# Estimation of Environmental Kuznets Curve for CO2 Emission: Role of Renewable Energy Generation in India

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# Estimation of Environmental Kuznets Curve for $CO_2$ Emission: Role of Renewable Energy Generation in India

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## Abstract

The existing literature on environmental Kuznets curve (EKC) is mainly focused on finding out the optimal sustainable path for any economy. Looking at the present renewable energy generation scenario in India, this study has made an attempt to estimate the EKC for $CO_2$ emission in India for the period of 1971-2015. Using unit root test with multiple structural breaks and autoregressive distributed lag (ARDL) approach to cointegration, this study has found the evidence of inverted U-shaped EKC for India, with the turnaround point at USD 2937.77. The renewable energy has found to have significant negative impact on $CO_2$ emissions, whereas for overall energy consumption, the long run elasticity is found to be higher than short run elasticity. Moreover, trade is negatively linked with carbon emissions. Based on the results, this study concludes with suitable policy prescriptions.

*Keywords*: India, $CO_2$ emission, EKC, ARDL, Renewable energy

## 1. Introduction

When an economy starts moving along the growth trajectory, then at the earliest stage of economic growth, environment deteriorates rapidly due to ambient air pollution, deforestation, soil and water contamination, and several other factors. With rise in the level of income, when economy starts to develop, the pace of deterioration slows down, and at a particular level of income, environmental degradation starts to come down and environmental quality improves. This hypothesized association between environmental degradation and income takes an inverted U-shaped form. This phenomenon is referred to as Environmental Kuznets Curve (EKC) hypothesis in the existing literature of environmental economics, named after Simon Kuznets [1], who described the inverted U-curve association between income inequality and stages of economic development. Grossman and Krueger [2] later found its resemblance with Kuznets' inverted U-curve relationship while establishing a relationship between pollution and economic growth in the context of North American Free Trade Agreement (NAFTA).

After Bharatiya Janata Party came into power, India has experienced a government-driven renewable energy generation impetus. As on 2015, India has 44,783.33 MW installed renewable energy generation capacity, and it is expected to reach 175,000.00 MW is 2022.[1] Across all the countries in the world, India is the first country in the world to set up a ministry for new and renewable energy, and it signifies the growth potential of renewable energy generation in India. Looking at the renewable energy generation perspective, India ranks 5th (after the US, China, Germany, and Spain). India needs to boost up the renewable energy sector, as environmental degradation due to air pollution is turning out to be a grave problem in India. By far, fossil fuel-based energy has been the major driver of economic growth in India, and in this process, a large amount of ambient air pollution is taking place. As far carbon dioxide ($CO_2$)

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[1] Ministry of New & Renewable Energy, Annual report, 2015-16

emission is considered, India ranks 3rd in the world (after China and the US). With the rise in economic growth, demand of energy is likely to rise in coming years, and this demand is both household and industrial. Therefore, from ecological perspective, India is a very critical context, where both environmental degradation problem and the policy level remedies are coexisting. Keeping up with this discussion, it is imperative to estimate a new EKC for $CO_2$ emissions in India and to investigate the role of renewable energy to be played in the newly found EKC.

In this study, we have analyzed the $CO_2$ emission data for India during 1971-2015. In EKC hypothesis, economic growth has been taken as the explanatory variable for environmental degradation, and economic growth has been parameterized in several ways in the existing literature. It has been primarily indicated as growth in per capita income and apart from income, this study has also taken trade volume and total factor productivity as two other explanatory variables. In order to investigate the possible impact of renewable energy generation on the nature of EKC for India, we have included renewable energy generation in our model.

In methodological terms, this study employs Autoregressive Distributed Lag (ARDL) bounds test on parameters validated by unit root tests with structural breaks. In most of the existing studies, this issue has been ignored and this study has tried to address this issue, before coming to a conclusion regarding the order of integration of the variables, which is a precursor of ARDL bounds test. Apart from this, the present study has also considered the methodological issues raised by Stern [3], while estimating the EKC in any context, e.g., serial dependence, stochastic trends in the time series, and omitted variable bias. Therefore, this study has a contribution in terms of methodological adaptation, as well.

The rest of the paper is distributed as per the following: section 2 describes the literature review, section 3 discusses the data and methodology, section 4 analyzes the results, and section 5 concludes the paper.

## 2. Literature review

The volume of literature on EKC hypothesis is quite extensive, starting with the seminal work of Grossman and Krueger [2]. In their work, they discovered an inverted U-shaped association between economic growth and environmental quality, while finding out the impact of North American Free Trade Agreement (NAFTA) on environment. Subsequent to this work, an extensive volume of empirical studies has been carried out on EKC estimation. Over the years, with the advancements in econometric tools and techniques, this hypothesis has been tested (a) for several pollutants and ecologically harmful substances, (b) from various perspectives and contexts, and (c) with numerous explanatory variables. Therefore, categorization of these studies can be done on the basis of the pollutants and contexts. As we are concerned about the EKC estimation of $CO_2$ emission in this study, we will try to limit our discussion around the studies on the EKC estimation for $CO_2$ emission only.

While studies on the EKC estimation for $CO_2$ emissions have largely focused on the fossil fuel energy consumption as an explanatory variable, the recent literature in energy economics has been advocating the incorporation of renewable energy consumption. One of the earliest EKC studies on $CO_2$ emissions to consider renewable energy consumption in the empirical framework was carried out by Richmond and Kaufmann [4]. The study was carried out for 36 countries over the period of 1973-1997, and the EKC was found to be inverted U-shaped, with the turnaround points between $29,687 and $110,599. Subsequent to this study, a number of studies started considering renewable energy consumption within the empirical framework of

EKC. Iwata et al. [5] carried out the EKC estimation study for 28 countries over the period of 1960-2003, and they have used mean group (MG), pooled mean group (PMG), and panel regression techniques for estimating the EKC. The results were different for the three estimation techniques: (a) using MG, no EKC was found, (b) using PMG, the EKC was found to be inverted U-shaped with the turnaround point at $77,126.73, and (c) using panel regression, the EKC was also found to be inverted U-shaped with the turnaround point at $141,682.59. Baek and Kim [6] estimated the EKC for Korea over the period of 1975-2006. Using the ARDL bounds test approach, they found the EKC to be inverted U-shaped with the turnaround point to be extremely large and outside the sample. Sulaiman et al. [7] have estimated the EKC for Malaysia over the period of 1980-2009. Using the ARDL bounds test approach, they found the EKC to be inverted U-shaped with the turnaround point to be at $8.77K. Bölük and Mert [8] estimated the EKC for 16 EU countries over the period of 1990-2008. Using panel regression technique, they found that the EKC to be monotonically increasing. Farhani and Shahbaz [9] have estimated the EKC for MENA countries over the period of 1980-2009. They have used fully modified OLS (FMOLS) and dynamic OLS (DOLS) techniques to estimate EKC, and they found the EKC to be inverted U-shaped, with the turnaround points between $34.03 and $377.55. Ben Jebli et al. [10] have estimated the EKC for 24 Sub-Saharan countries over the period of 1980-2010. They have used FMOLS to estimate EKC, and they found the EKC to be U-shaped, with the turnaround point at $244.65. Bölük and Mert [11] estimated the EKC for Turkey over the period of 1961-2010. Using the ARDL bounds test approach, they found the EKC to be inverted U-shaped with the turnaround point to be extremely large and outside the sample. Jebli and Youssef [12] estimated the EKC for Tunisia over the period of 1980-2009. They have used ARDL bounds test approach to estimate EKC, and they found the EKC to be U-shaped, with the turnaround points between

$2,878.6 and $3,259.37. Al-Mulali and Ozturk [13] estimated the EKC for 27 advanced economies over the period of 1990-2012. They have used FMOLS to estimate EKC, and they found the EKC to be inverted U-shaped, with the turnaround point to be extremely large and outside the sample. Dogan and Seker [14] estimated the EKC for 23 economies over the period of 1985-2011. They have used FMOLS and DOLS to estimate EKC, and they found the EKC to be inverted U-shaped, with the turnaround point to be between $25.40K and $35.33K. Jebli et al. [15] estimated the EKC for OECD countries over the period of 1980-2010. They have used FMOLS and DOLS to estimate EKC, and they found the EKC to be inverted U-shaped, with the turnaround point to be between $59,010.76 and $72,264.18. Sugiawan and Managi [16] estimated the EKC for Indonesia over the period of 1971-2010. They have used ARDL bounds test approach to estimate EKC, and they found the EKC to be inverted U-shaped, with the turnaround point to be at $7,729.24. Zambrano-Monserrate et al. [17] estimated the EKC for Indonesia over the period of 1971-2010. They have used cointegration approach to estimate EKC, and they found the EKC to be inverted U-shaped, with the turnaround point to be at $2,240.06.

If we look at the empirical evidences of EKCs with renewable energy consumption within the framework, then we can see that the studies have largely focused on the emerging or developing economies. In this study, we are focusing on the Indian context, and therefore, choice of this explanatory variable complies with the chosen context. As India is an emerging economy, and it is on the trajectory of shifting the fuel mix from non-renewable to renewable, therefore, it is necessary to incorporate renewable energy consumption within the empirical framework of EKC, and to assess its impact on $CO_2$ emissions being produced out of the production process.

## 3. Methodology

### 3.1. Model building and data

For analytical purpose, this study has employed a reduced form model, which is used to estimate the existence of EKC hypothesis in Indian context. In this model, we have incorporated the renewable energy consumption for capturing its effect on environmental quality in India. Over last few decades, the share of renewable energy consumption in the total energy mix in India has been going up gradually, and as on 2015, the share of renewable energy consumption is more than 40 percent of total energy consumption. Therefore, the rising dependence on renewable energy sources is bringing forth a structural change in the tradition fossil fuel based energy mix, and it is expected to have a significant impact on environmental quality of India. Based on this logic, our estimation model can be designed as per the following:

$$\ln C_t = \beta_0 + \beta_1 \ln Y_t + \beta_2 \ln Y_t^2 + \delta \ln REN_t + \epsilon_t \tag{1}$$

$$\ln C_t = \beta_0 + \beta_1 \ln Y_t + \delta \ln REN_t + \epsilon_t \tag{2}$$

Where, $C$ denotes $CO_2$ emission, $Y$ denotes per capita GDP, $REN$ denotes per capita renewable energy generation, and $\epsilon$ is the standard error term.

Now, our model is founded on two equations. Let us begin with the first equation. Eq. (1) has been derived based on the generalized EKC framework provided by Panayotou [18], which used the squared income as an explanatory variable for emissions, and also made the provision for other exogenous variables. This equation can elucidate about different forms of EKC, based on the coefficients of income.

(a) $\beta_1 = \beta_2 = 0$ signifies that income has no effect on environmental quality,

(b) $\beta_1 > 0$ and $\beta_2 = 0$ signifies that income has linearly increasing and positive effect on emission,

(c) $\beta_1 < 0$ and $\beta_2 = 0$ signifies that income has linearly decreasing and negative effect on emission,

(d) $\beta_2 < 0$ signifies that the income-emissions association takes the inverted U-shaped form, and

(e) $\beta_2 > 0$ signifies that the income-emissions association takes the U-shaped form.

Out of these five scenarios, the generally accepted form of EKC can be achieved in the fourth scenario. In this case, the EKC is expected to arrive at a turnaround point, and this is the level of economic growth, at which the environmental quality start to improve. Now, in order to compute income elasticity of environmental quality, we have adopted the model suggested by Narayan and Narayan [19] and Shahbaz et al. [20], and its functional form is given in Eq. (2). The expected positive effect of renewable energy consumption on environmental quality can be seen if the sign of $\delta$ is negative, and income elasticity of emissions is less for long run estimation, compared to that of the short run estimation.

Among several issues in EKC estimation, Stern [3] has identified the major ones, and one of those problems is the possibility of omitted variable bias. Along with this issue, Akbostancı et al. [21] also specified that an EKC model must address the scale effect, composition effect and technique effect, which were originally brought into the literature of environmental economics by Grossman and Krueger [2]. In order to address these effects, we have incorporated per capita energy consumption (*EC*), volume of foreign trade (*TRADE*), and total factor productivity (*TFP*) in our model. Energy consumption stimulates economic growth by catalyzing the production process, and the process itself generates large amount of emission, thereby degrading the environmental quality. In this way, energy consumption can exhibit the negative scale effect on environmental quality. Technological transfer from other parts of the world can have a positive technical effect on environmental quality, as it is hypothesized that modern clean technologies can generate less amount of emission, thereby protecting environmental quality ([22]). Therefore, total factor productivity can have a positive technical effect on environmental quality. Now, if we combine both these aspects, then we can see that international trade is an aspect, which can have both negative scale effect on environment by means of higher goods export, and positive technical effect on environment by means of higher technology import ([23]). Following this, trade can have a composition effect on environmental quality. In order to analyze these impacts in a segregated manner, we have considered four cases as per the following, while estimating the models:

- *Case I*: Linear EKC model without TFP
- *Case II*: Linear EKC model with TFP
- *Case III*: Quadratic EKC model without TFP
- *Case IV*: Quadratic EKC model with TFP

The data has been collected for India over the period 1971-2015. From the World Development Indicators, World Bank, we have obtained the data for $CO_2$ emissions (in metric tons per capita), per capita real GDP (in current US dollar), renewable energy generation (in kWh), electric power consumption (kWh per capita), and international trade (as percentage of GDP). Apart from that, we have obtained the data of total factor productivity from Penn World Table ([24]).

### 3.2. ARDL bounds testing of cointegration

For estimating the association between income and environmental quality, we have made use of ARDL bounds testing approach ([25]). One of the major advantages of this approach is that, this method is capable of handling the endogeneity issue, which has been identified by Stern [3]. Apart from that, this method is capable of handling small sample size, and in the present study, the sample size is only 45. While estimating the association between income and environmental quality, we need to estimate the long run and short run association, and using ARDL, we can estimate both of the associations simultaneously.

For estimating the cointegration between the considered variables, we will first estimate the Eq. (3).

$$\begin{aligned}\Delta \ln C_t = {} & \beta_0 + \sum_{\mathrm{i=1}}^{\mathrm{a}} \beta_{1i} \Delta\ln C_{t-i} + \sum_{\mathrm{i=0}}^{\mathrm{b}} \beta_{2i} \Delta \ln Y_{\mathrm{t-i}} + \sum_{\mathrm{i=0}}^{\mathrm{c}} \beta_{3i} \Delta \ln Y_{t-1}^{2} + \sum_{\mathrm{i=0}}^{\mathrm{d}} \beta_{4i} \Delta \ln REN_{t-i} + \\ & \sum_{\mathrm{i=0}}^{\mathrm{e}} \beta_{5i} \Delta \ln EC_{t-i} + \sum_{\mathrm{i=0}}^{\mathrm{f}} \beta_{6i} \Delta \ln TRADE_{t-i} + \sum_{\mathrm{i=0}}^{\mathrm{g}} \beta_{7i} \Delta \ln TFP_{t-i} + \alpha_1 \ln C_{t-1} + \\ & \alpha_2 \ln Y_{t-1} + \alpha_3 \ln {Y^2}_{t-1} + \alpha_4 \ln REN_{t-1} + \alpha_5 \ln EC_{t-1} + \alpha_6 \ln TRADE_{t-1} + \\ & \alpha_7 \ln TFP_{t-1} + \epsilon_t \qquad (3)\end{aligned}$$

Where, β are the short run coefficients and α are long run coefficients. The tests of cointegration are carried out by testing the join significance of the variables using Wald statistic. For testing the significance of the associations, we have used the critical values of F-statistics derived by Narayan [26], which are effective for small samples ([16]). The values are segregated by the nature of integration between the variables, i.e. the critical values are provided for I(0) and I(1). If the computed F-statistics fall below the lower bound or above the upper bound of the critical values, then the null hypothesis of no cointegration can be rejected. However, if the value falls between the bounds, then no results regarding the cointegration can be determined. If cointegration exists between variables, then the problem of multicollinearity can be overlooked (see [27], [28], [29]).

Now, in order to proceed with the model, we need to choose the lag length for each of the variables. For choosing the optimum lag lengths, we have used Akaike Information Criterion (AIC) and Schwarz's Bayesian criterion (SBC). Out of all the observations, the lag length with smallest values of AICs and SBCs are selected.

Once the cointegrating associations among the variables are found, we have estimated the long run model using the following equation:

$$\ln C_t = \beta_0 + \sum_{i=1}^{a} \beta_{1i} \ln C_{t-i} + \sum_{i=0}^{b} \beta_{2i} \ln Y_{t-i} + \sum_{i=0}^{c} \beta_{3i} \ln Y_{t-1}^{2} + \sum_{i=0}^{d} \beta_{4i} \ln REN_{t-i} + \sum_{i=0}^{e} \beta_{5i} \ln EC_{t-i} + \sum_{i=0}^{f} \beta_{6i} \ln TRADE_{t-i} + \sum_{i=0}^{g} \beta_{7i} \ln TFP_{t-i} + \epsilon_t \quad (4)$$

After estimating Eq. (4), we have estimated the short run model:

$$\Delta \ln C_t = \beta_0 + \sum_{i=1}^{a} \beta_{1i} \Delta \ln C_{t-i} + \sum_{i=0}^{b} \beta_{2i} \Delta \ln Y_{t-i} + \sum_{i=0}^{c} \beta_{3i} \Delta \ln Y_{t-1}^{2} + \sum_{i=0}^{d} \beta_{4i} \Delta \ln REN_{t-i} + \sum_{i=0}^{e} \beta_{5i} \Delta \ln EC_{t-i} + \sum_{i=0}^{f} \beta_{6i} \Delta \ln TRADE_{t-i} + \sum_{i=0}^{g} \beta_{7i} \Delta \ln TFP_{t-i} + \emptyset\, ECT_{t-1} + \epsilon_t \quad (5)$$

In Eq. (5), $\emptyset$ is the parameter indicating speed of adjustment, and $ECT_{t-1}$ is the lagged error correction term. Value of this error correction term is expected to be negative and significant.

Once the models are estimated, we have run a series of diagnostic tests, i.e. for checking serial correlation, normal distribution, heteroscedasticity, and goodness-of-fit. Finally, the cumulative sum (CUSUM) and cumulative sum of squares (CUSUMSQ) have been estimated for checking the stability of the model.

## 4. Analysis of results

We have started testing the model using the unit root tests, as it is important to know the order of integration of the variables. In order to carry out the ARDL bounds test, it is necessary that the variables should be integrated to order zero or one, i.e. I(0) or I(1), and they should not be integrated to order two, i.e. I(2). For checking the order of integration, we have applied augmented Dickey-Fuller (ADF) [30], Kwiatkowski-Phillips-Schimdt-Shin (KPSS) [31], Zivot-Andrews (ZA) [32] and Clemente-Montañés-Reyes [33] unit root tests. The results of the unit root tests are recorded in Table-1 and Table-2. It shows that the variables do not demonstrate the presence of unit roots after their first differences. Therefore, it can be concluded that the variables are integrated to order one, i.e. they are I(1) in nature.

<*Insert Table 1 here*>

<*Insert Table 2 here*>

Once the order of integration among the variables were found to be one, the cointegration using ARDL bounds test can be applied on Eq. (3). Estimation of long run association is carried out for both linear and the quadratic models. For both the cases, first energy consumption and trade are controlled, and then energy consumption, trade, and total factor productivity are controlled. Therefore, we will actually proceed with the estimation of four cases.

However, before proceeding with the ARDL bounds test, we need to determine the optimum lag length for each of the variables, and in order to achieve this, we have used AIC and SBC values. Table-3 contains the AIC and SBC values for the top five models, where the mentioned values are minimized. It is clearly visible that AIC and SBC values are suggesting different model specifications. However, as we have mentioned earlier, we have chosen the model with the minimum value of AIC and SBC. Therefore, we have ARDL(2,4,1,0,0) for case I, ARDL(2,4,3,2,0,0) for case II, ARDL(2,4,2,1,0,0) for case III, and ARDL(2,4,2,1,2,0,0) for case IV. In all the cases, the maximum lag length has been chosen as four.

<*Insert Table 3 here*>

Once the ARDL specifications for all the four cases are found, we can proceed with the ARDL bounds test for cointegration. The results are recorded in Table-4. It is evident from the results that the computed F-statistics exceed the 10 percent upper bounds of the critical values. Therefore, we may conclude that there is cointegrating relationship among the variables.

<*Insert Table 4 here*>

Once we have found the evidence for cointegration, now we can proceed with estimating the long run and short run coefficients using Eq. (4) and (5). The results are recorded in Table-5 and 6. We will start our discussion with the linear model. For linear model, we have estimated two cases, i.e. case I and II. For both the cases, the coefficients of the variables are having the expected signs. The coefficients of $Y$ and $\Delta Y$ are positive and significant, and it implies that rise in income eventually leads to rise in $CO_2$ emissions. Moving to the elasticity analysis of income, we can see that the long run income elasticity of $CO_2$ emissions has been reduced to 0.127 from the short run income elasticity of $CO_2$ emissions of 0.240 in case I, and from 0.174 to 0.128 in Case II. Our results contradict the findings of an earlier study by Ghosh [34] in terms of acknowledging the possibility of long run income elasticity of $CO_2$ emissions, which was covertly mentioned by Ahmad et al. [35]. However, limitations of both these studies were that these studies did not consider the influence of renewable energy aspects within their energy-growth-emission framework. This is an indication that the economic growth trajectory being attained by India is gradually moving toward ecological sustainability. The income generation process is gradually shifting their source from fossil fuel based energy consumption to clean energy consumption, and therefore, the long run income elasticity of $CO_2$ emissions is turning out to be lower compared to short run income elasticity of $CO_2$ emissions.

*<Insert Table 5 here>*

*<Insert Table 6 here>*

One of the major findings of this study is discovering the impact of renewable energy generation on $CO_2$ emissions. The long run and short run elasticities for both case I and II are negative, and it should also be observed that the long run elasticities are higher than the short run elasticities. This result is in the similar lines with the findings of Tiwari [36]. For the contexts other than India, this result is supported by Lund and Mathiesen [37] for Denmark, and Sugiawan and Managi [16] for Indonesia. The higher long run elasticity in this case indicates that environmental benefits of renewable energy generation will be achieved in the long run, and it might not be a temporary phenomenon. However, this value of elasticity needs to be assessed on a comparative basis, as the elasticity of income and energy consumption is higher than that of renewable energy generation. This signifies the negative environmental consequences of economic growth and energy consumption will surpass the environmental benefits of renewable energy generation. Therefore, in order to obtain the benefits of renewable energy generation, a threshold level of income must be achieved, which was indicated by Ghosh [34] and Ahmad et al. [35]. When this segment of result is coupled with the elasticity of income, then the arguments are further validated. This particular section of results indicates the need of EKC estimation for India using renewable energy generation, and that validates the need of our quadratic model.

The results for *EC* and $\Delta EC$ fall in the similar lines with the existing studies ([38], [39], [40], [41], [42], [43]), which indicate that the energy consumption pattern in India eventually gives rise to $CO_2$ emissions. For both case I and II, the long run elasticity is higher than the short run elasticity, which indicates the lack of efficient energy systems in India. In case II, the long run and short run elasticities for *TFP* and $\Delta TFP$ are positive. This indicates that India still lacks energy efficient technologies in production process. Whereas most of the researchers are of the opinion that the technological advancement can possibly bring forth positive environmental effects ([44], [3], [45]), our results contradict the earlier findings, at least in Indian context. However, another segment of our results support this argument, which is visible by the negative long run and short run elasticities of *TRADE* and $\Delta TRADE$. It signifies that trade has a significant positive impact on environmental quality by means of technology transfer. But the benefits of trade are surpassed by existing technologies, which continues to pollute the environment by creating emission. It signifies that the need of endogenous renewable energy generation processes, which can gradually replace the existing polluting technologies. It also validates the need of estimating a new EKC for India, which will elucidate us about the possible inflection point of income, at which the environmental benefits of technology will be realized. This again validates the need of our quadratic model.

Once the linear model using case I and II has been estimated, we will proceed towards the estimation of quadratic model using case III and IV. It is evident from the results recorded in Table-5 and 6 that except income, the natures of long run and short run elasticities for rest of the variables are almost similar to the previous cases. Except for long run coefficients in case IV, the coefficients of $Y$, $\Delta Y$, $Y^2$, and $\Delta Y^2$ are significant and the signs of the coefficients are as expected. Introduction of *TFP* in case IV can possibly cause the problem of multicolinearity in the model, as it has already indicated by Narayan and Narayan [19]. The long run coefficients of case III provides us with an inverted U-shaped association between income and $CO_2$ emissions, and it is the generally accepted form of EKC. The turnaround point in this case is estimated to be USD 2937.77. [2] This value of income lies outside the sample, as the highest per capita GDP of the sample is USD 1581.59. This is a case for an emerging economy, where the renewable energy generation has not yet reached the full potential, and the energy efficient technologies are yet to gain prominence in the economic system ([46]). Therefore, the possibility of the turnaround point outside the sample space cannot be disregarded.

Another observation regarding the short run estimates recorded in Table-6 demonstrate the significance of the error correction terms. The sign of this term is negative as expected, and it

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[2] $\exp(-\beta_1/2\beta_2) \cong 2937.77$

reinstates the existence of cointegration among the variables. The absolute values of the error correction terms indicate the speed of adjustment in presence of any shocks to the equilibrium.

Finally, we have run a series of diagnostic tests, and the results of these tests are recorded in Table-5. The results show that the results are free from serial correlation, non-normality and heteroscedasticity, and all the models are stable. As both the linear and quadratic forms are perfectly estimated and both of the forms are free from errors, then we will select the quadratic model over the linear model, as it will be more parsimonious. To conclude the study, we have employed the CUSUM and CUSUMSQ tests, and the results are recorded in Figure-1. The results show that the plots are within 5 percent critical bounds, and it signifies that the models are stable over the study period.

<*Insert Figure 1 here*>

Now, if we put all the segments of results together, then the present situation regarding economic growth, $CO_2$ emissions, renewable and non-renewable energy consumption and trade comes out to be clearer. India is presently shifting the energy source from fossil fuel based sources to renewable energy sources, and this shift has a significant impact on economic growth. Though the lower long run income elasticity of $CO_2$ emissions show that economic growth pattern is gradually turning out to be ecologically sustainable, a complete phase out of fossil fuel based energy sources can have a negative impact on economic growth. However, this gradual shift of energy sources can be visible from the lower long run fossil fuel energy elasticity of $CO_2$ emissions, especially when the model includes total factor productivity. This shift will require technology transfer, and that can take place by means of international trade. This is elucidated by the higher long run trade elasticity of $CO_2$ emissions. Despite all of these aspects in place, $CO_2$

emissions in India are still above the permissible level, and this is depicted by the turnaround point of EKC to be outside the sample space.

## 5. Conclusion and policy implications

The objective of this study is to estimate the EKC for $CO_2$ emissions in India for the period of 1971-2015, and to investigate about the impact of renewable energy on the EKC. The empirical framework also included trade, total factor productivity, and energy consumption. These three explanatory variables were considered for introducing the scale effect, composition effect, and technique effect in the model, and to address the omitted variable bias, at the same time. By far, in the EKC literature, this has been the first study, which has used the unit root test with multiple structural breaks, and addressed three the major methodological concerns indicated by earlier researchers.

Going by the derived results, we can find the evidence of EKC for $CO_2$ emissions in India. For the linear estimation model, the income-emission association was found to be positive. However, the long run elasticity was found to be decreasing. The quadratic estimation model showed the evidence of EKC hypothesis, and the turnaround point for India was found to be at USD 2937.77, which is outside the sample space. For both linear and the quadratic models, the renewable energy generation was found to have significant and negative effect on $CO_2$ emission, for both long run and short run scenarios. Though the positive impact of total factor productivity on $CO_2$ emissions was not found to be significant throughout, trade volume clearly has a negative and significant impact on $CO_2$ emissions.

As implementation of renewable energy is an expensive measure, it is never advisable to shift the energy source completely within a short duration, as it might cause harm to the economic growth. The government might take a phase-wise shift from non-renewable to renewable energy sources, which both household and industry can obtain by taking advances from the government. The rate of interests for these advances should be discriminatory, i.e. the rate of interest for rural households should be the lowest, and for industry, it should be the highest. The interest income obtained from urban households and industries can be utilized to subsidize the renewable energy sources for the rural households, and during a later stage, utilizing the accumulated income, government can implement renewable energy sources across the country. In this way, the exogenously supported economic growth via international trade can be reduced, and in this way, not only $CO_2$ emissions can be reduced without harming the course of economic growth, but also the endogenous generation of renewable energy can enhance the total factor productivity, thereby, adding to the reduction in $CO_2$ emissions. Apart from providing subsidies on tariffs, if the government provides discriminant subsidized advances, then the EKC can be flattened, and the turnaround point might come within the sample space.

We can conclude that based on our results and looking at the present developments in alternate energy discovery process in India, the turnaround point, which have not been achieved within the study period of 1971-2015, may possibly be achieved in the later stages of 2016-2017. However, in our study, we refrained to consider a variety of social variables, as our intention was to investigate whether any turnaround point exists for India, or not. Further study on this aspect can be taken up considering those variables and the economy-wide policy developments as well. These can bring forth significant insights about the nature of EKCs in India.

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## Table 1. Results of Unit Root tests on Log-transformed variables

| Variables | ADF | | ZA | | KPSS | |
|---|---|---|---|---|---|---|
| | No trend | Trend | No trend | Trend | No trend | Trend |
| *Level* | | | | | | |
| C | 0.925 | -1.934 | -2.664 (1998) | -2.283 (2005) | 0.855[a] | 0.132[a] |
| Y | -0.045 | -1.241 | -3.168 (2004) | -2.822 (1999) | 0.813[a] | 0.244[a] |
| $Y^2$ | 0.600 | -0.900 | -3.185 (2004) | -2.966 (1999) | 0.799[a] | 0.220[a] |
| REN | -3.125[b] | -1.084 | -1.759 (1995) | -3.116 (1997) | 0.686[b] | 0.681[a] |
| TFP | 0.638 | -1.073 | -2.781 (1979) | -4.703[b] (1988) | 0.575[b] | 0.286[a] |
| EC | -0.027 | -1.269 | -3.976 (1999) | -2.248 (1989) | 0.854[a] | 0.611[a] |
| TRADE | -0.931 | -1.670 | -3.244 (1981) | -2.824 (1987) | 0.826[a] | 0.561[a] |
| *First Differences* | | | | | | |
| C | -6.304[a] | -6.422[a] | -7.106[a] (1997) | -6.500[a] (1986) | 0.146 | 0.075 |
| Y | -6.036[a] | -5.962[a] | -7.085[a] (2003) | -6.477[a] (1992) | 0.122 | 0.113 |
| $Y^2$ | -5.930[a] | -5.942[a] | -7.143[a] (2003) | -6.383[a] (1992) | 0.176 | 0.110 |
| REN | -5.872[a] | -8.807[a] | -10.903[a] (1998) | -9.329[a] (2002) | 0.461 | 0.049 |
| TFP | -4.548[a] | -4.716[a] | -4.741[c] (1992) | -4.647[b] (1981) | 0.362 | 0.074 |
| EC | -5.120[a] | -5.054[a] | -6.122[a] (1995) | -5.269[a] (2001) | 0.089 | 0.156 |
| TRADE | -5.684[a] | -5.666[a] | -6.294[a] (1988) | -6.313[a] (1979) | 0.086 | 0.114 |

a value at 1% significance level

b value at 5% significance level

c value at 1% significance level

Breakpoint years are inside parentheses

## Table 2. Results of Clemente-Montañés-Reyes unit-root test with double Mean shift

| | Additive outlier | | Innovational outlier | |
|---|---|---|---|---|
| | Minimum t statistics | Breakpoints | Minimum t statistics | Breakpoints |
| *Level* | | | | |
| C | -2.614 | 1991, 2010 | -3.089 | 1983. 2004 |
| Y | -3.381 | 1989, 2008 | -3.730 | 1992, 2002 |
| $Y^2$ | -3.474 | 1991, 2008 | -3.563 | 1992, 2002 |
| REN | -3.382 | 1992, 2002 | -6.230 | 1998, 2014 |
| TFP | -2.669 | 1996, 2007 | -3.024 | 1974, 1998 |
| EC | -2.880 | 1987, 2006 | -3.610 | 1982, 2004 |
| TRADE | -3.716 | 1992, 2003 | -4.126 | 1990, 2002 |
| *First Difference* | | | | |
| C | -7.395 | 1998, 2004 | -7.330 | 1995, 2004 |
| Y | -5.548 | 1989, 2005 | -7.047 | 1990, 2001 |
| $Y^2$ | -5.515 | 1989, 2005 | -7.173 | 1990, 2001 |
| REN | -9.594 | 1991, 1996 | -9.912 | 1988, 1995 |
| TFP | -5.746 | 1987, 1992 | -6.507 | 1974, 1986 |
| EC | -6.492 | 1993, 2003 | -6.503 | 1994, 2002 |
| TRADE | -6.611 | 1978, 1987 | -6.655 | 1979, 1985 |

Note: critical value of t statistics at 5% level is -5.490

## Table 3. ARDL Model Selection Criteria

| *Linear Model* | | | | | | | |
|---|---|---|---|---|---|---|---|
| *Case I* | | | | *Case II* | | | |
| AIC | | SBC | | AIC | | SBC | |
| Value | ARDL | Value | ARDL | Value | ARDL | Value | ARDL |
| -4.94395 | 2,4,1,0,0 | -4.51812 | 2,4,2,0,0 | -4.82592 | 2,4,3,2,0,0 | -4.25916 | 1,2,0,0,0,0 |
| -4.90582 | 2,4,1,2,0 | -4.47028 | 2,4,1,1,0 | -4.70596 | 2,4,3,2,2,0 | -4.23495 | 2,2,1,0,0,0 |
| -4.86224 | 2,4,1,1,0 | -4.30254 | 2,2,2,0,0 | -4.67870 | 2,4,3,0,0,0 | -4.13316 | 2,2,0,0,0,0 |
| -4.74226 | 2,4,3,0,0 | -4.26923 | 1,1,0,0,0 | -4.62526 | 2,3,3,0,0,0 | -4.10856 | 2,2,1,1,0,0 |
| -4.66790 | 2,4,0,0,0 | -4.24126 | 2,2,0,0,0 | -4.55466 | 2,3,0,0,0,0 | -4.01152 | 1,0,0,0,0,0 |
| *Quadratic Model* | | | | | | | |
| *Case III* | | | | *Case IV* | | | |
| AIC | | SBC | | AIC | | SBC | |
| Value | ARDL | Value | ARDL | Value | ARDL | Value | ARDL |
| -4.87510 | 2,4,2,1,0,0 | -4.28460 | 1,2,0,0,0,0 | -4.83313 | 2,4,2,1,2,0,0 | -4.28891 | 2,3,2,1,0,0,0 |
| -4.79328 | 2,4,2,1,1,0 | -4.26577 | 2,2,2,1,0,0 | -4.82260 | 2,4,2,1,0,0,0 | -4.26422 | 2,3,2,1,2,0,0 |
| -4.61436 | 2,4,0,0,0,0 | -4.15656 | 1,1,1,0,0,0 | -4.54824 | 2,4,0,0,0,0,0 | -4.11471 | 2,3,1,0,0,0,0 |
| -4.60395 | 2,4,2,0,0,0 | -4.13208 | 2,2,1,0,0,0 | -4.49681 | 2,3,2,0,0,0,0 | -4.06522 | 1,1,0,0,0,0,0 |
| -4.53322 | 2,0,0,0,0,0 | -4.06790 | 1,0,0,0,0,0 | -4.44593 | 3,0,0,0,0,0,0 | -4.02025 | 2,2,0,0,0,0,0 |

## Table 4. Results of ARDL Bounds test for Cointegration

| | *Linear Model* | | | |
|---|---|---|---|---|
| | *Case I* | | *Case II* | |
| | *Value* | *K* | *Value* | *k* |
| F-statistic | 10.113 | 4 | 9.692 | 5 |
| *Critical Values for the bounds test** | *I(0)* | *I(1)* | *I(0)* | *I(1)* |
| 10% | 3.983 | 2.638 | 2.458 | 3.647 |
| 5% | 3.178 | 4.450 | 2.922 | 4.268 |
| 1% | 4.394 | 5.914 | 4.030 | 5.598 |
| | *Quadratic Model* | | | |
| | *Case III* | | *Case IV* | |
| | *Value* | *K* | *Value* | *k* |
| F-statistic | 7.505 | 5 | 7.181 | 6 |
| *Critical Values for the bounds test** | *I(0)* | *I(1)* | *I(0)* | *I(1)* |
| 10% | 2.458 | 3.647 | 2.327 | 3.541 |
| 5% | 2.922 | 4.268 | 2.764 | 4.123 |
| 1% | 4.030 | 5.598 | 3.790 | 5.411 |

* Critical values are taken from Narayan (2005), for unrestricted intercept and no trend

## Table 5. Long Run Estimates of the ARDL Models

| | *Linear* | | *Quadratic* | |
|---|---|---|---|---|
| | *Case I:* | *Case II:* | *Case III:* | *Case IV:* |
| | *ARDL (2,4,1,0,0)* | *ARDL (2,4,3,2,0,0)* | *ARDL (2,4,2,1,0,0)* | *ARDL (2,4,2,1,2,0,0)* |
| ln Y | 0.1268833$^b$ | 0.1278203$^a$ | 0.2372752$^b$ | 0.2329451 |
| ln $Y^2$ | - | - | -0.0148568$^a$ | -0.0154934 |
| ln REN | -0.0266008$^b$ | -0.0160769$^c$ | -0.0292036$^a$ | -0.0291068$^c$ |
| ln EC | 0.5852001$^a$ | 0.5733397$^a$ | 0.5989941$^a$ | 0.5992993$^a$ |
| ln TRADE | -0.1194747$^c$ | -0.0865679 | -0.1384388$^b$ | -0.1383989$^b$ |
| ln TFP | - | 0.0939222 | - | 0.0022007 |
| Constant | -3.8776180$^a$ | -4.1511230$^b$ | -2.4701290$^a$ | -2.4789630$^b$ |
| | | | | |
| $R^2$ | 0.76703556 | 0.79931523 | 0 .64115822 | 0 .64115997 |
| Adj. $R^2$ | 0.61629386 | 0.47821959 | 0 .44793572 | 0.42585595 |
| SE | 0.01808 | 0.02174 | 0.02070 | 0 .02111 |
| F-statistic | 5.09$^a$ | 2.49$^c$ | 3.32$^a$ | 3.70$^a$ |
| DW statistic | 2.023811 | 1.790182 | 2.269798 | 2.046369 |
| | | | | |
| *Diagnostic tests* | | | | |
| Serial correlation | 0.053 (p = 0.8172) | 1.206 (p = 0.2722) | 2.653 (p = 0.1034) | 0.131 (p = 0.7179) |
| Stability | 0.500 (p = 0.6882) | 0.190 (p = 0.9024) | 0.560 (p = 0.1802) | 0.040 (p = 0.9895) |
| Normality | 1.473 (p = 0.4788) | 3.307 (p = 0.1914) | 3.966 (p = 0.1377) | 0.354 (p = 0.8378) |
| Heteroscedasticity | 0.569 (p = 0.4507) | 0.091 (p = 0.7633) | 0.004 (p = 0.9486) | 0.001 (p = 0.9801) |

a value at 1% significance level

b value at 5% significance level

c value at 1% significance level

## Table 6. Short Run Estimates of the ARDL Models

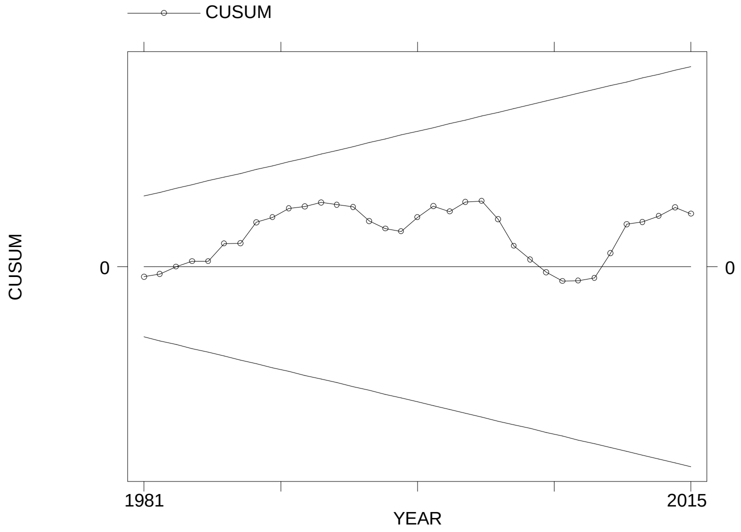
| | *Linear* | | *Quadratic* | |
|---|---|---|---|---|
| | *Case I:* | *Case II:* | *Case III:* | *Case IV:* |
| | *ARDL (2,4,1,0,0)* | *ARDL (2,4,3,2,0,0)* | *ARDL (2,4,2,1,0,0)* | *ARDL (2,4,2,1,2,0,0)* |
| Δ ln C(t-1) | -0.5938124$^a$ | -1.1277787$^a$ | -0.8348784$^a$ | -1.3146901$^a$ |
| Δ ln Y | 0.2401229$^c$ | 0.1743350$^b$ | 0.1147449$^c$ | 0.2064033$^c$ |
| Δ ln $Y^2$ | - | - | -0.0345241$^b$ | -0.0271253$^a$ |
| Δ ln REN | -0.0260743$^c$ | -0.0114672$^c$ | -0.0217189$^b$ | -0.0105087$^c$ |
| Δ ln EC | 0.5099935$^a$ | 0.6137868$^a$ | 0.5000873$^a$ | 0.6548362$^a$ |
| Δ ln TRADE | -0.0860802 | -0.0911559$^c$ | -0.1155796$^b$ | -0.0800318$^c$ |
| Δ ln TFP | - | 0.2735763$^a$ | - | 0.1719120 |
| ECT (t-1) | -2.466844$^a$ | -4.519301$^a$ | -2.041458$^a$ | -4.089892$^a$ |

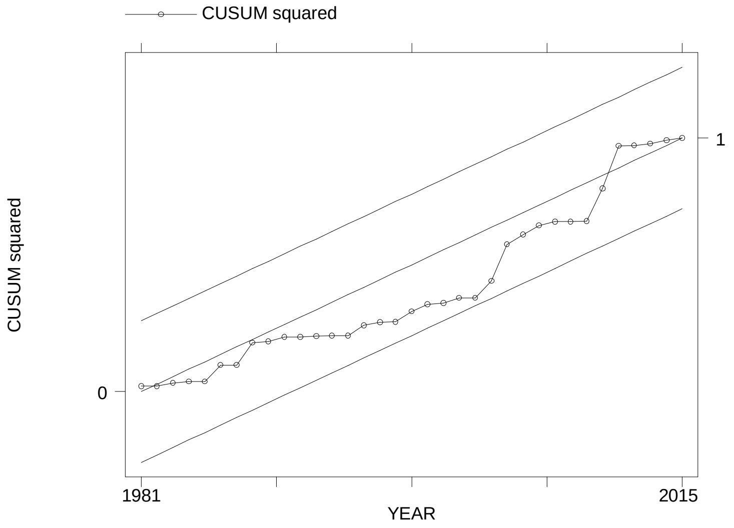
a value at 1% significance level

b value at 5% significance level

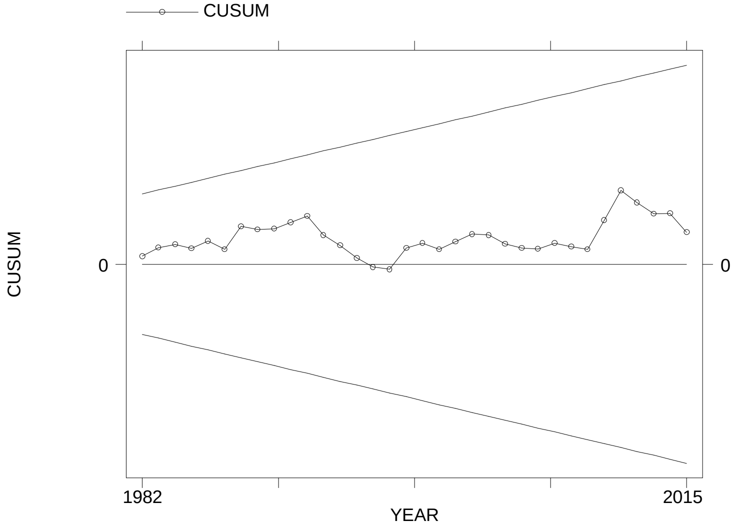
c value at 1% significance level

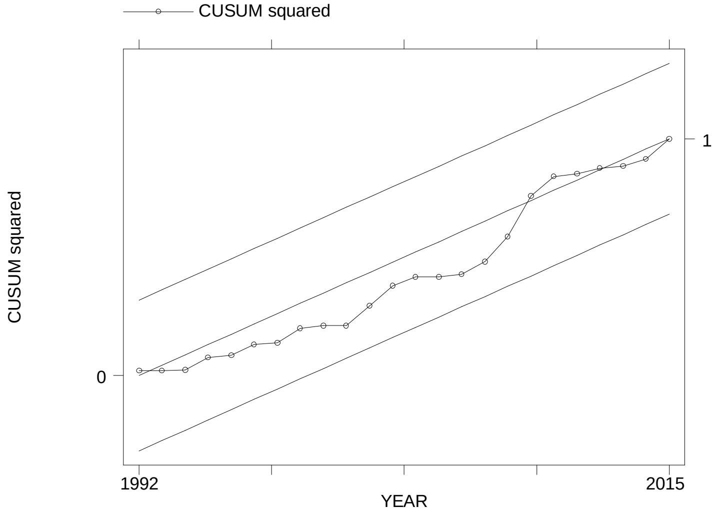
## Case I



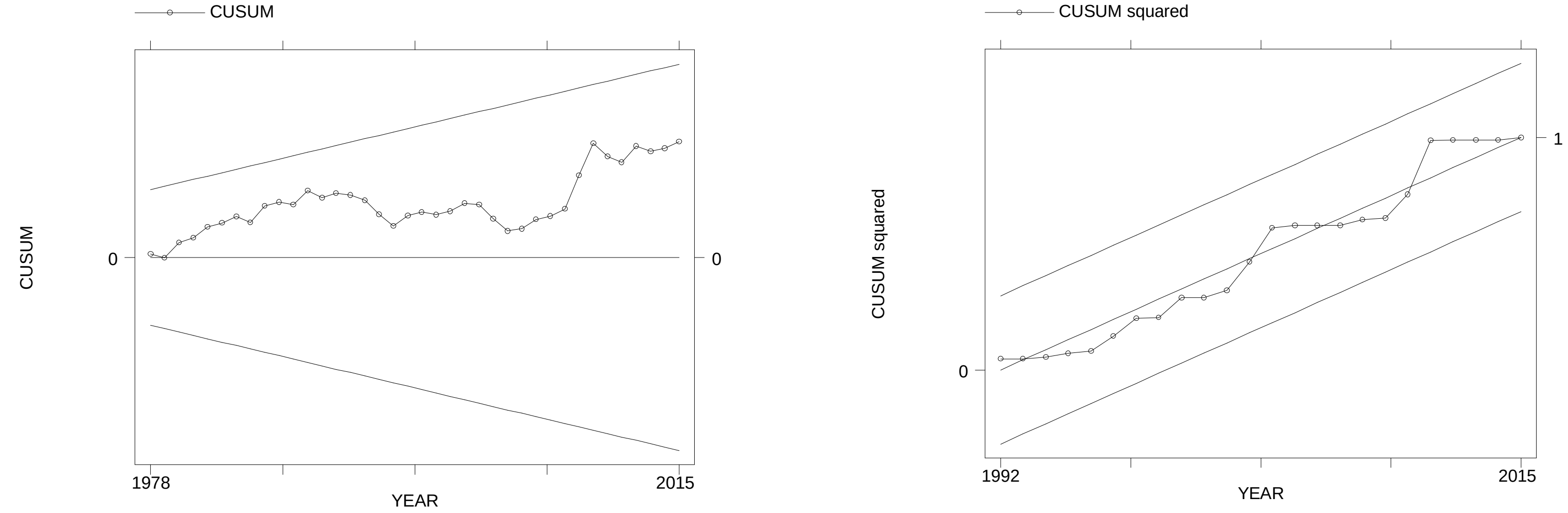


## Case II





## Case III



## Case IV

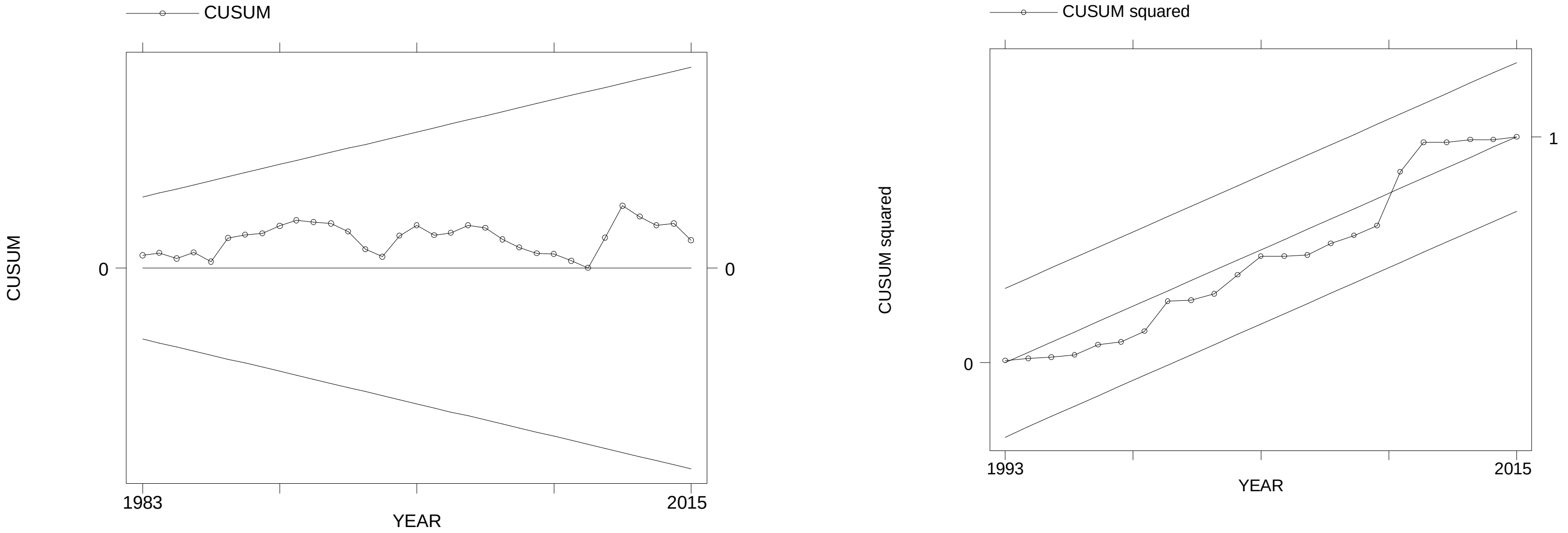


**Figure 1. CUSUM and CUSUM Squared plots for the estimated model**