

(Air) Pollution and Welfare

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Paris School of Economics

(Air) Pollution and Welfare

Outline for Today

- Meta-Skills: Combining Theory and Empirics
- Air Pollution
 - Coase Theorem: Payments for Ecosystem Services
 - Estimating Damages
 - Hedonic Approach
 - Bottom up: Health Effects and Defensive Behaviors
 - Estimating Abatement Costs
 - Distributional Considerations

Meta-Skills

What do I want you to get out of this class

- Approaches that can be applied to many questions.
 - How to model behavior
 - How to test a model
 - How to interpret a result

Combining Theory and Empirics

Taxonomy of Empirical Economics¹

All empirical work in economics is either structural or descriptive.

¹Borrowed shamelessly from Phil Haile's slides:

<https://www.dropbox.com/s/8kwtwn30dyac18s/intro.pdf?dl=0>

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Descriptive work:

- Establishes facts about the data - e.g PM 2.5 levels are higher in India than the US, and have been declining over time

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Structural work:

- Poses a model of the relationships between variables or the data-generating process
- Allows us to estimate 'counterfactuals' - what would happen if...

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What about Reduced Form?

A reduced form relationship is obtained by writing each endogenous variable as a function of *only* exogenous variables.

- e.g. solve for equilibrium quantities (price, quantities) in terms of exogenous parameters (technology, budget constraints, preferences)

We don't always need to explicitly solve the model. We just need to know what goes on which side of the equation and what restrictions our model implies.

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But there is still a model! (Even if it's implicit)

Pop Quiz

Are these claims descriptive or structural?

- Shutting down the coal plant caused pollution to fall.

Pop Quiz

Are these claims descriptive or structural?

- Shutting down the coal plant caused pollution to fall.
- An RCT showed that an information campaign increased clean cookstove adoption.

Internal vs External Validity

Internal Validity - Are the conclusions valid within the context of the study?

- Are the instruments really exogenous?
- Was there non-random attrition or measurement error?

External Validity - Would these results hold in other contexts?

- What would happen if we ran the same RCT in a different time/place?

Why does this matter?

Making a 'policy recommendation' requires understanding a counterfactual

- This means we are in structural world.
- It also requires a normative framework - in econ usually (but not always) maximizing WTP.

So as we read the papers, I want you to keep in mind:

- What is the model here (even if it's implicit)
- What are threats to internal validity
- What are threats to external validity

Air Pollution

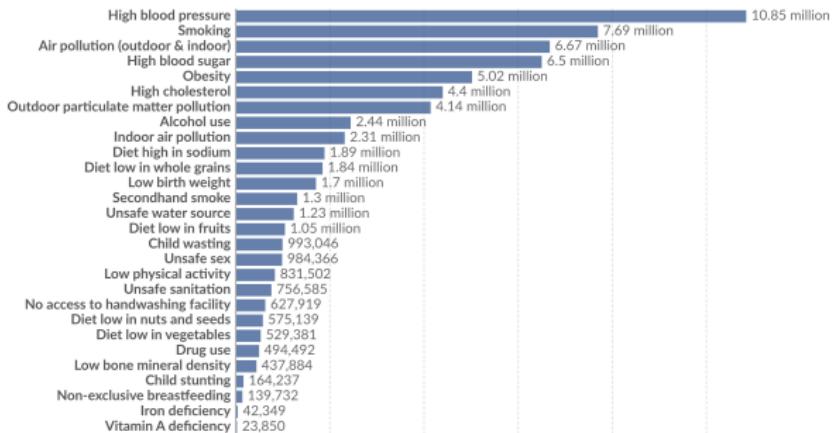
Stylized Facts

Air Pollution is a big problem

Our World
in Data

Deaths by risk factor, World, 2019

The estimated annual number of deaths attributed to each risk factor¹. Estimates come with wide uncertainties, especially for countries with poor vital registration².



Data source: IHME, Global Burden of Disease (2019)

OurWorldInData.org/causes-of-death | CC BY

Note: Risk factors are not mutually exclusive: people may be exposed to multiple risk factors, and the number of deaths caused by each risk factor is calculated separately.

1. Risk factor: A risk factor is a condition or behavior that increases the likelihood of developing a given disease or injury, or an outcome such as death. The impact of a risk factor is estimated in different ways. For example, a common approach is to estimate the number of deaths that would occur if the risk factor was absent. Risk factors are not mutually exclusive: people can be exposed to multiple risk factors, which contribute to their disease or death. Because of this, the number of deaths caused by each risk factor is typically estimated separately. Read more about risk factors and their impact in our article: How do researchers estimate the death toll caused by each risk factor, whether it's smoking, obesity or air pollution?

2. Civil and Vital Registration System: A Civil and Vital Registration System (CVRS) is an administrative system in a country that manages information on births, marriages, deaths and divorces. It generates and stores 'vital records' and legal documents such as birth certificates and death certificates. You can read more about how deaths are registered around the world in our article: How are causes of death registered around the world?

Stylized Facts

But a solvable problem

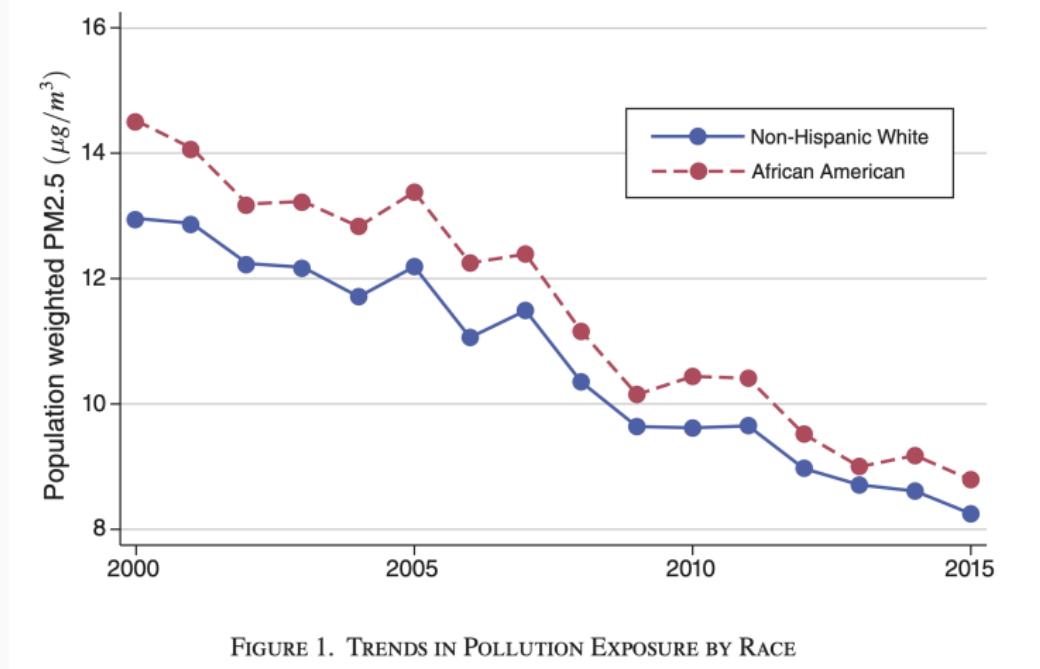


FIGURE 1. TRENDS IN POLLUTION EXPOSURE BY RACE

Stylized Facts

New Delhi today



Stylized Facts

Pittsburgh in the 1940s



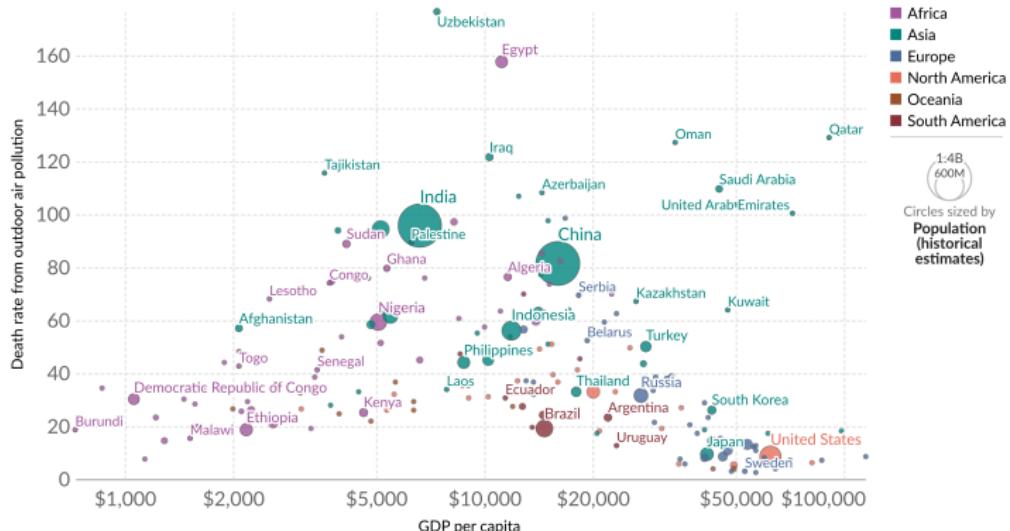
Stylized Facts

U-shaped relationship with income

Death rate from outdoor air pollution vs. GDP per capita, 2019

Our World
in Data

Death rates are measured as the number of premature deaths attributed to outdoor particulate matter air pollution per 100,000 individuals. Gross domestic product (GDP) per capita is measured in constant international-\$.



Data source: IHME, Global Burden of Disease (2019); Data compiled from multiple sources by World Bank
OurWorldInData.org/outdoor-air-pollution | CC BY

Coase Theorem: The Promise of Decentralization

What should we do about it?

Should we do anything?

- Coase Theorem says that if property rights are well-defined, transaction costs low, then the efficient outcome can be achieved by decentralized bargaining.

Does the existence of air pollution show that the Coase Theorem fails?

Coase in Action: Payments for Ecosystem Services

Jack, Jayachandran, Kala, and Pande: Money (Not) to Burn:
Payments for Ecosystem Services to Reduce Crop Residue Burning

- Farmers in Punjab burn crop stubble at end of planting season.
 - Why? Cheaper than renting machinery, labor
- Sends massive plume of smoke over densely populated areas.
- Why not pay them not to burn?

Money (Not) to Burn

Table 1: Contract Compliance and Not Burning

	Complied with Contract (1)	Not Burned (2)	CRM techniques	
			Baler (3)	Seeder (4)
Standard PES	0.085 (0.015)***	0.020 (0.030)	-0.010 (0.037)	-0.020 (0.023)
Upfront PES	0.183 (0.020)***	0.077 (0.032)**	0.096 (0.039)**	0.013 (0.026)
<i>p</i> -val: Standard PES = Up-front PES	0.000	0.071	0.014	0.157
Control mean	0.000	0.091	0.199	0.102
Standard PES mean	0.084	0.098	0.171	0.087
Upfront PES mean	0.185	0.161	0.295	0.112
N	1668	1664	1387	1387

Money (Not) to Burn

Table 3: Cost-Effectiveness

	Amount Paid per Acre (1)	Not Burned (2)	Cost per Unburned Acre (3)
Standard PES	105.6 (21.7)***	0.020 (0.030)	5156.5 (7156.0)
Upfront PES	310.5 (15.4)***	0.077 (0.032)**	4051.3 (1595.0)**
<i>p</i> -val: Standard PES = Upfront PES	0.000	0.071	0.864
N	1667	1664	

Rough back of the envelope suggests $\approx \$4,400$ per life saved.

- 86,000 premature deaths from crop burning, 53.5% from Kharif burning in Punjab, 4 million acres = .01 death/acre

Can we scale up Coase?

Challenges:

- Farmers liquidity constrained
- Coordination problem/transaction costs
- Verifications/additionality

A Normative Framework:

Regulate Air Pollution such that:

$$\min_A W = \sum_i \omega_i(C_i(A) + D_i(A)) \quad (1)$$

Conjecture: Marginal damages are much greater than marginal abatement costs.

- How would we know?
- For a normal good, we could measure the benefits of a change in supply by looking at market prices - these measure consumers' marginal willingness to pay
- The fundamental problem of environmental economics: there is no market for clean air
- This puts us in the world of non-market valuation

Estimating Damages: Hedonics

The Hedonic Method: Housing Values

Measuring willingness to pay for clean air: individuals get utility from a house: $U(q_1, \dots, q_n, A, u_i)$.

In equilibrium:

$$P_i = P(q_1, \dots, q_n, A_i, u_i) \quad (2)$$

(3)

Set up a regression:

$$\log P_i = \beta_1 q_{1i} + \dots + \beta_n q_{ni} + \beta_A A_i + u_i \quad (4)$$

Then $\frac{d \log P_i}{dA} = \beta_A$ gives willingness to pay for changes in A .

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- Question: Why logs?

The Hedonic Method: Reduced Form

Why doesn't this work?

- u_i could be correlated with A and P_i ;
- q_s are endogenous, could have been chosen as a result of A .
- We need a *reduced form*!

Chay and Greenstone (JPE) 2003: Look at changes in home prices resulting from 'exogenous' changes in air pollution (the Clean Air Act).

- Model restrictions: CAA changed A but not q_s or u_s .

From Model to Estimation

$$\log P_{it} = \theta A_{it} + q_{it}\beta + \mu_i + u_{it} \quad (5)$$

$$A_{it} = q_{it}\Pi + \gamma_i + \nu_{it} \quad (6)$$

First differencing gets rid of time invariant unobservables:

$$\log P_{i1} - \log P_{i2} = \theta(A_{i1} - A_{i2}) + (q_{i1} - q_{i2})\beta + u_{i1} - u_{i2} \quad (7)$$

$$A_{i1} - A_{i2} = (q_{i1} - q_{i2})\Pi + \nu_{i1} - \nu_{i2} \quad (8)$$

Now identification assumption is $E(\nu_{i1} - \nu_{i2})(u_{i1} - u_{i2}) = 0$.

$$A_{i1} - A_{i2} = Z_{it}\Gamma + (q_{i1} - q_{i2})\Pi + \nu_{i1} - \nu_{i2} \quad (9)$$

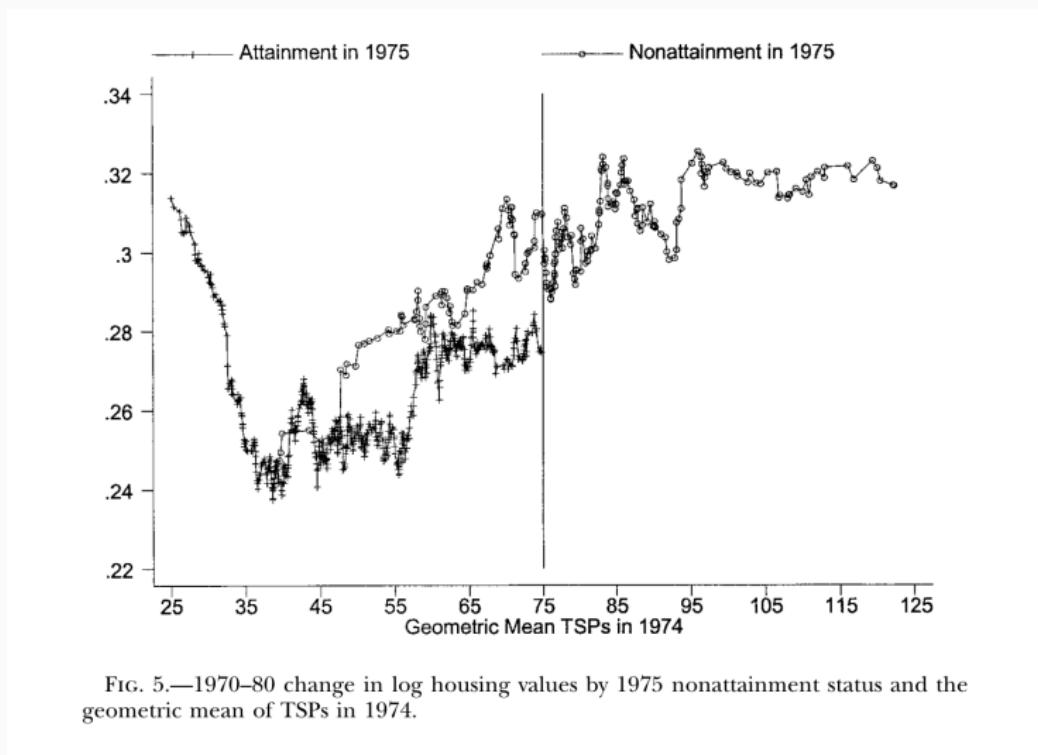
$$Z_{it} = \mathbf{1}_{\{A_{i1} > 75\}} + A_{i1} \quad (10)$$

Plug in $Z_{it}\widehat{\Gamma} + (q_{i1} - q_{i2})\widehat{\Pi}$ for $A_{i1} - A_{i2}$.

Now assumption is $E(Z_{it}(u_{i1} - u_{i2})) = 0$.

The Hedonic Method: Results

People are willing to pay for better AQ (about 2% per $1\mu\text{g}$).



Does this capture everything?

Why might some damages not capitalize into housing prices?

Does this capture everything?

Why might some damages not capitalize into housing prices?

How should we think about external validity?

- Free mobility between houses
 - See Christensen and Timmins (2022). Sorting or Steering: The Effects of Housing Discrimination on Neighborhood Choice
- Perfect information
- Well functioning capital markets

But maybe not a bad first approximation

- Muehlenbachs, Spiller and Timmins (AER, 2015) - Fracking
- Keiser and Shapiro (QJE 2018) - Clean Water Act
- and many more...

Estimating Damages: Bottom Up

Bottom up damage estimation

Health Costs

- Can we regress health status on ambient air pollution?
- What is our (implicit) structural model?
- How can derive a reduced form relationship?

The Mortality and Medical Costs of Air Pollution: Evidence from Changes in Wind Direction

Tatyana Deryugina

Garth Heutel

Nolan H. Miller

David Molitor

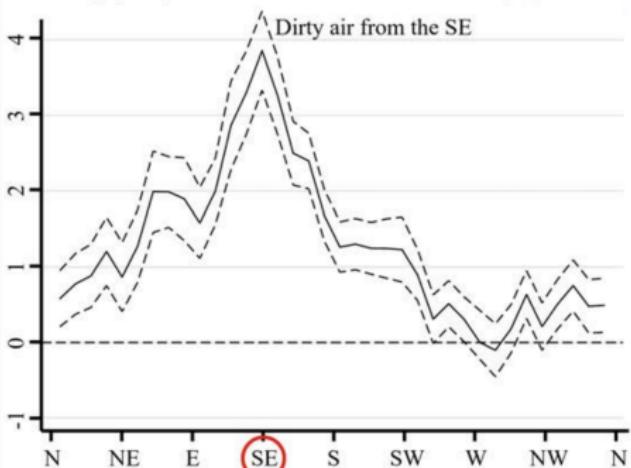
Julian Reif

AMERICAN ECONOMIC REVIEW
VOL. 109, NO. 12, DECEMBER 2019
(pp. 4178-4219)

Wind Direction as an IV

San Francisco, CA regional wind direction and pollution

PM 2.5 ($\mu\text{g}/\text{m}^3$) relative to wind from the West (W)



Into the weeds:

$$Y_{cdmy} = \beta PM2.5_{cdmy} + X_{cdmy}\gamma + \alpha_c + \alpha_s m + \alpha_{my} + e_{cdmy} \quad (11)$$

- Y_{cdmy} is outcome in county c on day d in month m and year y: three-day total death rate (d, d+1, d+2) per million, hospital admissions
- daily PM2.5 levels + 2 leads + 2 lags
- High dimensional controls: daily max temp into 17 bins, same for min temp, indicators for deciles of daily precipitation and wind speed, indicators for all possible interactions of these temp, precipitation, and wind speed variables (28,899)
- County c, state-by-month, and month-by-year FE
- Cluster se at the county level and weight

First stage:

$$PM2.5_{cdmy} = \sum_g \sum_{b=0}^2 WindDir_{cdmy}^{90b} + X_{cdmy}\sigma + \alpha_c + \alpha_s m + \alpha_{my} + e_{cdmy} \quad (12)$$

- $WindDir_{cdmy}^{90b} = 1$ if daily average wind direction in county c falls in $[90b, 90B + 90]$ and 0 otherwise
- 100 spatial group g for pollution monitors

Wind Direction as an IV: Results

Table 2: OLS and IV estimates of effect of PM 2.5 on elderly mortality, by age group

	(1) 65+	(2) 65–69	(3) 70–74	(4) 75–79	(5) 80–84	(6) 85+
Panel A: OLS estimates						
PM 2.5 ($\mu\text{g}/\text{m}^3$)	0.095*** (0.021)	0.041*** (0.014)	0.029 (0.018)	0.022 (0.022)	0.142*** (0.036)	0.425*** (0.072)
Dep. var. mean	385	131	197	312	508	1,127
Effect relative to mean, percent	0.025	0.032	0.015	0.007	0.028	0.038
Observations	1,980,549	1,980,549	1,980,549	1,980,549	1,980,549	1,980,549
Adjusted R-squared	0.254	0.080	0.085	0.082	0.077	0.110
Panel B: IV estimates						
PM 2.5 ($\mu\text{g}/\text{m}^3$)	0.685*** (0.061)	0.267*** (0.066)	0.329*** (0.068)	0.348*** (0.098)	0.877*** (0.159)	2.419*** (0.246)
F-statistic	298	285	292	303	309	315
Dep. var. mean	385	131	197	312	508	1,127
Effect relative to mean, percent	0.178	0.204	0.167	0.111	0.173	0.215
Observations	1,980,549	1,980,549	1,980,549	1,980,549	1,980,549	1,980,549

Notes: Table reports OLS and IV estimates of equation (1) from the main text. Dependent variable is the three-day mortality rate per million beneficiaries in the relevant age group. All regressions include county, month-by-year, and state-by-month fixed effects; flexible controls for temperatures, precipitation, and wind speed; and two leads of these weather controls. OLS (IV) estimates also include two lags and two leads of PM 2.5 (instruments). Estimates are weighted by the number of beneficiaries in the relevant age group. Standard errors, clustered by county, are reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Beyond Mortality: Defensive Expenditures

Health production function:

$$h(c, a(c)) \quad (13)$$

Total derivative with respect to c :

$$\frac{dh}{dc} = \frac{dh}{dc} + \frac{dh}{da} \frac{da}{dc} \quad (14)$$

Deschenes et al (2017) find NOx program benefits from reduced medical expenditures are about 60% of mortality benefits.

- Is this a welfare loss or a transfer to pharmaceutical companies?

Abatement Costs

Implications for Welfare

So damages are large - what does this tell us about how air pollution should be regulated?

Remember:

$$W = \sum_i \omega_i (B_i(A) - C_i(A)) \quad (15)$$

Also want to minimize abatement costs

Can Pollution Markets Work in Developing Countries? Experimental Evidence from India

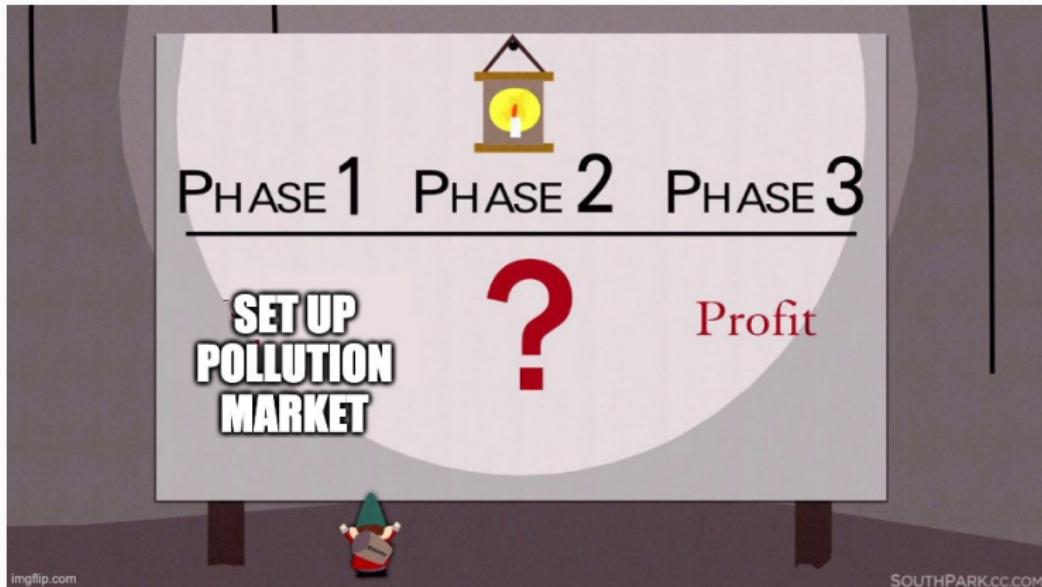
- "If the number of laws were any measure of their effectiveness, India would have one of the cleanest environments in the world." Menon et al. (2012)
- "Emissions markets trade in a commodity created by the state, and these markets cannot function if the state cannot uphold the value of that commodity."
- Context: Surat, India - a city of 7 million with a large textile manufacturing sector
- Status Quo: Firms required to install abatement equipment, incomplete enforcement (see previous work by this same team)

Surat's air is becoming poisonous, breathing becomes difficult

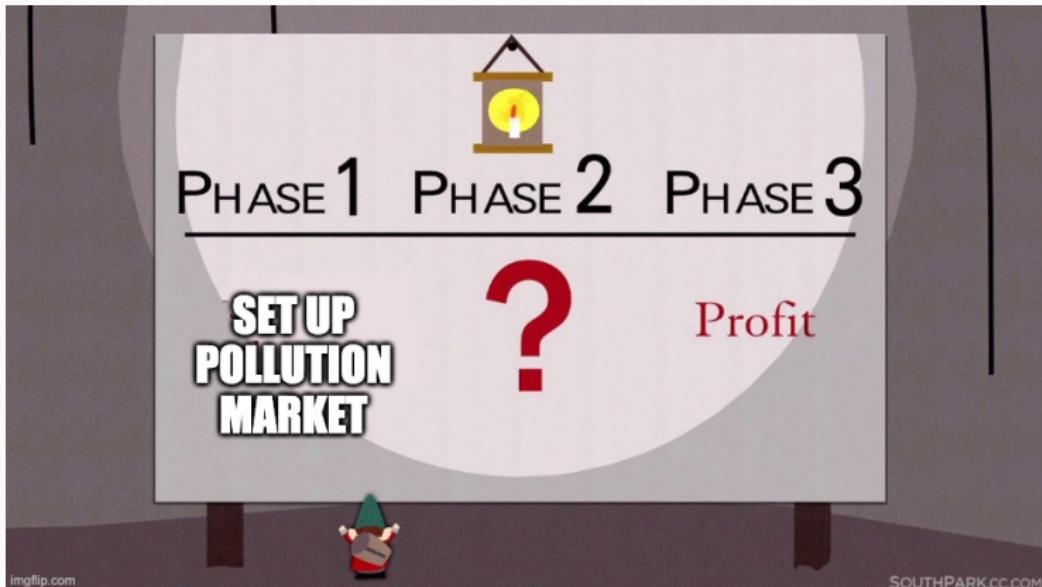


<https://www.patrika.com/surat-news/surat-air-pollution-is-poisonous-breathing-difficult-3816317/>

How to change the world

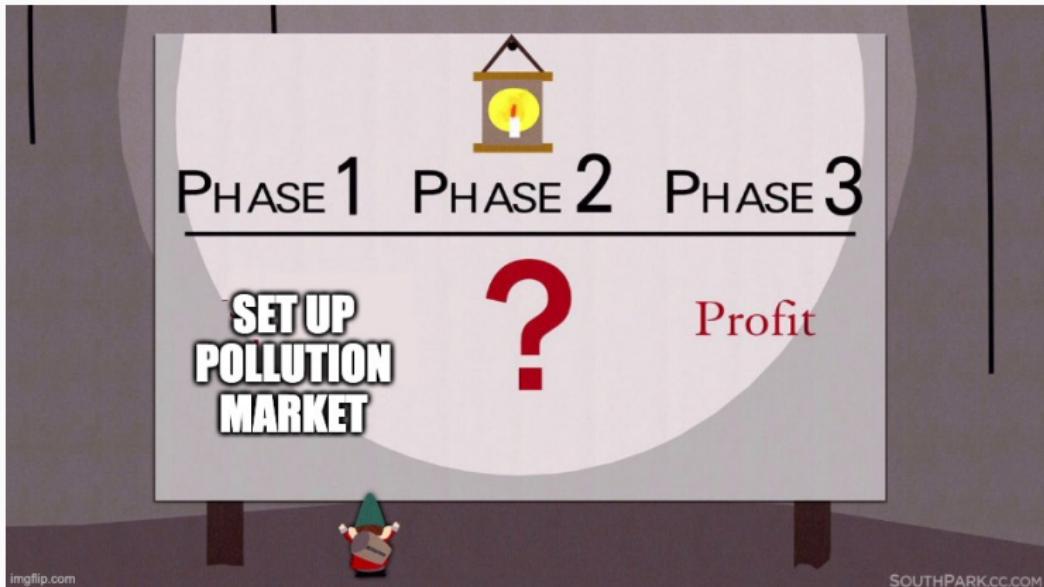


How to change the world



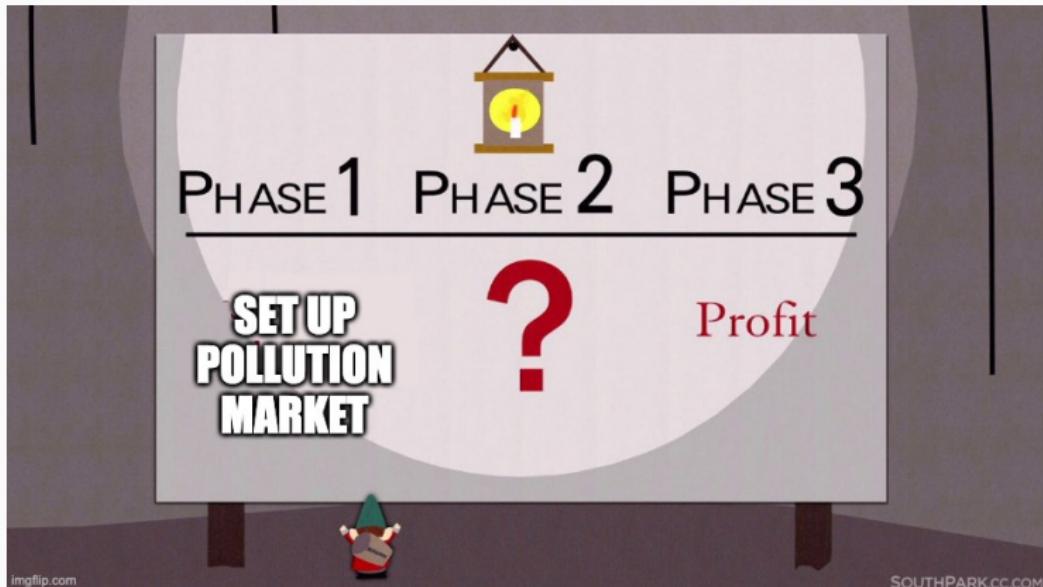
Get buy in from local regulator

How to change the world



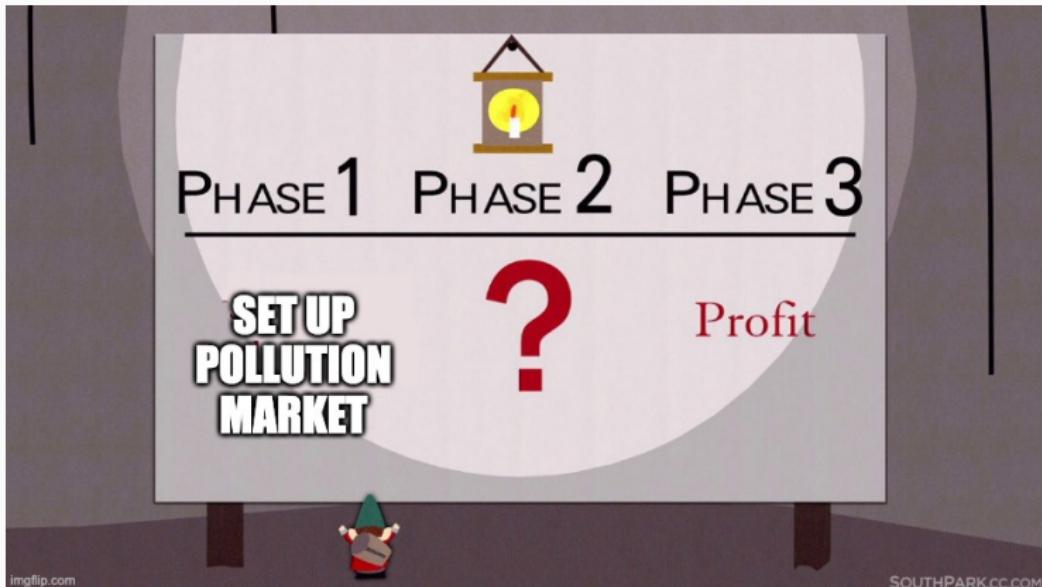
Convince them to install Continuous Emission Monitoring Systems
on every plant in their jurisdiction

How to change the world



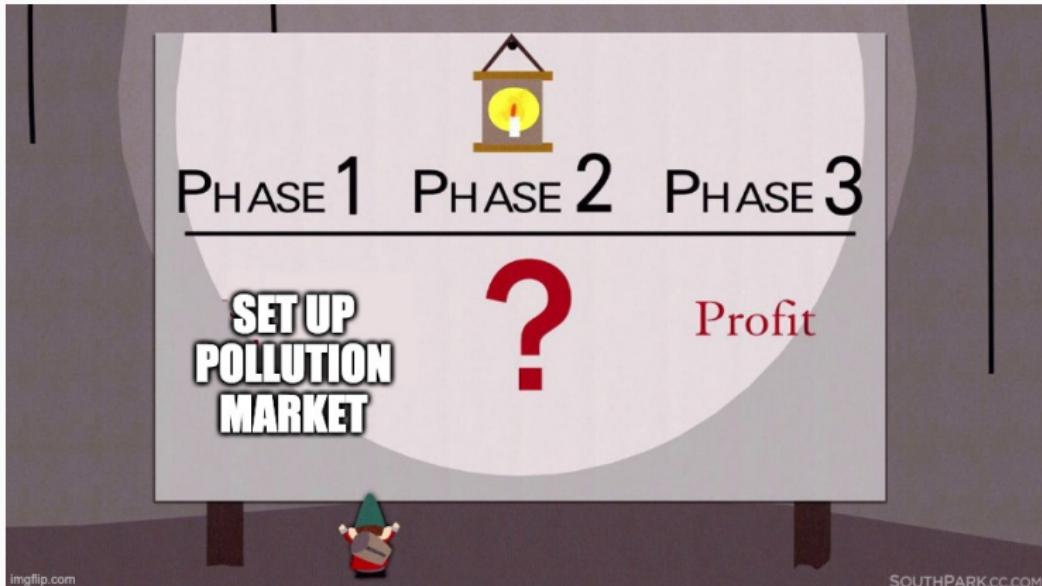
Establish a trading platform and teach firms how to use it

How to change the world



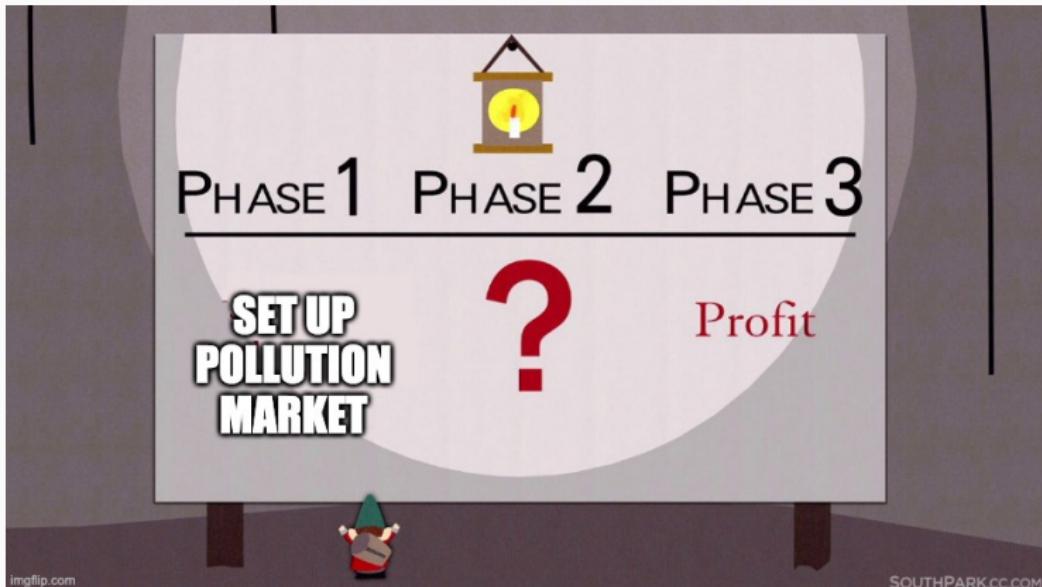
Decide how to allocate initial permits

How to change the world



Deal with missing data

How to change the world

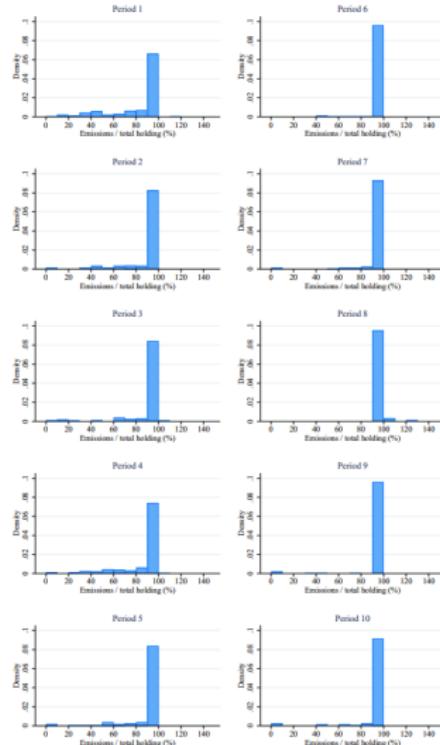


Have your experiment interrupted by COVID

Establish Credibility

Fined 2 plants and order 1 to close after first compliance period.

Figure 3: Distribution of Emissions over Final Permit Holdings by Compliance Period

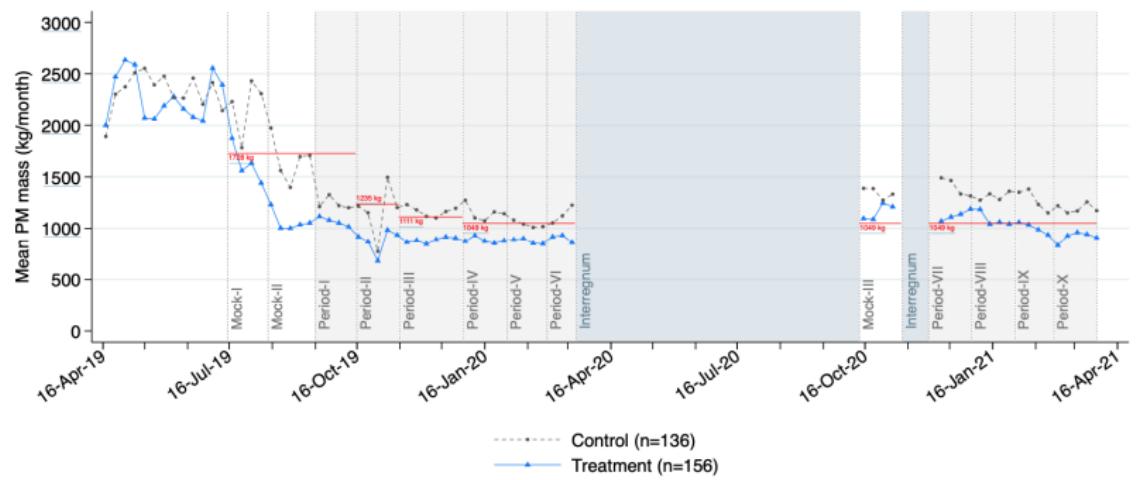


What effects do we expect?

- On pollution?
- On fixed costs?
- On variable costs?

Effects on Pollution

Figure 5: PM Emissions by Treatment Status



Effects on Costs

Table 4: Treatment effects on abatement costs in survey data

	Abatement capital costs (\$1000s)					Boiler house input costs (\$1000s)					
	All (1)	Cyclone (2)	Bag (3)	Scrubber (4)	ESP (5)	Total (6)	Capital (7)	Labor (8)	Electricity (9)	Fuel (10)	Materials (11)
ETS Treatment (=1)	-3.467 (3.089)	0.602** (0.266)	0.530* (0.318)	-0.222 (0.407)	-4.281 (3.344)	11.26 (26.31)	-7.178 (19.05)	1.561 (3.332)	25.21* (13.53)	26.87* (15.35)	-0.142 (0.596)
R ²	0.90	0.85	0.83	0.84	0.89	0.93	0.63	0.05	0.65	0.98	0.19
Control mean	44.04	7.80	9.85	9.69	16.70	578.48	190.88	47.86	162.13	299.50	4.33
Plants	276	276	276	276	276	185	218	262	247	225	283

This table reports the effects of treatment assignment on the capital cost of APCDs (columns 1-5) and boiler house input costs (columns 6-11). In columns 1-5, the abatement capital cost is the product of the number of abatement devices at a plant and the industry-standard cost for that device for the plant's given boiler house capacity. In columns 6-11, specifications use our best estimates for boiler house costs from the endline survey (FY 2019-20). All specifications control for a corresponding baseline value (FY 2017-18) but in some cases the components of the input cost aggregate differ slightly within a category between the baseline and endline survey. Electricity costs are only reported at the plant level so are not only for the boiler house. Robust standard errors are given in parentheses with statistical significance indicated by * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.

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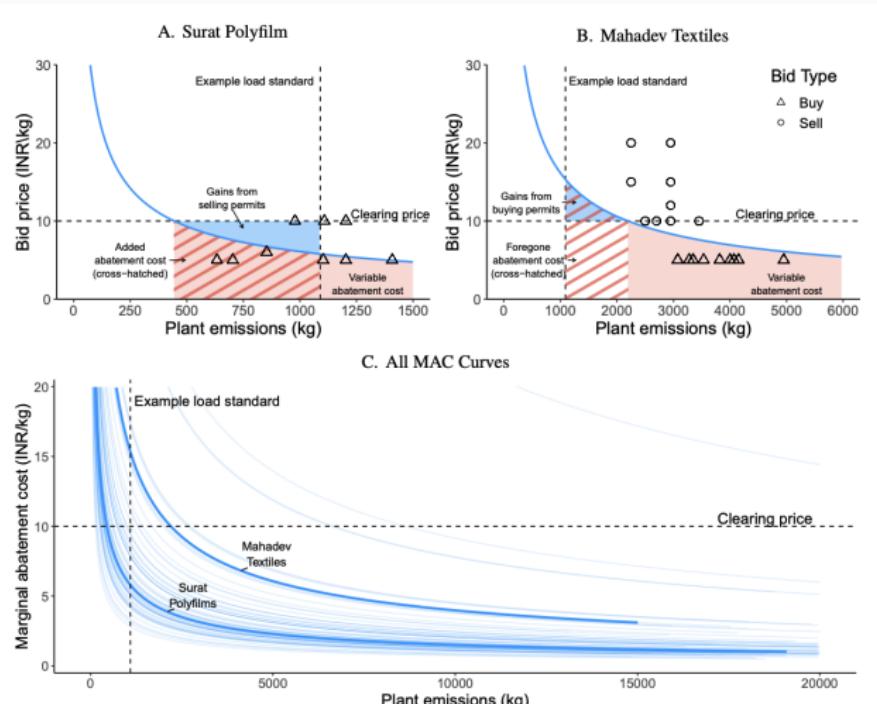
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...but emissions were not held constant

Model Intuition: MAC = P

Want to estimate marginal abatement cost curves for every plant so that we can estimate the gains from trade



Takeaways

The model allows us to estimate counterfactuals for different regulatory regimes

- Emissions market is 10% cheaper than command and control for same level of emissions
- For same cost, market would cut emissions by 48% (abatement costs not very elastic)
- Implies dramatic reductions in emissions possible for very little cost

What about distributional consequences?

- We haven't talked much about the ω s yet.

Distributional Considerations

Are Efficiency and Equity in Tension?

Inside Climate News

Pulitzer Prize-winning, nonpartisan reporting on the biggest crisis facing our planet.

Donate

Justice

Why Do Environmental Justice Advocates Oppose Carbon Markets? Look at California, They Say

Activists have long warned that cap and trade would jeopardize states' efforts to reduce carbon emissions and increase pollution in communities of color. New reports back up those assertions.

By Kristoffer Tigue  February 25, 2022



Related

Researchers Say Science Skewed by Racism is Increasing the Threat of Global Warming to People of Color



Is the California Coalition Fighting Subsidies For Rooftop Solar Banks



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By Kristoffer Tigue

Column: Washington's carbon tax doesn't address environmental justice

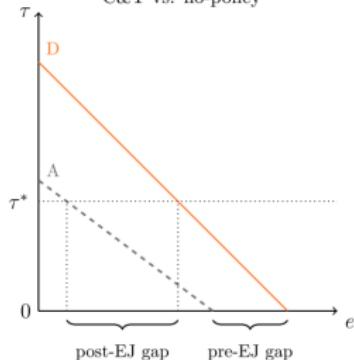
Byron Gould Nov 8, 2018 11:48 AM EST

Do environmental markets cause environmental injustice? Evidence from California's carbon market

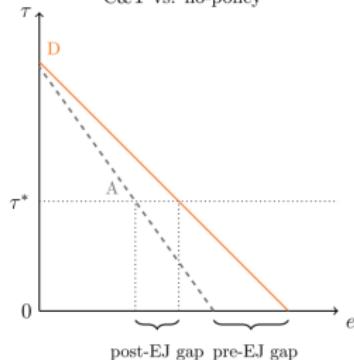
- Context: California has cap-and-trade program for large stationary emitters since 2013
- Plenty of empirical work showing low-income, minority households face higher pollution levels (the 'EJ Gap')
- Why might market based instruments increase the 'EJ Gap' even while lowering overall emissions?

Heterogeneous Marginal Abatement Costs

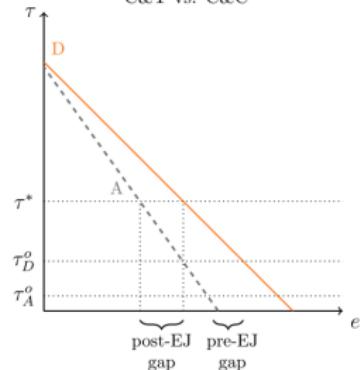
a DAC-upwind facility with steeper MAC
C&T vs. no-policy



b DAC-upwind facility with flatter MAC
C&T vs. no-policy



c DAC-upwind facility with flatter MAC
C&T vs. C&C

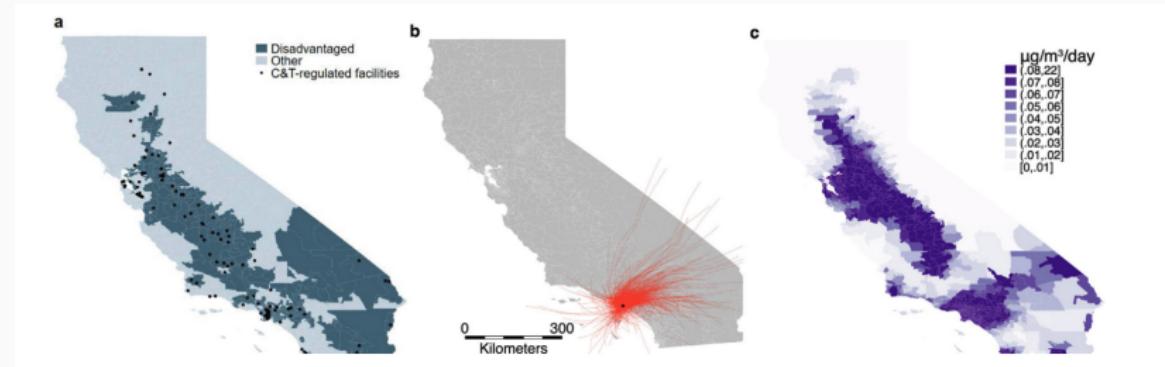


We clearly need to estimate *facility level* treatment effects.

Outline

1. Estimate facility specific treatment effects of the policy
2. Feed these estimated reductions into an air pollution dispersal model
3. Look at how spatial distribution of pollution changes

Baseline Exposure



Some (very?) strong assumptions

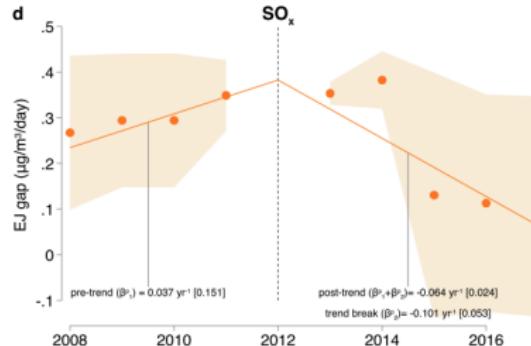
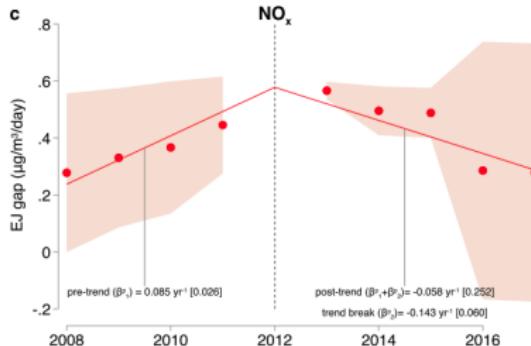
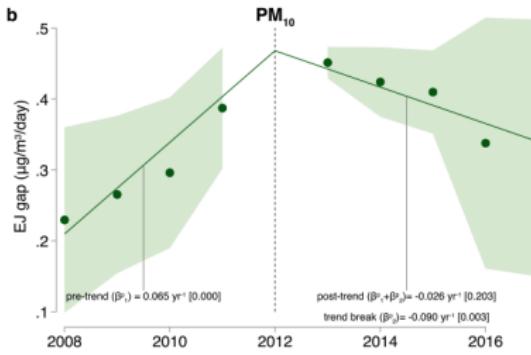
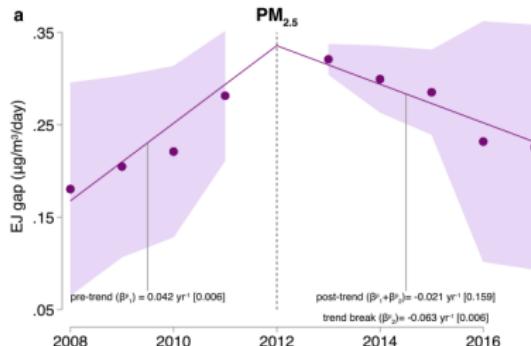
Estimate a 'trend-break' model - allows for differential pre-trends between regulated and unregulated facilities

- Control group: Regulated vs unregulated emission sources
 - Remove electricity generators, refineries, and facilities with emissions above 75 percentile.
 - SUTVA violations?
- Functional form: Linear trends, inverse hyperbolic sine of emissions
- Heterogeneity: Homogeneous percentage effect into heterogeneous facility level effects through fixed effects.

But some nice atmospheric physics

- Pollution dispersal model (previous literature typically used 1-3 mile buffer)

Cap and Trade Narrows EJ Gap



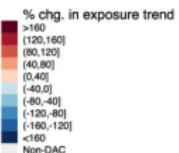
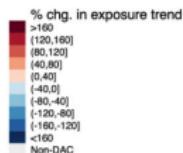
But Considerable Spatial Heterogeneity

a

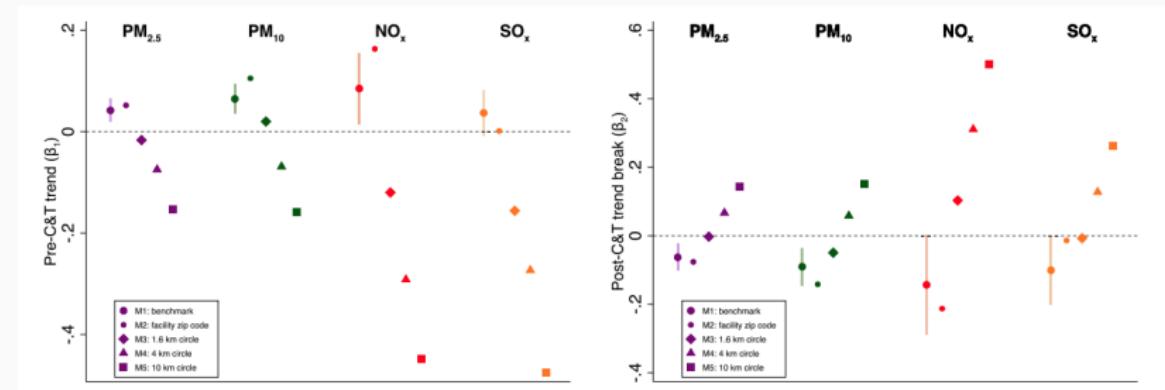
PM_{2.5}

b

PM₁₀



Importance of Pollution Modelling



Takeaways

- They didn't actually model heterogeneous marginal abatement costs!
- But the question is well posed and they show the importance of pollution dispersal modelling
- More work to be done here
 - Deschenes and Weber: Equity Impacts of a Market for Clean Air (Working Paper)
 - Muller and Mendelsohn (2009 AER): Efficient Pollution Regulation: Getting the Prices Right
 - Should we have spatially differentiated pollution taxes?

Other Recent Papers and Future Research

Better identifying abatement costs in different contexts, monitoring and evaluation

- Shapiro and Walker: Is Air Pollution Regulation too Stringent?
- Buntaine et al. Does the Squeaky Wheel Get More Grease? The Direct and Indirect Effects of Citizen Participation on Environmental Governance in China.
- Duflo, Greenstone, Pande, and Ryan: Truth-telling by third-party auditors and the response of polluting firms: Experimental evidence from India.

Long term (possibly intergenerational?) effects

- Colmer and Voorheis: The Grandkids Aren't Alright: The Intergenerational Effects of Prenatal Pollution Exposure.

Water pollution, solid waste, and other media

- Keiser and Shapiro: Consequences of the Clean Water Act and the Demand for Water Quality.