively.

The impact of linear and nonlinear terms of real GDP per capita is positive and negative. The coefficients of linear and nonlinear terms are 10.0674 and -0.4942 and it is statistically significant at 1 per cent level of significance respectively. The significance of both linear and non-linear terms of real GDP per capita provides the empirical evidence of inverted-U shaped relationship between economic growth and CO₂ emissions “so called environmental Kuznets curve” (EKC). The empirical exercise revealed that a 10.0674 per cent energy emissions are linked with 1 per cent increase in GDP per capita and inverse effect of squared term of real GDP per capita shows the delinking point of CO₂ emissions i.e. -0.4942 and real GDP per capita, once an economy achieves higher level of income. This empirical evidence provides the support for EKC revealing that CO₂ emissions increase at the initial stage of economic growth and decline after a threshold point i.e. Ind. Rupee 28131 (US\$ 531). These results are with existing literature such as He [61], Song et al. [6], Jalil and Mahmud [20], Fodha and Zaghoud [22] and Jayanthakumaran et al. [47] for China and India, Halicioglu [46] for Turkey, Lean and Smyth [28] for ASEAN countries, Nasir and Rehman [36] and Shahbaz et al. [37] for Pakistan.

The short run dynamics are also reported in lower segment of Table-6 and the results indicated that coal consumption is also main contributor to CO₂ emissions and it is statistically significant at 1 per cent level. Interestingly, international trade reduces energy emissions significantly at 5 per cent significance level. The coefficients of linear term of real GDP per capita and nonlinear i.e. squared term of real GDP per capita are positive and negative respectively. These estimates are significant at 1 per cent significance level. This further confirms existence of ECK which corroborates the long run ECK in case of India. The short run estimates are less than long run estimates which indicates the reliability and stability of estimated results.

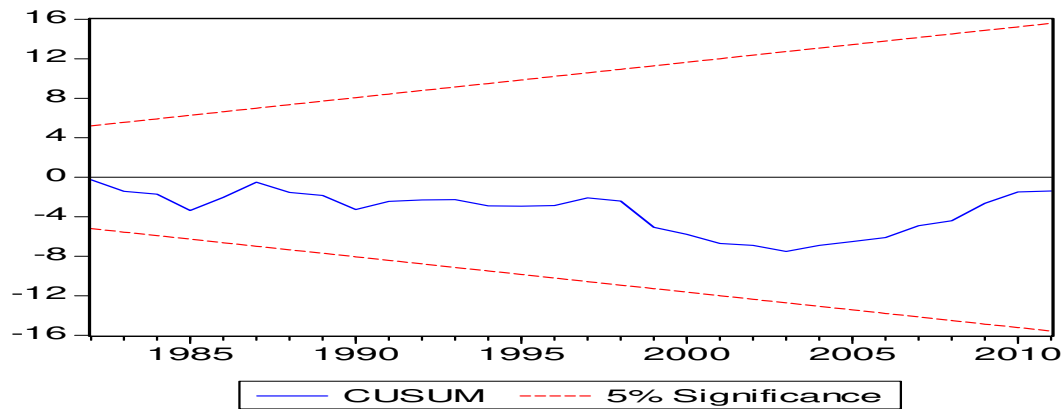
The estimated coefficient of the lagged ECM term is -0.2994 and significant at the 1% level. This establishes long run relationship among the running variables. This suggests that changes in CO₂ emissions from the short run to the long run are corrected by 29.94 per cent each year. The significance of lagged error correction term further confirms our established long run relationship between coal consumption, economic growth, trade openness and CO₂ emissions.

The diagnostics tests such as LM test for serial correlation, normality of residual term and white heteroscedasticity test for short run model are reported in Table-6. The findings suggest that the short-run model pass all diagnostic tests successfully. The evidence indicates that error term is normally distributed and there is an absence of serial correlation. There is no evidence of autoregressive conditional heteroscedasticity and

same inference for white heteroscedasticity. The short run model has passed Ramsay reset test which confirms that the functional form of short run model is correctly specified.

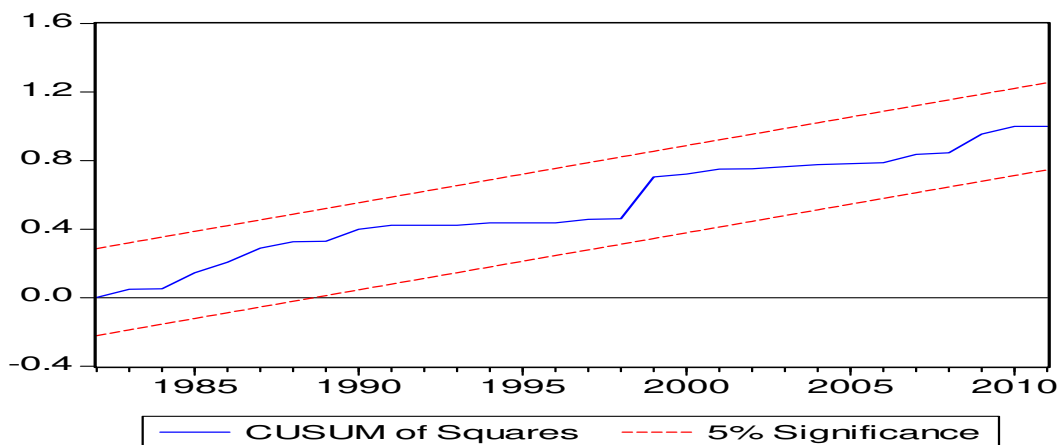
It is suggested by Browns et al. [53] that stability of long run and short run parameters can be tested by applying CUSUM and CUSUMsq tests. In doing so, the cumulative sum (CUSUM) and cumulative sum of squares (CUSUMsq) tests have been employed for parameter stability.

Figure-3: Plot of Cumulative Sum of Recursive Residuals



The straight lines represent critical bounds at 5% significance level.

Figure-4: Plot of Cumulative Sum of Squares of Recursive Residuals



The straight lines represent critical bounds at 5% significance level.

The results are shown in Figure 3 and 4. The graph should lie within the appropriate bounds if the parameters are stable (Pesaran et al. [51]). The graph of CUSUM at the 5% level and we can claim the stability of long-and-short runs parameters.

IV.I VECM Granger Causality Analysis

The presence of cointegration among the variables implies that causality relation must be existed at least from one side. The directional relationship between coal consumption, economic growth, international trade and CO₂ emissions will provide help in articulating comprehensive policy to economic growth by controlling environment from degradation and utilize energy efficient technologies importing from advanced countries. We applied Granger causality test within the VECM framework to detect the causality between the variables. Table-7 reports the results of VECM Granger causality analysis. The long run causality is captured by a significant t-test on a negative coefficient of the lagged error-correction term ECM_{t-1} . The jointly significant LR test on the lagged explanatory variables shows short-run causality.

Table-7: VECM Granger Causality Analysis

Dependent Variables	Direction of Causality										
	Short Run					Long Run	Joint (Long-and-short runs) Causality				
	$\ln CO_{2t}$	$\ln Y_t$	$\ln Y_t^2$	$\ln C_t$	$\ln T_t$	ECT_{t-1}	$\ln CO_{2t}, ECT_{t-1}$	$\ln Y_t, ECT_{t-1}$	$\ln Y_t^2, ECT_{t-1}$	$\ln C_t, ECT_{t-1}$	$\ln T_t, ECT_{t-1}$
$\ln CO_{2t}$	-- [0.0384]	3.6272** [0.0473]	3.3713** [0.0001]	12.8363* [0.0119]	5.1278** [-3.9339]	-0.4550* [0.0006]	--	7.5935* [0.0040]	6.9193* [0.0001]	9.3793* [0.0005]	7.8799*
$\ln Y_t$	4.6517** [0.0174]	--	8.1920* [0.0000]	1.5550 [0.2227]	6.1098* [0.0060]	-0.1632*** [-1.8427]	3.4984** [0.0274]	--	5.8590* [0.0019]	1.2920 [0.2952]	4.5041** [0.0101]
$\ln Y_t^2$	4.2919* [0.432]	8.4460* [0.0001]	--	0.9678 [0.3878]	5.8392* [0.0072]	-0.1535*** [-1.7716]	3.1922** [0.0377]	6.0750* [0.0045]	--	1.1602 [0.3412]	4.3125** [0.0121]
$\ln C_t$	12.5233* [0.0001]	0.5701 [0.5715]	0.5177 [0.6013]	--	2.7016* [0.0834]	-0.7704* [-4.2526]	10.0023* [0.0001]	6.5615* [0.0015]	6.6326* [0.0012]	--	7.2152* [0.0009]
$\ln T_t$	2.4178*** [0.1078]	4.6856** [0.0169]	4.5034** [0.0195]	1.0847 [0.3509]	--	--	--	--	--	--	--

Note: *, ** and *** show significant at 1%, 5% and 10% percent respectively.

In long run, our empirical evidence reports bidirectional causality relationship between income and CO₂ emissions. The feedback hypothesis exists between coal consumption and CO₂ emissions. Coal consumption and economic growth Granger cause each other. This finding is contradictory with Li and Li [62] who reported that coal consumption Granger causes economic growth while consistent with Paul and Bhattacharya [63] showed feedback between energy consumption and economic growth. This suggests that government should encourage energy exploration policies which in resulting spur economic growth and hence demand for energy. There is bidirectional causal relationship between economic growth and CO₂ emissions. These findings confirm our long run as well short run results that income has positive and negative effects on CO₂ emissions. This further validates the existence of environmental Kuznets curve (EKC). On contrary, Gosh [26] and Alam et al. [60] presented no causal relationship between income and CO₂ emissions. This shows the significance of our empirical evidence as we applied more specified economic model. Trade openness Granger causes economic growth, coal consumption and CO₂ emissions. This implies that trade openness stimulates economic activity and adds in energy demand (coal consumption) which emits CO₂ emissions.

In short run, bidirectional causality is found between economic growth and CO₂ emissions, coal consumption and CO₂ emissions, trade openness and CO₂ emissions. The findings indicated that the long run income elasticity for CO₂ emissions is less than the short run elasticity is further evidence for an EKC (See Narayan and Narayan, [30] for more). The feedback hypothesis also exists between trade and economic growth. The unidirectional causal relationship is found running from trade openness to coal

consumption and no causality exists between coal consumption and economic growth. The results of joint causality confirm the long-and-short runs findings.

V. Conclusion and Policy Implications

This paper investigated the dynamic linkages between coal consumption, economic growth, trade openness and CO₂ emissions in case of India over the period of 1966-2009. We have applied Ng-Perron [57] unit root test to test stationarity of the variables and Narayan and Pop [49] is accompanied to examine the robustness of empirical evidence. Further, ARDL bounds testing approach to cointegration has employed to investigated the long run relationship between the variables and Johansen multivariate cointegration is applied to test the strength of long run results. The present study has important policy implications for Indian economy. The empirical evidence of strong relationship between coal consumption and economic growth indicates that sustained level of economic growth can be achieved by exploring the new sources of energy supply for long span of time.

Our results confirmed that all the variables are cointegrated for long run relationship and long run results are robust. Coal consumption is main contributor to CO₂ emissions. A rise in economic growth raises demand for coal that emits energy pollutants. Trade openness is also positively linked with CO₂ emissions but in short run former declines later. Results also validated the existence of environmental Kuznets curve (EKC) in long run as well as in short run in case of India. The causality analysis explored the bidirectional causal relationship between economic growth and CO₂ emissions and

feedback hypothesis exists between coal consumption and CO₂ emissions. Coal consumption and economic growth Granger cause each other. Trade openness Granger causes economic growth, coal consumption and CO₂ emissions. Economic growth and CO₂ emissions granger cause trade openness in short run.

Hence, our results shows that dependence on the coal consumption as a factor that promotes economic growth might be feasible option for short run but in the long run we have to look for alternative of this. This is particularly because coal consumption increases CO₂ emissions and which indirectly have negative impact on the economic growth. The other interesting issues are the Granger-causal relationship between CO₂ emissions, trade openness, and coal consumption. Since trade openness is found to Granger-cause CO₂ emissions, we can suggest Indian policymakers on a few important points: (1) allowance of foreign investors to invest in the India particularly in know-how and advanced technologies (2) free entry of FDI because when FDI flows into a host country, FDI may transfer new ideas, technologies and managerial skills to domestic firms and which in turn expected to reduce CO₂ emissions (3) promotion of such activities through which foreign firms may provide continuous technological assistance, such as introduction of new technologies and training of workers, to the domestic firms which will lead to decrease in CO₂ emission in one hand and increase economic growth on the other. These processes are also expected to reduce dependence on the consumption of coal without harming the interest of higher economic growth.

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