Environmental Kuznets curve estimation for NO2 emission: A case of Indian cities

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1. Introduction

As economy moves along the growth trajectory, environment deteriorates at an increasing rate. With higher 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. In the literature of environmental economics, this phenomenon is referred to as Environmental Kuznets Curve (EKC) hypothesis. This phenomenon is termed after Simon Kuznets (1955), who described the inverted U-curve association between income inequality and economic development. While establishing a relationship between pollution and economic development, Grossman and Krueger (1991) found its resemblance with Kuznets' inverted U-curve relationship, and named it after Simon Kuznets.

By far, the existing studies on EKC hypothesis have focused on either cross-country analysis or intra-provincial analysis of a particular country. In this study, we have analyzed the NO_2 emission data for 139 Indian cities during 2001-2013. The analysis is done by segregating the entire dataset into industrial and residential category, and then segregating each of the two segments in terms of income level, i.e. low, medium, and high income. This bifurcation will allow us to visualize the income-pollution association at various levels of income, and therefore, analyzing policy implications can be more effective. The literature of EKC hypothesis has majorly looked into the income-pollution association without considering different income levels for any particular context. This is one area, which is largely unaddressed in the literature, and that is the focus of this study.

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 literature. It has been primarily indicated as growth in per capita income, and in some of the studies as trade, financial development, and technological advancement, as according to Hill and Magnani (2002), per capita income may not be the only indicator for economic growth. Apart from income, this study has taken electricity consumption and petroleum consumption as two other explanatory variables. These two variables are the proxy measures for energy consumption.

In methodological terms, this study employs fixed effect panel regression on parameters validated by auxiliary regressions on orthogonally transformed dataset. Due to usage of power terms, EKC models suffer from multicolinearity. In most of the existing studies, this issue has been ignored, and this has been pointed out by several researchers. This study has used orthogonal transformation of parameters, followed by auxiliary regression on transformed parameters for removing multicolinearity from the data. Contribution of this study is not only in terms of finding EKC for Indian cities, but also in terms of employing a more refined set of parameters, which have hardly been considered in the literature.

2. Review of literature

The literature on EKC hypothesis is extensive in the field of ecological economics. For NO_2 emission, studies have been carried out on cross-sectional data (Panayotou, 1993; Hill and Magnani, 2002) and panel data (Grossman and Krueger, 1995; Egli, 2001; Archibald et al., 2004; Welsch, 2004; Fonkych and Lempert, 2005; Song et al., 2013) and all of these studies are based on a group of countries. Apart from the works of Carson et al. (1997), Roumasset et al. (2006), Park and Lee (2011) hardly any study has attempted to analyze the EKC of a particular country. Moreover, for a country with high population density, it is not always feasible to end up with a single EKC only. Though the aforementioned studies have considered provincial differences in emission, no study has considered different income levels of a country and the differential impact of income levels on emission. In this study, we have segregated Indian cities in terms of three income levels, namely low, medium, and high income and observed the income-emission association under EKC framework.

We will now look into other pollutants, like carbon dioxide (CO_2) and sulphur dioxide (SO_2). For both of the cases, studies have been carried out cross-sectional data and panel data. For CO_2, studies are carried out by Holtz-Eakin and Selden (1995), Lindmark (2002), Friedl and Getzner (2003), Aldy (2005), Dijkgraaf and Vollebergh (2005), Auffhammer and Carson (2008), Aslanidis and Iranzo (2009), Musolesi et al. (2010) and others, and all of these studies are based either on cross-country of cross-province panel data. For SO_2, studies on cross-sectional data are carried out by Panayotou (1993), Taskin and Zaim (2000), Bimonte (2002), Khanna and Plassmann (2004) and others, and studies on panel data are carried out by Selden and Song (1994), Shafik (1994), Grossman and Krueger (1995), Kaufmann et al. (1998), List and Gallet (1999), Harbaugh et al. (2002), Millimet et al. (2003), Galeotti et al. (2006), Soytas et al. (2007), Apergis and Payne (2010), Al Sayed and Sek (2013) and many others. In this case also, studies looked into either cross-country of cross-province panel data.

Apart from that, while estimating EKC for any context, researchers have majorly taken indicators of economic growth, like trade (Suri and Chapman, 1998), financial development (Tamazian et al., 2009), and technological progress (Bhattarai and Hammig, 2001) as explanatory variables in EKC framework. These variables are different indicators of economic growth. For ambient air pollution, more specific explanatory variables are required, and a recent work of Onafowora and Owoye (2014) has considered this aspect. They have taken energy consumption as an explanatory variable, which is relevant for our study as well. As India is net oil importing nation, and Indian industries and households depend on commercial and combustible electricity consumption for their subsistence (Sinha and Mehta, 2014), we have taken energy consumption in the form of electricity consumption and petroleum consumption as explanatory variables in our study.

3. NO_2 emission in India

Due to rapid growth in industrialization, India has experienced a significant growth in the fossil fuel consumption. Adverse effects of this growth have been seen in the growth of ambient air pollution. During the last decade, CO_2 emission has gone up by 72%, SO_2 emission has gone up by 54%, and NO_2 emission has gone up by 42% (Lu et al., 2011; Haq et al., 2015). If we look at the emission affecting tropospheric region, then the NO_2 should be considered as the primary pollutant in this case, as 79% of the tropospheric atmosphere consists of nitrogen (N_2). It is majorly responsible for creation of ground-level ozone, a primary component of smog. It is also responsible for creation of various nitrate compounds, which add to the level of respiratory particulate matters in the lower atmosphere. Owing to these reasons, rise in the level of NO_2 emission can cause serious damage to ambient atmosphere.

In India, reasons behind rise in the level of NO_2 emission are different for industrial and residential areas. In industrial areas, rise in the NO_2 emission can be attributed to rise in the level of direct fossil fuel consumption, in the form of coal and oil. Consumption of coal majorly takes place at the thermal power plants, and due to the high temperature (more than 1700˚C) in the furnaces, molecular N_2 and oxygen (O_2) react with each other and form NO_2 (Zeldovich, 1946). This is the primary source of NO_2 emission in industrial areas. Apart from this, contribution of oil combustion stands second in the rise in NO_2 emission. This direct consumption of petroleum fuel is majorly visible in vehicular transportation, which is evident in the industrial cities in India. The first incident is referred to as the *Thermal* NO_2 and the second one is referred to as the *Fuel* NO_2.

Coming to residential areas, rise in the NO_2 emission can be attributed to rise in the vehicular congestion, level of humidity, heights of buildings, and improper usage of burners. Continuous rise in population in the residential areas has been creating pressure on the existing road transport infrastructure, and this can be experienced in the vehicular congestions in almost every city in India. Traffic fumes generated out of these congestions is the primary cause of NO_2 emission in residential areas in India (Bhaduri, 2013). Apart from that, emergence of high flame cooking can also be attributed to one of the reasons behind rise in NO_2 emission in the residential areas (Relwani et al., 1986). In this case, the fuel input rate and the color of flame have found to have significant impact on NO_2 emission. Yellow-tipping flames generate more amount of NO_2 in the indoor atmosphere compared to blue-tipping flames (Himmel and DeWerth, 1974). Heights of building and level of humidity do not directly add to the level of NO_2 emission, but they catalyze the growth and spreading. This scenario has already been experienced in other Asian cities, like Hong Kong (Lau, 2011). Heights of the building resist sunlight and ventilation in the neighborhood, and therefore, usage of air-conditioning systems rise in the neighborhood areas. Moreover, rooftop solar panels cannot be installed in the neighborhood areas due to lack of sunlight. These in one hand reduce energy efficiency by elevating the level of fossil fuel based energy consumption, and on the other hand, increase the level of humidity and outdoor temperature. This catalyzes the formation of smog in residential areas.

Central Pollution Control Board of India has already set a number of emission standards, according to which level of NO_2 emission should not be more than $40 \mu g/m^3$ in any industrial or residential cities of India. Bharat Stage emission standards are also in place for controlling the vehicular emissions. Presently, Bharat Stage IV has been implemented only across 14 cities[1] in

[1] National Capital Region, Mumbai, Kolkata, Chennai, Bengaluru, Hyderabad, Ahmedabad, Pune, Surat, Kanpur, Lucknow, Sholapur, Jamshedpur and Agra

2010, and Bharat Stage V is yet to be implemented in 2017. Based on the reports of Central Pollution Control Board, Supreme Court of India has passed a directive in 2001 for controlling ambient air pollution in 16 cities across India. However, in spite of these policies in place, NO_2 emission across several Indian cities is rising.

4. Econometric methodology and data

For the analysis, the entire dataset of 139 cities for 2001-2013 has been segregated into industrial and residential areas[2], as the emission pattern in these two areas differ significantly, and therefore, they should be analyzed in isolation. For analyzing the impact of pollution on level of income, dataset for each of the two areas has been segregated into three parts, namely low, medium, and high income. This will allow us to observe the income-emission association in a comparative manner.

For achieving the research objective, we have formulated the following regression model:

$$E_{ijk} = a_0 + a_1 C_{jkl} + a_2 POP_{jk} + a_3 Y_{jk}.POP_{jk} + a_4 Y_{jk} + a_5 Y_{jk}^2 + a_6 Y_{jk}^3 + \varepsilon_t \quad (1)$$

Where, *E* is the emission, *C* is the city specific effect, *POP* is the population, *Y* is the city level income, *i* is the pollutant (NO_2 in this case), *j* is the income level, *k* is the area classification, *l* is city specific effects, and ε is error term.

For Indian cities, most of the human made ambient air pollution can be attributed to fossil fuel consumption, and it can be further subdivided into commercial electricity consumption and combustion of petroleum products. Majority of the commercial electricity utilized in India is generated out of the thermal power plants, which run on coal and crude oil. On the other hand, direct utilization of petroleum products can be seen in transportation sector and in households. Over the years, researchers have identified commercial electricity consumption and combustion

[2] Central Pollution Control Board collects and publishes separate data for industrial and residential areas.

of petroleum products as primary sources of ambient air pollution in Indian cities (for a detailed review, see Mallik and Lal, 2014). Therefore, in our study, we have identified these two factors as city specific effects in our model.

Based on Eq. 1, we have formed two models, and those are as per the following:

$$E_{ijk} = a_0 + a_1 EC_{jk} + a_2 POP_{jk} + a_3 Y_{jk}.POP_{jk} + a_4 Y_{jk} + a_5 Y_{jk}^2 + a_6 Y_{jk}^3 + \varepsilon_t \qquad (2)$$

$$E_{ijk} = a_0 + a_1 PC_{jk} + a_2 POP_{jk} + a_3 Y_{jk}.POP_{jk} + a_4 Y_{jk} + a_5 Y_{jk}^2 + a_6 Y_{jk}^3 + \varepsilon_t \qquad (3)$$

Where, *EC* is electricity consumption, and *PC* is petroleum consumption. In future, we shall refer Eq. 2 as "Electricity consumption model" and Eq. 3 as "Petroleum consumption model".

The emission data for NO_2 (in $\mu g/m^3$) have been collected from the Central Pollution Control Board, India, electricity consumption data (in GWH) have been collected from the Ministry of Power, Govt. of India, petroleum consumption data (in Kg) have been collected from the Ministry of Petroleum & Natural Gas, Govt. of India, population data has been collected from the Census, Ministry of Home Affairs, Govt. of India, city level income data (in Rs. Lacs) have been collected from Directorate of Economic and Statistics of individual states. The unit of observation is city-wide, i.e. the income data collected for cities is the total annual income of the cities, and the NO_2 emission data is the city-wide annual average NO_2 emission. Both of the data are collected separately for residential and industrial areas.

Multicolinearity is a problem with the model (see Appendix 1D and 1E), in which the powered terms of the independent variables are used, and as a result, interactions among those independent variables increase the level of standard errors for their estimated coefficients. In order to handle this issue, the models have been specified by removing orthogonally transformed independent variables correlating with lower order terms through auxiliary regressions. Once a specification is chosen, the within model has been tested with the original data. Once the models are estimated, we have checked the robustness of the models (see Appendix 1F and 1G).

5. Data analysis for industrial area

For analyzing the EKC(s) for industrial area, electricity consumption model and petroleum consumption model have been tested and regression results have been recorded in Appendix 1A and Appendix 1B. Analyzing first order conditions (FOC) and second order conditions (SOC) recorded in Table 1, shape of EKCs can be estimated. If we look at the nature of elasticity of the EKC for all income levels in industrial area using electricity consumption model, then we can see that the EKC is inverted U-shaped (Figure 1).

$$\frac{d\,ln\,NO_2}{d\,ln\,Y}\begin{cases} > 0, & 0 < Y < 853.99 \\ < 0, & Y > 853.99 \end{cases}$$

Similarly, if we look at the nature of elasticity of the EKC for all income levels in industrial area using petroleum consumption model, then we can see that the EKC is inverted U-shaped (Figure 1).

$$\frac{d\,ln\,NO_2}{d\,ln\,Y}\begin{cases} > 0, & 0 < Y < 3902.43 \\ < 0, & Y > 3902.43 \end{cases}$$

Once we have estimated EKCs for all income levels in the industrial area, now we can proceed with EKC estimation for three income levels, i.e. low, medium and high income areas.

5.1. Analysis for low income industrial area

FOCs of both the models have been estimated and recorded in Table 4. For both the models, income-emission associations are parallel to horizontal axis with zero slopes (Figure 1).

5.2. Analysis for medium income industrial area

FOCs of both the models have been estimated and recorded in Table 4. Income-emission associations are linearly increasing with slope for electricity consumption model is 4.45, and for petroleum consumption model is 4.48 (Figure 1).

5.3. Analysis for high income industrial area

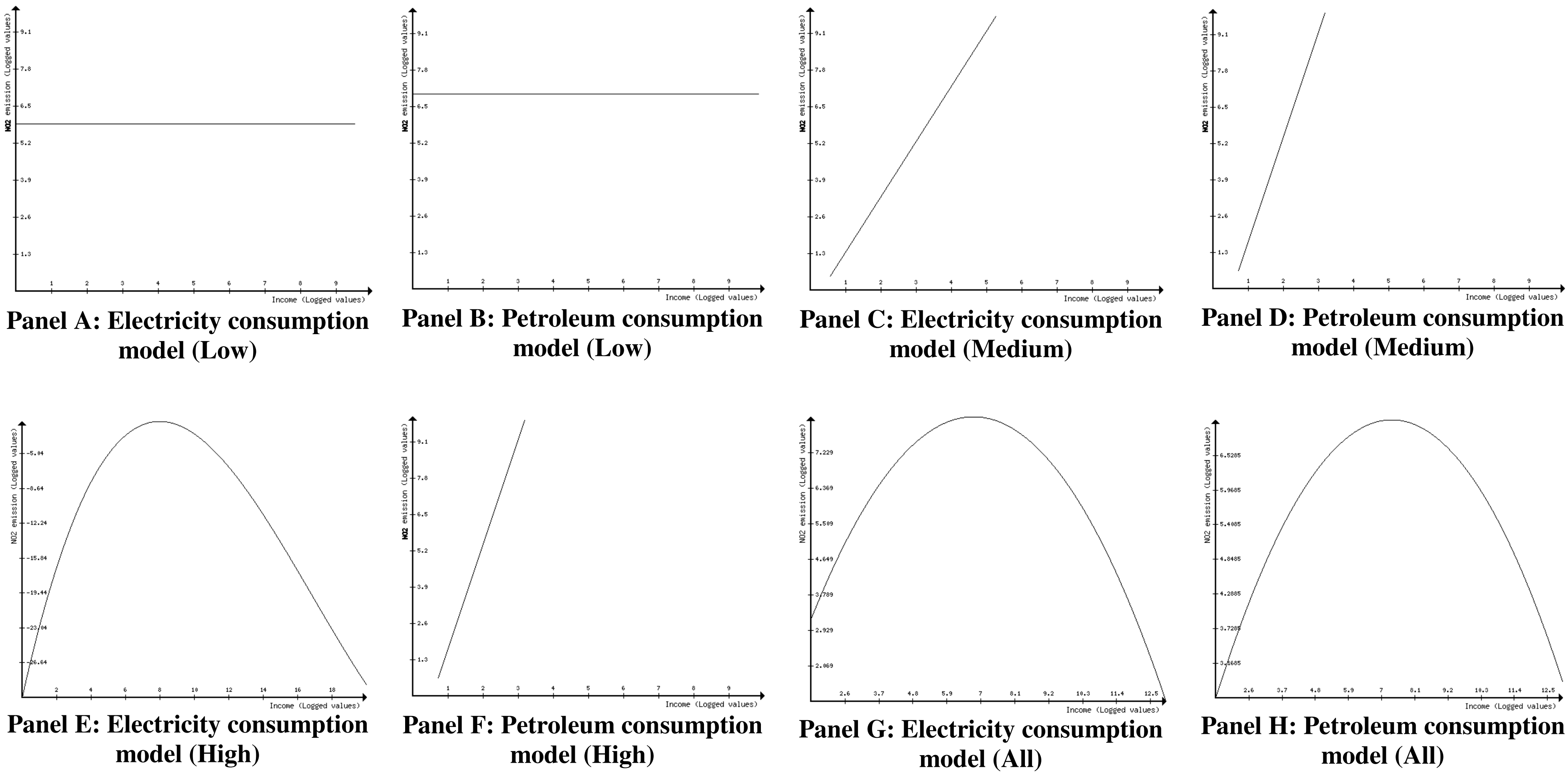
Equating the FOC to zero for the electricity consumption model, the turnaround point of the EKCs has been estimated and recorded in Table 4. Now we will estimate the shape of the EKC. If we look at the nature of elasticity of the EKC in this case, then we can see that the EKC is inverted U-shaped (Figure 1).

$$\frac{d\ ln\, NO_2}{d\ ln\, Y}\begin{cases} > 0, & 0 < Y < 2916.75 \\ < 0, & Y > 2916.75 \end{cases}$$

For petroleum consumption model, the SOC is zero, and therefore, the income-emission association is linearly increasing with slope of 6.89 (Figure 1).

Table 1: EKC Estimation for industrial area cities

Income level	*Electricity consumption model*	*FOC* $\left[\frac{d\ ln\ NO_2}{d\ ln\ Y}\right]$	*SOC* $\left[\frac{d^2\ ln\ NO_2}{d\ (ln\ Y)^2}\right]$	*Turnaround point (Rs. Lacs)*	*Shape of EKC*
Low	$\ln(NO_2) = 4.426 + 0.136 \ln(EC)$	0	-	-	Linear (Panel A)
Medium	$\ln(NO_2) = 25.853 – 2.402 \ln(POP) + 0.330 \ln(Y). \ln(POP)$	$0.330 \ln(POP)$	0	-	Linear (Panel C)
High	$\ln(NO_2) = 26.851 – 3.818 \ln(POP) + 0.574 \ln(Y). \ln(POP) – 0.656 (\ln Y)^2 + 0.013 (\ln Y)^3$	$0.574 \ln(POP) – 1.312 (\ln Y) + 0.039 (\ln Y)^2$	$– 1.312 + 0.078 \ln(Y)$	2916.75	Inverted U-shaped (Panel E)
All	$\ln(NO_2) = 15.188 – 1.581 \ln(POP) + 0.237 \ln(Y). \ln(POP) – 0.765 \ln(Y) – 0.177 (\ln Y)^2$	$– 0.765 + 0.237 \ln(POP) – 0.354 (\ln Y)$	– 0.354	853.99	Inverted U-shaped (Panel G)
Income level	*Petroleum consumption model*	*FOC* $\left[\frac{d\ ln\ NO_2}{d\ ln\ Y}\right]$	*SOC* $\left[\frac{d^2\ ln\ NO_2}{d\ (ln\ Y)^2}\right]$	*Turnaround point (Rs. Lacs)*	
Low	$\ln(NO_2) = 4.555$	0	-	-	Linear (Panel B)
Medium	$\ln(NO_2) = 25.094 – 2.437 \ln(POP) + 0.332 \ln(Y). \ln(POP)$	$0.332 \ln(POP)$	0	-	Linear (Panel D)
High	$\ln(NO_2) = 24.463 + 0.199 \ln(PC) – 2.941 \ln(POP) + 0.461 \ln(Y). \ln(POP)$	$0.461 \ln(POP)$	0	-	Linear (Panel E)
All	$\ln(NO_2) = 12.242 – 1.223 \ln(POP) + 0.164 \ln(Y). \ln(POP) – 0.157 (\ln Y)^2 + 0.002 (\ln Y)^3$	$0.164 \ln(POP) – 0.314 (\ln Y) + 0.006 (\ln Y)^2$	$– 0.314 + 0.012 \ln(Y)$	3902.43	Inverted U-shaped (Panel H)



Panel A: Electricity consumption model (Low)

Panel B: Petroleum consumption model (Low)

Panel C: Electricity consumption model (Medium)

Panel D: Petroleum consumption model (Medium)

Panel E: Electricity consumption model (High)

Panel F: Petroleum consumption model (High)

Panel G: Electricity consumption model (All)

Panel H: Petroleum consumption model (All)

Figure 1: Estimated EKCs for industrial area

6. Data analysis for residential area

For analyzing the EKC(s) for residential area, electricity consumption model and petroleum consumption model have been tested and regression results have been recorded in Appendix 1A and Appendix 1C. Analyzing first order conditions (FOC) and second order conditions (SOC) recorded in Table 5, shape of EKCs can be estimated. If we look at the nature of elasticity of the EKC for all income levels in industrial area using electricity consumption model, then we can see that the EKC is inverted U-shaped (Figure 2).

$$\frac{d\,ln\,NO_2}{d\,ln\,Y}\begin{cases} > 0, & 0 < Y < 1683.31 \\ < 0, & Y > 1683.31 \end{cases}$$

Similarly, nature of elasticity using petroleum consumption model reveals that the EKC is inverted U-shaped (Figure 1).

$$\frac{d\,ln\,NO_2}{d\,ln\,Y}\begin{cases} > 0, & 0 < Y < 975.51 \\ < 0, & Y > 975.51 \end{cases}$$

Once we have estimated EKCs for all income levels in the industrial area, now we can proceed with EKC estimation for three levels of income, i.e. low, medium and high income areas.

6.1. Analysis for low income residential area

FOCs of both the models have been estimated and recorded in Table 5. For electricity consumption model, income-emission association is parallel to the horizontal axis (Figure 2). For petroleum consumption model, income-emission associations is inverted N-shaped (Figure 2) and it is revealed by the nature of elasticity for this model.

$$\frac{d\,ln\,NO_2}{d\,ln\,Y}\begin{cases} < 0, & 0 < Y < 5.44 \\ > 0, & 5.44 < Y < 866.46 \\ < 0, & Y > 866.46 \end{cases}$$

6.2. Analysis for medium income residential area

Like the previous case, FOCs of both the models have been estimated and recorded in Table 5. For electricity consumption model, income-emission associations is inverted N-shaped (Figure 2) and it is revealed by the nature of elasticity for this model.

$$\frac{d\,ln\,NO_2}{d\,ln\,Y}\begin{cases} < 0, & 0 < Y < 752.80 \\ > 0, & 752.80 < Y < 4874.84 \\ < 0, & Y > 4874.84 \end{cases}$$

Similarly, for petroleum consumption model, income-emission associations is inverted N-shaped (Figure 2) and it is revealed by the nature of elasticity for this model.

$$\frac{d\,ln\,NO_2}{d\,ln\,Y}\begin{cases} < 0, & 0 < Y < 911.85 \\ > 0, & 911.85 < Y < 4015.02 \\ < 0, & Y > 4015.02 \end{cases}$$

6.3. Analysis for high income residential area

Like the previous two cases case, FOCs of both the models have been estimated and recorded in Table 5. For electricity consumption model, nature of elasticity of the model reveals that estimated EKC in this case is inverted U-shaped (Figure 2).

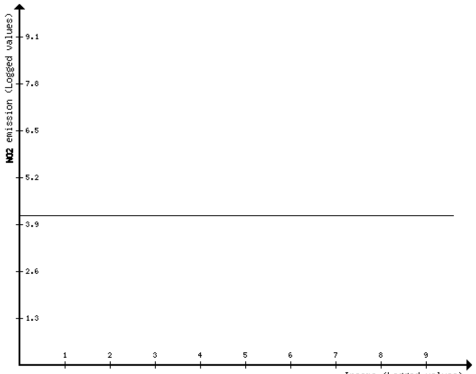
$$\frac{d\,ln\,NO_2}{d\,ln\,Y}\begin{cases} > 0, & 0 < Y < 109.50 \\ < 0, & Y > 109.50 \end{cases}$$

Similarly, for petroleum consumption model, nature of elasticity of the EKC reveals that estimated EKC in this case is inverted U-shaped (Figure 2).

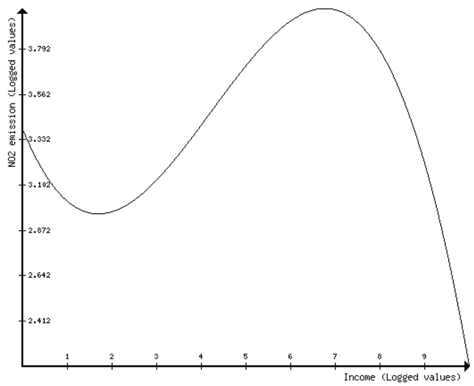
$$\frac{d\,ln\,NO_2}{d\,ln\,Y}\begin{cases} > 0, & 0 < Y < 141.91 \\ < 0, & Y > 141.91 \end{cases}$$

Table 2: EKC Estimation for residential area cities

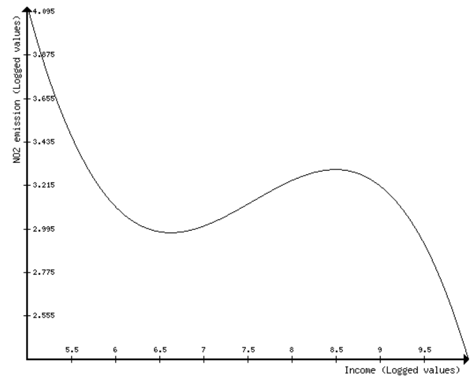
Income level	*Electricity consumption model*	*FOC* $\left[\frac{d\ ln\ NO_2}{d\ ln\ Y}\right]$	*SOC* $\left[\frac{d^2\ ln\ NO_2}{d\ (ln\ Y)^2}\right]$	*Turnaround point (Rs. Lacs)*	*Shape of EKC*
Low	$\ln(NO_2) = 9.013 + 0.293 \ln(EC) – 0.484 \ln(POP)$	0	-	-	Linear (Panel A)
Medium	$\ln(NO_2) = 67.610 – 1.761 \ln(POP) + 0.219 \ln(Y). \ln(POP) – 19.535 \ln(Y) + 2.222 (\ln Y)^2 – 0.098 (\ln Y)^3$	$0.219 \ln(POP) – 19.535 + 4.444 (\ln Y) – 0.294 (\ln Y)^2$	$4.444 – 0.588 (\ln Y)$	a. 752.80 b. 4874.84	Inverted N-shaped (Panel C)
High	$\ln(NO_2) = 12.147 – 1.006 \ln(POP) + 0.248 \ln(Y). \ln(POP) – 0.085 (\ln Y)^2 + 0.013 (\ln Y)^3$	$0.248 \ln(POP) – 0.970 (\ln Y) + 0.039 (\ln Y)^2$	$– 0.970 + 0.078 (\ln Y)$	109.50	Inverted U-shaped (Panel E)
All	$\ln(NO_2) = 13.380 – 1.339 \ln(POP) + 0.192 \ln(Y). \ln(POP) – 0.623 \ln(Y) – 0.132 (\ln Y)^2$	$0.192 \ln(POP) – 0.623 – 0.264 (\ln Y)$	$– 0.264$	1683.31	Inverted U-shaped (Panel G)
Income level	*Petroleum consumption model*	*FOC* $\left[\frac{d\ ln\ NO_2}{d\ ln\ Y}\right]$	*SOC* $\left[\frac{d^2\ ln\ NO_2}{d\ (ln\ Y)^2}\right]$	*Turnaround point (Rs. Lacs)*	
Low	$\ln(NO_2) = 18.238 + 0.196 \ln(PC) – 1.313 \ln(POP) + 0.105 \ln(Y). \ln(POP) – 1.797 \ln(Y) +0.203 \ln(Y)^2 – 0.016 (\ln Y)^3$	$0.105 \ln(POP) – 1.797 +0.406 \ln (Y) – 0.048 (\ln Y)^2$	$0.406 – 0.096 \ln (Y)$	a. 5.44 b. 866.46	Inverted N-shaped (Panel B)
Medium	$\ln(NO_2) = 67.358 – 1.555 \ln(POP) + 0.205 \ln(Y). \ln(POP) – 20.281 \ln(Y) + 2.335 (\ln Y)^2 - 0.103 (\ln Y)^3$	$0.205 \ln(POP) – 20.281 + 4.670 (\ln Y) – 0.309 (\ln Y)^2$	$4.670 – 0.618 \ln (Y)$	a. 911.85 b. 4015.02	Inverted N-shaped (Panel D)
High	$\ln(NO_2) = 11.527 – 1.031 \ln(POP) + 0.233 \ln(Y). \ln(POP) – 0.032 (\ln Y)^2 + 0.011 (\ln Y)^3$	$0.233 \ln(POP) – 0.864 (\ln Y) + 0.033 (\ln Y)^2$	$– 0.864 + 0.066 \ln (Y)$	141.91	Inverted U-shaped (Panel E)
All	$\ln(NO_2) = 18.076 – 1.766 \ln(POP) + 0.216 \ln(Y). \ln(POP) – 0.622 \ln(Y) – 0.166 (\ln Y)^2$	$– 0.622 + 0.216 \ln(POP) – 0.332 (\ln Y)$	$– 0.332$	975.51	Inverted U-shaped (Panel H)



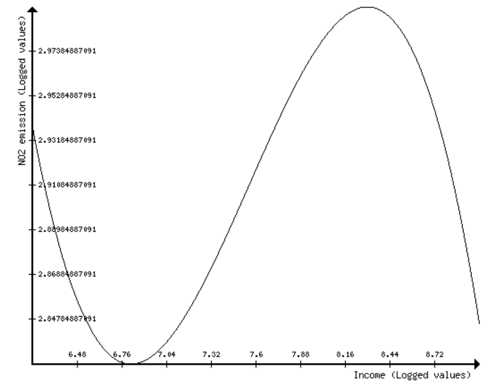
Panel A: Electricity consumption model (Low)



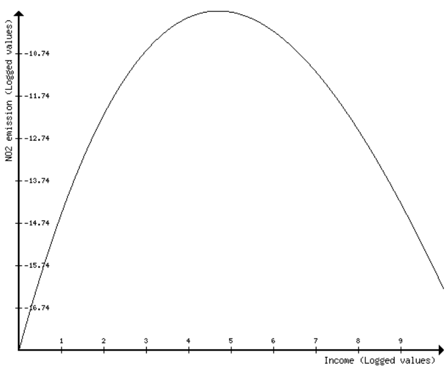
Panel B: Petroleum consumption model (Low)



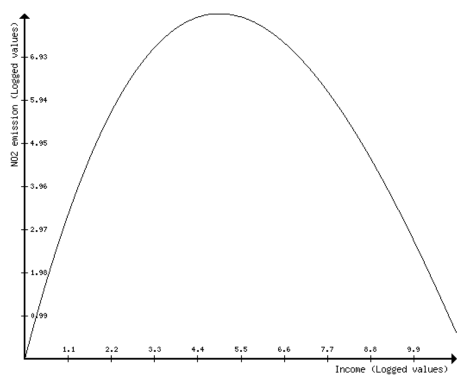
Panel C: Electricity consumption model (Medium)



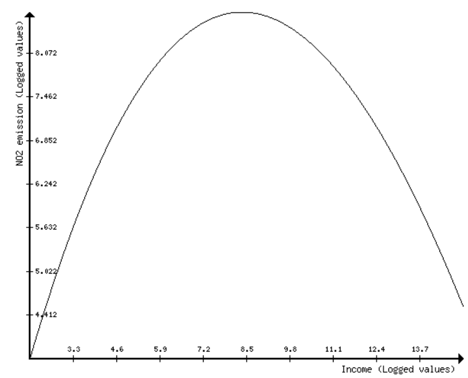
Panel D: Petroleum consumption model (Medium)



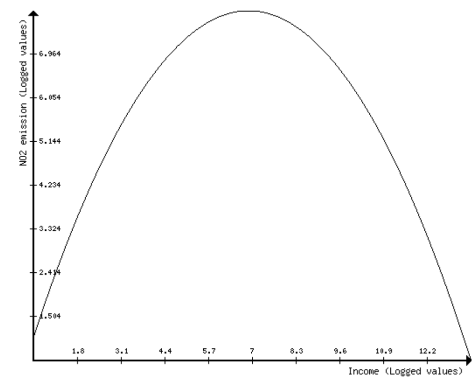
Panel E: Electricity consumption model (High)



Panel F: Petroleum consumption model (High)



Panel G: Electricity consumption model (All)



Panel H: Petroleum consumption model (All)

Figure 2: Estimated EKCs for industrial area

7. Policy implications

By far, we have analyzed the EKC hypothesis for 139 Indian cities for the period 2001-2013, and apart from inverted U-shaped EKC, we have also found the income-emission associations to be inverted N-shaped and linear (see Table 3 and 4). Now, we will analyze the scenarios for industrial and residential areas respectively.

Table 3: Summary of the results for full dataset (shape of EKC and corresponding turnaround points)

Category	*Electricity consumption model*		*Petroleum consumption model*	
	Shape of EKC	***Turnaround point (Rs. Lacs)***	***Shape of EKC***	***Turnaround point (Rs. Lacs)***
Industrial	Inverted U-shaped	853.99	Inverted U-shaped	3902.43
Residential	Inverted U-shaped	1683.31	Inverted U-shaped	975.51

Table 4: Summary of the results for segregated dataset (shape of EKC and corresponding turnaround points)

<table>
<tr><th rowspan="2">Income Level</th><th colspan="3">Electricity consumption model</th><th colspan="3">Petroleum consumption model</th></tr>
<tr><th>Shape of EKC</th><th colspan="2">Turnaround point (Rs. Lacs)</th><th>Shape of EKC</th><th colspan="2">Turnaround point (Rs. Lacs)</th></tr>
<tr><td colspan="7">Category: Industrial</td></tr>
<tr><td>Low</td><td>Linear</td><td colspan="2">-</td><td>Linear</td><td colspan="2">-</td></tr>
<tr><td>Medium</td><td>Linear</td><td colspan="2">-</td><td>Linear</td><td colspan="2">-</td></tr>
<tr><td>High</td><td>Inverted U-Shaped</td><td colspan="2">2916.75</td><td>Linear</td><td colspan="2">-</td></tr>
<tr><td colspan="7">Category: Residential</td></tr>
<tr><td>Low</td><td>Linear</td><td colspan="2">-</td><td>Inverted N-Shaped</td><td>5.44</td><td>866.46</td></tr>
<tr><td>Medium</td><td>Inverted N-Shaped</td><td>752.80</td><td>4874.84</td><td>Inverted N-Shaped</td><td>911.85</td><td>4015.02</td></tr>
<tr><td>High</td><td>Inverted U-Shaped</td><td colspan="2">109.50</td><td>Inverted U-Shaped</td><td colspan="2">141.91</td></tr>
</table>

7.1. Policy implications for industrial areas

For industrial areas, we have found the evidence of inverted U-shaped EKCs for the aggregate dataset. In case of segregated dataset, evidence of inverted U-shaped EKC can be found only for the high income areas using the electricity consumption model. In rest of the cases, the income-emission associations have been found to be linear. We will now discuss all of these cases one by one.

For low income cities, income-emission associations have been found to be linear and horizontal for both the models. Commercial electricity consumption has been found to have direct impact on level of NO_2 emission, whereas petroleum consumption has been found to have no impact on level of NO_2 emission. In both the cases, emission levels have found to be constant. The level of emission for electricity consumption model is 133.18μg/m^3, and for petroleum consumption model is 95.11μg/m^3. It can be seen that the level of emissions found in both of the cases are above the emission standards set by Central Pollution Control Board of India, i.e. 40μg/m^3. Hence, it is clearly visible that these areas need serious attention regarding emission control. These cities are majorly dominated by chemical plants, coal mines, thermal power plants, and automobile manufacturing plants. NO_2 emissions found in these cities are majorly generated out of these plants and mines, and contribution of vehicular emission is comparatively lower. Therefore, the income-emission pattern for petroleum consumption model is independent of the petroleum consumption, and for electricity consumption model, it is dependent on the commercial electricity consumption. In order to reduce emissions from these areas, plants in these areas should introduce selective catalytic reduction (SCR) technology, selective non-catalytic reduction (SNCR) technology, and low NO_x burners. Apart from that, switching from coal to natural gas for electricity generation can also reduce the level of NO_2 in these regions. Coming to vehicular emission, Bharat Stage IV has not yet been implemented in any of these cities. Therefore, presently there are no strict regulations in these cities for controlling vehicular emissions. As it is expected that the nationwide implementation of Bharat Stage IV will be completed by 2017, it can be assumed that the level of NO_2 generated vehicular emission can be controlled after that only.

For medium income cities, income-emission associations have been found to be linearly increasing for both the models. Slope of the diagram for electricity consumption model is 4.45, and for petroleum consumption model is 4.48. Both of the models show that the level of emission is rising with population and income, and the trend of growth is nearly similar for both of the cases. Most of these cities are in a socio-economic transformation phase, and it is majorly driven by the industrial growth being achieved in these cities. Due to rapid job creation in the industrial sector, these cities are experiencing migration of labors from low income areas. As the existing urban infrastructure has not yet been capable of accommodating this rise in population, therefore, a number of slum areas have developed around these cities. These are called the shadow cities (Neuwirth, 2005). Along with the industries, NO_2 emission is also caused by use of firewood and charcoal burning from the slums formed in the industrial belt. Apart from that, in order to accommodate industrial and population growth, these cities have been experiencing rapid deforestation programs, which is another reason for rise in NO_2 emission in these cities. Talking about vehicular emission, five cities under this category are already under Bharat Stage IV, whereas the others are yet to come under this scheme. Therefore, it can be understood that the income-emission association should be linearly increasing for these cities, irrespective of the energy consumption pattern. In order to control the emission in these cities, the municipal body should implement proper rehabilitation facilities for the slum dwellers, making them aware about the negative consequences of firewood and charcoal cooking, providing them with solar panels for green electrification purpose, and providing them with proper educational and healthcare facilities. The organizations, for which they are working, should also come forward in order to make this initiative a fruitful one. By virtue of public-private partnership, livelihood of those people can be uplifted, and in that way, level of human made NO_2 emission can be reduced.

For high income cities, income-emission associations have been found to be following the generally accepted inverted U-shaped form of EKC for electricity consumption model, and linearly increasing with a slope of 6.89 for petroleum consumption model. In most of these cities, Bharat Stage IV has already been implemented. However, due to inadequate road infrastructure, vehicular congestion is a very common phenomenon in these cities. During congestion period, NO_2 is generated out of traffic fumes. Apart from that, a huge number of small food chains around the industrial areas can be seen in these cities. These are the places, where majorly high flame cooking is followed. This is another way, through which NO_2 generation in these areas is augmented by extensive usage of yellow-tipping flames. Therefore, the rise in NO_2 in these cities is majorly due to *Fuel* NO_2. On the other hand, there are two reasons behind the fall in NO_2 emission from *Thermal* NO_2. First, cities with higher level of income in this particular stratum fall under the directive for emission passed by Supreme Court of India in 2001, and according to that directive, the active manufacturing and power plants need to use clean fuels, pollution control devices, clean technologies, and development of green belts. Second, these cities have experienced the rise of service industry over the years, and this industry contributes less amount of NO_2 compared to the secondary sector. Moreover, the commercial electricity consumed by this sector is also comparatively very less than the secondary sector. The percentage of service industry rises with the rise in income along this stratum. Therefore, inverted U-shaped EKC is found for this particular stratum. At the turnaround point of this EKC, emission level is found to be $30.81\mu g/m^3$, which is within the range specified by Central Pollution Control Board. Therefore, it can be stated that the existing pollution abatement policies are sufficient to control the ambient air pollution level in these cities. However, keeping in mind the linearly increasing income-emission association for petroleum consumption model, it can be said that the municipal bodies in these cities should consider improving the existing road infrastructure to minimize the level of vehicular congestion. On the other hand, the small food chains should also be brought under the pollution control directives, so that they can be aware of the negative consequences of high flame cooking. The latter cannot be achieved only by mere government intervention, and therefore, the local NGOs should come forward to collaborate with government for making the directives effective.

7.2. Policy implications for residential areas

For residential areas, we have found the evidence of inverted U-shaped EKCs for the aggregate dataset. In case of segregated dataset, evidence of inverted U-shaped EKC can be found only for the high income areas. In rest of the cases, the income-emission associations have been found to be linear and inverted N-shaped. We will now discuss all of these cases one by one.

For low income cities, income-emission associations have been found to be linear for electricity consumption model and inverted N-shaped for petroleum consumption model. Commercial electricity consumption has been found to have direct impact on level of NO_2 emission. The level of emission for electricity consumption model is 78.88μg/m^3. It can be seen that the level of emissions found in this case is above the emission standards set by Central Pollution Control Board of India, i.e. 40μg/m^3. Most of these cities under this stratum are low in population and income, and the housing infrastructure in these cities is comparatively lower compared to other cities in the remaining two strata. Therefore, the level of energy efficiency is comparatively lower, and it results in higher consumption of electricity in these buildings. This phenomenon is observable across this stratum, irrespective of the income level. The low energy efficiency of these buildings causes space heating, by means of heat radiation through walls. This is one of the major reasons behind rise in NO_2 emission is these cities, and this explains the horizontal income-emission association for electricity consumption model in these cities. On the other hand, consumption of petroleum based fuel in these cities rise with the rise in income. The first turnaround point on the inverted N-shaped income-emission association is achieved at Rs. 5.44 Lacs, which is lower than the minimum income level (= Rs. 24.01 Lacs) of this stratum. Therefore, this turnaround was achieved at the very earliest stage of the industrialization, and with rise in income and population, the NO_2 emission level started to rise. However, at the second turnaround point at Rs. 866.46 Lacs, the level of NO_2 emission is 22.74μg/m^3, and this emission level is below the emission standards set by Central Pollution Control Board of India, i.e. 40μg/m^3. In view of this evidence, it may be said that, when the energy efficiency is measured in terms of commercial electricity consumption, low income residential cities fail to meet the emission standards, whereas the same is met for petroleum consumption. One of the major reasons behind this can be the purchasing power, which enables them to afford the less costly electricity, compared to petroleum products. Hence, it is the energy consumption pattern, which derives the emission level in these cities. In order to mitigate this issue, government should come forward with energy-efficient landscaping initiatives to preserve energy by minimizing heat loss, and to implement low-energy housing strategy in order to lessen electricity consumption. The infrastructural development authority should also check the life-cycle of the old buildings in these cities, and plan the strategic implementation accordingly. They also need to make sure not to use high environmentally adverse products while demolishing or recycling the building, as it can cause more damage to environment.

For medium income cities, income-emission associations have been found to be inverted N-shaped for both the models. For electricity consumption model, at the first turnaround point, the level of NO_2 emission is 19.58μg/m^3, and at the second turnaround point, the level of NO_2 emission is 26.93μg/m^3. For petroleum consumption model, at the first turnaround point, the level of NO_2 emission is 16.90μg/m^3, and at the second turnaround point, the level of NO_2 emission is 19.99μg/m^3. In both of the cases, all of the four emission levels are below the emission standards set by Central Pollution Control Board of India, i.e. 40μg/m^3. In view of this evidence, it can be said that emission levels in the residential areas of cities under this stratum are within controllable limits. In both of the cases, the first turnaround points arise because of only one city, Thoothukudi. Though the income level of this city is the lowest in this stratum, it has a very high human development index (= 0.791). Because of the strict environmental policies followed by the municipal government in this city, it has been able to reduce the level of emission and achieve energy efficiency, and resulted in the first turnaround points. However, as most of these residential areas are formed around the industrial belts, rise in NO_2 emission in the residential areas can be seen in terms of smog formation. It rises with the rise in income, and vehicular congestion. As migration is increasing the population in these cities, therefore the incidences of vehicular congestion is a very common phenomenon in these cities. However, most of these cities have gradually started consumption of compressed natural gas (CNG) for the public transport, and this phenomenon is visible is the cities, which are on the higher side in income. Moreover, under this stratum, most of the cities with higher income level have started to use solar powered traffic light and street light mechanisms for reducing emission levels. This environmental awareness has made the income-emission association in these cities to reach the second turnaround point, and thereby, making the curve inverted N-shaped.

For high income cities, income-emission associations have been found to be following the generally accepted inverted U-shaped form of EKC for both the models. For electricity consumption model, the turnaround point arrives at the emission level of 22.08μg/m^3, and for petroleum consumption model, the turnaround point arrives at the emission level of 21.47μg/m^3. In both of the cases, emission levels are below the emission standards set by Central Pollution Control Board of India, i.e. 40μg/m^3. In view of this evidence, it can be said that emission levels in the residential areas of cities under this stratum are within controllable limits. Most of these cities follow the vehicular emission standards set by Bharat Stage IV, and therefore, the levels of vehicular emission in these cities are less. Nevertheless, vehicular congestion is a major problem in these cities, and it is majorly caused by rise in population. Apart from that, heights of the buildings can cause ventilation and blockage of sunlight in the neighboring areas. It catalyzes the use of air conditioning in the neighboring areas and it also resists them from using solar panels at the rooftops. This causes severe humidity and rise in outdoor temperature, thereby, reducing the energy efficiency and causing smog formations in these areas. In order to control this problem, the municipal authorities should try to implement energy-plus buildings in the high-rises, so that the neighboring areas can get surplus passive solar energy. It can not only enhance the energy efficiency in these areas, but also can reduce the chances of smog formation. Moreover, the municipal authority should focus more on improving the public transport infrastructure, so that people can avail public transport more than private vehicles. This step can reduce the vehicular congestions in these areas.

8. Conclusion

By far, we have estimated the EKCs for 139 Indian cities, by considering all them in single stratum, and then by segregating them into three levels of income. After analyzing both the industrial and residential areas, it has been found that the levels of emission are different for each of the stratum, and therefore, suggested policy decisions are also modified to address that particular stratum. However, if a suggested policy in a lower stratum is implemented in a higher stratum along with the policies suggested for that particular stratum, it can provide a multiplier effect in bringing down the emission level.

As a whole, keeping all the suggested policies in mind, it can be stated that bringing down the level of NO_2 emission requires improvement of existing road transport facilities, introduction of energy-plus buildings, reducing high flame cooking in restaurants and small food chains, and most importantly, engaging people and private organizations in increasing the level of environmental awareness among citizens. This public-people-private-partnership mechanism can make the emission reduction efforts much effective at the ground level.

We can conclude that based on our results and looking at the present developments in alternate energy discovery process in India, the turnaround points, which have not been achieved within the study period of 2001-2013, may possibly be achieved in the later stages of 2014. However, in our study, we did not consider the 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 development time frames, as well. These can bring forth significant insights about the nature of EKCs in Indian cities.

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Appendix 1A: Model estimation results for NO_2 using full dataset

Area	*Model*	*Effect*	a_0	a_1	a_2	a_3	a_4	a_5	a_6	*Wald Chi²*	*Prob. > Chi²*
Industrial	*Electricity Consumption*	*Fixed*	15.188[a]	-	-1.581[a]	0.237[a]	-0.765[a]	-0.177[a]	-	17.73	0.0000
			(6.90)	-	(-6.72)	(7.81)	(-3.19)	(-5.04)	-		
		Random	14.076[a]	-	-	-	-0.642[a]	-0.130[a]	0.001	98.03	0.0000
			(8.36)	-	-	-	(-2.93)	(-4.06)	(0.68)		
	Petroleum Consumption	*Fixed*	17.544[a]	0.016	-	-	-0.611[a]	-0.164[a]	-	15.36	0.0000
			(9.58)	(0.58)	-	-	(-2.79)	(-5.15)	-		
		Random	12.242[a]	-	-1.223[a]	0.164[a]	-	-0.157[a]	0.002[b]	83.50	0.0000
			(9.19)	-	(-8.35)	(8.39)	-	(-5.28)	(2.22)		
Residential	*Electricity Consumption*	*Fixed*	14.708[a]	-0.047	-1.555[a]	0.239[a]	-0.754[a]	-0.178[a]	0.002	18.06	0.0000
			(6.25)	(-0.99)	(-6.33)	(7.78)	(-3.14)	(-5.03)	(1.40)		
		Random	13.380[a]	-	-1.339[a]	0.192[a]	-0.623[a]	-0.132[a]	-	101.55	0.0000
			(7.39)	-	(-6.87)	(7.65)	(-2.85)	(-4.07)	-		
	Petroleum Consumption	*Fixed*	18.076[a]	-	-1.766[a]	0.216[a]	-0.622[a]	-0.166[a]	-	15.42	0.0000
			(9.25)	-	(-8.87)	(8.74)	(-2.83)	(-5.20)	-		
		Random	11.992[a]	-0.022	-	0.165[a]	-	-0.156[a]	0.002	82.48	0.0000
			(8.51)	(-0.72)	-	(8.38)	-	(-5.26)	(2.19)		

Energy Consumption model: $E_{ijk} = a_0 + a_1 EC_{jk} + a_2 POP_{jk} + a_3 Y_{jk}.POP_{jk} + a_4 Y_{jk} + a_5 Y_{jk}^2 + a_6 Y_{jk}^3 + \varepsilon_t$

Petroleum Consumption model: $E_{ijk} = a_0 + a_1 PC_{jk} + a_2 POP_{jk} + a_3 Y_{jk}.POP_{jk} + a_4 Y_{jk} + a_5 Y_{jk}^2 + a_6 Y_{jk}^3 + \varepsilon_t$

a value at 1% significance level, b value at 5% significance level, c value at 10% significance level; t-statistics are within parentheses

Note: models for respective stratum have been selected based on Hausman specification test

Appendix 1B: Industrial area model estimation results for NO_2 using segregated dataset

Model	*Effect*	a_0	a_1	a_2	a_3	a_4	a_5	a_6	*Wald Chi*^{2}	*Prob. > Chi*^{2}
					Low Income					
Electricity Consumption	*Fixed*	7.549[b]	0.150[b]	-	-0.051	-0.652	-	-	4.65	0.000
		(2.19)	(2.40)	-	(-0.98)	(-0.68)	-	-		
	Random	4.426[b]	0.136[b]	-	-	-0.772	-	-	24.57	0.000
		(1.85)	(2.23)	-	-	(-0.83)	-	-		
Petroleum Consumption	*Fixed*	9.393[b]	-	-0.416	-	-0.761	-	-0.012	4.03	0.001
		(2.56)	-	(-1.23)	-	(-0.79)	-	(-1.21)		
	Random	4.555[b]	0.066	-	-	-	0.218	-0.014	20.40	0.002
		(2.10)	(1.03)	-	-	-	(1.34)	(-1.37)		
					Medium Income					
Electricity Consumption	*Fixed*	26.520[b]	-0.025	-	-	-2.316	-0.107	-	16.65	0.000
		(2.24)	(-0.55)	-	-	(-0.49)	(-0.17)	-		
	Random	25.853[b]	-	-2.402[a]	0.330[a]	-	-	-0.002	100.18	0.000
		(2.19)	-	(-5.81)	(6.50)	-	-	(-0.08)		
Petroleum Consumption	*Fixed*	25.533[b]	0.015	-	-	-1.781	-	-	16.59	0.000
		(2.18)	(0.17)	-	-	(-0.38)	-	-		
	Random	25.094[b]	-	-2.437[a]	0.332[a]	-1.762	-	0.001	100.14	0.000
		(2.15)	-	(-5.57)	(6.36)	(-0.38)	-	(0.02)		
					High Income					
Electricity Consumption	*Fixed*	26.851[a]	-	-3.818[a]	0.574[a]	-	-0.656[b]	0.013[c]	8.94	0.000
		(4.32)	-	(-3.95)	(4.95)	-	(-2.40)	(1.71)		
	Random	12.781[b]	-0.005	-	-	2.296	-	0.014[c]	41.68	0.000
		(2.30)	(-0.08)	-	-	(1.16)	-	(1.76)		
Petroleum Consumption	*Fixed*	24.463[a]	0.199[b]	-2.941[a]	0.461[a]	-	-	0.006	9.80	0.000
		(3.90)	(-2.16)	(-2.81)	(4.09)	-	-	(0.64)		
	Random	11.063[c]	-0.141[c]	-	0.273[a]	-	-0.419	-	45.49	0.000
		(1.95)	(-1.81)	-	(2.69)	-	(-1.46)	-		

Energy Consumption model: $E_{ijk} = a_0 + a_1 EC_{jk} + a_2 POP_{jk} + a_3 Y_{jk}.POP_{jk} + a_4 Y_{jk} + a_5 Y_{jk}^2 + a_6 Y_{jk}^3 + \varepsilon_t$

Petroleum Consumption model: $E_{ijk} = a_0 + a_1 PC_{jk} + a_2 POP_{jk} + a_3 Y_{jk}.POP_{jk} + a_4 Y_{jk} + a_5 Y_{jk}^2 + a_6 Y_{jk}^3 + \varepsilon_t$

a value at 1% significance level, b value at 5% significance level, c value at 10% significance level; t-statistics are within parentheses

Note: models for respective stratum have been selected based on Hausman specification test

Appendix 1C: Residential area model estimation results for NO_2 using segregated dataset

Model	*Effect*	a_0	a_1	a_2	a_3	a_4	a_5	a_6	*Wald Chi²*	*Prob. > Chi²*
Low Income										
Electricity Consumption	*Fixed*	14.055[a]	-	-0.884[a]	0.039	-	0.258[c]	-	8.68	0.000
		(4.42)	-	(-3.03)	(0.84)	-	(1.80)	-		
	Random	9.013[a]	0.293[a]	-0.484[c]	-	-1.138	-	-0.013	47.21	0.000
		(3.29)	(4.23)	(-1.89)	-	(-1.34)	-	(-1.63)		
Petroleum Consumption	*Fixed*	18.238[a]	0.196[a]	-1.313[a]	0.105[b]	-1.797[b]	-	-0.016[c]	7.98	0.000
		(5.29)	(3.21)	(-4.30)	(2.23)	(-2.01)	-	(-1.90)		
	Random	10.392[a]	0.087	-0.696[a]	-	-	0.115	-	31.10	0.000
		(3.54)	(1.62)	(-2.60)	-	-	(0.80)	-		
Medium Income										
Electricity Consumption	*Fixed*	67.610[a]	-	-1.761[a]	0.219[a]	-19.535[a]	2.222[a]	-0.098[a]	11.14	0.000
		(4.49)	-	(-4.81)	(5.20)	(-3.22)	(2.80)	(-2.91)		
	Random	67.440[a]	0.017	-	0.211[a]	-	2.300[a]	-0.102[a]	65.22	0.000
		(4.46)	(0.43)	-	(5.01)	-	(2.92)	(-3.03)		
Petroleum Consumption	*Fixed*	67.795[a]	-	-1.777[a]	-	-19.534[a]	-	-0.098[a]	11.15	0.000
		(4.52)	-	(-4.57)	-	(-3.25)	-	(-2.93)		
	Random	67.358[a]	-	-1.555[a]	0.205[a]	-20.281[a]	2.335[a]	-0.103[a]	66.71	0.000
		(4.50)	-	(-4.38)	(4.85)	(-3.41)	(3.00)	(-3.10)		
High Income										
Electricity Consumption	*Fixed*	16.181[a]	-	-2.008[a]	0.268[a]	-	-0.361[c]	-	5.86	0.000
		(2.62)	-	(-3.17)	(3.91)	-	(-1.79)	-		
	Random	12.147[b]	-	-1.006[a]	0.248[a]	-	-0.085[b]	0.013[b]	38.66	0.000
		(2.10)	-	(-3.28)	(3.89)	-	(-2.46)	(2.04)		
Petroleum Consumption	*Fixed*	15.529[b]	-0.106	-1.635[b]	0.239[a]	-0.475	-	-	6.10	0.000
		(2.51)	(-1.51)	(-2.33)	(3.29)	(-0.25)	-	-		
	Random	11.527[b]	-	-1.031[a]	0.233[a]	-	-0.032[b]	0.011[c]	39.10	0.000
		(1.98)	-	(-2.82)	(3.51)	-	(-2.08)	(1.71)		

Energy Consumption model: $E_{ijk} = a_0 + a_1 EC_{jk} + a_2 POP_{jk} + a_3 Y_{jk}.POP_{jk} + a_4 Y_{jk} + a_5 Y_{jk}^2 + a_6 Y_{jk}^3 + \varepsilon_t$

Petroleum Consumption model: $E_{ijk} = a_0 + a_1 PC_{jk} + a_2 POP_{jk} + a_3 Y_{jk}.POP_{jk} + a_4 Y_{jk} + a_5 Y_{jk}^2 + a_6 Y_{jk}^3 + \varepsilon_t$

a value at 1% significance level, b value at 5% significance level, c value at 10% significance level; t-statistics are within parentheses

Note: models for respective stratum have been selected based on Hausman specification test

Appendix 1D: Correlations among independent variables (for industrial area)

	EC	*PC*	*POP*	*POP.Y*	*Y*	Y^2	Y^3
EC	1.0000						
PC	0.9408	1.0000					
POP	0.9484	0.8811	1.0000				
POP.Y	0.9728	0.9074	0.9754	1.0000			
Y	0.9814	0.9248	0.9641	0.9919	1.0000		
Y^2	0.9670	0.9051	0.9456	0.9937	0.9876	1.0000	
Y^3	0.9342	0.8698	0.9092	0.9744	0.9561	0.9900	1.0000

Appendix 1E: Correlations among independent variables (for residential area)

	EC	*PC*	*POP*	*POP.Y*	*Y*	Y^2	Y^3
EC	1.0000						
PC	0.8882	1.0000					
POP	0.8878	0.8614	1.0000				
POP.Y	0.9477	0.9040	0.9648	1.0000			
Y	0.9601	0.9139	0.9481	0.9923	1.0000		
Y^2	0.9528	0.9016	0.9232	0.9914	0.9888	1.0000	
Y^3	0.9282	0.8742	0.8851	0.9723	0.9607	0.9911	1.0000

Appendix 1F: Robustness check for Industrial area models (full dataset)

Models		*Core variables*		*Testing Variables*	
Electricity Consumption Model		*ln(Y)*	$(lnY)^2$	*ln(POP)*	*ln(Y).ln(POP)*
	Estimated model	- 0.765	- 0.177	-1.581	0.237
	Partial regressions				
	Regression 1	-0.091	-0.001	-	-
	Regression 2	-0.083	-0.001	-1.019	-
	Regression 3	-0.017	-0.008	-	0.014
	Regression 4	-0.076	-0.112	-1.379	0.190
Petroleum Consumption Model		$(lnY)^2$	$(lnY)^3$	*ln(POP)*	*ln(Y).ln(POP)*
	Estimated model	-0.157	0.002	-1.223	0.164
	Partial regressions				
	Regression 1	-0.011	0.001	-	-
	Regression 2	-0.010	0.001	-1.106	-
	Regression 3	-0.012	0.001	-	0.014
	Regression 4	-0.181	0.004	-1.155	0.162

Note: Robustness of the models for full dataset is ensured, as the coefficient signs of core variables remain unchanged.

Appendix 1G: Robustness check for Residential area models (full dataset)

Models		*Core variables*		*Testing Variables*	
Electricity Consumption Model		*ln(Y)*	$(lnY)^2$	*ln(POP)*	*ln(Y).ln(POP)*
	Estimated model	-0.623	-0.132	-1.339	0.192
	Partial regressions				
	Regression 1	-0.139	-0.008	-	-
	Regression 2	-0.151	-0.008	-0.025	-
	Regression 3	-0.085	-0.011	-	0.007
	Regression 4	-0.617	-0.098	-1.190	0.159
Petroleum Consumption Model		*ln(Y)*	$(lnY)^2$	*ln(POP)*	*ln(Y).ln(POP)*
	Estimated model	-0.622	-0.166	-1.766	0.216
	Partial regressions				
	Regression 1	-0.139	-0.008	-	-
	Regression 2	-0.151	-0.008	-0.025	-
	Regression 3	-0.085	-0.011	-	0.007
	Regression 4	-0.617	-0.098	-1.190	0.159

Note: Robustness of the models for full dataset is ensured, as the coefficient signs of core variables remain unchanged.