Testing relationship between PM10 concentration levels and Social Power Across 15 Indian States over 2007-2016 Using OLS Estimator Regression Analysis

Also checking the validity of Environmental Kuznets Curve

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Background

- The Environmental Kuznets Curve: an empirically observed “inverted U-shaped” relationship between Environmental Degradation and SDP per capita.
- In 1955, Simon Kuznets empirically found the Kuznets Curve between income inequality and per capita income.
- In 1963, he further hypothesised that power inequality also goes up with income inequality and capita income.

Background

- Grossman & Kruger explained that environmental degradation increases with the advancement of the country, but eventually the industrial makeup of the economy changes.
- Torras & Boyce's framework assumed that with an increase in social power of certain people in society, their influence of affecting change in policy and regulation also increases.
- One of their key results is that power inequality has a significantly negative impact on environmental degradation.

Torras and Boyce's Model

$$\mathrm{POL}=\alpha+\beta_1\,\mathrm{Y}+\beta_2\,\mathrm{Y}^2+\beta_3\,\mathrm{Y}^3+\delta_1\,\mathrm{GINI}+\delta_2\,\mathrm{LIT}+\delta_3\,\mathrm{RIGHTS}+\gamma_\mathrm{i}\,\mathrm{Z}_\mathrm{i}+\mu,$$

- POL= The pollution variable being tested;
- Y=per capita income;
- GINI=Gini coefficient;
- LIT=Literacy Rate,
- RIGHTS=political rights and civil liberties
- and Z_i is a vector of other covariates

Motivation

- In India, levels of air pollutants are on the rise, based on recent years analysis.
- PM10 emissions are a significant contributor and are linked to various respiratory and cardiovascular diseases.
- Our regression analysis can help in policy making by shedding light on what unexpected factors may have significant effects on PM10 level in India.

Description of Variables

Variable	Description	Acronym
Explained		
PM_{10} level	PM_{10} is particulate matter 10 micrometers or less in diameter ($\mu g/m^3$)	Pm10
Explanatory	**(Accepted in the final model)**	
State Domestic Product per Capita (INR per person)	Value of all goods & services produced within a state in a year divided by the population of the state	SDP

Square (State Domestic Product per Capita)	The values of SDP squared.	SDPsq
Cube (State Domestic Product per Capita)	The values of SDP cubed.	SDPcube
State Dummy Variables	14 dummy variables which represent 15 states.	State
Gini Index	Statistical measure used as a measure of economic inequality, income distribution or wealth distribution among a population.	GINI
Transnational Border Dummy ***	Value of "1" if state shares its border with another country or the coast or both. Else, a "0" value. Dummy variable categorizes 15 Indian states into 2 groups of 10 ("1") and 5 ("0").	TransBorder
Urban Literacy Rate	Total number of literate persons, expressed as a percentage of the total population of the state living in urban areas.	UrbanLit

*** : Check Appendix

Voter Gender Inequality Index ***	skewness by difference in vote distribution by gender	VGI
Election Lack of Competition Index ***	sum of squares of vote share by each party Range: 0- 10,000 High value ->low compet.	ELCI
State Assembly Power Equality Index ***	Sum of squares of seat share in state legislature Range: 0-10,000 High value -> more power equal distribution	SAPEI

***** : Check Appendix**

Agricultural Land Percentage	Percentage of Agricultural land to the total land. Agricultural activity is a major cause of air pollution including PM10 emissions as particulates are generated during the agricultural operations and processes.	AgrLand%
Rainfall	Areas with high rainfall reduces the level of pm10 particles in the air by settling them on the ground as shown by research.	Rain
Year	Trend variable with labels from 2007-2016	Year
Population Density	Number of people per unit square Kilometer. Acts as a control variable accounting for PM_{10} emission.	PopDens
Urban City Centres	Urban agglomeration - # central cities.	UrbanCen

Explanatory	**(Tested and rejected)**	1. Theoretically (Do we need it?) 2. Significance (p-values) and contribution 3. Multicollinearity (Checking VIF)
Literacy Rate (Not urban)	Total number of literate persons, expressed as a percentage of the total population of the state.	Lit
Margin of Election Victory	The maximum number of procured votes by a party subtracted to the second maximum number of votes divided by the sum of the number of votes of both parties.	MarginEV
Sanitation	Percentage of people with unavailability of latrines. Acts as a variable to depict access to basic amenities and hence acts as a variable accounting for spread of power.	San

Vehicles	Statewise total number of registered vehicles /1000. Acts as a control variable for the pm_{10} emissions from vehicles.	Veh
Life Expectancy	The average age an individual is expected to live. Life Expectancy is an indicator of the ability of a state's medical facilities and access to a healthy lifestyle	LifeExp
Forest Cover	Percentage of Forest land to the total land. Forests have been shown to have a significant counterbalance to pm10 levels in the air. Also, forest cover gives us a proxy to uninhabited areas that are dormant in terms of their ability to be places where there could be pollution	ForCov
Industry Fuel Consumed#	Combustion of industrial fuels is a major contributor to the levels of pm_{10} and hence it is chosen as a control variable.	InFuelCons

Length of Electricity Transmission Lines	Due to the build of static around the lines particulates in the air are attracted to that area.	ElecTransL
Herfindahl-Hirschman Index	Calculates the level of competitiveness of a market by summing squares of all market shares.	HHI
Mortality Rate	Mortality rate is the number of deaths per 1000 individuals. It is an indicator of power. Lower mortality rate reflects better access to medication, nutrition and a healthy lifestyle.	Mortality
Vehicle per road length	The state's #of motor vehicles per the km of road length.	VehByRoad

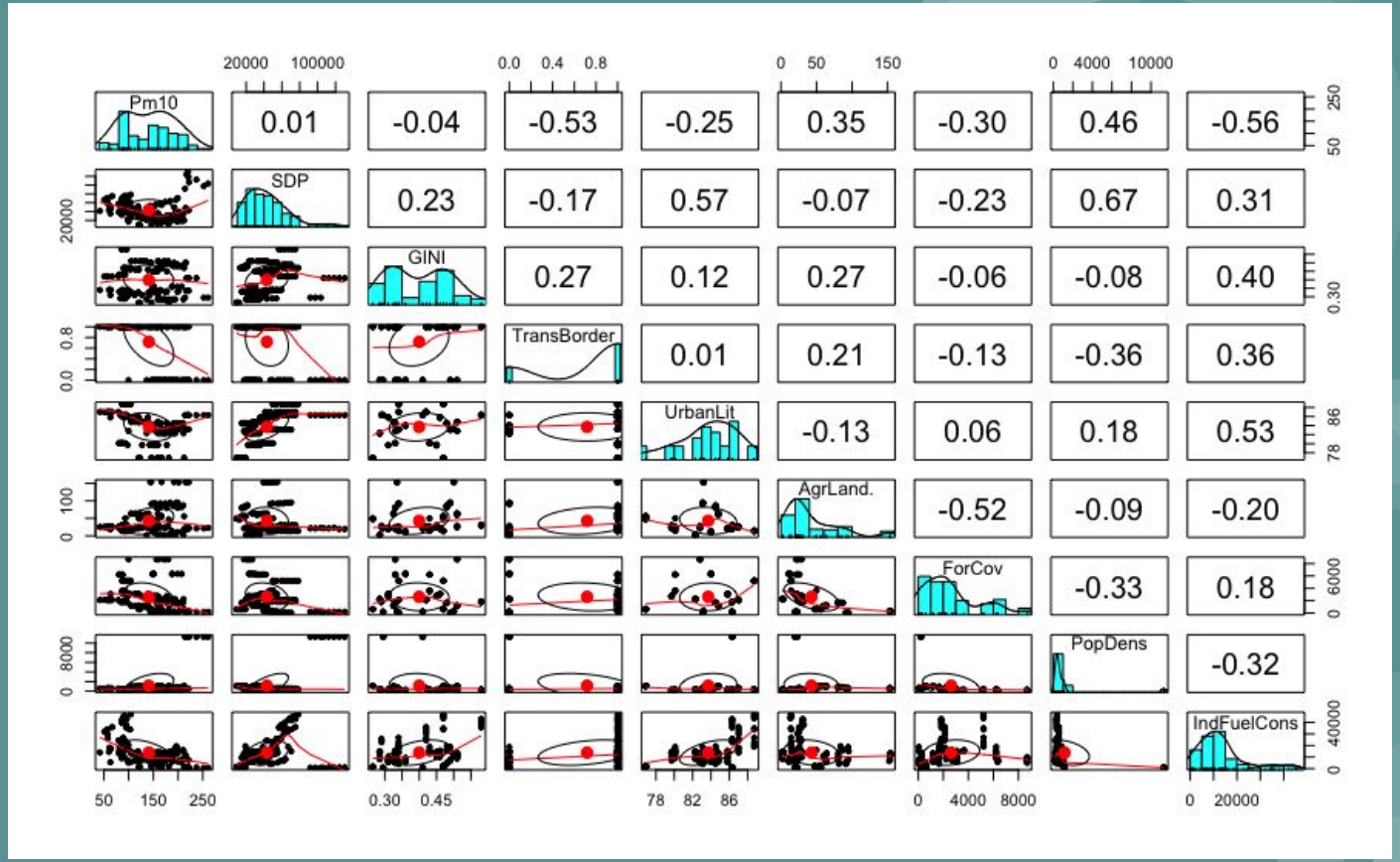
Data Summary

Variable Acronym	N	Mean	Median	SD	Minimum	Maximum
Pm10	138	140.65	146.00	50.39	41.70	329.00
SDP	138	43234	39096	23981.29	9070	130351
SDPsq	138	2.44e+09	1.52e+09	2950097304	8.22e+07	1.69e+10
SDPcube	138	1.72e+14	5.97e+13	3.44e+14	7.46e+11	2.21e+15
GINI	138	0.39	0.41	0.08	0.26	0.58
TransBorder	138	0.71	1.00	0.45	0.00	1.00

Variable Acronym	N	Mean	Median	SD	Minimum	Maximum
UrbanLit	138	83.69	84.00	3.11	76.90	88.70
VGI	138	58.00	46.84	43.57	0.51	182.72
ELCI	138	2720	2567	1431.56	1171	7765
SAPEI	138	6068	6150	1139.60	3228	8432
AgrLand%	138	42.93	25.87	38.76	1.80	154.31
Rain	138	948.3	1000.0	354.25	270.0	1700.0

Variable Acronym	N	Mean	Median	SD	Minimum	Maximum
PopDense	138	1137	414	2545.28	189	11297
Year	138	2011	2011	2.82	2007	2016
UrbanCen	138	25.07	22.00	15.86	1.00	67.00

Data Correlations



Model & Relevant Hypothesis

- Model 1 - averaged relationship across states and time
  - This model tests the relationship between PM10 and SDP and is controlled by the State over time.
  - $Pm10(i,t) = \beta_0 + \beta_1 SDP(i,t) + \beta_2 SDPsq(i,t) + \beta_3 SDPcube(i,t) + \sum^{17}_{k=4} \beta_k State(t)^{\#} + Year + U(i,t)$
  - Hypothesis (H_0)- No environmental kuznets curve observed between Pm10 and SDP across states over time.
  - We reject H_0 if => $\beta_1 > 0$, $\beta_2 < 0$

By State we mean to describe the 14 state dummy variables for 15 states.

Model & Relevant Hypothesis

- **Model 2 (I)**
  - The model tests the relationship between PM10 and SDP (income) and power inequality over years.
  - $PM10\ (i,t) = \beta_0 + \beta_1\ SDP\ (i,t) + \beta_2\ SDPsq\ (i,t) + \beta_3\ SDPcube\ (i,t) + \beta_4\ GINI\ (i,t) + \beta_5\ TransBorder\ (i) + \beta_6\ UrbanLit\ (i) + \beta_7\ VGI\ (i) + \beta_8\ ELCI\ (i,t) + \beta_9\ SAPEI\ (i,t) + \beta_{10}\ AgrLand\%\ (i) + \beta_{11}\ Rain\ (i,t) + \beta_{12}\ PopDens\ (i) + \beta_{13} UrbanCen\ (i) + \beta_{14}\ Year\ (t) + U\ (i,t)$

Model & Relevant Hypothesis

- **Model 2(II)**
  - The model tests the relationship between PM10 and SDP (income) and power inequality over years, and is controlled by the state.
  - $PM10\ (i,t) = \beta_0 + \beta_1\ SDP\ (i,t) + \beta_2\ SDPsq\ (i,t) + \beta_3\ SDPcube\ (i,t) + \beta_4\ GINI\ (i,t) + \beta_5\ TransBorder\ (i) + \beta_6\ UrbanLit\ (i) + \beta_7\ VGI\ (i) + \beta_8\ ELCI\ (i,t) + \beta_9\ SAPEI\ (i,t) + \beta_{10}\ AgrLand\%\ (i) + \beta_{11}\ Rain\ (i,t) + \beta_{12}\ PopDens\ (i) + \beta_{13} UrbanCen\ (i) + \sum^{27}_{k=14} \beta_k State(t)^{\#} + \beta_{28}\ Year\ (t) + U\ (i,t)$

- **Model 2 (I & II)**
  - Hypothesis (H_0)- The power inequality variables have no statistically significant effect on Pm10 levels.
  - We reject H_0 if =>
    - Power inequality variables turn out to be statistically significant.
    - SDP (income) variables become less significant.

Power Inequality Variables Individual Hypotheses

Var	Hypothesis (H_0)	Assumption & Expectation given control variables
Lit	H0: Lit has no significant effect on Pm10 concentration levels in a state.	Literacy is an indicator of education which is a general predictor of economic as well as social success.
UrbanLit	H0:UrbanLit has no significant effect on Pm10 concentration levels in a state.	UrbanLit may fit model better than Literacy in case our assumption that 'combined pm10 data taken from cities is generalisable to a state' does not hold.
SAPEI	H0:SAPEI has no significant effect on Pm10 concentration levels in a state.	SAPEI is a state variable. It measures power imbalance in state legislature by looking at each party's seat share. A more monopolistic system may undermine policy regulation action against air pollution. ***
ELCI	H0:EPI has no significant effect on Pm10 concentration levels in a state.	A measure of how competitive elections are overall. Low competition would, in theory, suggest power disparity in terms of ability to contest in elections. ***
VGI	H0:VGI has no significant effect on Pm10 concentration levels in a state.	VGI is a state variable. It indicates the Gendered power imbalance in voting. A higher value means higher power inequality along sex. ***
MarginalEV	H0:MarginalEV has no significant effect on Pm10 concentration levels in a state.	The size of election victory margin is a second measure of election competitiveness. A more competitive election would suggest a more equitable power distribution.
TransBorder	H0:Having a transnational border has no significant effect on Pm10 concentration levels for a state.	Border states export air pollution beyond borders. This reduces incentives for policy action against pm10. [M. Konisky, D., 2009] *** *** Check appendix for more background.

Regression Model 1 Results

- SDP, SDPsq and SDPcube are significant over states
- Coefficient of SDP(+ve), SDPsq(-ve) and SDPcube(+ve) therefore, we reject the null hypothesis H_0. H_a: Environmental Kuznets Curve is present.
- The trend variable Year is insignificant, it tells us that the progressive variation of pm10 within a state is very random.
- Statistical results:
  - Adjusted Rsq = 0.89 (High goodness of fit)
  - F-statistic: 57.89 on 18 , DF=119 , p-value <2.2e-16
  - Residual standard error = 17.31.

MODEL 1	Estimate	Standard Error	T values	P value
INTERCEPT *	5.472e+03	4.439e+03	1.233	0.220
SDP **	1.004e-02	3.013e-03	3.333	0.001
SDPsq ***	- 1.144e-07	3.224e-08	-3.548	5.57e-04
SDPcube **	4.131e-13	1.260e-13	3.278	0.001
stateBIHAR ***	2.011e+02	4.333e+01	4.641	9.00e-06
stateChattisgarh ***	1.404e+02	1.944e+01	7.219	5.34e-11
stateDELHI ***	1.149e+02	4.226e+01	2.719	0.008
stateHARYANA *	4.969e+01	2.047e+01	2.427	0.017
stateJHARKHAND ***	1.412e+02	2.016e+01	7.005	1.59e-10
stateMADHYA PRADESH ***	1.400e+02	2.458e+01	5.696	9.04e-08
statePUNJAB ***	8.766e+01	1.062e+01	8.257	2.36e-13
stateRAJASTHAN ***	1.009e+02	1.640e+01	6.156	1.04e-08
stateTAMIL NADU **	-5.483e+01	1.680e+01	-3.263	0.001439
stateUTTAR PRADESH ***	1.991e+02	3.423e+01	5.816	5.17e-08
stateWEST BENGAL ***	5.911e+01	1.085e+01	5.449	2.77e-07
stateMAHARASHTRA	-2.557e+01	2.074e+01	-1.233	0.220
stateKARNATAKA	1.068e+01	8.549e+00	1.249	0.214
stateGUJARAT	-2.521e+01	1.723e+01	-1.463	0.146
year	-2.799e+00	2.243e+00	-1.248	0.022

Regression Model 2(I) Results

- By comparing Model 1 to Model 2(I), we observe that SDP, SDPsq and SDPcube lost their significance. The power inequality variables turn out to be highly significant.
- Therefore, as the power inequality variables are statistically significant, we reject the null hypothesis H_0
- Coefficients of TransBorder(-ve), SAPEI(-ve) and UrbanCen(-ve) are different from what expected / hypothesised.
- Statistical results:
  - Adjusted Rsq = 0.87 (High goodness of fit)
  - F-statistic: 58.93 on 13 , DF=123 , p-value <2.2e-16
  - Residual standard error = 19.16

MODEL 2(I)	Estimate	Standard Error	T values	P value
Intercept ***	-1.356e+04	1.506e+03	-9.004	3.19e-15
SDP *	-1.702e-03	8.073e-04	-2.108	0.037
SDPsq	-5.540e-09	1.431e-08	-0.387	0.699
SDPcube	-2.567e-14	7.003e-14	0.379	0.705
TransBorder ***	-4.859e+01	4.378e+00	-11.100	< 2e-16
UrbanLit ***	3.723e+00	8.454e-01	4.404	2.27e-05
VGI ***	2.005e-01	5.397e-02	-3.716	0.001
ELCI ***	6.107e-03	1.637e-03	3.731	0.001
SAPEI ***	6.664e-03	1.805e-03	3.693	0.001
AgriLand ***	4.627e-01	5.069e-02	9.127	1.62e-15
UrbanCen **	-4.811e-01	1.473e-01	-3.265	0.001
Rain ***	-4.221e-02	5.899e-03	-7.155	6.41e-11
PopDens ***	1.736e-02	1.720e-03	10.092	< 2e-16
Year ***	6.700e+00	7.376e-01	9.084	2.06e-15

Regression Model 2(II) Results

- SDP, SDPsq and SDPcube regain significance on the inclusion of the State dummy variables.
- The State dummy variables turn out to be highly significant.
- The power inequality variables lose their significance in presence of the State dummy variables.
- This is happening because the variation of pm10 is so well captured by the state dummies, so that the variation of pm10 captured by power inequality variables become insignificant. In easier terms- A particular state has a similar amount of pm10.
- Statistical results:
  - Adjusted Rsq = 0.89 (High goodness of fit)
  - F-statistic: 44.36 on 23 , DF=114 , p-value <2.2e-16
  - Residual standard error = 17.51.

MODEL 2(II)	Estimate	Standard Error	T values	P value
Intercept	5.924e+03	5.993e+03	0.989	0.325
SDP **	9.163e-03	3.434e-03	2.669	0.009
SDPsq**	-1.065e-07	3.521e-08	-3.026	0.003
SDPcube**	3.844e-13	1.341e-13	2.866	0.005
TransBorder ***	-2.644e+02	6.695e+01	-3.980	0.001
UrbanLit **	-1.859e+01	5.833e+00	-3.186	0.002
VGI	-5.548e-02	7.400e-02	-0.750	0.455
ELCI	2.507e-03	1.836e-03	1.365	0.175
SAPEI	2.181e-03	3.251e-03	0.671	0.504
AgriLand	1.963e-01	3.568e-01	0.366	0.715
UrbanCen	4.828e-03	3.240e-01	0.015	0.988
Rain ***	-2.048e-01	5.632e-02	-3.636	0.001
PopDens ***	4.160e-01	1.220e-01	3.410	0.001
Year	-2.122e+00	2.797e+00	0.759	0.445

MODEL 2(II)	Estimate	Standard Error	T values	P value
stateBIHAR**	-1.462e+02	5.533e+01	-2.643	0.009
stateCHATTISGARH***	7.277e+01	1.789e+01	4.068	8.76e-05
stateDELHI**	-4.650e+03	1.420e+03	-3.275	0.001
stateGUJRAT***	6.375e+01	1.685e+01	3.784	0.001
stateHARYANA**	-3.374e+02	1.153e+02	-2.927	0.005
stateJHARKHAND	-7.589e+01	4.164e+01	-1.823	0.071
stateKARNATAKA***	1.832e+02	4.654e+01	3.937	0.001
stateMADHYAPRADESH	NA	NA	NA	NA
stateMAHARASHTRA***	1.378e+02	2.794e+01	4.931	2.80e-06
statePUNJAB	-3.5.5e+01	6.257e+01	-0.560	0.576
stateRAJISTHAN	3.058e+00	2.072e+01	0.148	0.884
stateTAMIL NADU	NA	NA	NA	NA
stateUTTAR PRADESH	NA	NA	NA	NA
stateWEST BENGAL	NA	NA	NA	NA

Some overall Steps/Results

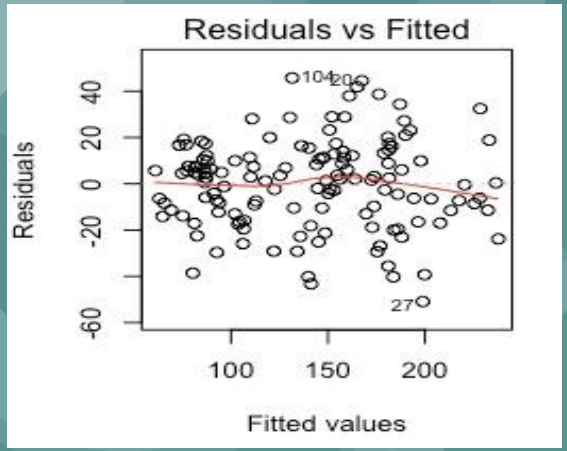
- These intuitive control variables were not included in the regression because they were highly insignificant variables: Temp, ForCov, Lit, Gini, MarginEV.
- 12 outliers were deleted from 150 data points
  - MarginalEV turns insignificant upon doing this.
  - Better goodness of fit.
  - More Homoskedasticity acheived.
- Multicollinearity : all variables have acceptable VIF values of near 1 if we disclude the sq and cube terms. If we include them, vif values of SDP and PopDens become near 5 which is not good.
- VehByRoad, a very interesting variable (especially due to the observed change in environment due to lockdown), was insignificant. Also it drove up PopDens vif value up. corr(VehByRoad, PopDens) = 0.78 (Which is clearly expected)

Limitations

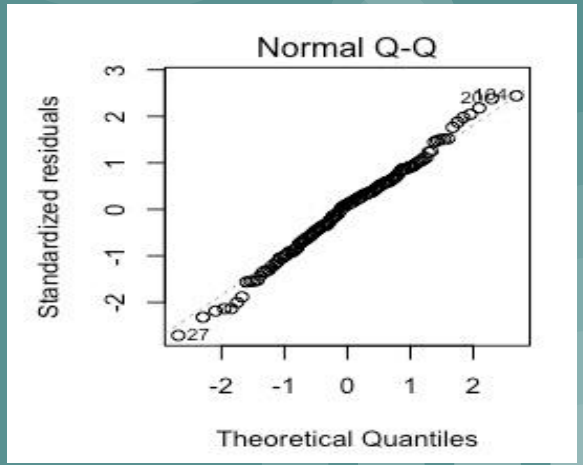
- OLS cannot handle fixed effects in panel data for state variables showing little to no variation over time in our sample. Eg. GINI(i) , Lit (i), VehByRoad.
- Sampling bias of data: It is observed that majority of the air pollution measuring stations were located in cities/ areas with high pollution. Therefore the data is primarily urban data. We tried to control for this bias by changing our variables to be ‘Urban’ biased, such as UrbanLiteracy vs Literacy.
- Geographical bias: interstate export of pollution, since PM10 is a property of air quality and the air pollution is transferred by wind.

Checking the Regression Assumptions

- Plot 1- Residual Plot
  - X- axis- Predicted PM10 Values
  - Y- axis- Residuals
- The Variation in the points seem to be constant here (Homoscedasticity)
- The red line is fairly flat, which tells us that the linearity assumption is met.

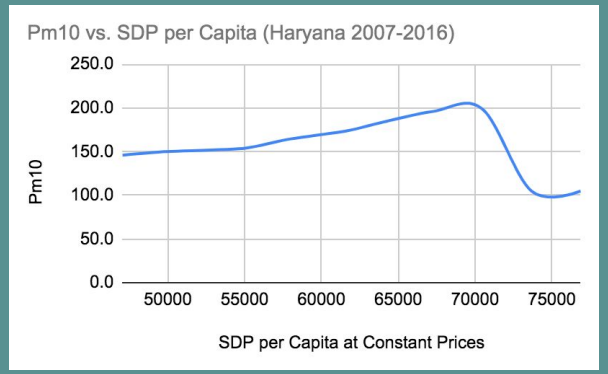


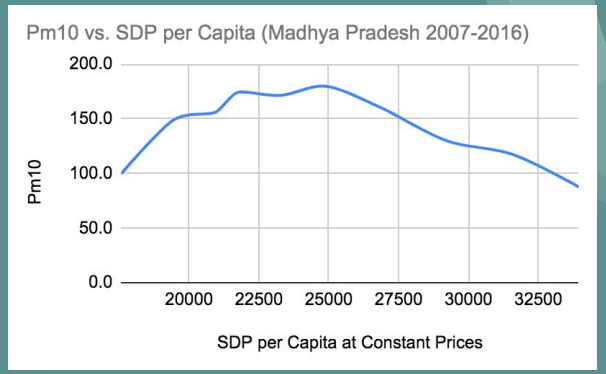
- Plot 2- Quantile-Quantile Plot
  - X- axis- Expected residuals, if the residuals are truly normally distributed
  - Y- axis- Ordered observed standardized residuals.
- The residuals fall roughly on the diagonal line, which means they're normally distributed.

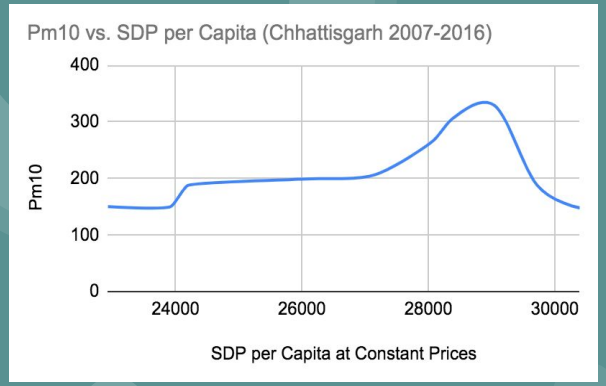


Discussion on The Environmental Kuznets Curve

The EKC was observed only within the states.
But can we call these curves EKC's?





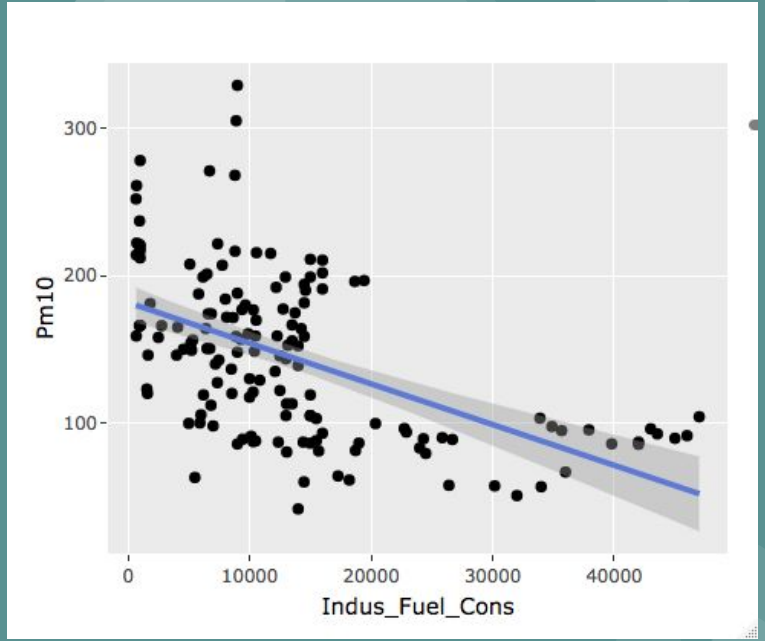


We believe that Environmental Kuznets curve is something that one observes over a large span of time (and not just 10 years). Although the coefficients of our SDP (income) variables turn out to be right for it to represent an EKC, we hesitate to say for sure that the states are following an EKC. We were very interested to study the graphs for a longer span, but unfortunately PM10 data was available only for 10 years in CPCB, which also is no longer there now.

An Interesting Variable- Industry Fuel Consumed

- It has a high negative correlation with Pm10 (-0.53).
- It can be observed in the plot itself that as the values of fuel consumed increases, Pm10 values decrease.
- Industry Fuel Consumed is defined by Annual Survey of Industries as-

Fuel Consumed represent total purchase value of all items of fuels, lubricants, electricity, water (purchased to make steam) etc. consumed by the factory during the accounting year except those which directly enter into products as materials consumed. It excludes that part of fuels, which is produced and consumed by the factory in manufacture i.e., all intermediate products and also fuels consumed by employees as part of amenities. It includes quantities acquired and consumed from allied concerns, their book value being taken as their purchase value and also the quantities consumed in production of machinery or other capital items for factory's own use.



Appendix

1. SAPEI : State Assembly Power Equality Index **(NOVEL INDEX CREATED BY US)**

Let # of parties in a state assembly be " **N** " and party index be " **i** ".
For consistency across all states, let the total # of each state assemblies' seats be scaled to " **100** ".
Let each party's seat share (out of 100) then be " p_i "
For each " p_i " , seat share allowed by **i** for other parties: **(100 - p_i)**

$$\text{SAPEI} = \sum_i^N p_i * (100 - p_i) = \sum_i^N (100\, p_i - p_i^{\,2})$$

This index captures a combination of equitability and diversity of power distribution in a given state assembly.

Taking 2 examples to illustrate the results of this index.....

1. Consider there are 2 parties:

Case 1: $p_1 = 50,\ p_2 = 50$
Case 2: $p_1 = 51,\ p_2 = 49$

Here, we see that both cases are equally diverse as " **N = 2** " but case 1 is barely more equitable than case 2 in terms of seat share.

Hence, **SAPEI 1 should be > SAPEI 2**, as it measures equality.

SAPEI 1 = 50*50 + 50*50 = 5000.
SAPEI 2 = 51*49 + 49*51 = 4998.

Correct!

Appendix

SAPEI ctd.....

2. Consider the following scenarios:

Case 1: 100 parties each with 1 seat. (N=100, $p_i = 1$)
Case 2 : 98 parties each with 1 seat and 1 party with 2 seats
Case 3: 1 party with 100 seats

SAPEI 1 = 1*99 + 1*99 + ... 100 times = 9900
SAPEI 2 = 2*98 + (1*99 + ... 98 times) = (2*98 + 99*98) = 9898
SAPEI 3 = 100*0 = 0

Range of SAPEI: 0 - 9900

SAPEI can also be interpreted as measuring the level of competition amongst parties in the state assembly. Herfindahl-Hirschman Index (HHI), in the same vein, captures the dominance of a monopoly in a free market place (inverse of SAPEI). (https://www.investopedia.com/terms/h/hhi.asp)

Correlation (HHI , SAPEI) = -0.99 (very high significance value)

Limitations :

- party coalition and other complicated collusion effects beyond scope.
- reserved seats effects beyond scope.

Appendix

2. ELCI- Election Lack of Competition Index **NOVEL INDEX CREATED BY US**

ELCI = $\sum_{i}^{N} v_i^2$, v_i = share of votes received by the participating party (out of 100) - logic of Herfindahl-Hirschman Index. This captures the HHI styled measure of market competitiveness. Higher value means less competition.

3. VGI - Voters Gender Inequality Index **NOVEL INDEX CREATED BY US**

VGI = 1000 * | 1 - (V_r / P_r) | V_r = male votes per female vote, P_r = male - female population ratio

We subtract the ratio of V_r / P_r from 1 because ratio of 1 would represent a perfect equality between genders.

So, VGI value gives us magnitude of skewness towards either gender.
This gives us a sense of power inequality at the level of ability to vote between genders.

Range: 0 (low inequality) - 1000 (high inequality)

4. TransBorder- Transnational Border Dummy **INDEX PROPOSED BY US**

- Border states export air pollution beyond borders to adjacent countries or the ocean. This has been shown to reduce incentives for policy action against pm10 in border districts of the United States. This is a free-riding problem. The cost of air pollution is essentially being exported and benefits of it being reaped by lessening enactment actions against this pollution. [M. Konisky, D., 2009] This may reflect a part of the power inequality in the state as the cost of pollution is also being borne, only in part however, ultimately by the less powerful folks of the same state too. (our assumption). Border states with other countries also import air pollution. This may cause something similar to an import-export war of pollution costs in some scenarios at the border between two countries. (our logical conclusion)
- States with coastal borders also have less pm10 concentration levels. [S Pillai, P., 2002]
- To see which effects of these effects are stronger overall, we include this variable as a simple dummy.

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