Opening the Brown Box: Production Responses to Environmental Regulation

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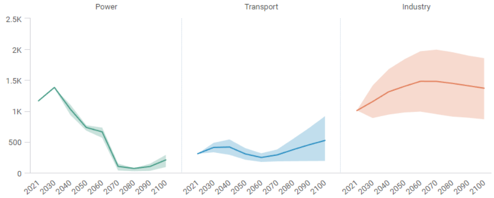
Focus on Reducing Industrial Emissions

- Industrial emissions $\approx \frac{1}{3}$ of total in 2022 (25.8% in India)
- Emissions of other sectors projected to decline, industrial emissions to rise
- Challenges are technological and uncertainty how to design regulation

Emissions Forecasts by Industry, Global

Emissions Forecasts by Industry, India



Units: Million metric tonnes of CO_2e.
Source: Rhodium Group Climate Deck Database.

CLIMATE ACTION

To decarbonize heavy industry, we must focus on industrial clusters

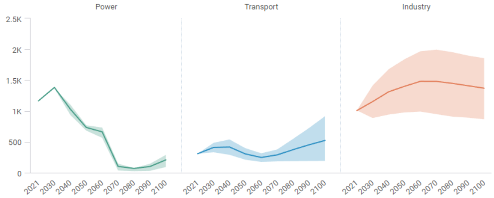
Jan 17, 2022

Focus on Reducing Industrial Emissions

- Industrial emissions $\approx \frac{1}{3}$ of total in 2022 (25.8% in India)
- Emissions of other sectors projected to decline, industrial emissions to rise
- Challenges are technological and uncertainty how to design regulation
- Robust evidence targeting firm emissions reduces them
  - → Often by shifting emissions and selling polluting assets
  - → Mixed evidence on firm-level and aggregate effects
  - → No evidence on *within-firm* production responses

Emissions Forecasts by Industry, Global

Emissions Forecasts by Industry, India



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This Paper

We combine:

- **Quasi-experiment:** Pollution index introduced in 2009 in India targeting place-based emissions; implementation based on pre-defined thresholds
  - $\rightarrow$ Difference-in-discontinuity around treatment thresholds
  - $\rightarrow$ Fixed effects: Firm and State $\times$ industry $\times$ Year
- **Unique data:** Inside the "brown box" of production processes and on firm outcomes
  - $\rightarrow$ Product-level inputs and outputs
  - $\rightarrow$ Abatement expenditures and action plans

Contributions:

- First to document within-firm production responses, both on the input and output side
- Evidence on which firms respond and which bear the burden
- Focus on industrial clusters and an emerging market

Results

- Improved pollution metrics at the cluster and product levels
  - → Multiple ways of measuring pollution suggest average cluster lowers emissions
  - → Wide variation in improvement
- Treated firms green production, invest in abatement
  - → Shift from high-emission and coal-dependent products
  - → Reduce product-level energy intensity
  - → Lower coal use and purchase electricity
  - → Make abatement investments
- Clusters with credible regulators and public-private cost sharing respond more strongly and bear the brunt of costs
  - → Suggest importance of enforcement, coordinating emissions regulation across sectors, and public-private cost sharing
- Firm and regulator actions lower cost, but loss of aggregate dynamism

Contribution to the Literature

- Quantify impact of environmental regulation on emissions
  - → Command-and-control and cap-and-trade policies can both lower targeted emissions (Fowlie, 2010; Harrison et al., 2019; Bartram et al., 2022; Ivanov et al., 2023, ...)
  - → Evidence for shifting emissions (Aichele and Felbermayr, 2015; Schiller, 2018; Ben-David et al., 2021; Dai et al., 2021a and 2021b; Kim and Xu, 2021, ...)
  - → **We focus on industrial clusters and use unique data and identification to study mechanisms**

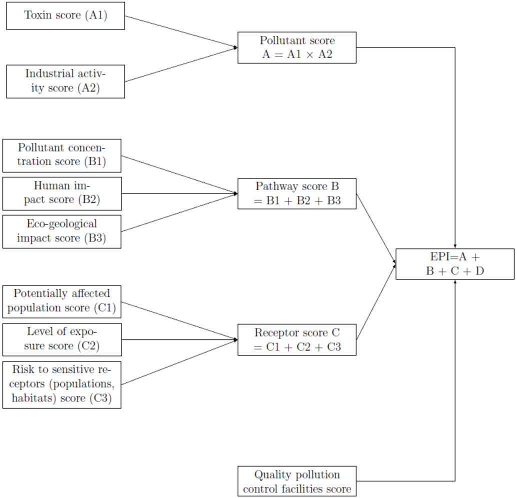
- Impact of emissions regulations on firm outcomes
  - → Mixed evidence on impact on productivity (Duflo et al., 2013; Kalmenovitz and Chen, 2021; Kala and Gechter, 2023, ...) and financial performance (Lenox and Eesley, 2009; Servaes and Tamayo, 2013; Fan et al., 2019; Naaraayanan et al., 2021, ...)
  - → **We document firm-level and within-firm production response**

- Broader literature on how firms impact the environment
  - → Highlighted importance of nature of ownership (Dimson et al., 2015, 2021; Krueger et al., 2020; Naaraayanan et al., 2021; Azar et al., 2021; Atta-Darkua et al., 2023; Berg et al., 2023; Ilhan et al., 2023, ...), disclosures (Jouvenot and Krueger, 2019; Bonetti et al., 2023; Tomar, 2023, ...), financial institutions (Kacperczyk and Peydro, 2022; De Haas, 2023; De Haas and Popov, 2023; Ivanov et al., 2023, ...), and self-commitment (Dahlmann et al., 2019; Comello et al., 2021; Freiberg et al., 2021; Duchin et al., 2022; Bolton and Kacperczyk, 2023, ...), trade (Barrows and Ollivier 2021)

INSTITUTIONAL BACKGROUND

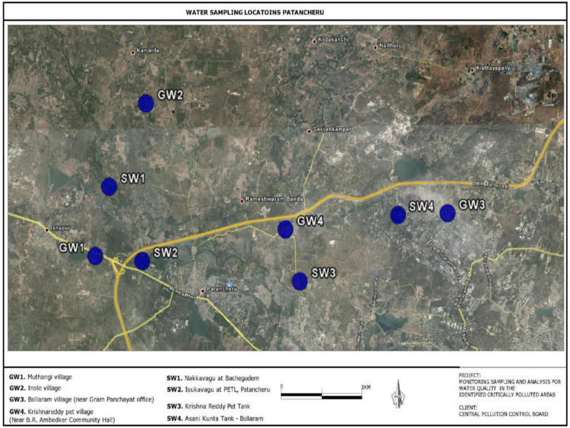
2009 Comprehensive Environmental Pollution Index (CEPI)

Methodology and Assessment



2009 Comprehensive Environmental Pollution Index (CEPI)

Methodology and Assessment



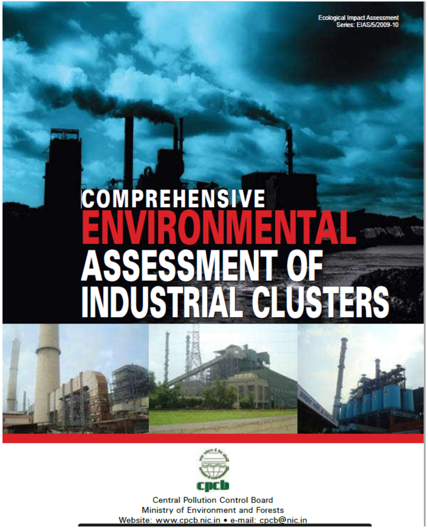
Ambient Air Monitoring Station. Sujana Metals Unit-IV

Surface Water Sampling Point. Isukavagu

Ground Water Sample Point. Bollaram Village

Ground Water Sample Point. Krishnareddypet

2009 Comprehensive Environmental Pollution Index (CEPI)



2009 Comprehensive Environmental Pollution Index (CEPI)

Table 5 CEPIs of various Industrial areas/ clusters for Air Environment

No.	Industrial Cluster/Area	A1	A2	A	B1	B2	B3	B	C1	C2	C3	C	D	AIR CEPI
1	Agra (Uttar Pradesh)	6.00	2.50	15.00	8.00	3.00	3.00	14.00	5.00	3.00	5.00	20.00	10.00	59.00
2	Ahmedabad (Gujarat)	6.00	5.00	30.00	7.75	3.00	3.00	13.75	3.00	3.00	0.00	9.00	10.00	62.75
3	Aligarh (Uttar Pradesh)	6.00	2.50	15.00	8.00	3.00	3.00	14.00	3.00	3.00	5.00	14.00	10.00	53.00
4	Angul Talcher (Orissa)	2.00	5.00	10.00	3.00	3.00	3.00	9.00	5.00	5.00	5.00	30.00	15.00	64.00
5	Ankleshwar (Gujarat)	5.00	5.00	25.00	8.00	6.00	6.00	20.00	3.00	4.00	5.00	17.00	10.00	72.00

2009 Comprehensive Environmental Pollution Index (CEPI)

Table 7 CEPIs of various Industrial areas/ clusters for Land (Soil & Groundwater)

No.	Industrial Cluster/Area	A1	A2	A	B1	B2	B3	B	C1	C2	C3	C	D	LAND CEPI
1	Agra (Uttar Pradesh)	5.50	2.50	13.75	7.00	0.00	0.00	7.00	5.00	4.75	5.00	28.75	10.00	59.50
2	Ahmedabad (Gujarat)	3.00	5.00	15.00	8.00	3.00	3.00	14.00	3.00	3.00	5.00	14.00	15.00	58.00
3	Aligarh (Uttar Pradesh)	2.00	2.50	5.00	8.00	3.00	3.00	14.00	3.00	3.00	5.00	14.00	15.00	48.00

2009 Comprehensive Environmental Pollution Index (CEPI)

Table 6 CEPIs of various Industrial areas/ clusters for Surface Water

No.	Industrial Cluster/Area	A1	A2	A	B1	B2	B3	B	C1	C2	C3	C	D	WATER CEPI
1	Agra (Uttar Pradesh)	5.50	2.50	13.75	7.00	0.00	3.00	10.00	5.00	5.00	5.00	30.00	10.00	63.75
2	Ahmedabad (Gujarat)	3.00	5.00	15.00	8.00	3.00	3.00	14.00	3.00	3.00	5.00	14.00	15.00	58.00
3	Aligarh (Uttar Pradesh)	2.00	2.50	5.00	8.00	3.00	3.00	14.00	3.00	3.00	5.00	14.00	15.00	48.00

2009 Comprehensive Environmental Pollution Index (CEPI)

Table 8 The CEPI scores for industrial areas/ clusters descending order

No.	Industrial Cluster/Area	AIR	WATER	LAND	CEPI	
1.	Ankleshwar (Gujarat)	72.00	72.75	75.75	88.50	Ac_Wc_Lc
2.	Vapi (Gujarat)	74.00	74.50	72.00	88.09	Ac_Wc_Lc
3.	Ghaziabad (Uttar Pradesh)	68.50	75.25	71.50	87.37	Ac_Wc_Lc
4.	Chandrapur (Maharashtra)	70.75	67.50	66.50	83.88	Ac_Wc_Lc

2009 Comprehensive Environmental Pollution Index (CEPI)

- Implementation
  - → **Cutoff 1**: Clusters with CEPI ≥ 60 subject to central monitoring at the national level, rather than the relatively weak local control, and quarterly emissions audits
  - → **Cutoff 2**: Clusters with CEPI ≥ 70 additionally must submit a remedial action plan for approval detailing emission reduction actions and timelines at the cluster and firm levels
- Failure to comply with the directives of the action plan:
  - → Lose their Environmental Clearance and Consent to Operate permits that allow firms to function within the formal economy
  - → Consent to Establish permits could not be issued to new operations

Enforcement case study: Coal India

DATA AND EMPIRICAL STRATEGY

Datasets

Multiproduct firms in the manufacturing sector

- 2009 policy documents from the CPCB on pollution index (CEPI) construction
- Location of industrial clusters in 2009 Construction
- Cluster-level air emissions from satellite readings
  - → Emission Database for Global Atmospheric Research (industrial layer) Construction
  - → Van Donkelaar $PM_{2.5}$
- Prowess and CapEx databases from Centre for Monitoring the Indian Economy
  - → Financial statements
  - → Product inputs and outputs mandated by Companies Act
  - → CAPX project announcements
- CO_2 conversion factors: Energy and Resources Institute and Central Electricity Authority
- Business registrar from the Ministry of Corporate Affairs
- 2001 Population Census

Balance Tables Merge

Descriptive Statistics: Industrial Multiproduct Firms in CEPI Clusters

Firm-year panel (1,984 firms)

	Obs	Mean	Std. dev.	Min.	Median	Max.
Assets (000 INR)	11,452	3,524	8,864	6.70	621	52,664
Sales (000 INR)	11,452	3,282	7,274	3.90	755	40,262
Leverage	10,307	0.27	0.20	0.00	0.25	1.13
Exporting Intensity	11,452	16.30	26.09	0.00	1.64	97.84
Ln(Revenue Productivity)	11,452	3.07	1.86	1.02	2.54	8.63
Number Product Lines	11,452	2.84	2.02	1.00	2.00	22.00
Profitability	11,452	0.11	0.08	-0.09	0.10	0.30
Investments/Assets	10,394	0.67	0.41	0.03	0.61	2.42
Raw Materials/Sales	11,451	0.58	0.22	0.03	0.60	1.01
Wages/Sales	11,451	0.05	0.05	0.00	0.04	0.30
Market-to-book	1,949	0.88	1.23	0.02	0.41	6.86

Firm-product-year panel (7,936 products)

	Obs	Mean	Std. dev.	Min.	Median	Max.
Ln(Product Sales)	30,143	4.44	2.78	-2.30	4.76	9.63
Ln(Unit Cost)	15,589	-4.97	3.86	-15.35	-3.85	3.44
Ln(Unit Price)	16,329	-4.92	3.87	-15.24	-3.73	3.37
Margin (%)	15,589	0.01	0.70	-5.67	0.14	0.64
Ln(Per Unit CO_2 Emissions)	1,163	-2.35	2.80	-9.83	-1.85	2.42

Empirical Specification

Cluster, firm, and product level specifications

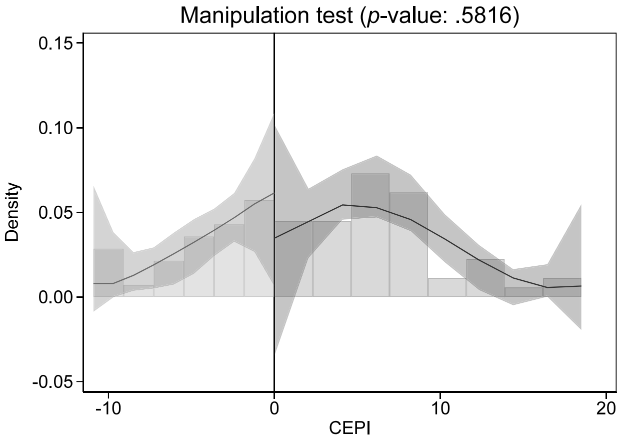
$$Y_{kijcst} = \beta_1 Post_t \times CEPI_c^{[60,70)} + \beta_2 Post_t \times CEPI_c^{[70,100]} + \\ + \beta_3 CEPI_c + \beta_4 Post_t + \gamma_i + \kappa_{jst} + \epsilon_{kijcst}$$

- k,i, j, c, s, and t represent a product, firm, industry, city, state, and year, respectively.
- $CEPI_c^{[60,70)}$ is one if the firm's industrial cluster has a **max** CEPI score $\geq$ 60 and below 70, and zero otherwise.
- $CEPI_c^{[70,100]}$ is one if the firm's industrial cluster has a **max** CEPI score $\geq$ 70, and zero otherwise.
- $Post_t$ is one after the regulation was implemented in 2009, and zero otherwise.
- Fixed effects: Firm (γ_i) and State $\times$ industry $\times$ Year (κ_{jst})
- Cluster standard errors at the cluster-level
- Estimate within a bandwidth of 10 CEPI ranking
- β_1: difference in discontinuity effect of crossing the treatment threshold at CEPI = 60

Identification Assumptions

DiD + RD = DiRD

1. No manipulation of the running variable (Cattaneo, Jansson and Ma (2020))



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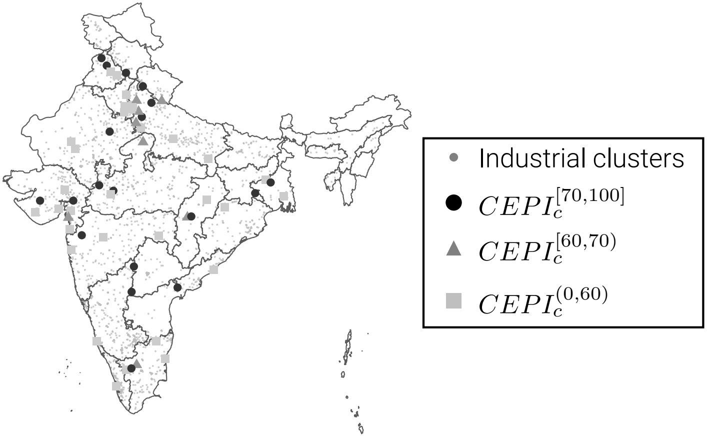

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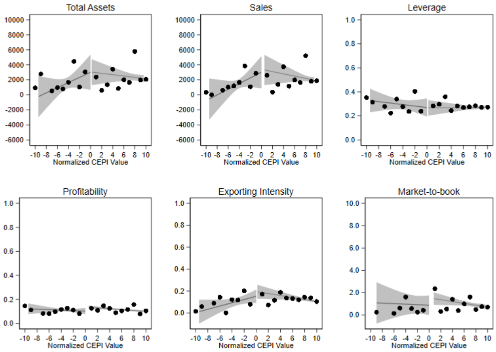
3. No jumps in firm and product characteristics around the threshold Balance: Firm Balance: Product



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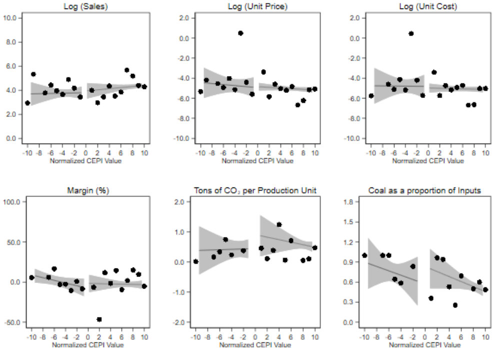

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DiD + RD = DiRD

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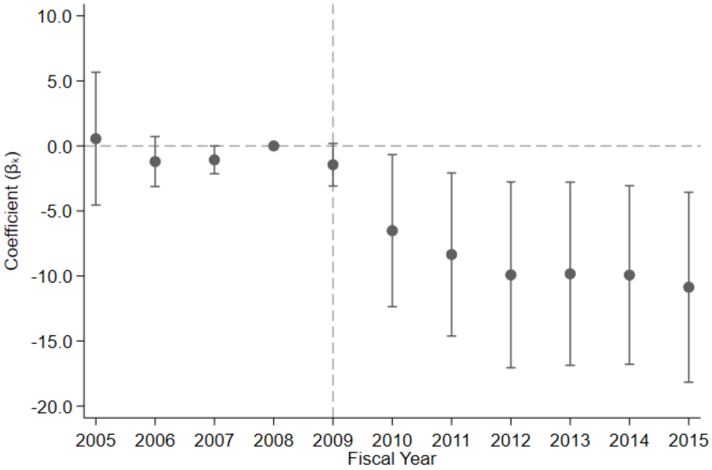
2. No geographic clustering Balance: Cluster
3. No jumps in firm and product characteristics around the threshold Balance: Firm Balance: Product
4. Parallel trends Covariates

IMPACT ON CLUSTER-LEVEL EMISSIONS

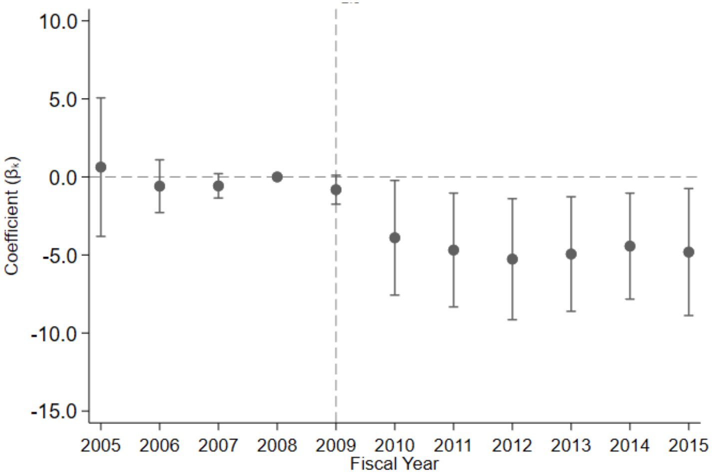
Cluster-Level Satellite Readings: Industrial Emissions, All Pollutants

Units: mg per month



Cluster-Level Satellite Readings: Particulate Matter $< 2.5\mu$

Units: mg per month



Cluster-Level Satellite Readings

Dependent variable:	Pollution Measurement			
Pollutant(s):	All	$PM_{2.5}$	PM_{10}	NO_x
Post $\times$CEPI$^{[60,70)}$ (β_1)	-7.232**	-3.686*	-7.113	-10.898*
	(3.597)	(2.054)	(5.653)	(6.536)
Post $\times$CEPI$^{[70,100]}$ (β_2)	-7.109**	-3.489*	-7.669	-10.169*
	(3.225)	(1.813)	(4.748)	(5.937)
2008 Dependent Variable Mean (Control)	23.09	16.86	38.95	13.45
R^2	0.932	0.949	0.946	0.836
Observations	54,648	18,216	18,216	18,216
p-value $[\beta_1 - \beta_2 = 0]$	0.935	0.843	0.840	0.600
DiD	-7.144	-3.545	-7.512	-10.375
	[2.185]	[1.928]	[1.550]	[1.702]

Notes. All models estimated within bandwidth of 10 CEPI; include Firm and State $\times$ industry $\times$ year FE.

- 10 $\mu g/m^3 \downarrow$ in exposure to $PM_{2.5} \Rightarrow$ 4-6% $\downarrow$ mortality risk (Pope et al. 2002; Hoek et al. 2013).

Van Donkelaar $PM_{2.5}$

Cluster-Level Satellite Readings: Energy Sector Placebo

No effect on emissions of un-treated sector

Dependent variable:	Pollution Measurement			
Pollutant(s):	All	$PM_{2.5}$	PM_{10}	NO_x
Post ×CEPI$^{[60,70)}$ (β_1)	-0.229	-0.112	-0.170	-0.405
	(0.715)	(0.274)	(0.542)	(1.415)
Post ×CEPI$^{[70,100]}$ (β_1)	-0.169	-0.181	-0.184	-0.143
	(0.755)	(0.304)	(0.549)	(1.520)
2008 Dependent Variable Mean (Control)	8.18	1.78	3.34	19.43
R^2	0.756	0.795	0.823	0.734
Observations	29,808	9,936	9,936	9,936
p-value $[\beta_1 - \beta_2 = 0]$	0.915	0.765	0.975	0.792
DiD	-0.186	-0.161	-0.180	-0.217
t-statistic	[0.266]	[0.579]	[0.357]	[0.153]

Notes. All models estimated within bandwidth of 10 CEPI; include Firm and State × industry × year FE.

HOW DO FIRMS REDUCE EMISSIONS?

Observing how firms alter their inputs

- We use detailed product energy input data unique to India
  - → Annual expenditure and consumption (with units) of energy sources—coal, electricity, fuel, etc. by product line

- Mandated by an 1988 amendment to the Companies Act of 1956
  - → All firms report value of energy inputs at firm level
  - → Largest firms have to report at product level and by fuel source
  - → 10% of firms in our sample report in 2009

Prob. File

Discontinuity Prob. File

Product Energy Inputs

Firms reduce energy and coal use while electrifying production

Dependent variable	Ln(Value Energy Input)	$\mathbb{1}_{\text{Coal Use}}$	Proportion Purchased Electricity
Post $\times$CEPI$^{[60,70)}$ (β_1)	-1.006***	-0.289*	0.196***
	(0.219)	(0.150)	(0.059)
Post $\times$CEPI$^{[70,100]}$ (β_2)	-0.818**	-0.301***	0.100**
	(0.294)	(0.092)	(0.036)
Ln(Production Quantity)	-0.208	0.033	-0.034
	(0.300)	(0.027)	(0.036)
2008 Dependent Variable Mean (Control)	8.906 M INR	0.17	0.46
R^2	0.795	0.496	0.786
Observations	901	565	901
p-value $[\beta_1 - \beta_2 = 0]$	0.549	0.905	0.124
DiD	-0.773	-0.308	0.151
t-statistic	[5.465]	[3.350]	[3.159]

Notes. All models include Firm and State $\times$ industry $\times$ year FE.

Firm-level Production Dynamics

Evidence from annual reports

JK Lakshmi Cement Limited Annual Report, Fiscal Year 2011

> During the year, the Company further improved its operating efficiencies. There was reduction in consumption of both power and fuel per unit of production. In addition, the Company improved usage of alternate fuel of bio-mass from 2% to 6%. These improvements have enabled the Company to also reduce the carbon footprint.

Product-Line Emissions

- We compute CO_2 emissions
  - → Multiply energy consumption by source-specific CO2 emissions factors and sum over energy types (Martin, 2012; Marin and Vona, 2019; Forslid et al., 2018; Barrows and Ollivier, 2021)
    - Electricity coded as coal
  - → Assumes energy source has a fixed carbon content irrespective of production or abatement technologies

Product-Level Emissions

Product emissions fall, consistent with cluster level evidence

Dependent variable:	Ln(Product CO_2 Emissions)	Ln(Per Unit CO_2 Emissions)
Post $\times$CEPI$^{[60,70)}$ (β_1)	-1.083***	-0.885***
	(0.283)	(0.306)
Post $\times$CEPI$^{[70,100]}$ (β_2)	-0.944**	-0.687**
	(0.346)	(0.270)
Ln(Production Quantity)	0.801**	
	(0.334)	
2008 Dependent Variable Mean (Control)	162,229.58	2.79
R^2	0.893	0.774
Observations	901	901
p-value [$\beta_1 - \beta_2 = 0$]	0.691	0.579
DiD	-1.414	-0.755
t-statistic	[5.460]	[3.709]

Notes. All models include Firm and State $\times$ industry $\times$ year FE.

Dynamics

Product Portfolio Weights

Relative shift away from dirtiest products

Dependent variable:	Product with Highest Coal Weight$_{2008}$	Product with Highest Emissions Weight$_{2008}$
Post $\times$CEPI$^{[60,70)}$ (β_1)	-0.309**	-0.318**
	(0.123)	(0.118)
Post $\times$CEPI$^{[70,100]}$ (β_2)	-0.139	-0.184*
	(0.114)	(0.101)
2008 Dependent Variable Mean (Control)	0.78	0.65
R^2	0.775	0.758
Observations	705	705
p-value $[\beta_1 - \beta_2 = 0]$	0.123	0.215
DiD	-0.181	-0.218
t-statistic	[1.438]	[1.981]

Notes. All models include Firm and State $\times$ industry $\times$ year FE.

Dynamics

Abatement Expenditures from Financial Statements

Abatement expenditures increase on extensive and intensive margins

Dependent variable:	$\mathbb{1}_{\text{Abatement}}$	Abatement/Assets
Post $\times$CEPI$^{[60,70)}$ (β_1)	0.048	0.039*
	(0.031)	(0.020)
Post $\times$CEPI$^{[70,100]}$ (β_2)	0.077**	0.038**
	(0.029)	(0.016)
2008 Dependent Variable Mean (Control)	0.06	0.01
R^2	0.725	0.753
Observations	10,752	10,752
p-value $[\beta_1 - \beta_2 = 0]$	0.029	0.933
DiD	0.072	0.038
t-statistic	[2.419]	[2.385]

Notes. All models include Firm and State $\times$ industry $\times$ year FE. Abatement expenditures include all funds used on pollution reduction in production.

Taking Stock of Results

1. Aggregate reduction in cluster-level emissions
   - → Independent evidence shows decreased manufacturing emissions
   - → Persistent decline follows reform and increases gradually over following five years
   - → No decrease in the energy sector, which was not treated

2. Reduction achieved through changes in input mix
   - → Reduce the amount spent on energy and energy use per product
   - → Increase electricity use
   - → Shift from dirtiest fuels
   - → Shift away from coal-intensive and highest-emission products
   - → Increase abatement expenditures

Delving even deeper:

Place-based regulation: **Who complies?**

Porter hypothesis: **Is there a tradeoff between reducing emissions and firm productivity and profitability?**

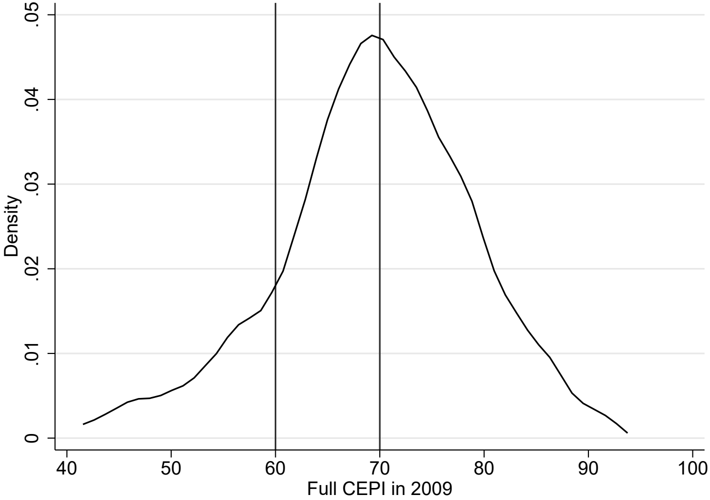
WHO COMPLIES?

Across-cluster heterogeneity

- Large variation in which clusters reduce emissions ex post

Comprehensive Environmental Pollution Index (CEPI)

Subsequent assessments



Comprehensive Environmental Pollution Index (CEPI)

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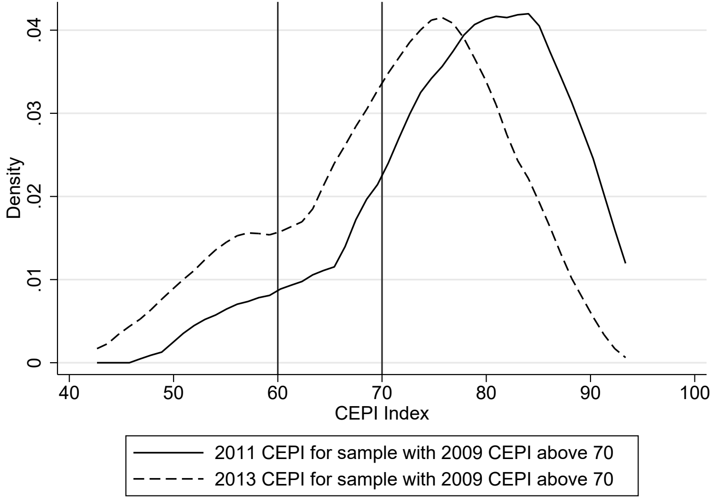
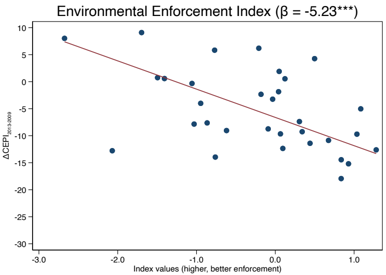
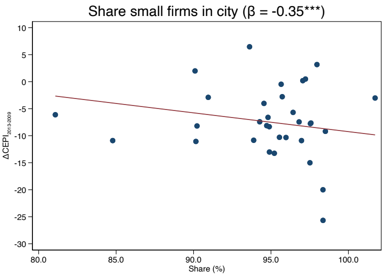


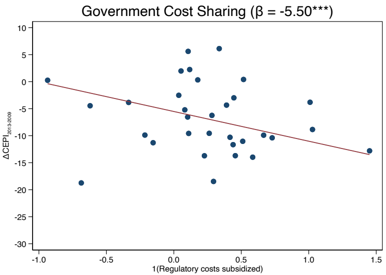
2. Across-cluster heterogeneity

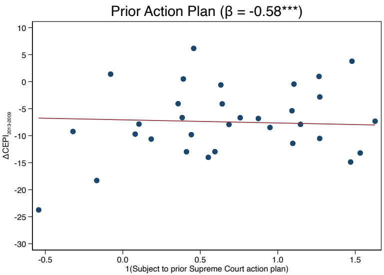
- Large variation in which clusters reduce emissions ex post
- Ex-ante predictors of success include:
  - → Environmental regulation historical effectiveness index (Kattumuri and Lovo (2018))
  - → Prior regulator action plans targeting city vehicle emissions (Greenstone and Hanna (2014))
  - → Regulator cost-sharing policies in action plans (2009 CEPI action plans) Cost sharing evidence
  - → Proportion of small firms in city (firm registry)

Ex-ante Predictors of CEPI Improvement









Firm and Aggregate Effects and Other Explanations

Firm Productivity and Profitability

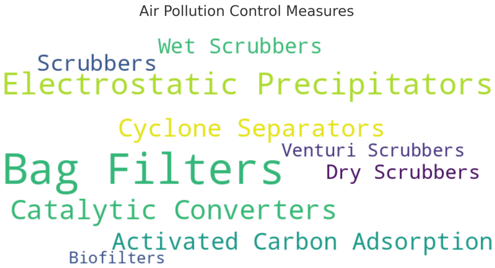
Dependent variable:	Ln(Revenue Productivity)	EBITDA/ Sales	Product Margin
Post $\times$CEPI$^{[60,70)}$ (β_1)	0.100	0.004	0.037
	(0.075)	(0.015)	(0.081)
Post $\times$CEPI$^{[70,100]}$ (β_2)	0.127***	0.008	0.147***
	(0.039)	(0.014)	(0.054)
2008 Dependent Variable Mean (Control)	2.77	0.10	0.00
Adjusted-R^2	0.851	0.638	0.722
Observations	10,752	10,752	15,225
p-value $[\beta_1 - \beta_2 = 0]$	0.695	0.556	0.123
ATE	0.122	0.007	0.124
	[3.238]	[0.496]	[2.731]

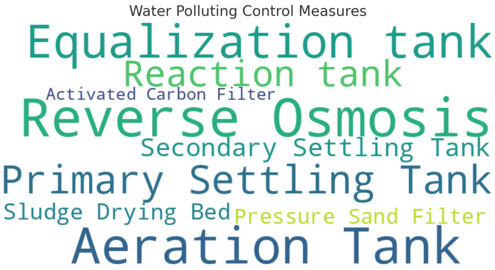
Notes. All models include Firm and State $\times$ industry $\times$ year FE.

Framework

Profitability Inputs

Abatement technologies: Evidence From Action Plans





Abatement technologies: Evidence From Action Plans

12. Summary of proposed action points

12.1 Short Term Action Points (up to 1 year, including continuous Activities)

Sr No	Action Points (including source & mitigation measures)	Responsible Stake Holders	Time limit	Cost	Remarks
WATER					
1. Standard flow meter at final outlet of ETP					
1	Identification of units having effluent quantity more than 25 m^3/day.	GPCB, Concerned industries, CIA	Completed 30.06.2010	-----	To control overflowing of CIA pipeline in future, it is necessary to control the discharge of excessive quantity of wastewater from the industrial units. **Identification completed**
	Industrial Association will issue the circular to their member to provide the Standard flow meter.	Concerned industries, CIA	31.12.2010	3.30 lacs	It is necessary to have metering system consisting of Standard Flow Meter (MFM) at the final outlet for industries having discharge more than 25 m3/day. **Out of identified units, four industries have already provided the flow meter and rest has procured for installation during connection to the conveyance system.**

Industry-level actions

Abatement technologies: Evidence From Action Plans

Name	Technology adopted during last one year			Time frame
	Air	Water	Land	
5. Tata Chemicals Ltd.	1. Dry Fog system and water sprinkling System. (Coal Handling plant, coke Handling plant, Material Handling System, Wagon Trippler) 2. Fully covered Wagon Tippler and conveyor belts . (Coal unloading station). 3. Green Belt Development. Within factory premises. 4. Power plant with 16 nos of WHRBs. Along with the process.	1. Boiler blow down water is mixed with quenching pond water and is used for Coke quenching purpose in 2 rows 2. Cooling Tower discharge water is mixed with quenching pond water and is used for Coke quenching purpose in other 2 rows 3.Quenching	1.Coke Swamp breeze is the only solid waste (non – hazardous in nature) generated from the process. The average generation of swamp breeze is approx 1000 tons per month which is being sold to third party completely 2. Total 15000 (approx) numbers of trees planted till date, nearly 2000 saplings have been planted	Already impleme nted

Firm-level actions

Aggregate Effect and Other Explanations

- Product variety decreases >

- Evidence consistent with lower firm entry
  - → All (formal) firms >
  - → Large firms >

- Leakage: No evidence firms shift production
  - → No effect on mergers and acquisitions >
  - → No effect on new plant announcements or closures >

Aggregate Effect and Other Explanations

- Product variety decreases >

- Evidence consistent with lower firm entry
  - → All (formal) firms >
  - → Large firms >

- Leakage: No evidence firms shift production
  - → No effect on mergers and acquisitions >
  - → No effect on new plant announcements or closures >
  - → 2018: Firms forcibly moved out of New Delhi, to a location allocated by lottery.
    - Gechter and Kala (2023): 18.3 ↑ probability of firm exit, increasing in distance from initial location

Open the “Brown Box:” Production Responses to Emissions Regulation

We find:

- Firms lower emissions by (1) shifting away from high-emission energy sources, (2) electrifying production, and (3) investing in abatement
- Successful improvement a function of regulator effectiveness and government cost sharing
- Regulated clusters exhibit lower firm entry and product variety

Open the “Brown Box:” Production Responses to Emissions Regulation

Implications:

- Important for environmental regulation design when enforcement and monitoring are weak (Greenstone and Jack 2015, Duflo et al. 2018)
- Can cap geographically-tied emissions, but exacts economic cost
- Design of risk and cost-sharing between industry and government
- Need for coordinating decarbonization policies: industrial and electricity generation

Worldwide Focus on Reducing Industrial Emissions

Electrifying Industry

The Economist

Briefing | The burning question

First electric cars. Next, electric factories?

They could be a major new way to slow global warming

IMAGE: RICARDO TOMÁS

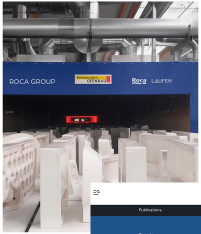
Feb 15th 2024 | FORT COLLINS

ROCA GROUP

Roca Group successfully commissions the world's first electric tunnel kiln for the production of sanitary ceramics

28/11/2023

- The operation was carried out through a pioneering partnership with specialist kiln manufacturer



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sabic

BASF, SABIC AND LINDE START CONSTRUCTION OF THE WORLD'S FIRST LARGE-SCALE ELECTRICALLY HEATED STEAM CRACKER FURNACES

01/09/2022

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Published: 19 January 2023

Transitioning Industrial Clusters towards Net Zero

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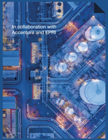
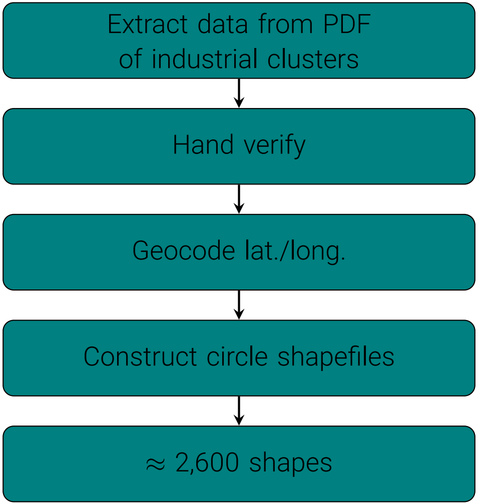
This insight report highlights the experiences and perspectives of 11 industrial clusters that are a part of the Transitioning Industrial Clusters towards Net Zero initiative. These clusters, despite facing unique geographical, infrastructure, policy and sectoral challenges, have all developed comprehensive strategies to rapidly and equitably decarbonize their operations.



THANK YOU!

Cluster data construction



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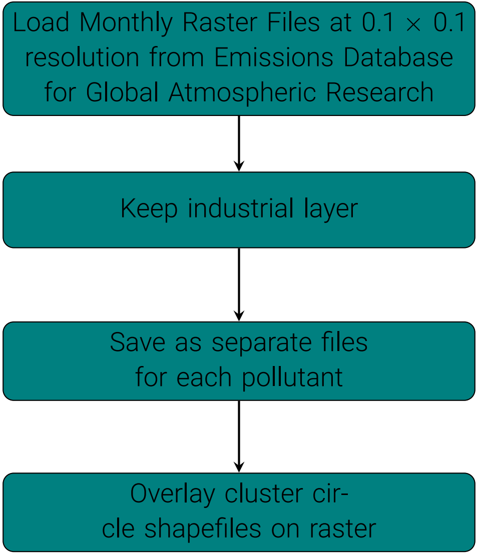
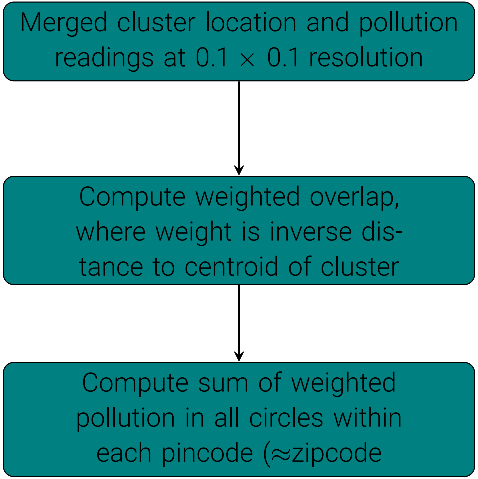
Extracting pollution data (1)



Extracting pollution data (2)



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Cluster-Level Satellite Readings: Van Donkelaar $PM_{2.5}$ Measure

Dependent variable:	Fine $PM_{2.5}$ (μ g/m^3)	
Radii of circle:	5 kilometers	500 meters
Post $\times$CEPI$^{[70,100]}$ (β_1)	-2.311***	-1.893**
	(0.775)	(0.743)
Post $\times$CEPI$^{[60,70)}$ (β_2)	-1.018	-0.560
	(0.756)	(0.673)
p-value $[\beta_1 + \beta_2 = 0]$	0.025	0.069
2008 Dependent Variable Mean (Control)	84.0	84.0
R^2	0.963	0.959
Observations	17,952	18,216

Notes. All models estimated within bandwidth of 10 CEPI; include Cluster & State $\times$ year-month FE.

- Reduction in $PM_2.5$ emissions of 4% relative to the pre-regulation control mean.

Back

Cluster-Level Satellite Readings: Energy Sector Placebo

No effect on emissions of un-treated sector.

Dependent variable:	Pollution Measurement			
Pollutant(s):	All	$PM_{2.5}$	PM_{10}	NO_x
Post $\times$CEPI$^{[60,70)}$ (β_1)	-0.229	-0.112	-0.170	-0.405
	(0.715)	(0.274)	(0.542)	(1.415)
Post $\times$CEPI$^{[70,100]}$ (β_1)	-0.169	-0.181	-0.184	-0.143
	(0.755)	(0.304)	(0.549)	(1.520)
2008 Dependent Variable Mean (Control)	8.18	1.78	3.34	19.43
R^2	0.756	0.795	0.823	0.734
Observations	29,808	9,936	9,936	9,936
p-value $[\beta_1 - \beta_2 = 0]$	0.915	0.765	0.975	0.792
DiD	-0.186	-0.161	-0.180	-0.217
t-statistic	[0.266]	[0.579]	[0.357]	[0.153]

Notes. All models estimated within bandwidth of 10 CEPI; include Firm and State $\times$ industry $\times$ year FE.

Back

Descriptive Statistics: Firms

	Obs	Mean	Std. dev.	Min.	Median	Max.
Assets (000 INR)	11,452	3,524	8,864	6.70	621	52,664
Sales (000 INR)	11,452	3,282	7,274	3.90	755	40,262
Leverage	10,307	0.27	0.20	0.00	0.25	1.13
Exporting Intensity	11,452	16.30	26.09	0.00	1.64	97.84
Ln(Revenue Productivity)	11,452	3.07	1.86	1.02	2.54	8.63
Number Product Lines	11,452	2.84	2.02	1.00	2.00	22.00
Profitability	11,452	0.11	0.08	-0.09	0.10	0.30
Investments/Assets	10,394	0.67	0.41	0.03	0.61	2.42
Raw Materials/Sales	11,451	0.58	0.22	0.03	0.60	1.01
Wages/Sales	11,451	0.05	0.05	0.00	0.04	0.30
Market-to-book	1,949	0.88	1.23	0.02	0.41	6.86

Back

Descriptive Statistics: Products

	Obs	Mean	Std. dev.	Min.	Median	Max.
Ln(Product Sales)	30,143	4.44	2.78	-2.30	4.76	9.63
Ln(Unit Cost)	15,589	-4.97	3.86	-15.35	-3.85	3.44
Ln(Unit Price)	16,329	-4.92	3.87	-15.24	-3.73	3.37
Margin (%)	15,589	0.01	0.70	-5.67	0.14	0.64
Ln(Per Unit CO_2 Emissions)	1,163	-2.35	2.80	-9.83	-1.85	2.42

Back

Balance: Firms

	All	Below	Above	Difference	RD Estimate	*p*-value
Assets (000 INR)	2,443	1,916	2,526	-610	-1,342	0.63
Sales (000 INR)	2,418	1,853	2,519	-665	-348	0.90
Leverage	0.27	0.29	0.27	0.02	-0.041	0.39
Exporting Intensity	0.25	0.23	0.25	-0.022	0.095	0.17
Ln(Revenue Productivity)	3.3	3.3	3.3	-0.0028	-0.18	0.72
Number of Products	2.9	2.9	2.9	-0.035	0.35	0.35
Profitability	0.11	0.11	0.12	-0.0064	0.023	0.16
Investments/Assets	0.70	0.77	0.69	0.083	-0.16	0.14
Raw Materials/Sales	0.57	0.60	0.57	0.037	0.0006	0.99
Wages/Sales	0.064	0.059	0.065	-0.0055	0.029	0.15
Market-to-book	1.1	0.95	1.1	-0.14	0.81	0.35

Back

Balance: Products

	All	Below	Above	Difference	RD Estimate	*p*-value
Ln(Product Sales)	4.1	3.8	4.1	-0.30	-0.48	0.47
Ln(Unit Cost)	-5.0	-4.7	-5.0	0.33	-0.37	0.52
Ln(Unit Price)	-5.0	-4.7	-5.0	0.36	-0.26	0.59
Margin(%)	-2.3	-1.5	-2.5	1.00	-4.5	0.57
Ln(Unit CO_2 Emissions)	-2.5	-2.2	-2.5	0.36	-0.85	0.27
Coal's Proportion of Inputs	0.65	0.66	0.65	0.01	0.35	0.09

Back

Balance: Cluster

	All	Below	Above	Difference	Estimate	*p*-value
City roads, km, 1981	337.21	268.94	391.82	-122.89	-297.23	0.49
Log(population), 2001	13.33	13.02	13.57	-0.56	0.40	0.69
Population density (000 per Sq. km), 2001	8.63	9.39	7.99	1.39	-1.08	0.80
Average rent (per Sq. m.), 2008	953.70	907.78	990.43	-82.65	356.07	0.42
Proximity index, 2008	0.07	0.00	0.12	-0.11	-0.00	0.97
Nearest waterway (km), 2008	13.90	17.66	10.95	6.71	-16.69	0.182
Potential yields (tons/ha), 2008	1.44	1.49	1.41	0.08	0.11	0.12
Diameter from center (km), 2008	4.86	3.87	5.71	-1.84	2.22	0.51
Area footprint (Sq. km.), 2008	187.83	114.28	250.07	-135.79	184.25	0.49

Back

Product Energy Inputs

Dependent variable	Ln(Value Energy Input)	$\mathbb{1}_{\text{Coal Use}}$	Proportion Electricity
Post $\times$CEPI$^{[70,100]}$ (β_1)	-0.464	-0.476***	0.023
	(0.464)	(0.143)	(0.065)
Post $\times$CEPI$^{[60,70)}$ (β_2)	-0.539	-0.341	0.173
	(0.338)	(0.208)	(0.119)
Post $\times$CEPI$^{[70,100]}$ $\times$ High-Polluting (β_3)	-0.600	0.371	0.157*
	(0.673)	(0.238)	(0.079)
Post $\times$CEPI$^{[60,70)}$ $\times$ High-Polluting (β_4)	-1.100	-0.327	0.002
	(0.712)	(0.321)	(0.147)
Ln(Production Quantity)	-0.200	0.027	-0.036
	(0.292)	(0.025)	(0.036)
2008 Dependent Variable Mean (Control)	8.906M	0.17	0.46

Back

Product-Level Emissions

Dependent variable:	Ln(Product CO_2 Emissions)	Ln(Per Unit CO_2 Emissions)	Highest Coal Product Weight_{2008}
Post $\times \text{CEPI}^{[70,100]}$ (β_1)	-0.515	-0.273	-0.007
	(0.526)	(0.646)	(0.102)
Post $\times \text{CEPI}^{[60,70)}$ (β_2)	-0.591	-0.369	-0.060
	(0.391)	(0.469)	(0.090)
Post $\times \text{CEPI}^{[70,100]}$ $\times$ High-Polluting (β_3)	-0.750	-0.725	-0.175*
	(0.638)	(0.877)	(0.083)
Post $\times \text{CEPI}^{[60,70)}$ $\times$ High-Polluting (β_4)	-1.112	-1.196	-0.531*
	(0.779)	(0.945)	(0.262)
Ln(Production Quantity)	0.811**		
	(0.325)		
2008 Dependent Variable Mean (Control)	162,229.6	2.788	0.780

Back

Factors of Production

Dependent variable:	Wage Bill	Raw Material Exp.	Investment
Post $\times$CEPI$^{[70,100]}$ (β_1)	-0.002	-0.035	0.020
	(0.003)	(0.027)	(0.024)
Post $\times$CEPI$^{[60,70)}$ (β_2)	-0.005	-0.030	0.019
	(0.005)	(0.029)	(0.031)
2008 Dependent Variable Mean (Control)	0.05	0.54	0.89
Firm & State $\times$ industry FE	Yes	Yes	Yes
Bandwidth	Yes	Yes	Yes
R^2	0.806	0.793	0.826
Observations	10,752	10,752	9,643

Factors of Production

Dependent variable:	Wage Bill	Raw Material Exp.	Investment
Post $\times$CEPI$^{[70,100]}$ (β_1)	-0.003	-0.039	0.018
	(0.003)	(0.027)	(0.024)
Post $\times$CEPI$^{[60,70)}$ (β_2)	-0.004	-0.055*	0.028
	(0.007)	(0.029)	(0.032)
Post $\times$CEPI$^{[70,100]}$ $\times$ High-Polluting (β_3)	0.005**	0.011	0.009
	(0.002)	(0.011)	(0.017)
Post $\times$CEPI$^{[60,70)}$ $\times$ High-Polluting (β_4)	-0.003	0.087***	-0.027
	(0.008)	(0.031)	(0.032)
2008 Dependent Variable Mean (Control)	0.05	0.54	0.89
Firm & State $\times$ industryFE	Yes	Yes	Yes
Bandwidth	Yes	Yes	Yes
R^2	0.806	0.794	0.826
Observations	10,752	10,752	9,643

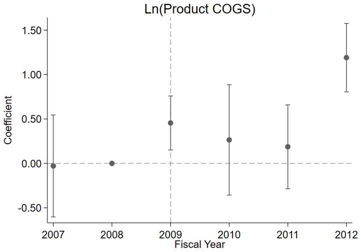
Back

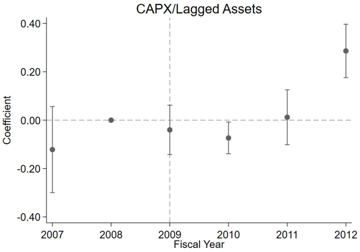
Quantity Productivity

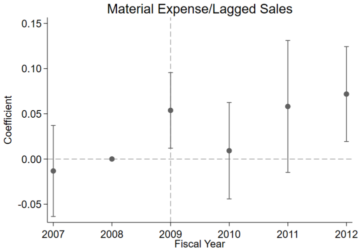
Dependent variable:	Log(Quantity-based Productivity)	
Post $\times$CEPI$^{[60,70)}$ (β_2)	-0.287	-0.190
	(0.176)	(0.302)
Post $\times$CEPI$^{[60,70)}$ $\times$ High-Polluting (β_4)		-0.189
		(0.376)
2008 Dependent Variable Mean (Control)	8.6	8.6
Firm FE	Yes	Yes
State $\times$ industry $\times$ year FE	Yes	Yes
Bandwidth	Yes	Yes
R^2	0.824	0.825
Observations	1,898	1,898

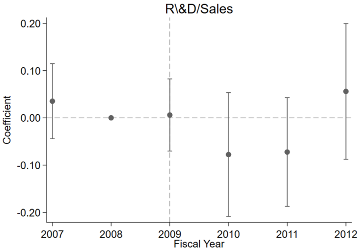
Back

Robustness: Parallel trends









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Probability of Filing Energy Inputs

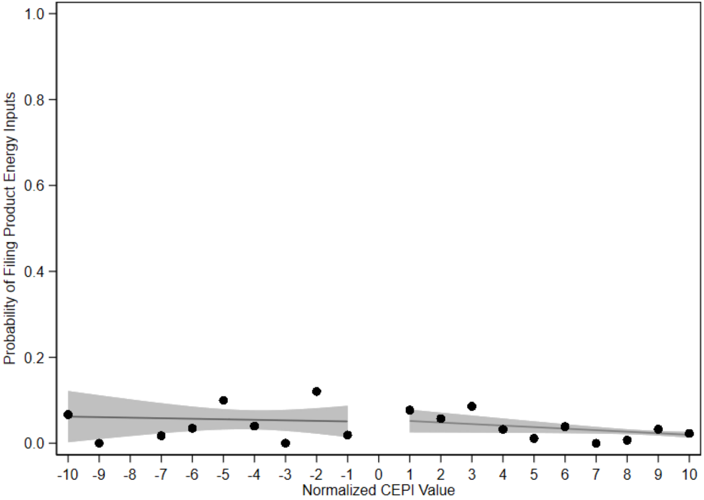
No discontinuity in the probability of reporting energy inputs around the reform.

Dependent variable:	$\mathbb{1}_{\text{File Energy Inputs}}$		
Sample:	All	Regression	
Post	-0.007***		
	(0.001)		
Post $\times$CEPI$^{[60,100]}$		-0.010	
		(0.010)	
Post $\times$CEPI$^{[70,100]}$			-0.011
			(0.010)
Post $\times$CEPI$^{[60,70)}$			-0.008
			(0.013)
Firm & State $\times$ industry $\times$ year FE	Yes	Yes	Yes
Bandwidth	Yes	Yes	Yes
R^2	0.408	0.417	0.417
Observations	119,943	32,299	32,299

Back

Probability of Filing Energy Inputs

No discontinuity in the probability of reporting energy inputs around the thresholds at baseline.



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Cluster business dynamism decreases from lower firm entry

Prowess sample (large firms)

Dependent variable:	$\mathbb{1}_{\text{New Firm}}$	Log(No. of firms)	$asinh$(No. of firms)	No. of firms (Poisson)
	(1)	(2)	(3)	(4)
Post $\times$CEPI$^{[60,70)}$ (β_1)	-0.003	0.001	0.001	-0.289
	(0.017)	(0.016)	(0.021)	(0.440)
2008 Dependent Variable Mean (Control)	0.01	0.01	0.01	0.01
Adjusted-R^2	0.172	0.212	0.213	
Observations	4,416	4,416	4,416	678

Notes. All models estimated within bandwidth of 10 CEPI; include Firm and State $\times$ industry $\times$ year FE.

Back

Thursday, 7 March, 2024

The Statesman

CIL output to fall short of target

Statesman News Service | New Delhi | December 23, 2010 5:31 pm

NEW DELHI, 23 DEC: Coal India today said its production would fall short of target by 16 million tons this financial year and might miss the expected output by 39 million tons in fiscal 2011-12 due to extension of tough environmental norms. "**Comprehensive Environmental Pollution Index** (CEPI) was supposed to be reviewed in October, but it has been extended till March. As a result, we clearly estimate an impact of 16 million tons reduction this year (on production)," Coal India chairman Mr Partha Bhattacharya told reporters here on the sidelines of a Parliamentary Standing Committee meeting. He added: "If it continues in 2012, then it will affect additional 39 million tons, which means it will take away the growth process (of Coal India)". Coal India has set a production target of 260.5 MT in 2010-11 and it has planned to produce 486.5 MT of coal in 2011-12.

Back

Firm-level energy input

Dependent variable:	Ln(Value Firm Energy Input)
Post $\times$CEPI$^{[60,70)}$ (β_1)	-0.667***
	(0.138)
Post $\times$CEPI$^{[70,100]}$ (β_2)	0.031
	(0.095)
2008 Dependent Variable Mean (Control)	219.92
Adjusted-R^2	0.959
Observations	10,752
p-value $[\beta_1 - \beta_2 = 0]$	0.003

Notes. All models estimated within bandwidth of 10 CEPI; include Firm and State $\times$ industry $\times$ year FE.

Return

Cost of compliance: Evidence from action plans

Return

Sl. No.	Action Points (including source & mitigation measures)	Responsible Stake Holders	Time Limit	Cost	Remarks
1	Installation of CETP	Industry Association & Industry, WBPCB, MOEF as per CETP cost sharing principle of MOEF coordinated by SPCB	By June 2012	1.5 Crore	Necessary funding may be granted through WBPCB
2	Installation of AAAQM	Industry Association & Industry	By June 2012	02 Crore	Necessary funding may be granted through WBPCB
3	Development of proper drainage facility	Industry Association & Industry	By June 2012	02 Crore	Necessary funding may be granted through WBPCB. The possibility of accessing Infrastructural Funding Assistance from GOI will be explored.

Evidence from media

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The Statesman

Thursday, 7 March, 2024

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CIL output to fall short of target

Statesman News Service | New Delhi | December 23, 2010 5:31 pm

NEW DELHI, 23 DEC: Coal India today said its production would fall short of target by 16 million tons this financial year and might miss the expected output by 39 million tons in fiscal 2011-12 due to extension of tough environmental norms. "**Comprehensive Environmental Pollution Index** (CEPI) was supposed to be reviewed in October, but it has been extended till March. As a result, we clearly estimate an impact of 16 million tons reduction this year (on production)," Coal India chairman Mr Partha Bhattacharya told reporters here on the sidelines of a Parliamentary Standing Committee meeting. He added: "If it continues in 2012, then it will affect additional 39 million tons, which means it will take away the growth process (of Coal India)". Coal India has set a production target of 260.5 MT in 2010-11 and it has planned to produce 486.5 MT of coal in 2011-12.

Lower Product Variety

Return

Dependent variable:	Ln(Product-level Production	Ln(No. of Products)	$\mathbb{1}_{\text{Add Product}}$	$\mathbb{1}_{\text{Remove Product}}$
Post $\times$CEPI$^{[60,70)}$ (β_1)	-0.110	0.013	-0.117***	0.003
	(0.182)	(0.078)	(0.041)	(0.036)
Post $\times$CEPI$^{[70,100]}$ (β_2)	0.030	0.007	-0.057*	0.023
	(0.130)	(0.072)	(0.034)	(0.030)
2008 Dependent Variable Mean (Control)	29,784	2.71	0.27	0.17
R^2	0.582	0.746	0.263	0.242
Observations	15,521	10,752	10,752	10,752
p-value $[\beta_1 - \beta_2 = 0]$	0.429	0.904	0.094	0.314
ATE	0.007	0.008	-0.068	0.019
t-statistic	[0.063]	[0.118]	[2.138]	[0.621]

Notes. All models estimated within bandwidth of 10 CEPI; include Firm and State $\times$ industry $\times$ year FE.

Lower Product Variety Return

Dependent variable:	Ln(Product-level Production)	Ln(No. of Products)	$\mathbb{1}_{\text{Add Product}}$	$\mathbb{1}_{\text{Remove Product}}$
Post $\times$CEPI$^{[60,70)}$ (β_1)	-0.331	0.003	-0.141***	-0.028
	(0.235)	(0.076)	(0.041)	(0.042)
Post $\times$CEPI$^{[70,100]}$ (β_2)	-0.008	0.015	-0.051	0.013
	(0.137)	(0.073)	(0.034)	(0.032)
Post $\times$CEPI$^{[60,70)}$ $\times$ High-Polluting (β_3)	0.621***	0.025	0.073	0.107**
	(0.222)	(0.083)	(0.052)	(0.050)
Post $\times$CEPI$^{[70,100]}$ $\times$ High-Polluting (β_4)	0.090	-0.036*	-0.030	0.036*
	(0.105)	(0.019)	(0.025)	(0.019)

Notes. All models estimated within bandwidth of 10 CEPI; include Firm and State $\times$ industry $\times$ year FE.

Cluster business dynamism decreases from lower firm entry

Return

Full firm registry

Dependent variable:	$\mathbb{1}_{\text{New Firm}}$	Log(No. of firms)	$asinh$(No. of firms)	No. of firms (Poisson)
Post $\times$CEPI$^{[60,70)}$ (β_1)	-0.009	-0.011	-0.014	-0.105
	(0.011)	(0.010)	(0.013)	(0.138)
2008 Dependent Variable Mean (Control)	0.08	0.20	0.20	0.20
R^2	0.449	0.570	0.570	
Observations	33,534	33,534	33,534	19,958
ATE	-0.013	-0.010	-0.013	-0.169
t-statistic	[1.360]	[1.206]	[1.189]	[1.582]

Notes. All models estimated within bandwidth of 10 CEPI; include Firm and State $\times$ industry $\times$ year FE.

Large firms

No evidence firms shift production location Return

No effect on mergers and acquisitions

Dependent variable:	$\mathbb{1}_{\text{Target}}$	$\mathbb{1}_{\text{Acquired}}$
Post $\times$CEPI$^{[60,70)}$ (β_1)	0.018	-0.000
	(0.012)	(0.008)
	(0.009)	(0.007)
2008 Dependent Variable Mean (Control)	0.00	0.00
Adjusted-R^2	0.193	0.148
Observations	10,752	10,752
ATE	0.007	0.003
t-statistic	[0.740]	[0.534]

Notes. All models estimated within bandwidth of 10 CEPI; include Firm and State $\times$ industry $\times$ year FE.

No evidence firms shift production location Return

No affect on new plant announcements or plant abandonments

Dependent variable:	$\mathbb{1}_{\text{New Plant}}$	$\mathbb{1}_{\text{Abandon Plant}}$
Post $\times$CEPI$^{[60,70)}$ (β_1)	0.008	0.003
	(0.013)	(0.011)
2008 Dependent Variable Mean (Control)	0.00	0.00
R^2	0.350	0.284
Observations	10,752	10,752
ATE	-0.007	-0.002
t-statistic	[0.590]	[0.238]

Notes. All models estimated within bandwidth of 10 CEPI; include Firm and State $\times$ industry $\times$ year FE.

Production Return

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Framework Return

Assume (following literature):

- Cobb-Douglas production function $Q = AE^{\alpha_E}K^{\alpha_K}M^{\alpha_M}L^{\alpha_L}$
- Main effect of regulation is to increase the price of energy services E and firms take factor costs as given

Then:

- Baumol and Oates (1988): **Unchanged TFPR**
- Greenstone et al. (2012): Assume to comply firms divert an exogenous share φ of their inputs (e.g., L) to uses that don't contribute to observed output: **Lower TFPR**

$$Q* = AE^{\alpha_E}K^{\alpha_K}M^{\alpha_M}(\varphi L)^{\alpha_L} = \varphi^{\alpha_L}Q, \varphi < 1$$

- Colmer et al. (2024): Assume firms can pay fixed cost κ to switch to a more productive production technology that uses less energy: **Higher TFPR if PDV of switching** $> \kappa$
  - → Assume new tech is less energy intensive, more capital-intensive, and has higher TFP: $\alpha_E^* = \alpha_E - \zeta_\alpha$; $\alpha_K^* = \alpha_K + \zeta_\alpha$; $A^* = A + \zeta_A$
  - → Compliers: switching cost was higher than gain before the regulation raised energy costs

Merging the Data Return

- **Challenge 1:** Firm location proxy as headquartered city
  → To the extent treated firms operate in control clusters also (or vice versa), attenuates effects

- **Challenge 2:** Firm-city to cluster match
  → There can be more than one cluster in a city
  → Assign treatment using the maximum cluster CEPI score