Regulation of Environmental Externalities
BREAD-IGC Virtual PhD Course

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October 26, 2023

Outline

1. **Regulation builds missing markets**
2. Constraints to regulation: Agency problems
   - Third-party auditors
   - Emissions trading
3. Constraints to regulation: Monitoring
   - Transportation
4. Constraints to regulation: Political economy
   - Groundwater depletion
   - Water pollution
5. Directions for research

Air pollution is much higher in low-income countries

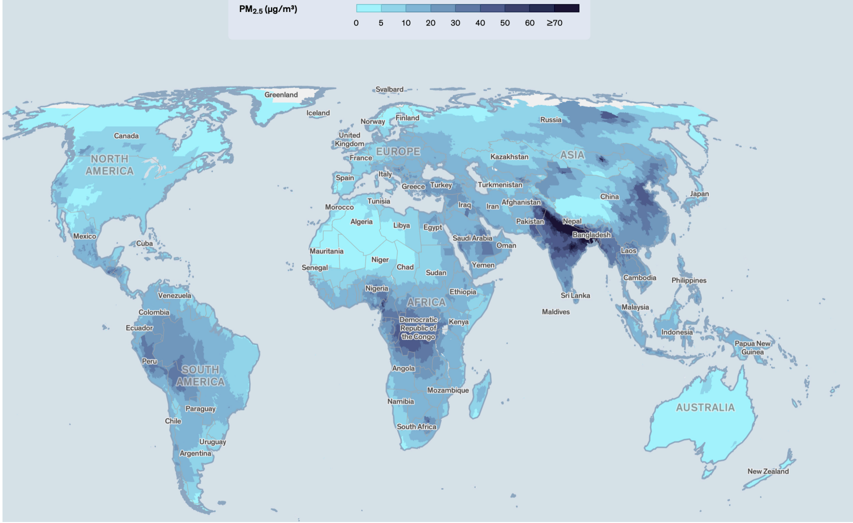
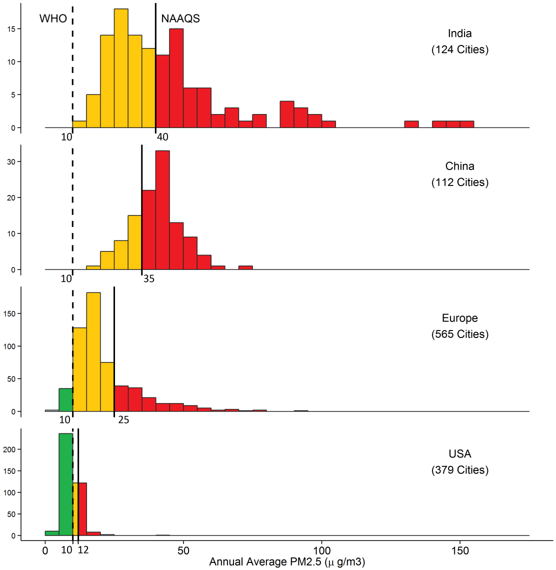
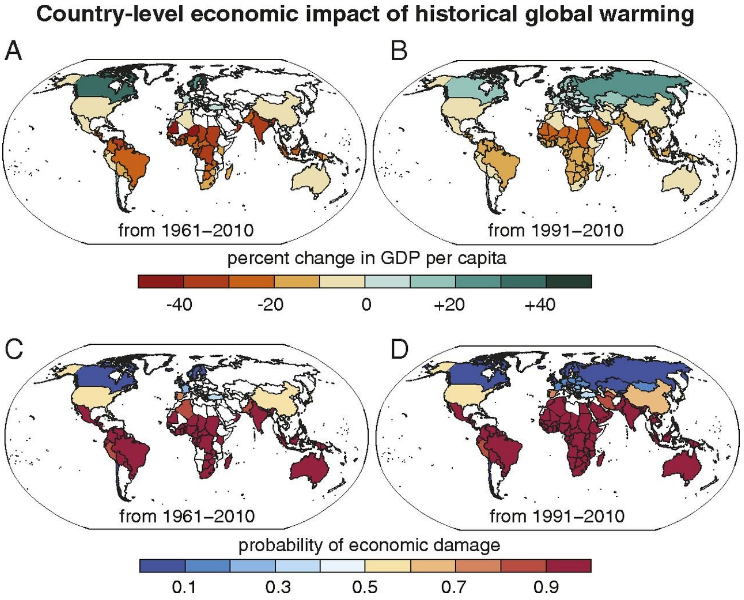


Figure: PM 2.5 Concentrations Around the World



Between-country: Warming ~ income inequality



Regulation builds missing markets

- Environmental economics deals with missing markets
  - Clean air and water are not commodities
  - Most environmental harms are not priced
- First-best regulation: build the missing markets
  - Establish property rights (Coase, 1960) $\Rightarrow$ Cap-and-trade
  - Price externalities (Pigou, 1920) $\Rightarrow$ Pigouvian taxation
- So why is there anything to study at all? Are we done?

Example: Air pollution from crop burning

Delhi's smog blamed on crop fires - but farmers say they have little choice

Poor north Indian farmers think they are scapegoats for a wider problem

by Hannah Ellis-Petersen in Haryana

The pounding beats of bhangra music blare out of Satish's tractor as it roars across the charred, black earth of his farm. Fresh seeds are scattered in its wake. Yet hanging thick in the air, over this scene of new beginnings, is the tell-tale smoky stench of what came before.

- Hundreds of thousands of farmers, with emissions affecting the air quality of millions of people.
- Could a "Coasean" solution work? What would fully efficient trades look like?
- Possibly **very** complicated. Informational burden to estimate heterogeneous marginal damages and costs and make transfers high.

Regulation builds missing markets

Coase (1960) set out the property rights solution to externalities, but turned immediately to emphasize its limitations:

> *The argument has proceeded up to this point on the assumption that there were no costs involved in carrying out market transactions. This is, of course, a very unrealistic assumption. In order to carry out a market transaction it is necessary to discover who it is that one wishes to deal with, to inform people that one wishes to deal and on what terms, to conduct negotiations leading up to a bargain, to draw up the contract, to undertake the inspection needed to make sure that the terms of the contract are being observed, and so on. These operations are often extremely costly . . .*

Regulation builds missing markets

- There are constraints **everywhere** on the use of first-best environmental instruments
  1. Monitoring, contracting (Coase's "transactions costs")
  2. Agency problems (corruption)
  3. *Other* missing markets (credit, insurance)
  4. Political economy (equity, externalities)

- These constraints are different in degree, but not in kind, in low-capacity states
  - Weaker contracts and more corruption make agency problems worse
  - Lower technology adoption makes monitoring harder
  - Political economy concerns depend on income, growth.

- Our lecture will draw out examples from the empirical literature on regulatory enforcement to highlight how these constraints shape regulation.

- While we focus on air pollution and water, many of these lessons apply for regulating greenhouse gases

Interlinked challenges

- **Linkage with inequality** Countries least responsible for producing GHG are most vulnerable to its effects. Within countries: wealthier communities can shield themselves from impacts
- **Linkage with governance** Climate change will expose gaps between high- and low-capacity governments (e.g. capable systems for adaptation, mitigation, and resilience)
- **Effective regulations will need to address these interlinked challenges**.
  - State capacity: credibility in regulations, and ability to implement policies.
  - Data: weak information flows to the state is one of the most common governance challenges in LMICs.
  - Democratic systems that work: those affected by climate breakdowns have recourse.

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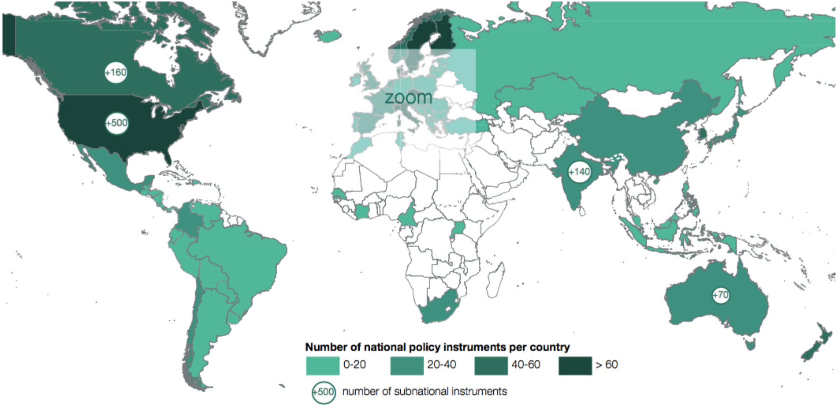
India has many environmental regulations on the books

Figure: Global distribution of environmental police instruments



Source: OECD policy instruments database

Database

Should environmental regulation do more?

> *I must emphasise that standards are not enough. They must also be enforced which is often difficult. . . . It is also necessary to ensure that these regulatory standards do not bring back the License Permit Raj which we sought to get rid of in the wake of economic reforms of the nineties.*

Former Indian Prime Minister Manmohan Singh, Delhi Sustainable Development Summit, 2011.

- Most environmental regulation is command-and-control
  - High cost and inefficient at inducing abatement action; large, infrequent penalties (Duflo, Greenstone, Pande and Ryan, 2013; 2018)
  - Inefficient regulation means policy-makers will choose to regulate less

- The same limits on monitoring and incentives make it difficult to move to more theoretically efficient regulations like markets

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Gujarat audit reform: Standards and enforcement

- National command-and-control regulations
  - Water Act (1974), Air Act (1981), Environment Protection Act (1986)
  - Maximum allowable concentrations for emissions, which states can tighten but not relax
- Enforcement via State Pollution Control Boards
- Private third-parties have a growing role:
  - Capacity/expertise, flexibility and cost.
  - Support environmental standards like ISO 14001 and carbon offsets
- Audited company hiring the auditor can create a conflict of interest.

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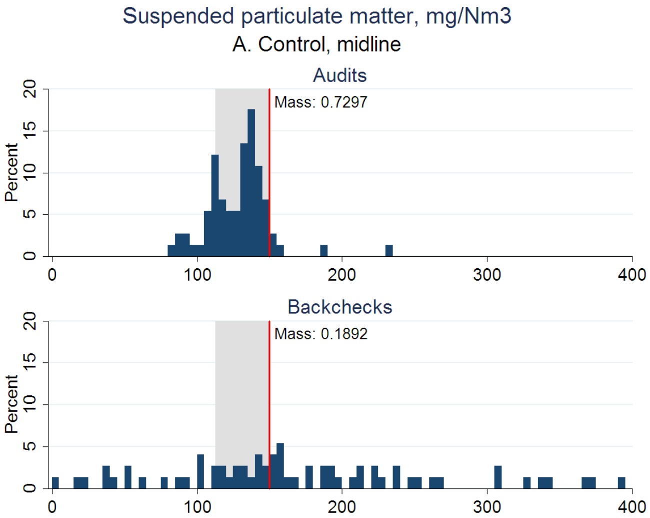
Gujarat audit reform: Status quo

- Audit scheme implemented for regulated high polluting firms
- Plant responsible for hiring and paying auditor who takes pollution readings and submits to regulator
- Perception that auditor shopping is widespread and that plants can buy good reports

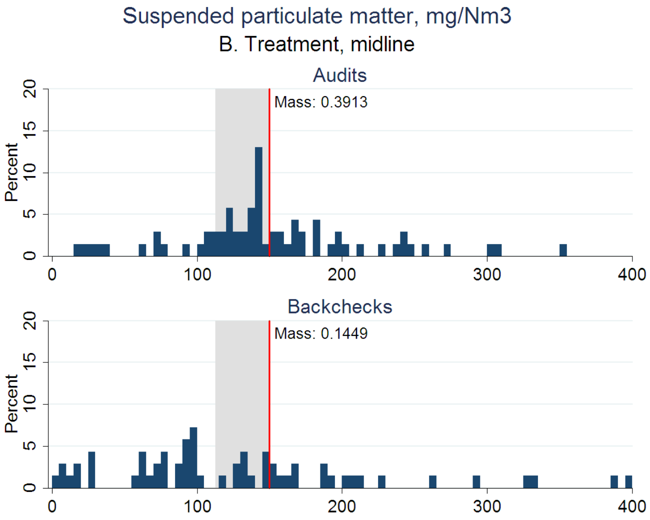
Gujarat audit reform: Field experiment at scale

- Audit treatment reforms three aspects of status quo system on a pilot basis for 233 of 473 plants (mostly textile processing)
  1. Random assignment of auditors and fixed payment from central pool (independence).
  2. Backcheck auditors on performance (monitoring).
  3. In year 2 of the experiment, additionally, auditors paid for accuracy relative to backchecks (accuracy incentives).

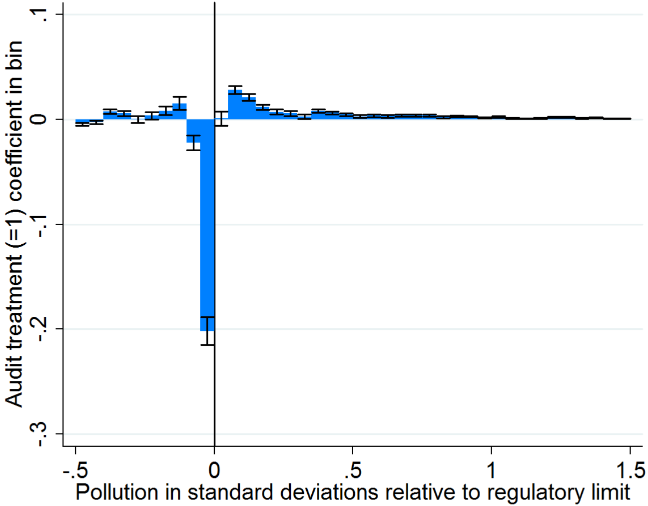
Gujarat audit reform: SPM audits in Control



Gujarat audit reform: SPM audits in Treatment



Gujarat audit reform: Treatment effect



Gujarat audit reform: Results

Pollution in treatment group $\downarrow$ 0.21 standard deviations

- Presumably because they understood regulator would receive more reliable audit reports
- Reductions concentrated among plants with the highest readings
- In practice, the regulator reserves harshest penalties for such plants

Learnings from auditor study for carbon credit systems

- Kyoto Protocol and Paris Agreement focus on voluntary country commitments to specified percent reduction in carbon emissions from a chosen base year

- The unregulated voluntary market was $2bn in 2021
  - 2/3 of 227.7 million offsets from land-use sector (excluding agri.) traded in carbon markets;

- World's leading certifier Verra requires projects to employ auditors to certify these projects

- *2023 Science* article:Growing evidence of large differences between project ex ante baseline re. carbon reductions and ex post counterfactuals.

- Prices of carbon offsets traded via Xpansiv market CBL, the world's largest spot carbon exchange, fell by over 80% in last 18-20 months.

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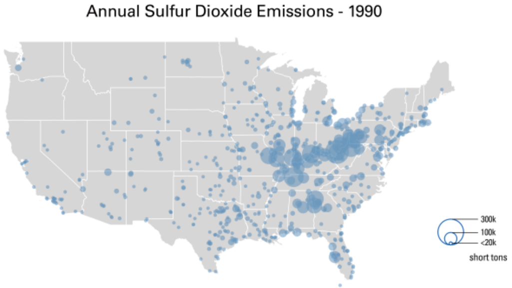
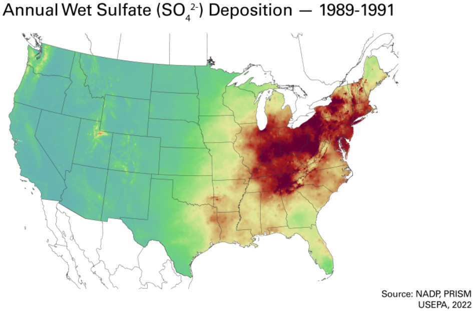
The Acid Rain program showed the potential of market-based regulation to reduce pollution at a low cost





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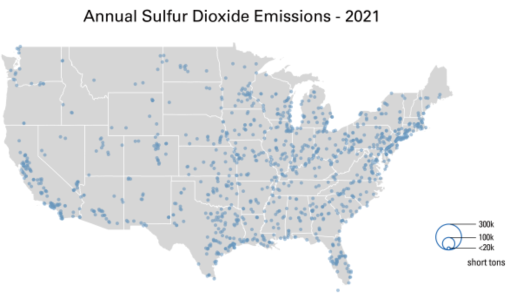
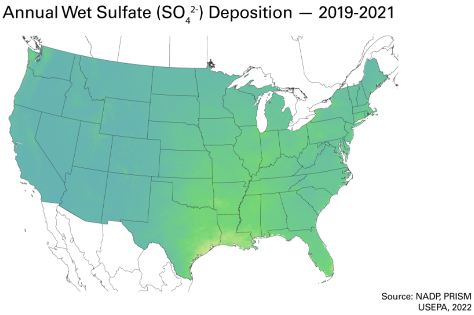




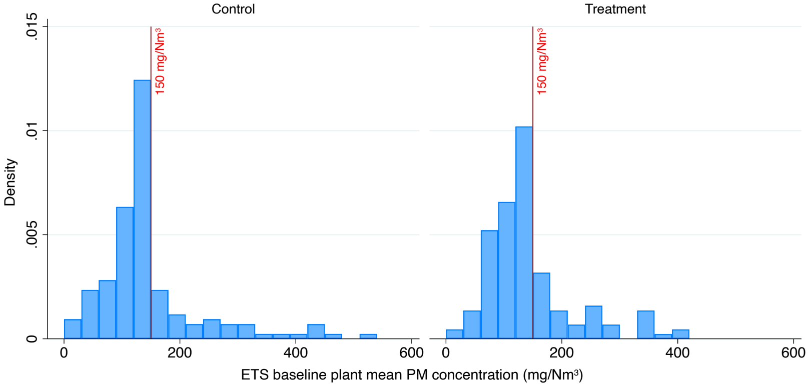
Can pollution markets work in developing economies?

- Pollution markets abate pollution at the lowest possible cost (Dales, 1968)
  - Tremendous success of cap-and-trade or pollution markets in the US and EU (e.g., US SOx and NOx markets and EU ETS)

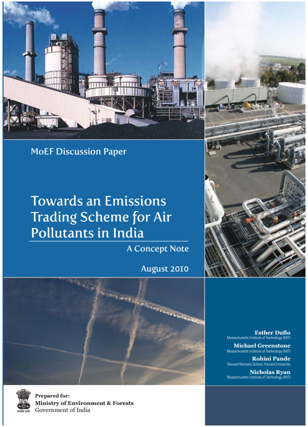
- But basic assumptions of pollution markets may be violated in emerging economies:
  1. Unreliable monitoring of emissions (Duflo, Greenstone, Pande and Ryan, 2013)
  2. Insufficient force or credibility of the regulator to ensure polluters hold sufficient permits (Duflo, Greenstone, Pande and Ryan, 2018)

  → Pollution markets are rarely adopted to regulate pollution in emerging economies

Many plants do not comply with status quo regulations



Worked with regulators to design and launch the world's first particulates emissions market



White paper

- 2010: White paper
- 2013: CEMS standards
- 2013: CEMS installations start
- 2014: CEMS national mandate
- ...
- 2019: MoEFCC greenlight
- 2019: CEMS installation complete
- 2019: Trading platform complete
- 2019: Market launch

Market covers industrial point sources in Surat, Gujarat, India

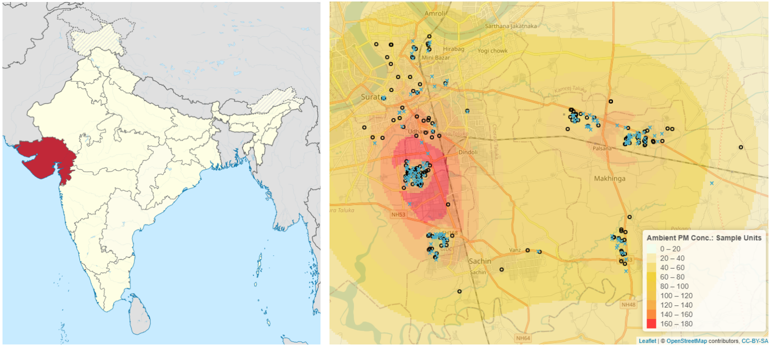
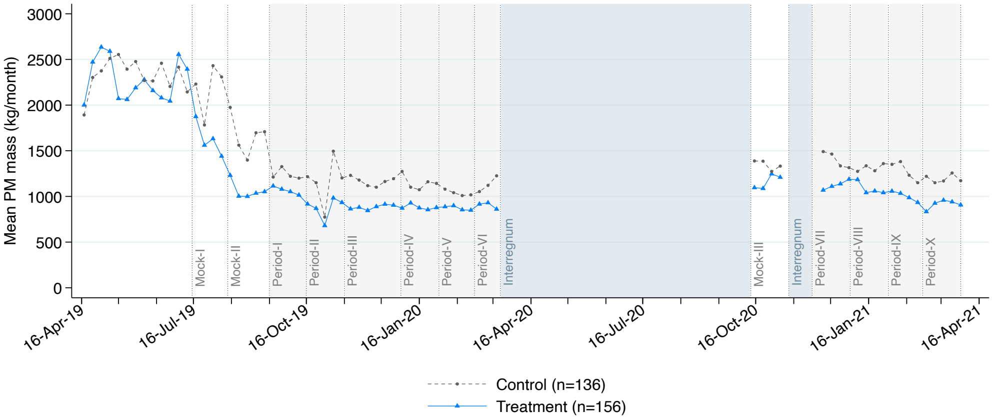


Figure: Gujarat (left) and Surat, Gujarat airshed (right)

1. Surat is the eighth largest city by population and the fastest growing city in India
2. Launch pollution market as a randomized control trial in sample of 342 plants
    - Most use coal (65%), lignite (32%) as fuel
    - Average 2017 gross sales revenue: 13.1 million USD

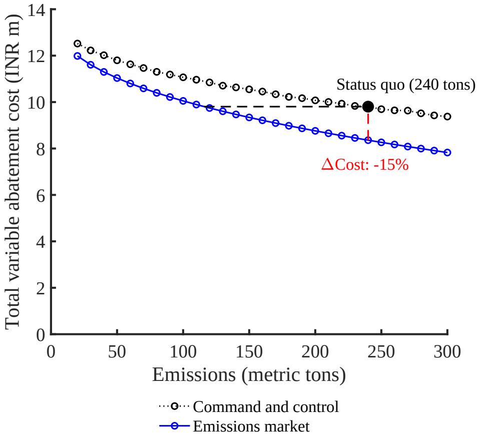
Emissions market reduced pollution



- Treatment emissions below cap (at cap, with imputed emissions)
- Gap between treatment and control emissions of 20-30% opens during first mock trading period and stays open thereafter

Use model of trading to calculate abatement cost savings of approximately 15% at the status quo level of emissions

Figure: Total variable abatement costs by regime



Specification: Capacity-Based Rate with i.i.d. Error, Period 4.

Large mortality damages imply high benefit-cost ratio for market

Expanding the ETS for one year to all industrial plants in Surat:

	Emissions reduction		
	10%	30%	50%
Per Ebenstein et al. (2017) estimates of mortality impact of pollution:			
Monitoring costs + Δ(abatement costs)	\$3.4m	\$3.9m	\$4.6m
Reduction in ambient $PM_{2.5}$	$2.8 \mu g/m^3$	$8.5 \mu g/m^3$	$14.2 \mu g/m^3$
Gain in life-years per 1 year of ETS	29,736	89,208	148,680
Value of gain in life-year	\$282m	\$847m	\$1,412m
Benefit-cost	83:1	215:1	303:1
Per Correia et al. (2013) estimates of mortality impact of pollution:			
Benefit-cost	30:1	77:1	108:1

- Ebenstein, Avraham, Maoyong Fan, Michael Greenstone, Guojun He, and Maigeng Zhou. 2017. "New evidence on the impact of sustained exposure to air pollution on life expectancy from China's Huai River Policy." *Proceedings of the National Academy of Sciences of the United States of America*, 114(39): 10384-10389.
- Correia, Andrew W, C Arden Pope III, Douglas W Dockery, Yun Wang, Majid Ezzati, and Francesca Dominici. 2013. "The effect of air pollution control on life expectancy in the United States: an analysis of 545 US counties for the period 2000 to 2007." *Epidemiology (Cambridge, Mass.)*, 24(1): 23.

Successful pilot can inform policy

1. **Control group**. Has been moved into emissions market in Surat.

2. **Other cities**. Market in Ahmedabad started in September, 2023.

3. **Other pollutants**. Government of Gujarat has announced their intention to start a market for CO_2 emissions. Government of Maharashtra intends to start a market for SO_2 emissions

Gujarat inks MoU to develop India's first carbon market

The MoU was signed in the presence of Chief Minister Bhupendra Patel and officials from climate change and mines and industries department.

By: Express News Service | Ahmedabad |
May 24, 2022 5:42:04 am

Source: Indian Express

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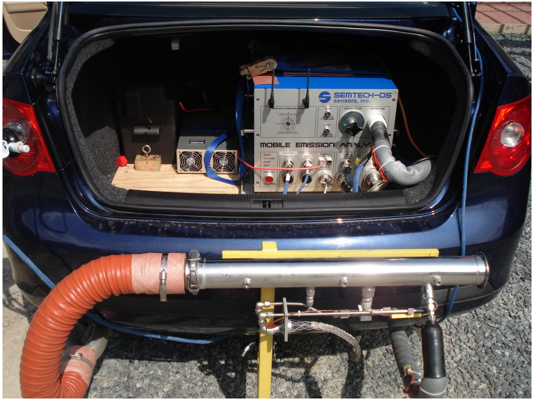
Example: Transportation tailpipe emissions

Figure: Portable emissions measurement system



- Measurement of emissions is very costly.
- Damages are heterogeneous in time and space.
- No feasible Pigouvian or Coasean solution.
- What should we do instead?

Transportation

- Regulations target different stages of the production of tailpipe emissions.
  - Lower regulatory costs, but target only a proxy for emissions

- Consider moving from a very coarse regulation to close to an efficient regulation:
  1. Vehicle use itself
     Davis (2008), Barahona, Gallego and Montero (2020)
  2. Fuel content standards (Euro IV)
     Auffhammer and Kellogg (2011)
  3. Car technology for new vehicles (catalytic converters)
     Jacobsen, Sallee, Shapiro and van Benthem (2023)
  4. Emissions testing for old vehicles (smog check)
     Oliva (2015)
  5. Emissions measurement in real-time

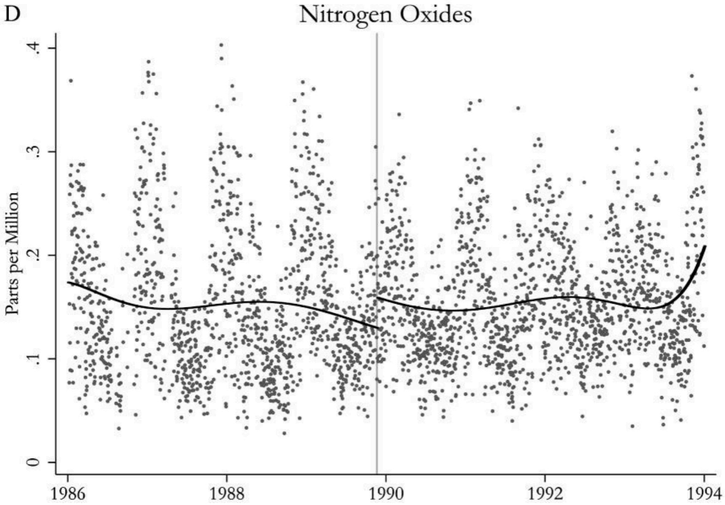
- A major, general question in the study of regulation is: what is the social loss from using constrained regulation, instead of the first-best? What are the binding constraints?

Transportation: Davis (2008)

Davis, L. W. (2008). The effect of driving restrictions on air quality in Mexico City. Journal of Political Economy, 116(1), 38-81.

- Because regulating car-by-car is so costly, cities often resort to desparate measures like bans
- Mexico City introduced a restriction that banned some vehicles for one day per week based on the last number in their license plate. The ban has the great advantage of being enforceable.
- But, the ban did not work. Emissions did not decline.
- More total vehicles and a change in composition toward high-emission cars. Likely mechanishm: people substituted towards clunker cars on their day "off".

Transportation



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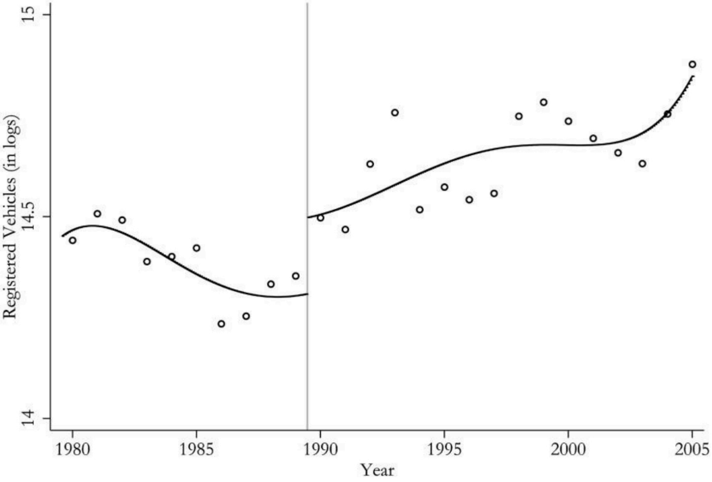


FIG. 9.—Registered vehicles in Mexico City, 1980–2005. Source: INEGI, Estadísticas de Transportes, Vehículos de Motor Registrados en Circulación, 2007.

Transportation: Auffhammer and Kellogg (2011)

Auffhammer, M. and R. Kellogg (2011). Clearing the Air? The Effects of Gasoline Content Regulation on Air Quality. *American Economc Review*, 101 (6): 2687-2722.

- Regulations often vary in flexibility. For example, markets versus command-and-control.
  - More flexibility: lower costs, allowing lower targets.
  - Less flexibility: higher costs, but perhaps higher certainty.

- This paper studies such a trade-off in the regulation of gasoline content, which contributes to ozone formation in ambient air
  - Federal / most state standards: Reid Vapor Pressure (RVP), measuring all Volatile Organic Compounds
  - California: reformulated gasoline (RFG), restricting specific chemical content of VOCs from March 1996 onwards

- This problem is general because some "pollutants" like PM2.5 are really aggregates

Transportation

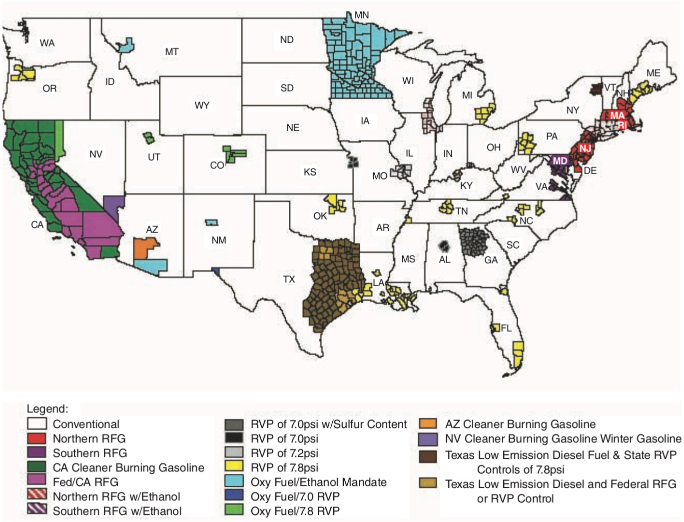


FIGURE 2. MAP OF RVP PHASE II AND RFG REGULATIONS AS OF 2006

Transportation

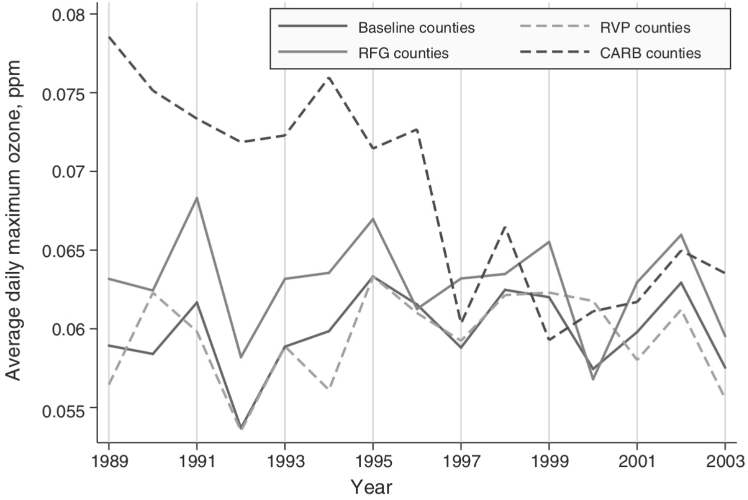


FIGURE 3. MEAN SUMMER OZONE CONCENTRATIONS
(Broken out by regulation type)

Transportation: Jacobsen et al. (2023)

Jacobsen, Sallee, Shapiro and van Benthem (2023). Quarterly Journal of Economics., 138 (3): 1907-1976.

- Regulation of emissions in real-time may be costly, but could instead regulate:
  1. Technology (e.g. "Best available control technology" for industrial air pollution)
  2. "Representative" emissions from a sample/type

- The main question then is how well these proxies stand in for regulation of actual emissions. In the case of vehicle *registrations*, we saw the proxy was very bad.

- Vehicle emissions standards are of this general type
  - Cars tested when new then set loose on the road
  - Neglects temporal and spatial heterogeneity in emissions
  - Smog check for used cars incomplete

Transportation

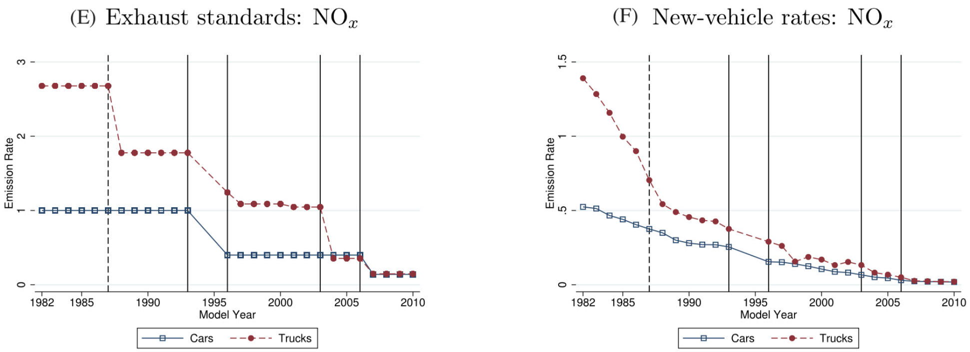
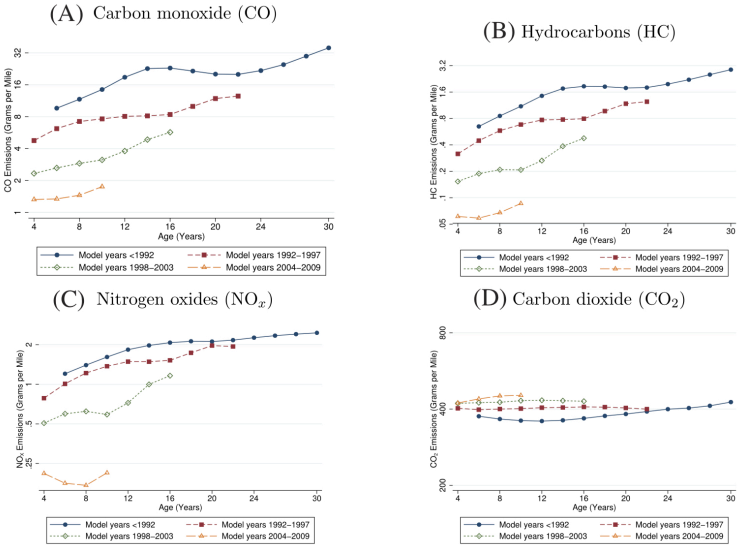


FIGURE II

Exhaust Standards and Emission Rates, Cars versus Trucks

Transportation



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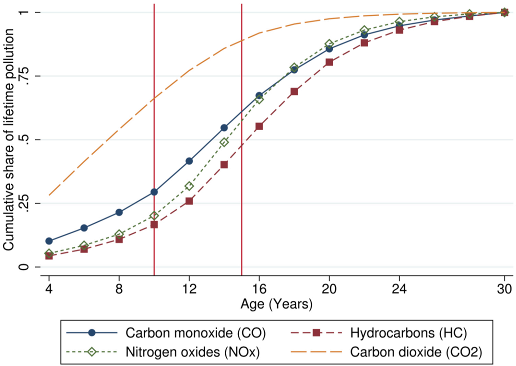

FIGURE VII

Cumulative Share of Fleet Emissions from Each Vehicle Age

- Strict regulation of new vehicles and depreciation of pollution control implies that most emissions are from old cars
- Cost-benefit analysis finds social gains from exhaust standards on the scale of \$20-30 billion/year
- However, taxing old cars to encourage scrap would increase social welfare further (Jacobsen and van Benthem, 2015)

Transportation: Oliva (2015)

Oliva, P. (2015). Environmental regulations and corruption: Automobile emissions in Mexico City. Journal of Political Economy, 123(3), 686-724.

- Studies smog check inspections of automobiles in Mexico City
- Observe high correlation in test results within testing centers over time across "different" cars. Centers use donor cars to produce clean results and pass clunkers.
- Uses this pattern to estimate that about 10% of tests are fraudulent for cars at least 10 years old. Estimates suggest that it would be costly to vehicle owners to eliminate this loophole.

All of these regulations on transportation emissions are flawed, but some still have social benefits exceeding costs.

- "Happy families are all alike, every unhappy family is unhappy in its own way."

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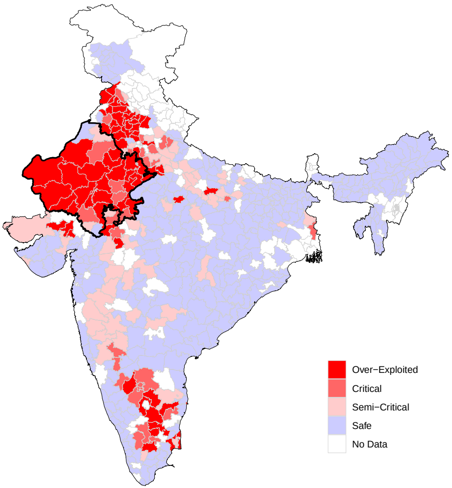
Example: Groundwater depletion

- India uses more groundwater than the United States and China combined

- The crisis is blamed squarely on policy towards groundwater:
  - **Not Coasean.** Water is not excludable and rights are not defined.
  - **Anti-Pigouvian.** Power is priced near zero or at zero for farmers.

Figure: Groundwater exploitation



India's groundwater policy

- *De facto*, electricity rationing is the only policy to manage the commons
- We find that rationing binds on farmers' power (and therefore water) use
- Rationing also binds on the extensive margins of number and size of pumps

▸ Extensive margin

Figure: Electricity ration

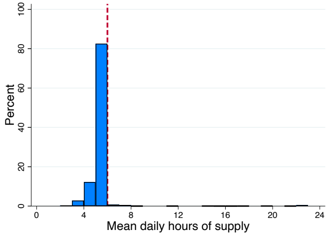
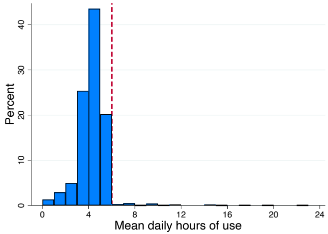


Figure: Electricity use



The farmer's problem

Farmers maximize profits

$$\Pi_i(L_i, X_i^*, K_i^*, H_i^*) = \max_{X_i, K_i, H_i} \Omega_i F(L_i, X_i, K_i, W_i(H_i, D_i)) - w_i X_i - r_i K_i - p_e P_i H_i$$

subject to ration and water extraction function:

$$\begin{aligned} W_i(H_i, D_i) &= \rho \frac{P_i H_i}{D_i} \\ H_i &\leq \overline{H}. \end{aligned}$$

Inputs are land, labor, capital, and water. Water use depends on the electricity ration:

- A farmer runs their pump for H_i hours in the day to lift water from well depth D_i underground
- Water is inversely proportional to depth D_i, as more energy is required to lift water from further down
- ρ is a physical constant.

Write profit as a function of water

Define production and profit functions with water as the only argument.

$$\begin{aligned} \widetilde{F}_i(W_i) &= F(L_i, X_i^*, K_i^*, W_i) \\ \widetilde{\Pi}_i(W_i) &= \Omega_i \widetilde{F}_i(W_i) - w_i X_i^* - r_i K_i^* \end{aligned}$$

where labor and capital $\{X_i^*, K_i^*\}$ are chosen optimally as water varies.

The state's problem

Let the opportunity cost of water be λ_W per liter extracted.

The state sets a ration (assumed binding) to solve:

$$\max_{\overline{H}} \sum_i \left[\widetilde{\Pi}_i(W_i(\overline{H}, D_i)) - c_E P_i \overline{H} - \rho_i \frac{\overline{H}}{D_i} \lambda_W \right].$$

The first-order condition for an optimal ration $\overline{H}^*$ is

$$\underbrace{\sum_i \frac{d\widetilde{\Pi}_i(W_i(\overline{H}^*, D_i))}{d\overline{H}^*}}_{\text{Marginal benefit}} = \underbrace{\sum_i c_E P_i + \frac{\rho_i}{D_i} \lambda_W}_{\text{Marginal social cost}} \tag{1}$$

Ration balances:

1. Marginal benefit of additional farmer profits;
2. Marginal cost of power and the marginal opportunity cost of water.

Estimation of loss due to rationing

$$\underbrace{\sum_i \frac{d\widetilde{\Pi}_i(W_i(\overline{H}^*, D_i))}{d\overline{H}^*}}_{\text{Marginal benefit}} = \underbrace{\sum_i c_E P_i + \frac{\rho_i}{D_i}\lambda_W}_{\text{Marginal social cost}} \qquad (2)$$

- The rationing regime suppresses the variation that would enable us to estimate the marginal benefit term.
- Consider two approaches one might try:

1. **Direct approach: estimate effect of varying the ration $\overline{H}$.**
   Problem: The ration does not vary.
2. **Revealed preference: estimate demand for power**
   Problem: With a binding ration, farmer "choices" are not on their demand curves.

Idea: estimate marginal benefit of power ration from marginal return to water in agriculture

All demand for power is derived from demand for water. The marginal benefit of an increase in the electricity ration $\overline{H}$ is

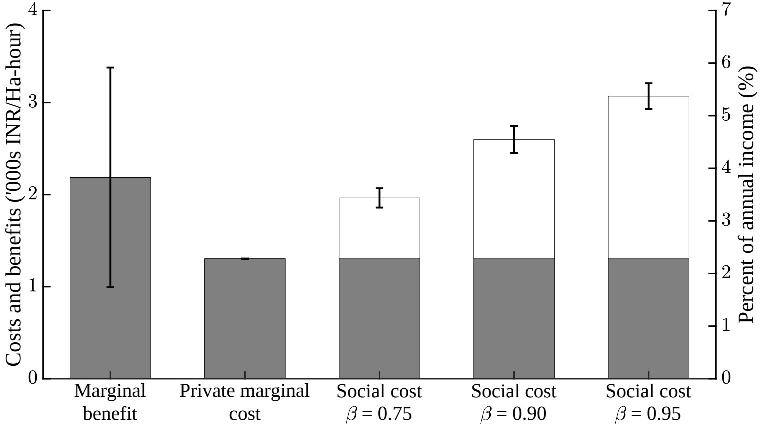
$$\sum_i \frac{d\widetilde{\Pi}_i(W_i(\overline{H}, D_i))}{d\overline{H}} = \sum_i \frac{d\widetilde{\Pi}_i}{dW_i}\frac{dW_i}{d\overline{H}} \quad (3)$$

$$= \sum_i \frac{d\widetilde{\Pi}_i}{dW_i}\left(-\frac{dW_i}{dD_i}\frac{D_i}{H_i}\right) \quad (4)$$

$$= \sum_i -\frac{d\widetilde{\Pi}_i}{dD_i}\frac{D_i}{H_i}. \quad (5)$$

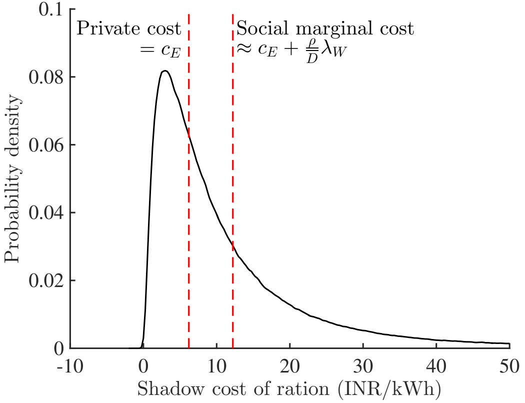
- Pumping for *longer* or pumping from a *shallower* well both yield more water.
- Use D_i variation to mimic (non-existent) H_i variation

Efficiency of rationing



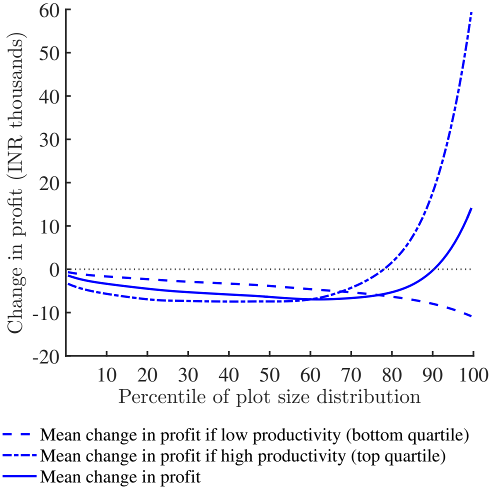
- One hour longer ration increases profit by 4% of household income.
- $PMC \leq MB < SMC$. Ration about right, or somewhat too high.
- A discount factor of $\beta = 0.82$ exactly rationalizes the observed ration. State bonds have a nominal yield around 10%.

Shadow cost of ration



- Ration imposes a fairly high shadow cost, *on average*
- There is wide heterogeneity, with many shadow costs near zero, and other farmers facing shadow costs above twice social cost
- Pigouvian reform would increase profits by 12% of mean farmer income

Counterfactual outcomes: equity



- Productive farmers lose more at small plot sizes, but **gain** at large plot sizes, since they were heavily constrained under rationing.

Constraints to regulation: Political economy

- Rationing used widely in an environment where better regimes are clearly feasible from a technical point of view. Many customers have electricity meters!

- The key to estimating the social loss of the policy is the dispersion in marginal returns
  - The paper uses farmer profits to estimate marginal returns
  - Pigouvian reform would increase profits by 12% of farmer income

- However, such a reform would involve complex patterns of redistribution, especially towards productive, large landholders who are heavily constrained

Outline

1. **Regulation builds missing markets**
2. **Constraints to regulation: Agency problems**
   - Third-party auditors
   - Emissions trading
3. **Constraints to regulation: Monitoring**
   - Transportation
4. **Constraints to regulation: Political economy**
   - Groundwater depletion
   - Water pollution
5. **Directions for research**

Constraints to regulation: Political economy

- Pollution is an externality: there is no market price on using air, water and other natural resources.
- Governments have tools to internalize externalities.
- Yet there is a tension in whether governments are willing and able to regulate
  - Local governments will have better information and may be better able to enforce regulations. Indeed, they are often responsible for enforcement.
  - Yet pollution does not respect administrative boundaries. Local levels of government may not internalize the external costs of pollution.

Constraints to regulation: Political economy

Idea of Lipscomb and Mobarak (2016):

- River pollution is a good context to study how transboundary pollution affects externalities, since the direction of externalities is well defined: downstream (Sigman, 2002)
- We may then expect that countries / states / counties / towns would pollute more, the more their pollution will flow to downstream units
- An empirical concern with testing this idea is that there may be omitted variables bias.
  - For example, smaller counties may have less stringent regulatory enforcement or worse technology, and also expect a greater share of their pollution to harm others.
- Propose to address this by using cases where borders *change*. If a county shrinks, does it no longer internalize the externalities?

Effect of border split

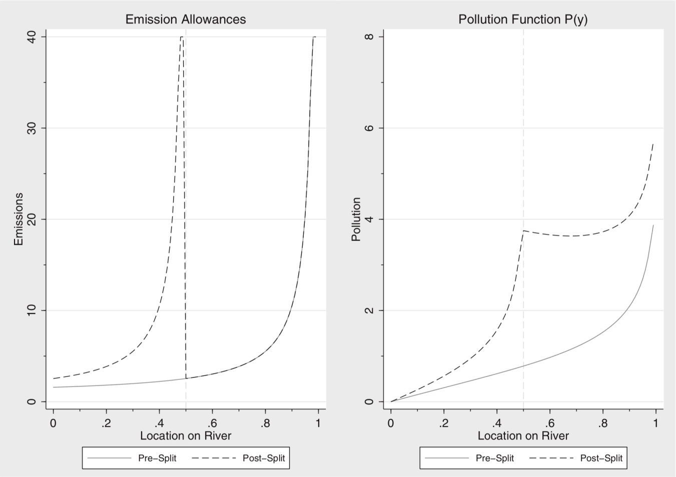


FIGURE 2
Emissions allowance and pollution functions uniform population density

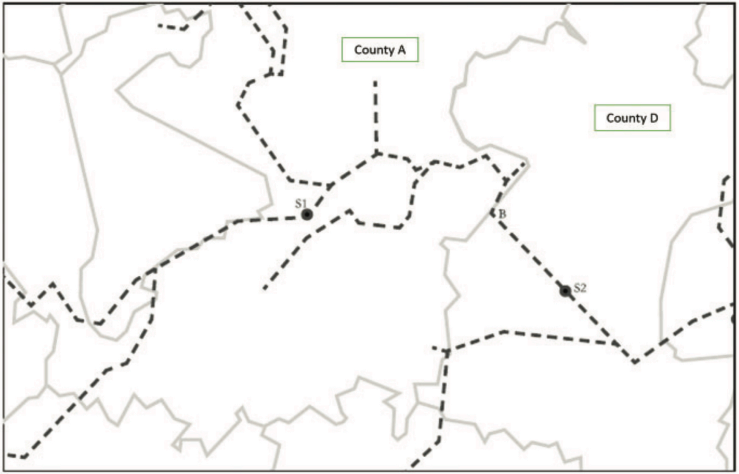
- Model of regulatory choice of emissions quantity. No agency/informational failure.
- People get utility from consumption which is produced with pollution.
- Government sets consumption/pollution level to trade-off utility against downstream harm.

Model predictions

Then show several predictions from this basic model:

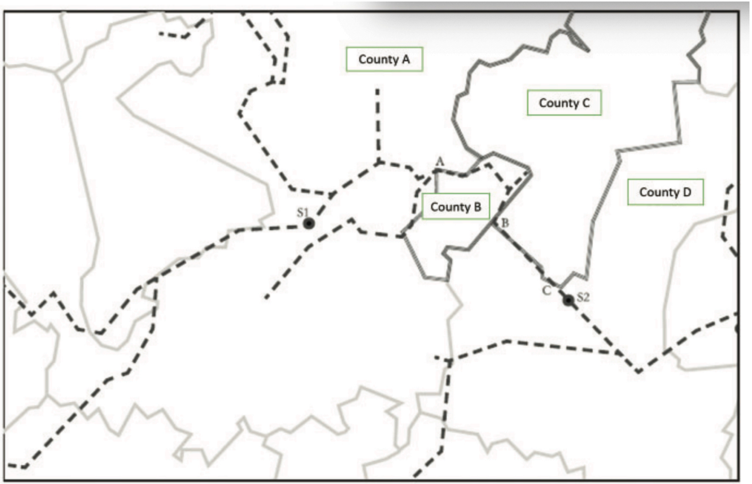
1. Pollution increases within a jurisdiction towards the downstream border
2. Pollution increases at an increasing rate as the river approaches the border
3. There is a discontinuous drop (structural break) in pollution at the border
4. There is a larger increase in pollution between points if a river crosses more borders

Brazil splits counties over time



1991 Map

Brazil splits counties over time



1998 Map

Distances upstream and downstream

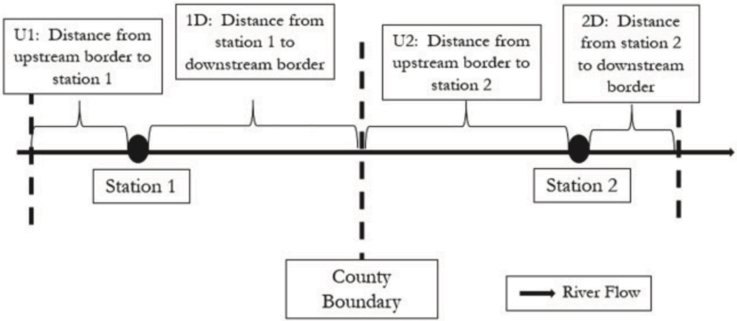


FIGURE 4
Notation on distances

Water quality monitors in Brazil

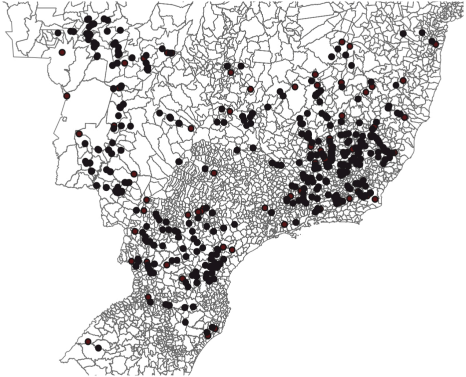


FIGURE 5
Water quality monitoring stations and county boundaries in 1991

- Use data on 372 station pairs in Brazil
- Water quality (biological oxygen demand, or BOD) measured on a quarterly basis
- County boundaries redrawn four times within the sample: increased from 4,492 counties in 1991 to 5,807 in 2005

Pollution increases after county splits

Station-pair regressions: change in pollution from upstream to downstream station over time

Dependent Variable: Log Difference in BOD (downstream minus upstream)*100				
Number of borders crossed between station 1 and station 2	3.200*	3.595**	3.418**	3.886*
	(1.647)	(1.536)	(1.494)	(1.550)
Distance from station 1 to downstream border (1D)		1.526*	1.771*	1.740*
		(0.885)	(1.029)	(1.028)
Distance from upstream border to station 2 (U2)		−3.101	−3.347	−3.442
		(1.965)	(2.108)	(2.097)
Outside station-pair control variable: distance from upstream border to station 1 (U1)		−1.676	−1.597	−2.179
		(2.244)	(2.244)	(2.257)
Outside station-pair control variable: distance from station 2 to its downstream border (2D)		−0.115	0.119	0.076
		(0.522)	(0.606)	(0.609)
Distance river follows the border to upstream station			0.401	0.590*
			(0.331)	(0.344)
Distance river follows the border to downstream station			1.472	1.302
			(2.274)	(2.273)
Distance river follows the border between stations			0.403	0.320
			(0.640)	(0.624)

- Station-pair fixed effects and trends in all specifications
- Empirical concern: County splits may be indicative of faster population growth. Regression controls for county population upstream and downstream.
- Go on to run placebo checks, look at counties that themselves did not split but had splits upstream: still find positive effect of borders on pollution

Clean test of a simple theory

The novelty here is the empirics

- Theory simple and clear that cross-boundary pollution may be internalized less than pollution within borders
- The challenge is to test this idea. There are two features here that make the empirics especially clean
  - Directional flow of pollution
  - Dynamic nature of boundaries in Brazil

See also:

He, G., Wang, S., & Zhang, B. (2020). Watering down environmental regulation in China. *The Quarterly Journal of Economics*, 135(4), 2135-2185.
Wang, S., and Z. Wang (2022). The environmental and economic consequences of internalizing border spillovers. *Mimeo*, University of Chicago.

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Directions for research

- We have given a whirlwind tour of recent literature on environmental regulation
- Most regulation is 2nd-best (or 3rd-best, or 4th-best, . . .). Therefore certain research questions are evergreen:
  - What are the constraints?
  - What are the benefits and costs of the regulations actually used?
  - What is the efficiency loss?
  - What are the *feasible* gains from reform?
- Frontier research has several common features
  - Clear institutional understanding of a generally relevant problem
  - Data that is novel or exceptional in coverage or depth
  - Policy, quasi-experimental or experimental variation to estimate key parameters or validate model predictions

Directions for research

1. **Better data**.
    - Remote sensing for air pollution, water extraction, land use, etc.
    - Regulatory and government partnerships for administrative records
    - Wide-scale and personal monitoring of heterogeneous damages
2. **More of the world**.
    - Geographic scope is heavily weighted towards major US regulations like the Clean Air Act
    - There are many heterogeneous regulatory regimes around the world to learn from and pollution is much higher in low-income countries.
    - The constrained optimal regulatory regime will differ with pre-existing market failures, which are the object of study in development
3. **Micro-foundations of responses to regulation**.
    - Approach regulation as a mechanism design problem.
    - Identify and estimate constraints and find the constrained optimum.
    - Environmental regulation seems behind the comparable literatures on market design in education, health, etc. We *know* the status quo is inefficient–what to do instead?