Estimation of environmental Kuznets curve for SO2 emission: A case of Indian cities

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Estimation of Environmental Kuznets Curve for SO_2 emission: A Case of Indian Cities

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Interaction between environmental degradation and economic growth is a growing matter of interest among policymakers. In this study, we have estimated Environmental Kuznets Curve (EKC) for 139 Indian cities considering SO_2 emissions. Study has been done for 2001-2013, and the data have been segregated by residential and industrial areas, and as well as low, medium, and high income areas. Fixed and random effect panel regressions have been used for analysis, along with a series of auxiliary regressions on orthogonally transformed dataset. By virtue of different forms of EKC being found, policy level decisions have been designed. Moreover, non-rejection of EKC hypothesis reemphasized the impact of growth catalyzing economic policy decisions on environment.

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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 literature of environmental economics, named after Simon Kuznets (1955), who described the inverted U-curve association between income inequality and economic development. Grossman and Krueger (1991) later found its resemblance with Kuznets' inverted U-curve relationship while establishing a relationship between pollution and economic development.

The existing studies on EKC hypothesis have so far focused on either cross-country analysis or intra-provincial analysis of a particular country. In this study, we have analyzed the SO_2 emission data for 139 Indian cities during 2001-2013. The analysis is done by segregating the entire dataset into industrial and residential categories, and then segregating each of the two segments in terms of income level, i.e. low, medium, and high income. This schema of segmentation was designed 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 has remained 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 apart from income, this study has also taken electricity consumption and petroleum consumption as two other explanatory variables. These two variables have been considered as the proxy measures for energy consumption.

In methodological terms, this study employs 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 study has tried orthogonal transformation of parameters, followed by auxiliary regression on transformed parameters to remove multicolinearity from the data.

2. Review of literature

The literature on EKC hypothesis is extensive in the field of ecological economics. The studies have been carried out on various pollutants, like NO_2 (Panayotou, 1993; Grossman and Krueger, 1995; Egli, 2001; Hill and Magnani, 2002; Archibald et al., 2004; Welsch, 2004; Fonkych and Lempert, 2005; Song et al., 2013; Sinha, 2016; Sinha and Bhattacharya, 2016), CO_2 (Moomaw and Unruh, 1997; Roberts and Grimes, 1997; Roca and Alcántara, 2001; Martínez-Zarzoso and Bengochea-Morancho, 2004; Galeotti et al., 2006; Sinha, 2014; Sinha and Bhattacharya, 2014; Sinha, 2015; Alam et al., 2016; Shahbaz et al., 2016), SPM (Selden and Song, 1994; Vincent, 1997; Matsuoka et al., 1998; Torras and Boyce, 1998; Dinda et al., 2000; Wheeler, 2001; Binti Borhan and Musa Ahmed, 2010; Miah et al., 2011), RSPM (McConnell, 1997; Wheeler, 2001; Dasgupta et al., 2002; Rupasingha et al., 2004; Alpay, 2005; Kumar and Foster, 2009; Orubu and Omotor, 2011; Feizpour and Shahmohammadi Mehrjardi, 2014), and many others. As our present study relates to EKC estimation for SO_2 emission, therefore we will focus our review of literature at the studies, which have considered SO_2 as the primary pollutant.

For SO_2 emission, studies have been carried out on cross-sectional data (Panayotou, 1993; Taskin and Zaim, 2000; Bimonte, 2002; Khanna and Plassmann, 2004) and panel data (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 all of these studies are based on a group of countries. Apart from the works of Lantz and Feng (2006), Akbostancı et al. (2009), Song et al. (2013), 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 these studies have considered provincial differences in emission, no study has so far 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.

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 (Sinha and Mehta, 2014), we have considered energy consumption in the form of electricity consumption and petroleum consumption as explanatory variables in our study.

3. SO_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, SO_2 emission has gone up by 54% (Lu et al., 2011; Haq et al., 2015). Looking at the emission affecting stratospheric region, SO_2 is considered as the primary pollutant in this case, as the sulphur aerosols formed in this region are majorly caused by SO_2 emission (Friend et al., 1973; Whitby, 1978; Turco et al., 1979; Surratt et al., 2007). Apart from that, SO_2 is soluble in airborne water globules, and thereby, forming sulphurus and sulphuric acid in the form of acid rains (Penkett et al., 1979). Formation of aerosols after reacting with particulate matters can create severe respiratory problems (Brain and Valberg, 1979), and even premature births (Hastwell, 1975). Mainly for these reasons, rise in the level of SO_2 emission can cause serious damage to ambient atmosphere, and the human life.

In India, reasons behind rise in the level of SO_2 emission differ between industrial and residential areas. In industrial areas, rise in the SO_2 emission can be attributed to rise in the level of direct fossil fuel consumption, in the form of coal and crude oil. Majority of these two fossil fuels used in India are high in sulphur content. Consumption of coal is majorly seen in the thermal power plants and manufacturing sectors, whereas the crude oil with greater sulphur content, i.e. sour crude oil is used in the transportation sector. Combustion of these fossil fuels at high temperature (more than 1500˚C) oxidizes the sulphur contents (Krawczyk et al., 2013). Burning of coal is the major source of SO_2 emission in industrial areas. Apart from that, direct consumption of sour crude oil, i.e. low quality high-speed diesel and petrol in vehicular transportation leads towards emission of SO_2 in the industrial areas. As there are only two stratovolcanos in India (Barren Island and Narcondam), and out them, only Barren Island is currently active, therefore, the SO_2 generation out of volcanic eruption may not be considered in this case.

For the residential areas, the level of SO_2 emission is comparatively lower than the emission level in industrial areas (Hindy et al., 1990; Mathew et al., 2015). Even if small, the growth in emission in residential areas can be attributed to burning of coal and sour crude oil for cooking purpose. Kerosene, the form of sour crude oil used in domestic purpose is the mostly used petroleum product in the households. This case is similar to that of the cases of Chinese and Japanese households, where coal-stoves (Chen et al., 2005) and kerosene heaters (Ritchie and Oatman, 1983) are primarily used for cooking purpose. Burning of these fuels generate SO_2 in the indoor atmosphere. This problem is catalyzed by means of the lack of ventilation in the residential area cities. Heights of building and level of humidity do not directly add to the level of SO_2 emission, but they catalyze the growth and spreading by restricting ventilation. 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 massive usage of air-conditioning systems in the neighborhood areas aggravates the situation. 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.

4. Econometric methodology and data

We have collected data of 139 Indian cities for the duration of 2001-2013. For the analysis, the entire dataset 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.[3] This will allow us to observe the income-emission association in a comparative manner. Descriptive statistics of the data has been provided in Appendix 1A. Profile of the cities and their zonal divisions are provided in Appendix 1F and 1G.

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 (SO_2 in this case), *j* is the income level, *k* is the area classification, *l* is city specific effects, and *ε* is error term. Basic form of this estimation equation has been adapted from Dinda (2004). Following the argument of Panayotou (1993), the interaction between *POP* and *Y* has been considered to measure the elasticity values.

We will now discuss the city specific effects *C*. 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 (Pachauri and Spreng, 2002; Raghuvanshi et al., 2006; Hubacek et al., 2007; Pachauri and Jiang, 2008) and combustion of petroleum products (Reddy and Venkataraman, 2002; Mukhopadhyay and Forssell, 2005; Sinha and Bhattacharya,

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

[3] The income levels are decided based on the average income level of the cities over the study period. The income levels are decided in this manner: low income is for average income less than Rs. 1000 lacs, medium income is for average income between Rs. 1000 lacs and Rs. 5000 lacs, and high income is for average income above Rs. 5000 lacs.

2016). 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. The emission generated by the transportation sector can be attributed to industrial sector, as this sector is used by the industrial sector for commuting their products (Deolalikar and Evenson, 1989; Azar et al., 2003; Anand et al., 2006). Over the years, researchers have identified commercial electricity consumption and combustion of petroleum products as primary sources of ambient air pollution in Indian cities (for a detailed review, see Mallik and Lal, 2014). Moreover, the share of renewable energy in India is still less than 10 percent (India Brand Equity Foundation, 2016). Therefore, in our study, we have identified electricity consumption and petroleum consumption as city specific effects in our model.

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

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

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

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 SO_2 (in μg/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 have 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.

Researchers have identified several problems in the econometric techniques used for estimating the EKCs, like, serial dependence, stochastic trends in the time series, and omitted variable bias (Stern, 2004). In this study, we have tried to address some of those problems, like handling multicolinearity, ensuring stationarity of the data, checking the robustness of the estimated models. Multicolinearity is a problem with the model, 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 (see Appendix 1B and 1C). 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. Before applying auxiliary regressions, stationarity of the data has been checked by applying LLC (Levin et al., 2002) and IPS (Im et al., 2003) panel unit root tests, and we found all the orthogonally transformed variables to be stationary at level (Appendix 1D). Once the models are estimated, following Barslund et al. (2007), we have checked the robustness of the models by conducting partial regressions for each of the models for full dataset (see Appendix 1E).[4]

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 Table 1 and 2. Analyzing first order conditions (FOC) and second order conditions (SOC) recorded in Table 1, shape of EKCs can be estimated. In this case, we find that the income-emission association for electricity consumption model is inverted U-shaped (Figure 1), and it is

[4] As the tested models on full dataset for residential area do not have any component of income, which is the core variable of the estimated models, so the robustness check has only been carried out for the models pertaining to industrial areas. The results are recorded in Appendix 1E.

divulged by the nature of elasticity of the association. This association follows the generally accepted form of EKC.

$$\frac{d\, ln\, SO_2}{d\, ln\, Y}\begin{cases} > 0, & 0 < Y < 452.24 \\ < 0, & Y > 452.24 \end{cases}$$

Similarly, in this case also, we find that the income-emission association for petroleum consumption model is inverted U-shaped (Figure 1), and it is divulged by the nature of elasticity of the association. This association follows the generally accepted form of EKC.

$$\frac{d\, ln\, SO_2}{d\, ln\, Y}\begin{cases} > 0, & 0 < Y < 287.52 \\ < 0, & Y > 287.52 \end{cases}$$

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. However, the regression coefficients are insignificant for medium income cities, and therefore, no EKC can be found for this area. So, we will proceed with EKC estimation for low and high income areas.

Table 1: Model estimation results for SO_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*	2.101	0.028	-0.195	-	-	-0.132[a]	0.004[a]	6.19	0.0000
			(0.95)	(0.89)	(-0.83)	-	-	(-3.75)	(3.12)		
		Random	4.783[a]	-	-0.396[b]	0.072[a]	-	-0.106[a]	0.003[b]	30.52	0.0000
			(2.70)	-	(-2.02)	(2.77)	-	(-3.25)	(2.31)		
	Petroleum Consumption	*Fixed*	0.330	0.111[b]	-	0.061[b]	0.281	-	0.004[a]	6.99	0.0000
			(0.14)	(2.33)	-	(1.99)	(1.17)	-	(3.06)		
		Random	3.066	0.112[a]	-	0.065[b]	-	-0.102[a]	0.003[b]	37.70	0.0000
			(1.61)	(2.66)	-	(2.49)	-	(-3.10)	(2.27)		
Residential	*Electricity Consumption*	*Fixed*	6.278[a]	0.083[a]	-0.432[b]	0.023	-	-	0.000	3.72	0.0011
			(3.23)	(2.74)	(-2.12)	(0.90)	-	-	(0.38)		
		Random	4.265[a]	0.101[a]	-0.281[c]	-	0.090	-	0.001	20.58	0.0022
			(2.78)	(3.45)	(-1.67)	-	(0.44)	-	(1.03)		
	Petroleum Consumption	*Fixed*	6.050[a]	0.008	-0.413[c]	-	-	-0.024	-	2.46	0.0226
			(2.92)	(0.20)	(-1.94)	-	-	(-0.73)	-		
		Random	3.627[b]	0.033	-	0.021	-	-	0.001	9.51	0.1468
			(2.23)	(0.95)	-	(0.94)	-	-	(0.93)		

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, t-statistics are within parentheses

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

Table 2: Industrial area model estimation results for SO_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*	0.334	-	-	-	1.293[b]	-0.295[a]	0.017[a]	2.41	0.027
		(0.14)	-	-	-	(2.24)	(-2.93)	(2.89)		
	Random	1.860	-	-0.208	-	-	-0.286[a]	0.016[a]	13.11	0.041
		(0.83)	-	(-0.94)	-	-	(-2.83)	(2.80)		
Petroleum Consumption	*Fixed*	-	0.056	-0.035	0.028	1.355[b]	-	-	2.33	0.032
		-	(0.99)	(-0.14)	(0.77)	(2.32)	-	-		
	Random	0.518	0.103[b]	-	-	1.335[b]	-0.298[a]	0.017[a]	16.10	0.013
		(0.22)	(1.96)	-	-	(2.30)	(-2.93)	(2.95)		
Medium Income										
Electricity Consumption	*Fixed*	16.249	-	-	0.025	-6.930	-	-0.033	3.44	0.003
		(1.01)	-	-	(0.33)	(-1.00)	-	(-0.88)		
	Random	8.082	-	0.166	-	-2.981	0.293	-	15.63	0.016
		(0.51)	-	(0.26)	-	(-0.44)	(0.33)	-		
Petroleum Consumption	*Fixed*	-	0.264[b]	0.904	-0.015	-7.324	-	-	4.08	0.001
		-	(2.05)	(1.32)	(-0.20)	(-1.07)	-	-		
	Random	4.945	0.098	-	0.014	-	0.247	-0.010	16.59	0.011
		(0.31)	(0.99)	-	(0.18)	-	(0.28)	(-0.26)		
High Income										
Electricity Consumption	*Fixed*	18.471[b]	-	-2.077[b]	0.283[b]	-	-0.332[b]	0.008[b]	5.83	0.000
		(2.61)	-	(-2.15)	(2.28)	-	(-2.09)	(2.00)		
	Random	16.776[a]	-	-1.820[b]	-	0.400	-	0.007[c]	35.84	0.000
		(2.74)	-	(-2.16)	-	(0.52)	-	(1.87)		
Petroleum Consumption	*Fixed*	18.286[b]	0.007	-	0.230[b]	0.501	-0.329[c]	-	5.83	0.000
		(2.32)	(0.09)	-	(2.14)	(0.61)	(-1.94)	-		
	Random	16.036[b]	-	-1.730[c]	0. 232[b]	-	-0.276[c]	0.007[c]	36.11	0.000
		(2.44)	-	(-1.95)	(2.11)	-	(-1.84)	(1.72)		

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, t-statistics are within parentheses

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

Table 3: Residential area model estimation results for SO_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*	9.023[a]	0.241[a]	-0.828[a]	0.053	-	-	0.003	7.04	0.000
		(3.21)	(3.34)	(-3.03)	(1.21)	-	-	(0.49)		
	Random	6.537[b]	0.257[a]	-0.602[b]	-	0.326	-	-	39.56	0.000
		(2.49)	(3.73)	(-2.34)	-	(0.46)	-	-		
Petroleum Consumption	*Fixed*	10.888[a]	-	-1.058[a]	0.095[b]	0.249	-	0.005	5.38	0.000
		(3.62)	-	(-3.70)	(2.13)	(0.34)	-	(0.76)		
	Random	7.145[b]	0.024	-0.729[a]	-	-	-0.166	-	24.66	0.000
		(2.54)	(0.45)	(-2.71)	-	-	(-1.42)	-		
Medium Income										
Electricity Consumption	*Fixed*	28.118	-	0.864[c]	-0.109[b]	-	1.665[c]	-	1.63	0.137
		(1.51)	-	(1.91)	(-2.09)	-	(0.09)	-		
	Random	26.899	-	0.734[c]	-0.105[b]	-	-	-0.060	9.94	0.127
		(1.45)	-	(1.71)	(-2.02)	-	-	(-1.46)		
Petroleum Consumption	*Fixed*	24.146	0.259[a]	1.364[a]	-0.144[a]	-12.900[c]	1.792[c]	-0.071[c]	3.27	0.004
		(1.31)	(3.15)	(2.86)	(-2.73)	(-1.75)	(1.85)	(-1.73)		
	Random	24.015	0.195[a]	1.017[b]	-0.129[b]	-	1.566	-	18.06	0.006
		(1.31)	(2.82)	(2.32)	(-2.49)	-	(1.64)	-		
High Income										
Electricity Consumption	*Fixed*	5.122	0.119[a]	-0.266	-	-	0.017	-	1.70	0.119
		(0.80)	(2.62)	(-0.40)	-	-	(0.08)	-		
	Random	7.895	0.128[a]	-	-	-0.775	-	-0.002	10.09	0.121
		(1.30)	(2.87)	-	-	(-0.45)	-	(-0.35)		
Petroleum Consumption	*Fixed*	4.827	.044	-	-.006	-.215	-	-	0.61	0.725
		(0.74)	(0.61)	-	(-0.08)	(-0.11)	-	-		
	Random	7.548	-	-0.209	-	-	0.103	-	1.99	0.921
		(1.23)	-	(-0.30)	-	-	(0.47)	-		

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, t-statistics are within parentheses

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

5.1. Analysis for low income industrial area

Equating the FOC to zero for both the models, the turnaround points of the EKCs have been estimated and recorded in Table 4. Now we will estimate the shape of the EKCs.

Firstly, we find that the income-emission association for electricity consumption model is N-shaped (Figure 1), and it is divulged by the nature of elasticity of the association.

$$\frac{d\,ln\,SO_2}{d\,ln\,Y}\begin{cases} > 0, & 0 < Y < 18.87 \\ < 0, & 18.87 < Y < 5604.37 \\ > 0, & Y > 5604.37 \end{cases}$$

Similarly, we find that the income-emission association for petroleum consumption model is also N-shaped (Figure 1), and it is divulged by the nature of elasticity of the association.

$$\frac{d\,ln\,SO_2}{d\,ln\,Y}\begin{cases} > 0, & 0 < Y < 20.51 \\ < 0, & 20.51 < Y < 5799.40 \\ > 0, & Y > 5799.40 \end{cases}$$

5.2. Analysis for high income industrial area

Like the previous scenario, we will estimate the shape of the EKCs for both the models. In this case, we find that the income-emission association for electricity consumption model is inverted U-shaped (Figure 1), and it is divulged by the nature of elasticity of the association. This association follows the generally accepted form of EKC.

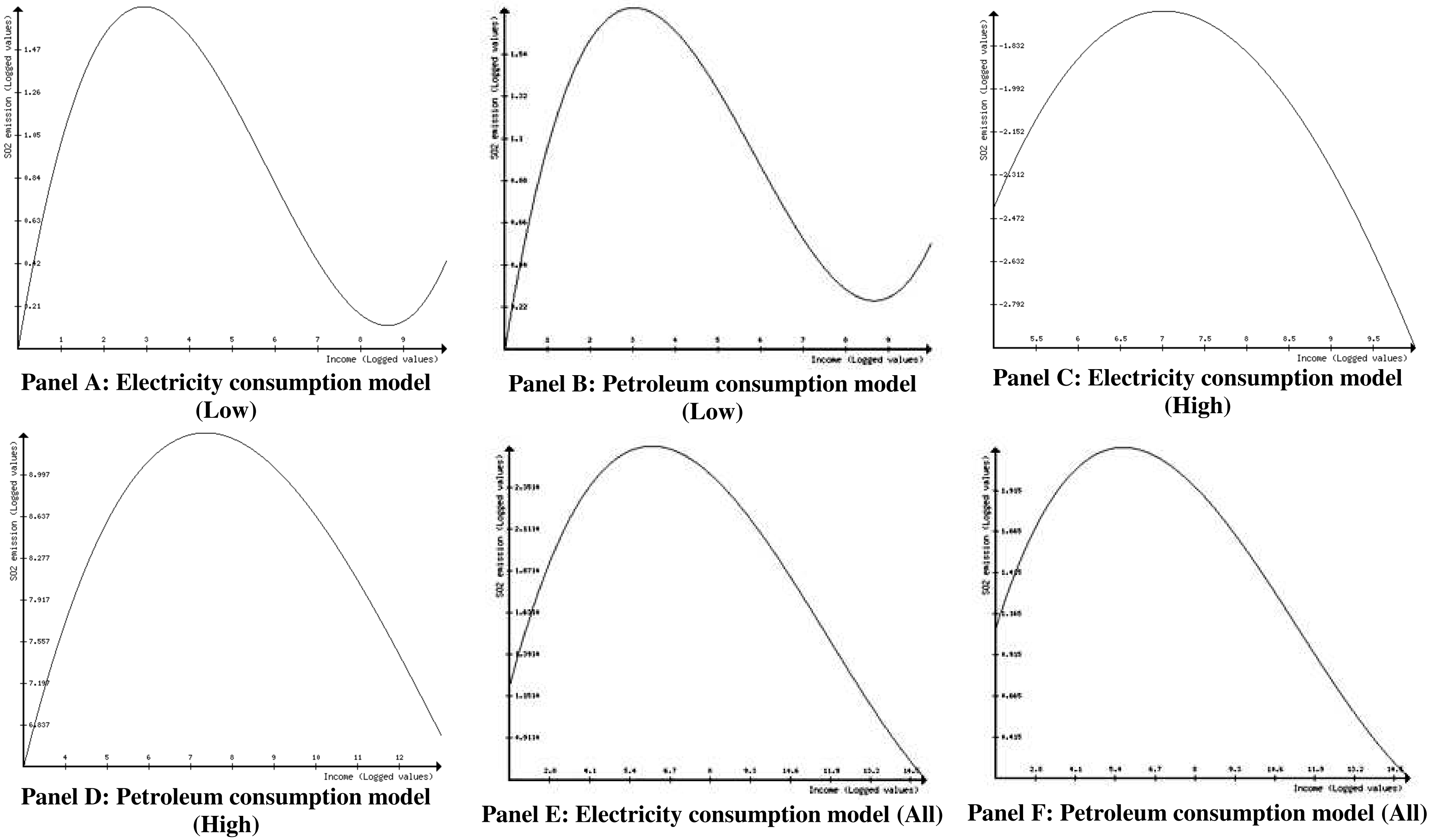
$$\frac{d\,ln\,SO_2}{d\,ln\,Y}\begin{cases} > 0, & 0 < Y < 1110.10 \\ < 0, & Y > 1110.10 \end{cases}$$

Similarly, in this case also, we find that the income-emission association for petroleum consumption model is inverted U-shaped (Figure 1), and it is divulged by the nature of elasticity of the association. This association follows the generally accepted form of EKC.

$$\frac{d\,ln\,SO_2}{d\,ln\,Y}\begin{cases} > 0, & 0 < Y < 1564.36 \\ < 0, & Y > 1564.36 \end{cases}$$

Table 4: EKC Estimation for industrial area cities

Income level	*Electricity consumption model*	*FOC* $\left[\frac{d\ ln\ SO_2}{d\ ln\ Y}\right]$	*SOC* $\left[\frac{d^2\ ln\ SO_2}{d\ (ln\ Y)^2}\right]$	*Turnaround point (Rs. Lacs)*	*Shape of EKC*
Low	$\ln(SO_2) = 1.293 \ln(Y) – 0.295 (\ln Y)^2 + 0.017 (\ln Y)^3$	$1.293 – 0.590 (\ln Y) + 0.051 (\ln Y)^2$	$– 0.590 + 0.102 \ln(Y)$	a. 18.87 b. 5604.37	N-shaped (Panel A)
Medium	-	-	-	-	No EKC
High	$\ln(SO_2) = 18.471 – 2.077 \ln(POP) + 0.283 \ln(Y). \ln(POP) – 0.332 (\ln Y)^2 + 0.008 (\ln Y)^3$	$0.283 \ln(POP) – 0.664 (\ln Y) + 0.024 (\ln Y)^2$	$– 0.664 + 0.048 \ln(Y)$	1110.10	Inverted U-shaped (Panel C)
All	$\ln(SO_2) = 4.783 – 0.396 \ln(POP) + 0.072 \ln(Y). \ln(POP) – 0.106 (\ln Y)^2 + 0.003 (\ln Y)^3$	$0.072 \ln(POP) – 0.212 \ln(Y) + 0.009 (\ln Y)^2$	$– 0.212 + 0.018 \ln(Y)$	452.24	Inverted U-shaped (Panel E)
Income level	*Petroleum consumption model*	*FOC* $\left[\frac{d\ ln\ SO_2}{d\ ln\ Y}\right]$	*SOC* $\left[\frac{d^2\ ln\ SO_2}{d\ (ln\ Y)^2}\right]$	*Turnaround point (Rs. Lacs)*	
Low	$\ln(SO_2) = 0.103 \ln(PC) + 1.335 \ln(Y) – 0.298 (\ln Y)^2 + 0.017 (\ln Y)^3$	$1.335 – 0.596 (\ln Y) + 0.051 (\ln Y)^2$	$– 0.596 + 0.102 \ln(Y)$	a. 20.51 b. 5799.40	N-shaped (Panel B)
Medium	-	-	-	-	No EKC
High	$\ln(SO_2) = 16.036 – 1.730 \ln(POP) + 0.232 \ln(Y). \ln(POP) – 0.276 (\ln Y)^2 + 0.007 (\ln Y)^3$	$0.196 \ln(POP) – 0.552 (\ln Y) + 0.021 (\ln Y)^2$	$– 0.552 + 0.042 \ln(Y)$	1564.36	Inverted U-shaped (Panel D)
All	$\ln(SO_2) = 0.112 \ln(PC) + 0.065 \ln(Y). \ln(POP) – 0.102 (\ln Y)^2 + 0.003 (\ln Y)^3$	$0.065 \ln(POP) – 0.204 \ln(Y) + 0.009 (\ln Y)^2$	$– 0.204 + 0.018 \ln(Y)$	287.52	Inverted U-shaped (Panel F)



Panel A: Electricity consumption model (Low)

Panel B: Petroleum consumption model (Low)

Panel C: Electricity consumption model (High)

Panel D: Petroleum consumption model (High)

Panel E: Electricity consumption model (All)

Panel F: 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 Table 1 and 3. Analyzing first order conditions (FOC) and second order conditions (SOC) recorded in Table 2, shape of EKCs can be estimated. In this case, we find that the income-emission associations for both the models are linear and parallel to horizontal axis (Figure 2).

Once we have estimated the income-emission associations for all income levels in residential area, now we can proceed with three levels of income. However, the regression coefficients are insignificant for high income cities, and therefore, no EKC can be found for this area. So, we will proceed with EKC estimation for low and medium income areas.

6.1. Analysis for low income residential area

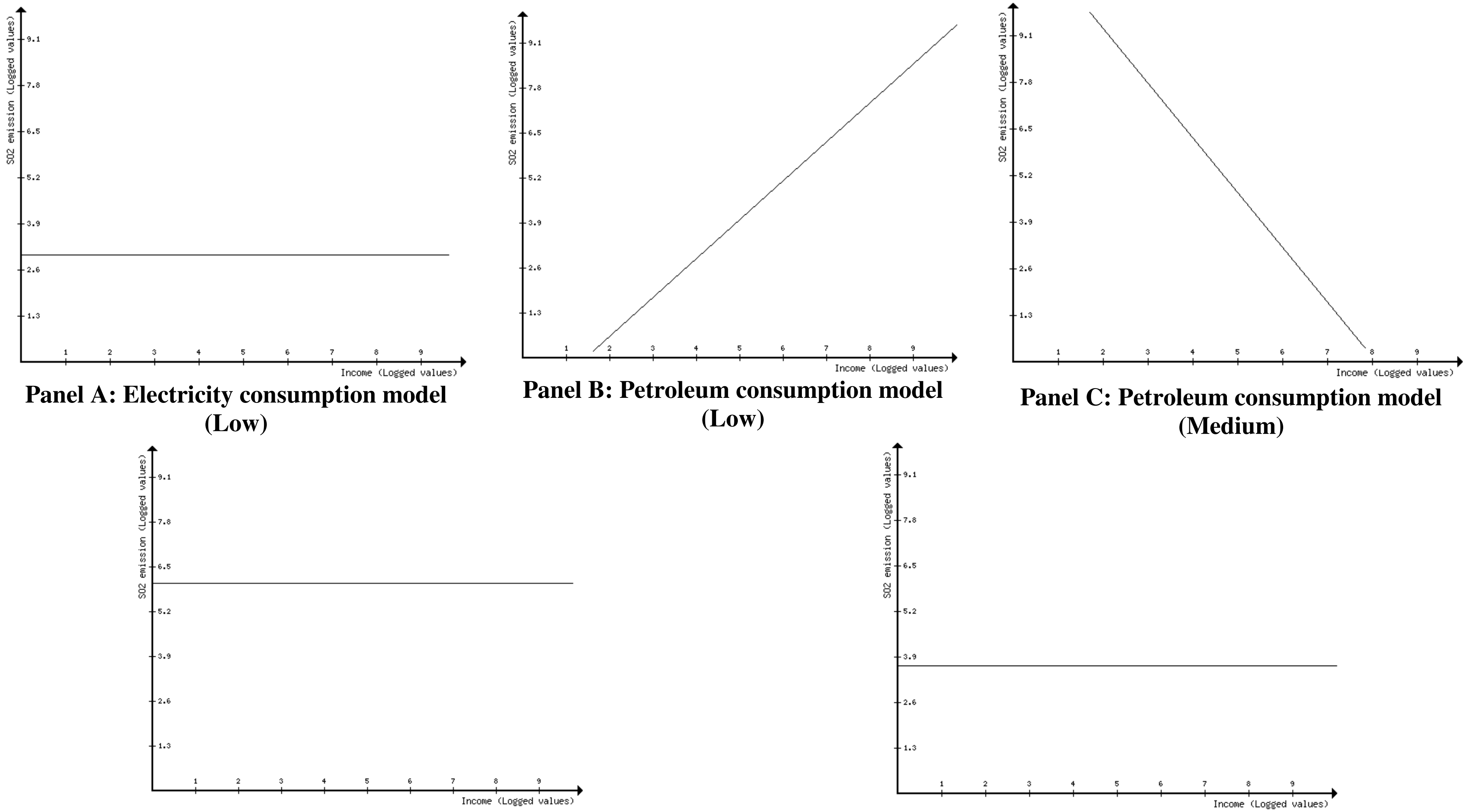
FOCs of both the models have been estimated and recorded in Table 5. In this case, we find that the income-emission association for electricity consumption model is linear and parallel to horizontal axis (Figure 2), and it is divulged by the nature of elasticity of the association. On the other hand, we find that the income-emission association for petroleum consumption model is linearly increasing (Figure 2), and it is divulged by the nature of elasticity of the association.

6.2. Analysis for medium income residential area

FOC for petroleum consumption model has been estimated and recorded in Table 5. In this case, we find that the income-emission association for petroleum consumption model is linearly decreasing (Figure 2), and it is divulged by the nature of elasticity of the association. However, no significant income-emission association has been found for electricity consumption model.

Table 5: EKC Estimation for residential area cities

Income level	*Electricity consumption model*	*FOC* $\left[\frac{d\, ln\, SO_2}{d\, ln\, Y}\right]$	*SOC* $\left[\frac{d^2\, ln\, SO_2}{d\, (ln\, Y)^2}\right]$	*Turnaround point (Rs.)*	*Shape of EKC*
Low	$\ln(SO_2) = 6.537 + 0.257 \ln(EC) - 0.602 \ln(POP)$	0	-	-	Linear (Panel A)
Medium	-	-	-	-	No EKC
High	-	-	-	-	No EKC
All	$\ln(SO_2) = 4.265 + 0.101 \ln(EC) - 0.281 \ln(POP)$	0	-	-	Linear (Panel D)
Income level	*Petroleum consumption model*	*FOC* $\left[\frac{d\, ln\, SO_2}{d\, ln\, Y}\right]$	*SOC* $\left[\frac{d^2\, ln\, SO_2}{d\, (ln\, Y)^2}\right]$	*Turnaround point (Rs.)*	
Low	$\ln(SO_2) = 10.888 - 1.058 \ln(POP) + 0.095 \ln(Y). \ln(POP)$	1.12	0	-	Linear (Panel B)
Medium	$\ln(SO_2) = 0.195 \ln(PC) + 1.017 \ln(POP) - 0.129 \ln(Y). \ln(POP)$	-1.77	0	-	Linear (Panel C)
High	-	-	-	-	No EKC
All	$\ln(SO_2) = 3.627$	0	-	-	Linear (Panel E)



Panel A: Electricity consumption model (Low)

Panel B: Petroleum consumption model (Low)

Panel C: Petroleum consumption model (Medium)

Panel D: Electricity consumption model (All)

Panel E: Petroleum consumption model (All)

Figure 2: Estimated EKCs for residential 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 N-shaped and linear (see Table 6 and 7). Now, we will analyze the scenarios for industrial and residential areas respectively.

Table 6: 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	452.24	Inverted U-shaped	287.52
Residential	Linear	-	Linear	-

Table 7: 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>N Shaped</td><td>18.87</td><td>5604.37</td><td>N Shaped</td><td>20.51</td><td>5799.40</td></tr>
<tr><td>Medium</td><td>-</td><td colspan="2">-</td><td>-</td><td colspan="2">-</td></tr>
<tr><td>High</td><td>Inverted U-Shaped</td><td colspan="2">1110.10</td><td>Inverted U-Shaped</td><td colspan="2">1564.36</td></tr>
<tr><td colspan="7">Category: Residential</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>-</td><td colspan="2">-</td><td>Linear</td><td colspan="2">-</td></tr>
<tr><td>High</td><td>-</td><td colspan="2">-</td><td>-</td><td colspan="2">-</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 for both the models. In rest of the cases, the income-emission associations have been found to be 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 N-shaped for both the models. First turnaround point of this association is achieved at Rs. 18.87 Lacs for electricity consumption model and Rs. 20.51 Lacs for petroleum consumption model. For both of the cases, the turnaround points are lower than the minimum income level (= Rs. 20.89 Lacs) of this stratum. Both of these turnaround points were achieved at the very earliest stage of the industrialization. For electricity consumption model, SO_2 emission level at the first turnaround point is 5.38μg/m^3, and for petroleum consumption model, SO_2 emission level at the first turnaround point is 6.16μg/m^3. Both of these emission levels are below the emission standard set by Central Pollution Control Board of India, i.e. 40μg/m^3. One of the major reasons behind this fall in SO_2 emission in these areas is a result of shifting in the pattern of fossil fuel usage in plants. Gradual improvement in combustion technologies and usage of petroleum products with low-sulphur content has resulted in the reduction of SO_2 emission in these areas. Moreover, transport density in these cities is comparatively lower than the other strata, and other than Jharia, there are no coal mines in these cities. Therefore, the chances of transport and coal borne SO_2 emission are also low. Within this stratum, with the rise in income, usage of petroleum products with low-sulphur content in thermal power plants rises. This brings down the curve of income-emission association to its second turnaround point. For both the models, the second turnaround points are achieved at higher income levels, and at those emission levels, which are even lower than that of the previous turnaround points. Beyond the second turnaround points, rise in the level of income may result in rise in the vehicular density, which may cause rise in the level of SO_2 emission, and thereby, resulting in the N-shaped income-emission association. To curb down this level of SO_2 emission, the active thermal power plants should reduce the usage of imported coal, which may has high sulphur content. Moreover, the power plants, which are using lignite and diesel, may shift their fuel mix for power generation.

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 $33.92 \mu g/m^3$, and for petroleum consumption model, the turnaround point arrives at the emission level of $34.41 \mu g/m^3$. In both of the cases, emission levels are just below the emission standards set by Central Pollution Control Board of India, i.e. $40 \mu g/m^3$. Though these emission levels are below the emission standard set by Central Pollution Control Board of India, the differences are marginally low. 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 SO_2 compared to the secondary sector. Apart from that, in most of these cities, Bharat Stage IV has already been implemented, and therefore, in spite of having high vehicular congestion, fuel SO_2 emission is under control. Therefore, inverted U-shaped EKC is found for this particular stratum. However, keeping the level of turnaround points into consideration, 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.

7.2. Policy implications for residential areas

For residential areas, the income-emission associations have found to be linear for the aggregate dataset. In case of segregated dataset also, income-emission associations have 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 for both electricity consumption model and petroleum consumption model. The level of emission for electricity consumption model is 1.45μg/m^3. In this case, emission level is below 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. 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. On the other hand, consumption of petroleum based fuel in these cities rise with the rise in income, as it is indicated by positively sloped (= 1.124) the income-emission association for the petroleum consumption model. People in these cities mostly use kerosene and coal for cooking and lighting purpose, and this may raise the level of SO_2

emission in these areas. In order to mitigate this problem, government should make them aware about the negative consequences of using the low quality petroleum products, and should provide LPGs at a subsidized rate. Apparently, this level of SO_2 emission is desirable, but there are chances that the emitted SO_2 may translate into sulphate based particulate matters. Therefore, further monitoring is required to check this kind of particulate matters in these particular cities.

For medium income cities, income-emission association has been found to be linear for petroleum consumption model, and electricity consumption model did not fit. In this case, it has been found that the level of SO_2 emission falls with the rise in income. Most of these cities under this stratum 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. As the level of income in these cities is comparatively higher than the previous one, people tend to use LPGs for cooking purpose, and direct consumption of petroleum product is less visible. 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 be linearly falling. However, implementation of this particular mechanism in the cities with comparatively lower income can also bring down the emission level, and also can bring forth energy efficiency.

8. Conclusion

In this paper, we have estimated the EKCs for SO_2 emission in 139 Indian cities for 2001-2013, by considering all of them in single stratum, and then by segregating them into three levels of income. In order to ensure the accuracy of the data, we have orthogonally transformed the variables, the correlated lower-order terms were removed after auxiliary regressions, and the within models have been tested. The stationarity of the data has been checked by applying unit root tests, and we found the variables to be stationary at level. 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, suggests for policy decisions to be 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 create a multiplier effect in bringing down the emission level.

While carrying out the analysis, we have found the generally accepted inverted U-shaped EKC for high income industrial areas, and for the overall industrial area. Apart from that, we have also found the income-emission associations to be N-shaped and linear. The linearity in the income-emission association has been found in the residential areas only, whereas the other N-shaped association has been found in the industrial areas only.

After analyzing the results, it can be said that government should take the responsibility of implementing the pollution control policies in a more effective manner. In order to control the vehicular emission, *Bharat Stage emission standards* are already in place, and *Central Pollution Control Board* has set several restrictions for emission discharges from 104 industries. In spite of that, due to rapid industrial growth and lack of proper urban infrastructure, the newly industrialized areas are experiencing increased number of slum areas, where the standard of living is pretty low. These are the areas, where a substantial amount of emission takes place. This emission is nothing but a result of social imbalance, which government has to take care by implementation of proper rehabilitation policies. Apart from that, it is the responsibility of the citizens as well to become aware about the environmental problems and this can become possible, if they are given proper education, healthcare, and adequate vocational opportunities. Awareness of citizens aligned with governmental regulatory pressures can be a possible solution to this problem. Apart from this, government should encourage the Central Pollution Control Board to introduce more numbers of emission monitoring stations across the cities, so that more data on emission can be gathered for making more effective and focused pollution control policies.

Government initiatives regarding discovery and invention of alternate energy sources is an indicator of the growing concern and anxiety about the reducing pool of natural resources and the level of ambient air pollution. By looking at the present scenario regarding energy policies in India, it can be seen that a great amount of emphasis is being put forth on harnessing of solar and wind power, which can solve the problems of clean and green energy. By and large, this is the primary objective of the *Saffron Revolution*[5], which is being targeted at patronizing solar energy throughout India, and the establishment of India's largest solar plant in Neemuch, Madhya Pradesh, was one of the first stepping stone towards achievement of objectives of this revolution. Current developments in Indian socio-political scenario take us back to the results being obtained by us, which was pointing towards efficient pollution abatement policy implementations.

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 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 Indian cities.

[5] *Saffron Revolution* is an initiative taken up by Government of India in 2014, to boost the Indian solar power industry.

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Appendix 1A: Descriptive statistics of the variables

Area	Variable	Units	No. of Obs.	Mean	Std. Dev.	CV.
Industrial	SO_2	in $\mu g / m^3$	1131	13.702	8.795	0.642
	Y	in Rs. Lacs	1131	9416.416	22320.720	2.370
	POP	in number	1131	1968134.587	3417774.263	1.737
	EC	in GWH	1131	1155.911	2469.734	2.136
	PC	in KG	1131	77.614	9.243	0.119
Residential	SO_2	in $\mu g / m^3$	1547	9.228	6.434	0.697
	Y	in Rs. Lacs	1547	7888.848	18705.770	2.371
	POP	in number	1547	1700928.882	2807138.969	1.650
	EC	in GWH	1547	996.222	2139.684	2.148
	PC	in KG	1547	74.948	9.634	0.129

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

	EC	*PC*	*POP*	*POP.Y*	*Y*	Y^2	Y^3
EC	1.0000						
PC	0.9411	1.0000					
POP	0.9486	0.8816	1.0000				
POP.Y	0.9728	0.9077	0.9754	1.0000			
Y	0.9814	0.9251	0.9643	0.9919	1.0000		
Y^2	0.9670	0.9052	0.9457	0.9937	0.9876	1.0000	
Y^3	0.9341	0.8698	0.9093	0.9743	0.9560	0.9900	1.0000

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

	EC	*PC*	*POP*	*POP.Y*	*Y*	Y^2	Y^3
EC	1.0000						
PC	0.8923	1.0000					
POP	0.8920	0.8677	1.0000				
POP.Y	0.9495	0.9074	0.9659	1.0000			
Y	0.9613	0.9178	0.9503	0.9922	1.0000		
Y^2	0.9541	0.9041	0.9251	0.9915	0.9882	1.0000	
Y^3	0.9287	0.8747	0.8858	0.9716	0.9587	0.9907	1.0000

Appendix 1D: Results of unit root tests on orthogonally transformed variables

	Variables	LLC		IPS	
		Without Trend	*With Trend*	*Without Trend*	*With Trend*
Industrial area	*ln(Y)*	-8.5627[a]	-10.0685[a]	-4.4671[a]	-15.4322[a]
	$(lnY)^2$	-5.9109[a]	-25.0644[a]	-31.3367[a]	-13.1338[a]
	$(lnY)^3$	-3.9976[a]	-9.9739[a]	-56.5222[a]	-14.8918[a]
	ln(POP)	-4.4164[a]	-10.0227[a]	-34.1699[a]	-8.3011[a]
	ln(Y).ln(POP)	-6.0434[a]	-12.3384[a]	-16.9003[a]	-18.6761[a]
	ln(EC)	-12.1441[a]	-13.0610[a]	-22.3276[a]	-9.7671[a]
	ln(PC)	-6.0831[a]	-14.2160[a]	-2.4002[a]	-17.3172[a]
		Without Trend	*With Trend*	*Without Trend*	*With Trend*
Residential area	*ln(Y)*	-7.7429[a]	-12.4642[a]	-4.7271[a]	-14.3999[a]
	$(lnY)^2$	-7.1864[a]	-13.1143[a]	-42.6987[a]	-42.1084[a]
	$(lnY)^3$	-10.2980[a]	-11.7841[a]	-47.1364[a]	-32.9357[a]
	ln(POP)	-6.2765[a]	-12.4928[a]	-33.4914[a]	-45.5356[a]
	ln(Y).ln(POP)	-14.3848[a]	-11.2802[a]	-2.6048[a]	-3.1417[a]
	ln(EC)	-13.5331[a]	-15.7696[a]	-5.3273[a]	-2.3755[a]
	ln(PC)	-7.8263[a]	-9.7770[a]	-3.6766[a]	-4.6469[a]

a Value at 1% significance level

For IPS test, W-t-bar values are reported
For LLC test, Adjusted t-statistics are reported

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

Models		*Core variables*		*Testing variables*	
Electricity Consumption Model		$ln(Y)^2$	$(lnY)^3$	*ln(POP)*	*ln(Y).ln(POP)*
	Estimated model	-0.106	0.003	-0.396	0.072
	Partial regressions				
	Regression 1	-0.006	0.001	-	-
	Regression 2	-0.124	0.001	-0.115	-
	Regression 3	-0.039	0.002	-	0.021
	Regression 4	-0.101	0.002	-0.421	0.075
Petroleum Consumption Model		$(lnY)^2$	$(lnY)^3$	*ln(PC)*	*ln(Y).ln(POP)*
	Estimated model	- 0.102	0.003	0.112	0.065
	Partial regressions				
	Regression 1	-0.006	0.001	-	-
	Regression 2	-0.124	0.001	-0.115	-
	Regression 3	-0.039	0.002	-	0.021
	Regression 4	-0.101	0.002	-0.421	0.075

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

Appendix 1F: Profile of the cities considered for the study

Northern zone cities

Cities	*Category*	*Area (in km^2)*	*Average Income (in Rs. Lacs)*
Agra	R & I	4028.00	2757.73
Allahabad	R	70.50	1969.87
Amritsar	R & I	2683.00	5120.72
Anpara	I	179.00	33.09
Bathinda	I	210.00	1199.01
Chandigarh	I	114.00	11545.39
Delhi	R & I	1484.00	141540.54
Dera Baba Nanak	R	74.00	30.75
Dera Bassi	I	157.00	104.14
Faridabad	R & I	2151.00	6891.56
Firozabad	R & I	2362.00	933.02
Gajraula	R & I	3.00	85.20
Ghaziabad	I	133.30	3255.79
Gobindgarh	R & I	110.00	342.37
Hisar	R	215.00	1550.41
Jalandhar	R & I	3401.00	3742.07
Jhansi	R	5028.00	883.88
Kanpur	R & I	403.70	4860.48
Khanna	R & I	28.00	546.07
Khurja	R & I	142.00	218.19
Lucknow	R & I	2528.00	4575.94
Ludhiana	R & I	310.00	7041.89
Meerut	R	141.90	2275.02
Naya Nangal	R	79.00	216.13
Noida	R & I	203.00	898.82
Patiala	R & I	339.90	1849.33
Varanasi	R	1550.00	2311.78
Yamunanagar	I	255.00	1697.51

Eastern zone cities

Cities	*Category*	*Area (in km^2)*	*Average Income (in Rs. Lacs)*
Angul	R & I	6232.00	101.51
Asansol	I	127.30	3483.23
Balasore	R	3076.00	413.54
Berhampur	R	86.82	825.29
Bhubaneshwar	R	135.00	1972.63
Cuttack	R	398.00	1545.48
Dhanbad	R	2052.00	2579.06

Southern zone cities

Cities	*Category*	*Area (in km^2)*	*Average Income (in Rs. Lacs)*
Alappuzha	R & I	46.18	1183.72
Bangalore	R & I	741.00	27833.29
Belgaum	I	94.00	2104.68
Chennai	R & I	426.00	35175.94
Chittoor	I	95.97	16345.00
Coimbatore	R & I	246.80	8484.66
Gulbarga	R	64.00	1849.82
Guntur	R	230.00	29531.17
Hassan	R	6814.00	584.94
Hubli-Dharwad	R & I	404.00	3257.90
Hyderabad	R & I	217.00	23908.91
Kakinada	R	31.51	2380.17
Khammam	R	94.37	16931.76
Kochi	R & I	732.00	8865.43
Kollam	R & I	73.03	4193.20
Kottayam	R & I	2208.00	1418.18
Kozhikode	R & I	128.00	7912.58
Kurnool	R	65.91	24195.29
Madurai	R & I	243.00	6074.51
Malappuram	I	33.61	5852.29
Mangalore	I	184.45	2175.75
Mysore	I	132.00	3390.89
Nalgonda	R	105.00	21183.45
Nellore	R	48.39	17839.74
Palakkad	I	1363.00	1240.79
Patancheru	R	122.00	18160.77
Pathanamthitta	R	23.50	176.15
Salem	R	124.00	3800.27
Thoothukudi	R & I	50.66	1586.06
Thrissur	R	101.40	6607.24
Trivandrum	R & I	214.90	6772.38
Vijayawada	R & I	61.88	7465.44
Visakhapatnam	R & I	540.00	25727.63
Warangal	R	407.80	21277.51

Western zone cities

Cities	*Category*	*Area (in km^2)*	*Average Income (in Rs. Lacs)*
Ahmedabad	R & I	464.00	28261.90

Durgapur (WB)	R & I	154.00	1622.43	Alwar	R & I	150.00	802.27
Haldia	I	162.00	560.93	Amravati	R & I	122.00	3261.53
Howrah	R & I	1467.00	13675.52	Anklesvar	R & I	213.00	638.82
Jamshedpur	I	209.00	2828.23	Aurangabad (MS)	R	139.00	5828.57
Jharia	I	280.00	209.68	Chandrapur	R & I	77.00	1641.59
Kolkata	R & I	185.00	40475.25	Greater Mumbai	I	4355.00	65021.10
Patna	R	3202.00	2063.98	Jaipur	R & I	111.80	7115.57
Ranchi	R	175.00	2324.72	Jamnagar	R	53.30	2849.73
Rayagada	R & I	7073.00	162.13	Jodhpur	R & I	78.60	2653.26
Rourkela	R	340.00	1283.99	Kolhapur	R	66.82	2875.63
Sambalpur	R	6702.70	613.82	Kota	R & I	318.00	2291.08
Sindri	I	65.00	196.50	Lote	R & I	144.00	277.01
Talcher	I	2025.00	94.34	Mahad	R & I	175.00	140.17
Central zone cities				Mumbai	R & I	603.00	93969.58
Cities	*Category*	*Area (in km^2)*	*Average Income (in Rs. Lacs)*	Nagpur	R & I	217.60	12603.27
Bhilai Nagar	R & I	45.20	2574.87	Nashik	R & I	360.00	7604.93
Bhopal	R & I	285.90	3695.98	Navi Mumbai	R & I	344.00	855.59
Dewas	R & I	535.00	572.51	Pune	R & I	700.00	24672.11
Gwalior	R	780.00	2191.14	Rajkot	R & I	170.00	6200.10
Indore	R & I	530.00	4139.85	Roha	R & I	120.00	107.19
Jabalpur	R	367.00	2563.17	Sangli	R & I	118.20	2608.01
Khajuraho	R	175.00	48.21	Solapur	R & I	148.90	4895.32
Korba	R	316.00	881.79	Surat	R & I	326.50	19780.00
Nagda	R & I	120.00	208.66	Tarapur	I	627.00	36.78
Raipur	R & I	226.00	2493.15	Thane	R & I	147.00	53789.04
Sagar	R	6375.00	740.34	Udaipur	R & I	37.00	1130.71
Satna	R & I	200.00	561.41	Vadodara	R & I	235.00	8368.20
Singrauli	R	2200.00	441.38	Vapi	R & I	425.89	665.21
Ujjain	R & I	152.00	1031.14				
North-Eastern zone cities							
Cities	*Category*	*Area (in km^2)*	*Average Income (in Rs. Lacs)*	*Cities*	*Category*	*Area (in km^2)*	*Average Income (in Rs. Lacs)*
Bongaigaon	R	6.00	1462.12	Nagaon	R	128.00	5572.44
Daranga	R	78.00	1831.42	Nalbari	R	160.00	1558.21
Dibrugarh	R	66.14	2670.31	North Lakhimpur Town	R	15.00	2077.97
Golaghat	R	3502.00	2149.91	Sibsagar	R	2667.70	2340.84
Guwahati	R	215.00	1904.49	Silchar	R	15.75	341.35
Hailakandi	R	1327.00	1302.50	Tezpur	R	40.00	139.26
Margherita	R	162.00	54.36	Tinsukia	R	3791.00	2658.54

Note: "R" signifies Residential; "I" signifies Industrial; "R & I" signifies Residential and Industrial

Appendix 1G: Zonal division of the states