Opening the Brown Box:
Production Responses to Environmental Regulation

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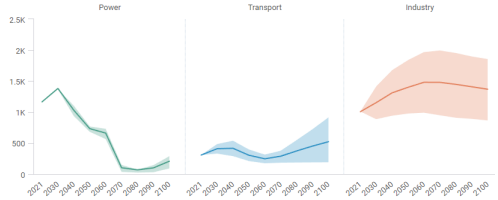
Focus on Reducing Industrial Emissions

- 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
- Robust evidence targeting firm emissions reduces them
  - → Often by shifting emissions and polluting assets elsewhere
  - → 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



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

Production Response to Emissions Regulation

We combine:

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

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  - → Satellite emissions readings
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- Across clusters, those with higher regulator reputation, lower corruption, and public-private regulatory cost sharing improve
- Firm and regulator actions lower cost, but loss of aggregate dynamism
  - → Decline in new firm entry and product variety
  - → No evidence of leakage — production location

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)
  - → **We demonstrate importance of coordinating emissions policies & cost-sharing**

INSTITUTIONAL BACKGROUND

Comprehensive Environmental Pollution Index (CEPI)

- Central Pollution Control Board (CPCB) develops a composite index in 2009 to capturing the impact of emissions on human health
  - → **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

Comprehensive Environmental Pollution Index (CEPI)

Methodology and Assessment

Ambient Air Monitoring Station.
Sujana Metals Unit-IV

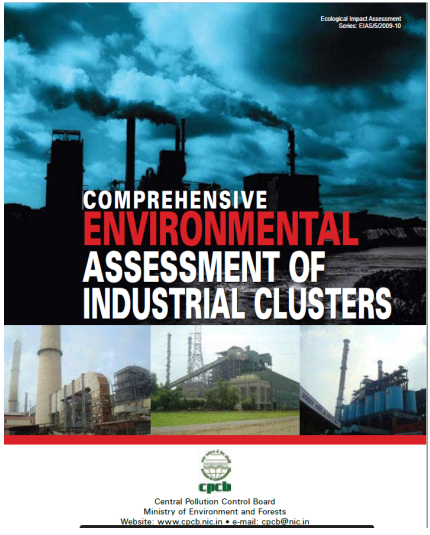
Surface Water Sampling Point. Isukavagu

Ground Water Sample Point. Bollaram Village

Ground Water Sample Point. Krishnareddypet

Comprehensive Environmental Pollution Index (CEPI)

Methodology and Assessment

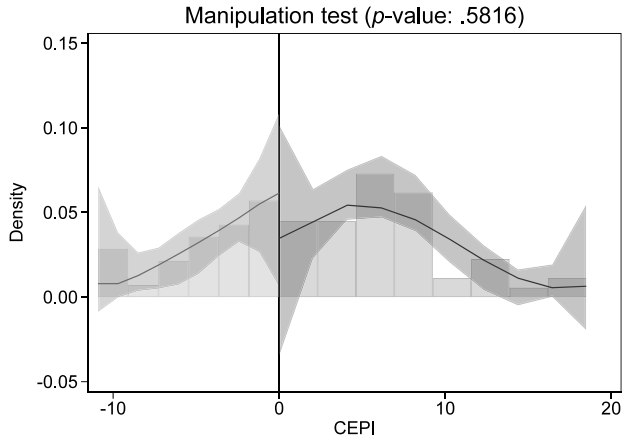


Data and Empirical Strategy

- Combine detailed firm, product input and output data
- Main specification: Difference-in-discontinuity around the CEPI 60 threshold and the 2009 introduction of the pollution index
  - → Fixed effects: Firm and State $\times$ industry $\times$ Year
  - → Cluster standard errors at cluster level
  - → Estimate within a bandwidth of 10 CEPI ranking
  - → Compare LATE vs. ATE by estimating DiD specification
- Other specifications
  - → Controlling for effect of crossing the CEPI 70 threshold (Implementation)
  - → Interacted with indicator of highly polluting industry (Heterogeneity)

Testing the Identification Assumptions

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



Testing the Identification Assumptions

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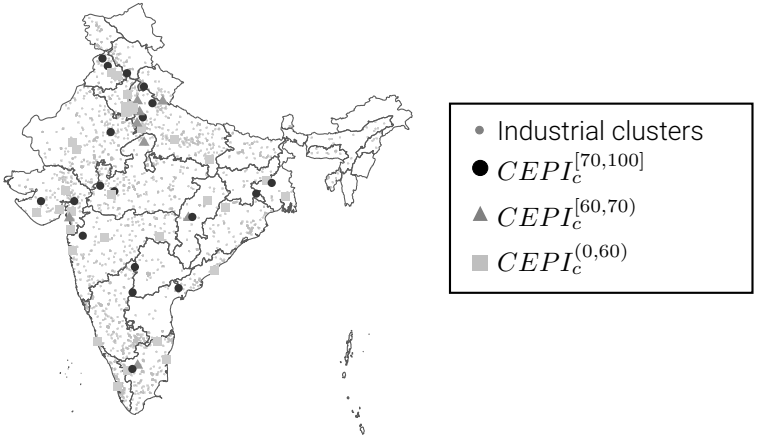

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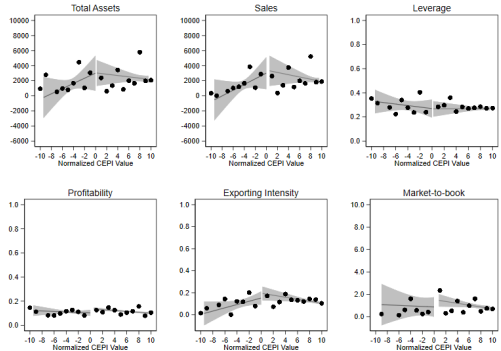
3. No jumps in firm and product characteristics around the threshold Balance: Firm Balance: Product



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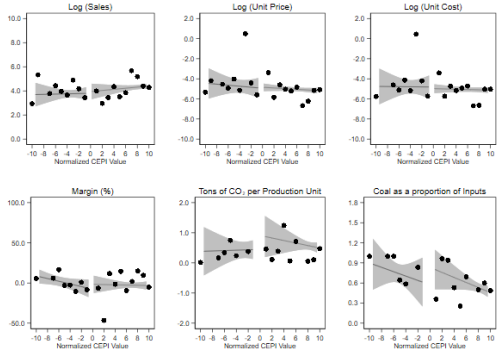

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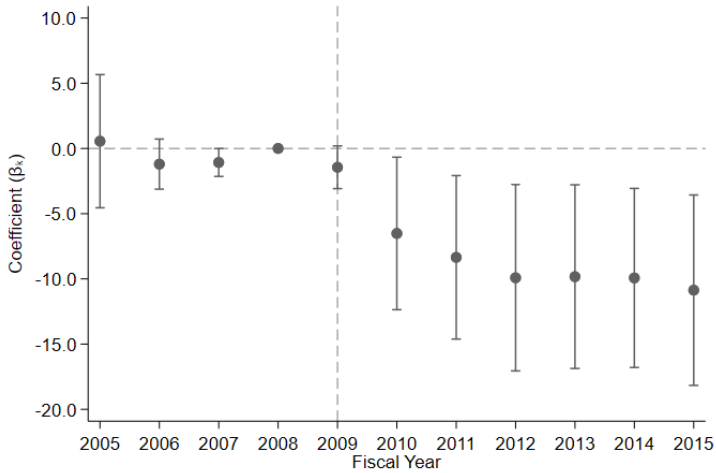
1. No manipulation of the running variable (Cattaneo, Jansson and Ma (2020))
2. No geographic clustering Balance: Cluster
3. No jumps in firm and product characteristics around the threshold Balance: Firm Balance: Product
4. Parallel trends Covariates

IMPACT ON CLUSTER-LEVEL EMISSIONS

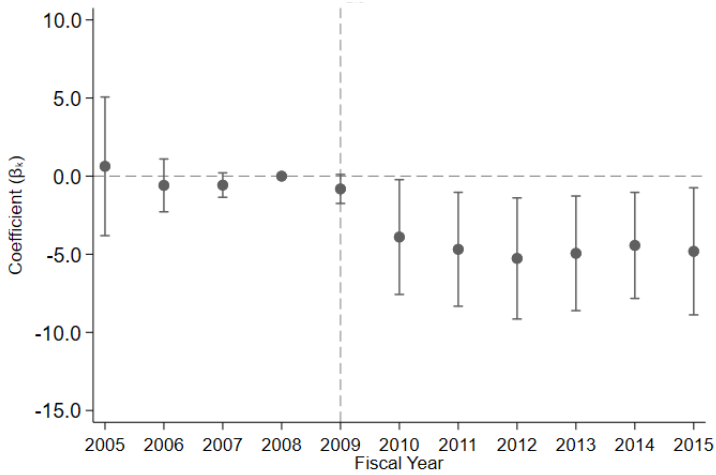
Cluster-Level Satellite Readings: Industrial Emissions, All Pollutants

Units: mg per month



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

Units: mg per month



Regressions | Van Donkelaar $PM_{2.5}$ | Placebo

HOW DO FIRMS REDUCE EMISSIONS?

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)
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
ATE	-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

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)
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
ATE	-1.414	-0.755
t-statistic	[5.460]	[3.709]

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

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)
2008 Dependent Variable Mean (Control)	0.78	0.65
R^2	0.775	0.758
Observations	705	705
ATE	-0.181	-0.218
t-statistic	[1.438]	[1.981]

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

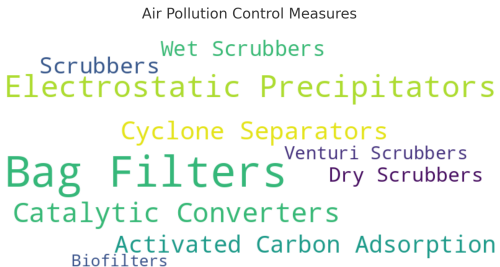
Abatement Expenditures from Financial Statements

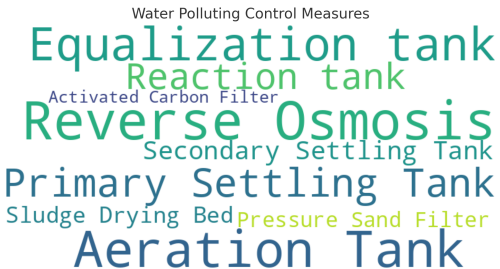
Abatement expenditures increase on extensive and intensive margins

Dependent variable:	$\mathbb{1}_{\text{Abatement}}$	Abatement/Assets
Post $\times$CEPI$^{[60,70)}$ (β_1)	0.048	0.039*
	(0.031)	(0.020)
2008 Dependent Variable Mean (Control)	0.06	0.01
R^2	0.725	0.753
Observations	10,752	10,752
ATE	0.072	0.038
t-statistic	[2.419]	[2.385]

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

Abatement technologies: Evidence From Action Plans





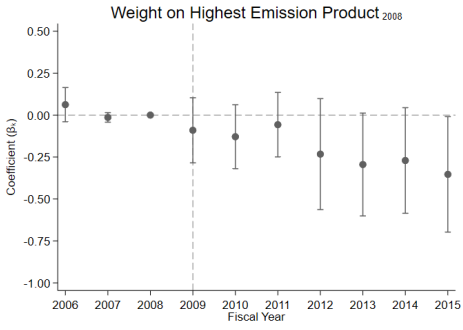
WHO COMPLIES?

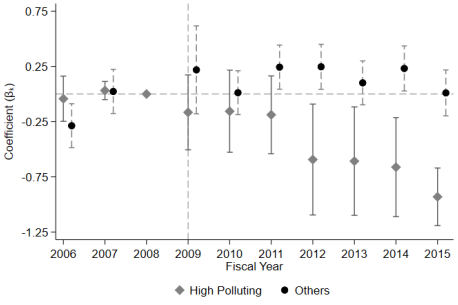
Intra-cluster dynamics

Who bears the cost?

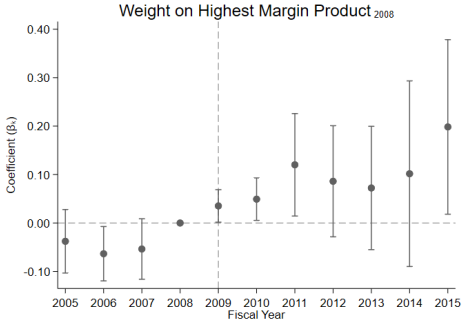
- Pollution Control Board previously classified some industries as “highly-polluting” (HPI)
- HPI Firms face stricter enforcement and have less scope to abate emissions (Harrison, Hyman, Martin and Nataraj (2019))
  - → Monitoring stations more likely to be placed near HPI plants
  - → HPI firms in $CEPI^{[70,100]}$ clusters subject to specific emission mandates in action plans
- Complementary evidence in our setting that HPI firms received higher treatment intensity

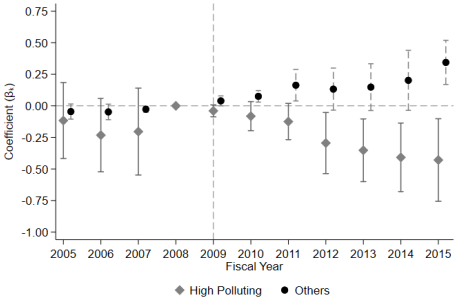
Changes to Firm Emissions: Portfolio Shifts





Changes to Firm Profitability: Portfolio Shifts





Who complies: 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.

Who complies: Evidence from media

Thursday, 7 March, 2024

The Statesman

HOME INDIA WORLD BUSINESS SPORTS ENTERTAINMENT OPINION LAW LIFESTYLE DAINIK STATESMAN MORE EPAPER

India .

CIL output to fall shoft of target

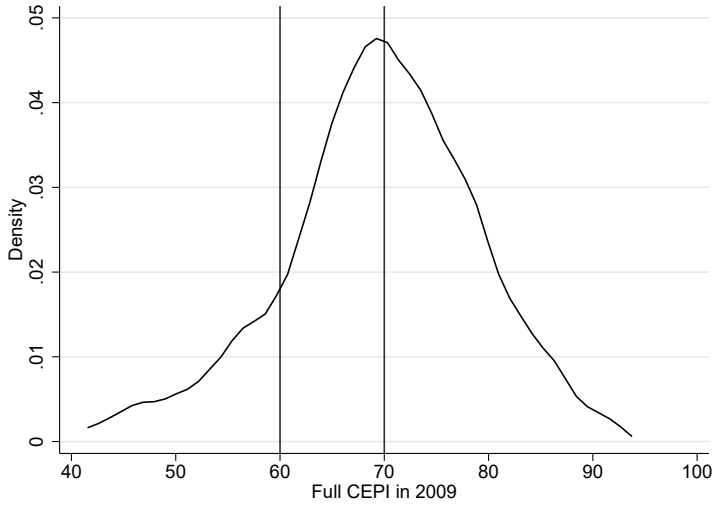
Statesman News Service | New Delhi | December 23, 2010 5:31 pm

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.

DETERMINANTS OF COMPLIANCE

Comprehensive Environmental Pollution Index (CEPI)

Subsequent assessments



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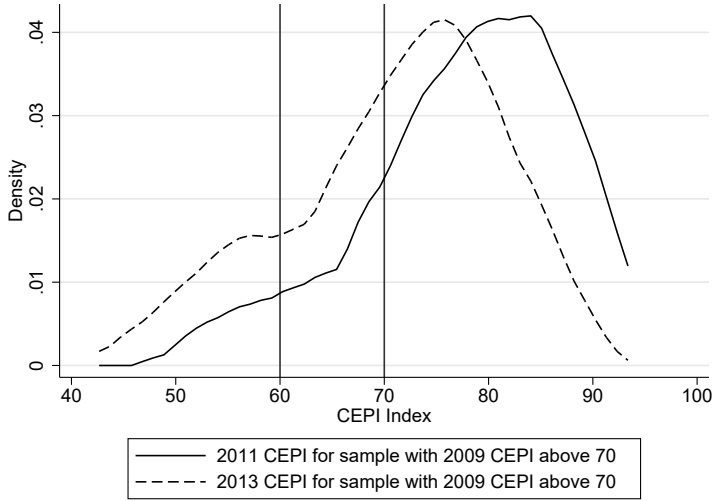
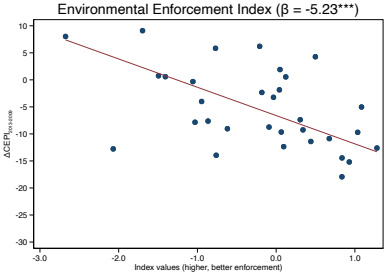
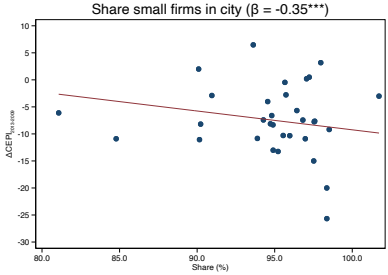
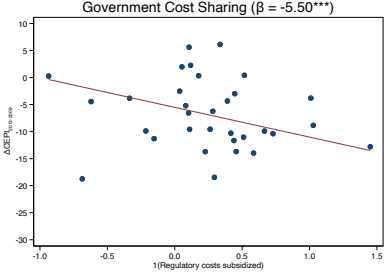
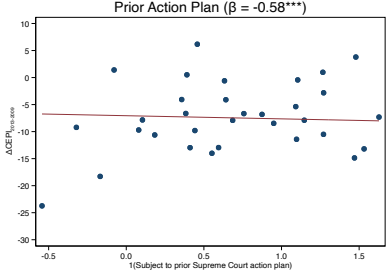


Ex-ante predictors of improvement









Firm Productivity and Profitability

- Highly polluting industries ('hard-to-abate') bear higher costs >...
  - → ...but achieve significant emission reductions >
- Productivity and profitability fall in higher intent-to-treat clusters >
  - → PCA using ex-ante predictors of emissions reduction Details

Aggregate Effect and Other Explanations

- Product variety decreases >
- Business dynamism decreases from lower firm entry
  - → All (formal) firms >
  - → Large firms >
- Leakage: No evidence firms shift production
  - → No effect on mergers and acquisitions >
  - → No affect on new plant announcements >

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
- In aggregate, productivity and profitability maintained but
- Regulated clusters exhibit lower firm entry and product variety
- More highly regulated firms reduce emissions the most and bear the brunt of costs

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

Thank You!

Empirical Specification

Return

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 city level
- Estimate within a bandwidth of 10 CEPI ranking
- β_1: difference in discontinuity effect of crossing the treatment threshold at CEPI = 60

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
ATE	-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.

Return

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)
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.

Return

Cluster-Level Satellite Readings: Energy Sector Placebo

Return

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)
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
ATE	-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.

Firm-level energy input

Dependent variable:	Ln(Value Firm Energy Input)	
Post $\times$CEPI$^{[60,70)}$ (β_1)	-0.667***	-0.821***
	(0.138)	(0.189)
Post $\times$CEPI$^{[60,70)}$ $\times$ High-Polluting (β_3)		0.392*
		(0.223)
2008 Dependent Variable Mean (Control)	219.92	0.214
Adjusted-R^2	0.959	0.959
Observations	358	358

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

Return

Lower Product Variety

Return

Adjust product portfolio to lower product variety

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)
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
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.

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.

Firm Entry: Prowess (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.

Return

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 announcement or plant abandonment

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.

Productivity and Profitability

Return

Dependent variable:	Ln(TFP)	EBITDA/ Sales	Raw Material Expense
Post $\times$CEPI$^{[60,70)}$ (β_1)	0.100	0.004	-0.033
	(0.075)	(0.015)	(0.030)
2008 Dependent Variable Mean (Control)	2.77	0.10	0.56
R^2	0.851	0.638	0.641
Observations	10,752	10,752	10,752

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

Quantity Productivity

Productivity and Profitability

Return

Firms in non-HPI drive productivity gains

Dependent variable:	Ln(TFP)	EBITDA/ Sales	Raw Material Expense
Post $\times$CEPI$^{[60,70)}$ (β_1)	0.131*	0.008	-0.061**
	(0.074)	(0.015)	(0.030)
Post $\times$CEPI$^{[60,70)}$ $\times$ High-Polluting (β_3)	-0.114	-0.016	0.095***
	(0.161)	(0.011)	(0.032)

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

Quantity Productivity

Return

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

Competitive Effect? Return

No change in pricing; margins likely driven by portfolio shift

Dependent variable:	Highest Margin Product Weight$_{2008}$	Product Margins	Ln(Unit Price)	Ln(Unit Cost)
Post $\times$ CEPI$^{[60,70)}$ (β_1)	0.120**	0.037	-0.059	-0.016
	(0.050)	(0.081)	(0.225)	(0.194)
2008 Dependent Variable Mean (Control)	0.72	0.00	0.72	0.89
R^2	0.880	0.722	0.592	0.599
Observations	15,984	15,225	15,984	15,225
ATE	0.124	0.126	-0.116	-0.183
t-statistic	[2.731]	[2.179]	[0.538]	[0.966]

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

Competitive Effect? Return

HPI de-emphasize highest-margin product because it is high emission?

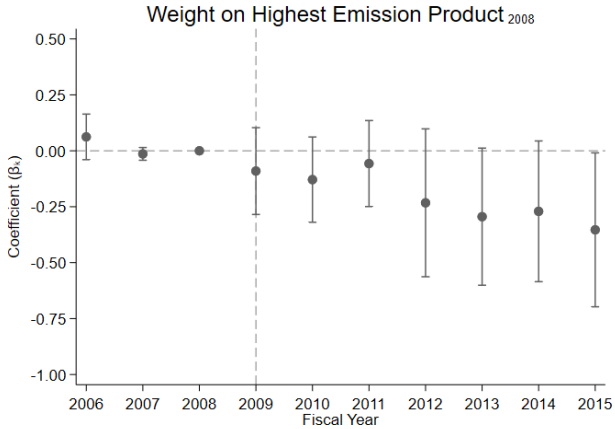
Dependent variable:	Highest Margin Product Weight$_{2008}$	Product Margins	Ln(Unit Price)	Ln(Unit Cost)
Post $\times$CEPI$^{[60,70)}$ (β_1)	0.166***	0.018	-0.055	0.024
	(0.053)	(0.096)	(0.218)	(0.193)
Post $\times$CEPI$^{[60,70)}$ $\times$ High-Polluting (β_3)	-0.122**	0.043	0.003	-0.084
	(0.058)	(0.078)	(0.185)	(0.207)

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

Product Portfolio: Weight Highest Emission Product

Return

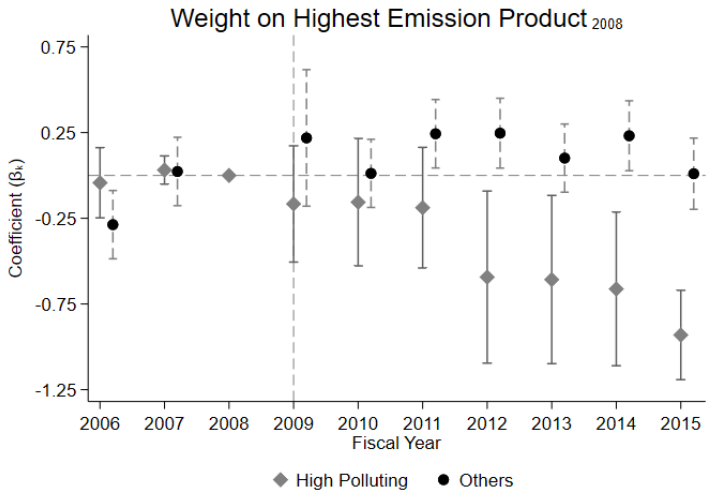
Production changes driven by firms in HPI



Product Portfolio: Weight Highest Emission Product

Return

Production changes driven by firms in HPI



Productivity and Profitability

Return

Dependent variable:	Ln(Revenue Productivity) (1)	Ln(Quantity Productivity) (2)	EBITDA/ Sales (3)
Post $\times$CEPI$^{[60,100]}$	0.063	-0.719	0.039
	(0.042)	(1.128)	(0.140)
2008 Dependent Variable Mean (Control)	6.88	8.61	0.10
Adjusted-R^2	0.863	0.926	0.504
Observations	3,546	761	3,546

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

Productivity and Profitability

Return

Treatment Interacted with Regulation Intensity

Dependent variable:	Ln(Revenue Productivity) (1)	Ln(Quantity Productivity) (2)	EBITDA/ Sales (3)
Post $\times$CEPI$^{[60,100]}$	0.063	-0.719	0.039
	(0.042)	(1.128)	(0.140)
Post $\times$CEPI$^{[60,100]}$ $\times$ High-Polluting	-0.059*	-1.817*	-0.159
	(0.035)	(1.046)	(0.116)
Post $\times$CEPI$^{[60,100]}$ $\times$ High-Polluting $\times$ Regulation	-0.320**	-2.703	-0.545
	(0.136)	(4.174)	(0.453)
Adjusted-R^2	0.909	0.960	0.529
Observations	3,546	761	3,546

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

Summarizing across-cluster heterogeneity Return

- 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 environmental action plans (Greenstone and Hanna (2014))
  - → Cost-sharing policies (2009 CEPI action plans) Cost sharing evidence
  - → Proportion of small firms in city (firm registry)
  - → City corruption score, population density, renewable energy capacity and generation, CEPI improvement by 2011, incidence of not completing a prior environmental action plan, number of firms in compliance and number of firms that exited in prior action plan, poverty
- Principal components isolate predictive variation in model-free manner
  - → First two principal components explain 64% of the variation in predictive variables
  - → 73% correlation with CEPI improvement in clusters with 2009 CEPI of at least 70
  - → 49% correlation with air emissions reduction from satellite data