The Implications of Carbon Pricing for Environmental Inequality

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Preliminaries

- Thank yous and apologies
- Revision updates
- Slides & replication project available

Overview

Research Question

Do carbon pricing policies exacerbate inequalities in air pollution concentrations?

Background Carbon pricing policies are big globally, more common domestically, and popular amongst economists—but little is known about *how* these policies affect the distribution of local air pollution

Method Study the effect of a carbon price on electricity generation in California on air pollution disparities across the Western US

1. Model: Build a model of carbon pricing and environmental inequality
2. Simulation: Use the model and data to estimate environmental inequalities under a range of carbon prices

Overview (contd.)

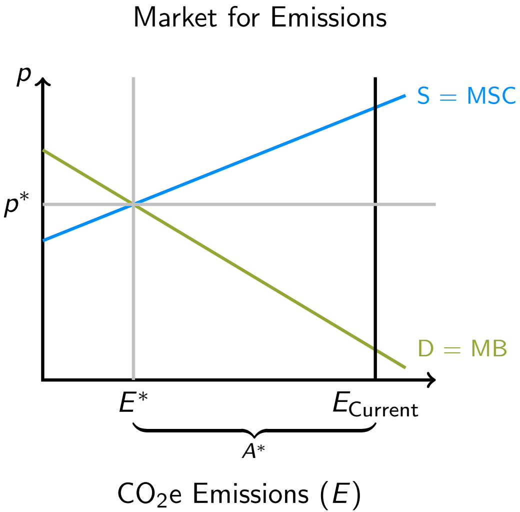
Results

- Concentration of nitrous oxide emissions increases by in disadvantaged communities, but decreases by in non-disadvantaged communities
- Sulfur dioxide & particulate matter concentration disparities do not meaningfully change
- Effects are driven by differences in coverage under the regulation

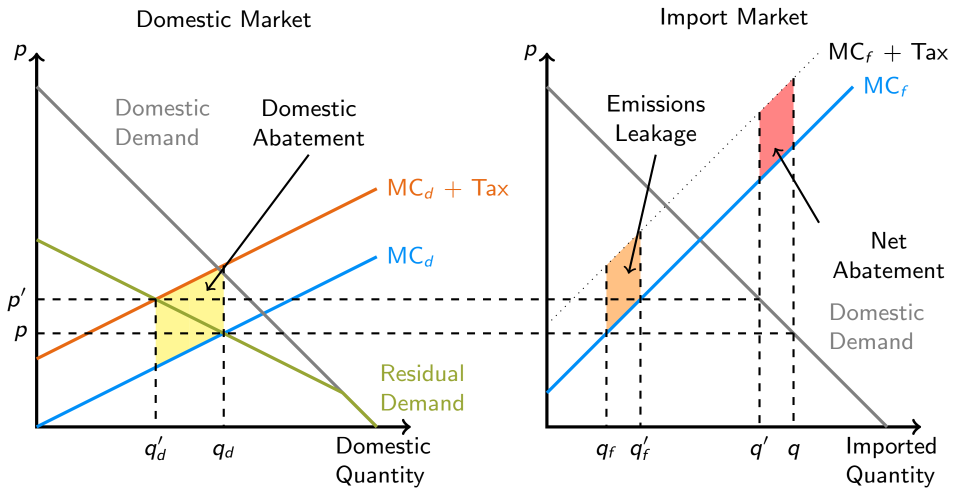
Implications

- Exposes potential flaw of ex-post analyses that look exclusively at the regulated geography
- Warrants additional research on combined cap-and-trade + localized pollution control policies

Carbon Pricing



Emissions Leakage



Gobal Air Pollution v. Local Air Pollution

Global Air Pollutants

- Carbon dioxide (CO_2), Methane (CH_4), Nitrous oxide (N_2O)
- Primarily long-run consequences
- Location does not matter

Local Air Pollutants

- Nitrogen oxides (NO_x), Sulfur dioxide (SO_2), Particulate matter (PM2.5)
- Mix of long- and short-run consequences
- Location does matter

Motivation & Ex-Post Research

- CARB Cap-and-Trade FAQ Page

- Descriptive Analysis: Yes, California's cap-and-trade program increased disparities (Cushing et al., 2018; Pastor et al., 2022)

- Causal Analysis: No, California's cap-and-trade program decreased disparities (Hernández-Cortés and Meng, 2023)

Methodological Contributions

- Ex-ante model to anticipate changes in air pollution disparities
- *How* do carbon pricing policies shift local air pollution across jurisdictions?
- Weber (2021) creates a similar model, but does not:
    1. Formally model disparities in air pollution concentrations
    2. Consider leakage and the redistribution outside of California

Model Overview

Agents N fossil fuel power plants

Environ.
- Geography: R regions, each with its own wholesale market for electricity
- Constraints: Demand, (Capacity,) Transmission
- Markets: Perfectly competitive

Actions
1. Initial investment decision
2. Hourly generation decisions

Behavior Maximize discounted sum of future profits

Equilibrium Minimize total investment and generation costs $\rightarrow$ Generation outcomes $\rightarrow$ Air pollution disparity outcomes

Action 1: Investment Decision

Heat Rate: How efficiently can a generator turn combustion into electricity?

- ρ_i : Power plant i's heat rate (Btu/kWh)
- Affects both costs and emissions

Action 1: Power plant i chooses a level of investment j_i to decrease its heat rate

- Decrease generation costs in future periods
- Incurs a current cost for investment of $\Gamma(j_i)$

Action 2: Operating Decision(s)

Action 2: Power plant i chooses whether or not to operate in period t, and if so, what regional wholesale market to sell its electricity on

$$q_{itr} = \overline{q}_i \cdot \mathbb{1}(r = a_{it}) \tag{1}$$

Endogenous:

- a_{it} : Power plant i's operating decision in time t, $a_{it} \in \{0, 1, \ldots, R\}$

Exogenous:

- $\overline{q}_i$: Power plant i's nameplate capacity (maximum generation) (kW)

Marginal Costs

$$mc_{ir} = \rho_i(u_{f_i} + e_{f_i}\tau_r) = \underbrace{\rho_i u_{f_i}}_{\text{Fuel Cost}} + \underbrace{\rho_i e_{f_i}\tau_r}_{\text{Emissions Cost}} \quad (2)$$

Endogenous:

- ρ_i : Power plant i's heat rate (Btu/kWh)

Exogenous:

- u_{f_i} : Power plant i's unit fuel cost (\$/Btu)
- e_{f_i} : Power plant i's CO_2e emissions intensity (tonnes CO_2e/Btu)
- τ_r : Emissions price in region r (\$/tonne CO_2e)

Equilibrium Generation in Period t

$$C^*(j \mid \text{Demand}_t) = \min_{a_t} \{C(a_t \mid j)\} \\ \text{s.t.} \begin{cases} \text{Market Clearing Constraints} \\ \text{Transmission Constraints} \end{cases} \tag{3}$$

Given the profile of investment decisions j, choose the profile of operating decisions that minimizes total costs $C(a_t \mid j)$ in period t

Equilibrium Investment in Period 0

$$j^* = \arg\min_{j \in \mathcal{J}^N} \Bigg\{ \underbrace{\Gamma(j)}_{\substack{\text{Investment} \\ \text{Phase Costs}}} + \underbrace{\sum_{t=0}^{T} \delta^t C^*(j \mid \text{Demand}_t^e)}_{\text{Generation Phase Costs}} \Bigg\} \tag{4}$$

Choose the profile of investment decisions j that minimizes the sum of investment costs and discounted equilibrium generation costs.

Generation Outcomes → Air Pollution Concentration Disparities

For air pollutant w, power plant i's period t emissions are:

$$w_{it}^{*} = e_i^w \rho_i^* q_{it}^* \tag{5}$$

Endogenous:

- ρ_i^* : Power plant i's equilibrium heat rate (Btu/kWh)
- q_{it}^* : Power plant i's equilibrium generation in period t (kWh)

Exogenous:

- e_i^w : Power plant i's emissions intensity for pollutant w (tonnes w/Btu)

Create a nondescript function that maps power plant i's generation in period t to changes in the concentration of w in all communities

The Environmental Inequality Gap (EI Gap)

Divide M communities into two groups: Disadvantaged communities (DAC) and Non-Disadvantaged Communities (non-DAC)

The EI Gap

Let $\Phi_w^A(T)$ denote the average equilibrium concentration of air pollutant w in a group of communities A after T periods. Then the EI Gap for pollutant w after T periods is defined by:

$$\text{EIGap}_w = \Phi_w^{\text{DAC}}(T) - \Phi_w^{\text{non-DAC}}(T). \tag{6}$$

Model Takeaways

Everything goes back to marginal costs:

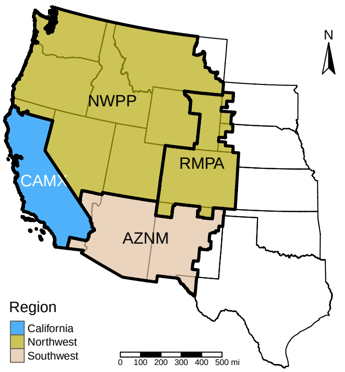
$$mc_{ir} = \rho_i(u_{f_i} + e_{f_i}\tau_r)$$

Apart from small changes due to investment, we only get redistribution of generation and emissions through relative changes along the supply curve (marginal costs)

1. $\Delta e_f : \uparrow \tau_r \quad \Rightarrow \quad \uparrow \Delta e_f \tau_r \quad \Rightarrow \quad \uparrow \Delta mc$
2. $\Delta \tau_r : \uparrow \tau_r \quad \Rightarrow \quad \uparrow \Delta \tau_r \quad \Rightarrow \quad \uparrow \Delta mc$ (New!)

Simulation Environment

- Simulate generation across the Western US power grid (Western Interconnection)
- Focus only on fossil fuel generation: coal, (natural) gas, oil



Simulation Policy Scenarios

- Border Carbon Adjustments (BCAs): "Carbon tariff" on electricity California imports from elsewhere

- Nine policy scenarios with a combination of BCAs and carbon prices

Scenario	BCA?	Tax ($/tonne)
A	No	0
B	No	20
C	No	40
D	No	60
E	No	80
F	Yes	20
G	Yes	40
H	Yes	60
I	Yes	80

k-Means Clustering

- Problem: Constrained optimization problems are too large

- Generation Problem
  - Simplify N: k-means cluster power plants into thirty groups

- Investment Problem
  - Simplify T: k-means cluster electricity demand into a "representative day"
  - Simplify N: k-means cluster generation clusters into four clusters

Generation $\rightarrow$ Pollutant Concentrations

- Most basic measure of concentration: tonnes of pollutant w per square mile

- EI Gap implementation:

$$\text{EIGap}_w = \text{Mean}_{\text{DAC}} \left[\frac{\text{Annual Emissions}}{\text{Area}} \right] - \text{Mean}_{\text{non-DAC}} \left[\frac{\text{Annual Emissions}}{\text{Area}} \right] \tag{7}$$

- Forthcoming: Census tracts + buffer zones

Generation Data

Power Plants

- 2019 Emissions & Generation Resource Integrated Database (eGRID) from the EPA
- All power plants with capacity ≥ 1 MW
- Initial heat rates, emissions factors, locations, fuel types

Electricity Demand

- 2019–2021 EIA's Hourly Electric Grid Monitor Regional Files
- Regional demand at every hour and generation by fuel type
- Compute residual demand for each hour

Disadvantaged Communities

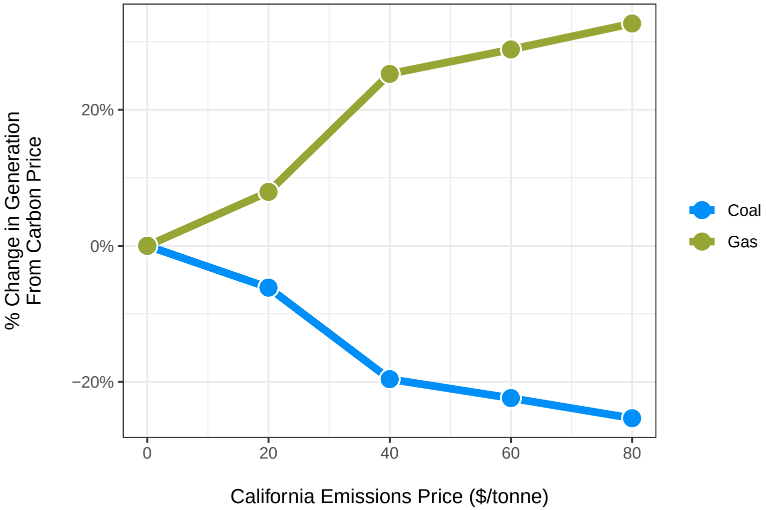
Disadvantaged Communities in California:

- California SB 535 requires Census tracts to be designated as "Disadvantaged" or not to allocate revenue generated by the cap-and-trade program
- State develops a metric called CalEnviroScreen and set of criteria to make designations

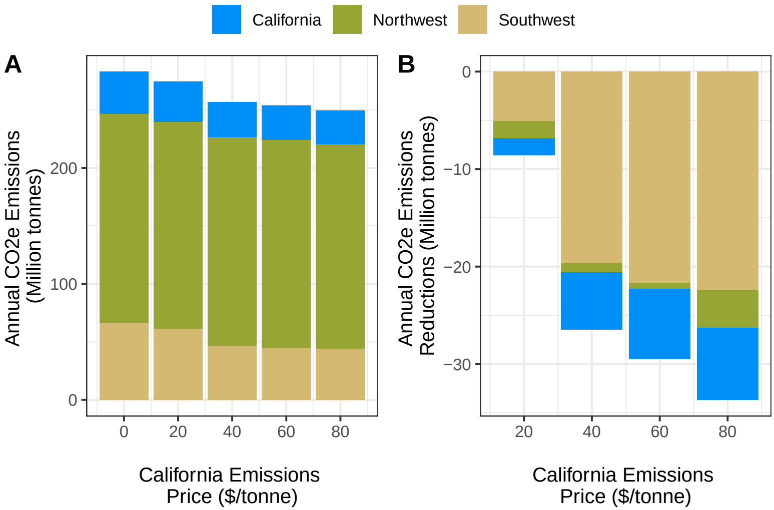
Disadvantaged Communities outside of California:

- Must define for the analysis
- Use data from EPA's Environmental Justice Screening tool to create similar metric and designate Census tracts with the analogous criteria

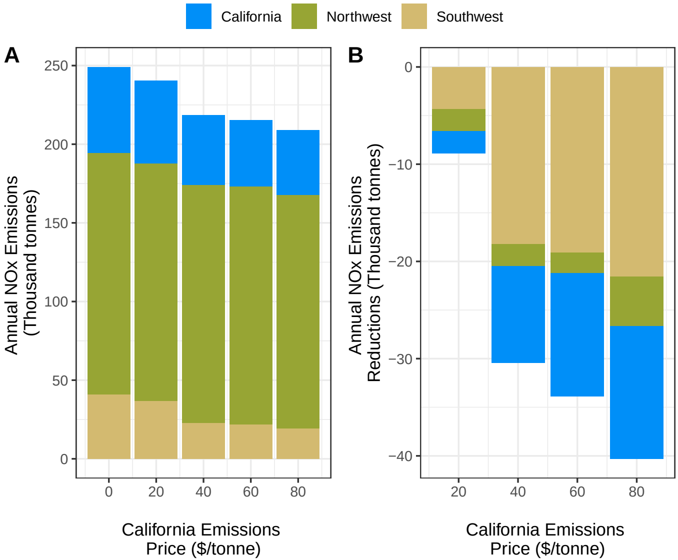
Generation


% Change in Generation
From Carbon Price
20%
0%
−20%
0
20
40
60
80
California Emissions Price ($/tonne)
Coal
Gas

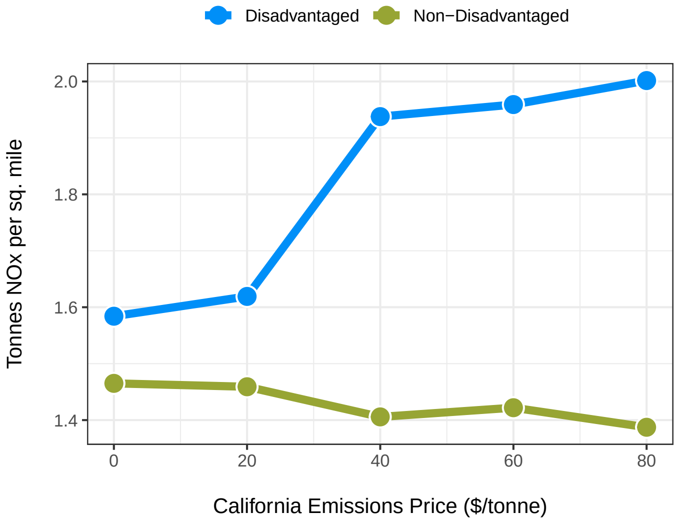
Greenhouse Gas Emissions



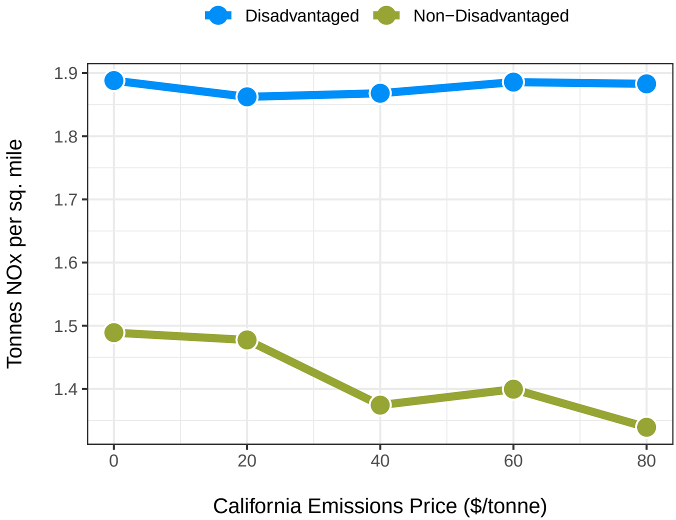
Total NO_x Emissions



The EI Gap (NO_x)



The EI Gap (NO_x) in California



Unpacking the EI Gap (NO_x)

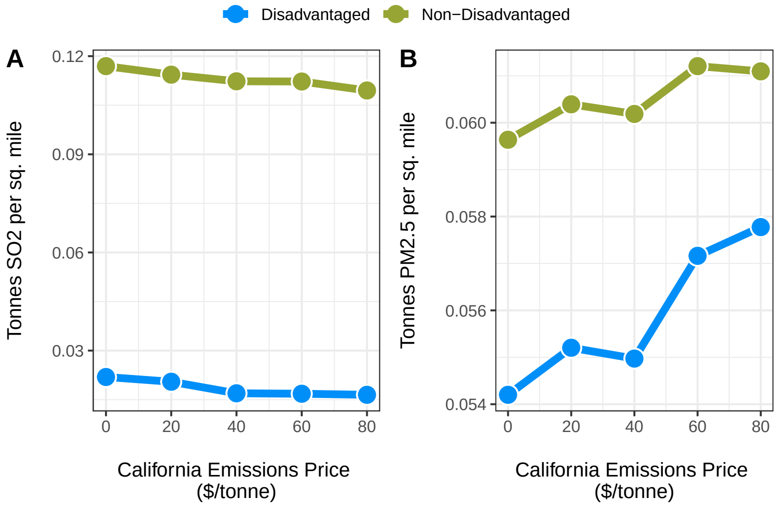
Overall EI Gap (\$0 $\rightarrow$ \$80 per tonne):

- NO_x Concentration in DACs: $\uparrow$ 26.4%
- NO_x Concentration in non-DACs: $\downarrow$ 5.3%
- EI Gap: $\uparrow$ 416%

California EI Gap (\$0 $\rightarrow$ \$80 per tonne):

- NO_x Concentration in DACs: $\downarrow$ 0.3%
- NO_x Concentration in non-DACs: $\downarrow$ 10.1%
- EI Gap: $\uparrow$ 36.2%

EI Gap (Others)



Simulation Upshots

1. Carbon pricing *does* have the potential to exacerbate disparities in air pollution concentrations

2. Need more research that grapples with more intricate policy scenarios—namely combinations of cap-and-trade and localized pollution controls

3. Accounting for redistribution outside of the regulated jurisdiction matters

Limitations & Future Work

What is next for me:

- Copyediting
- Diagnostics
- Alternative concentration measurements
- Expanding discussion of results

What would be ideal:

- Better modeling of air pollution concentrations
- Simulate more nuanced policies/more accurate counterfactuals

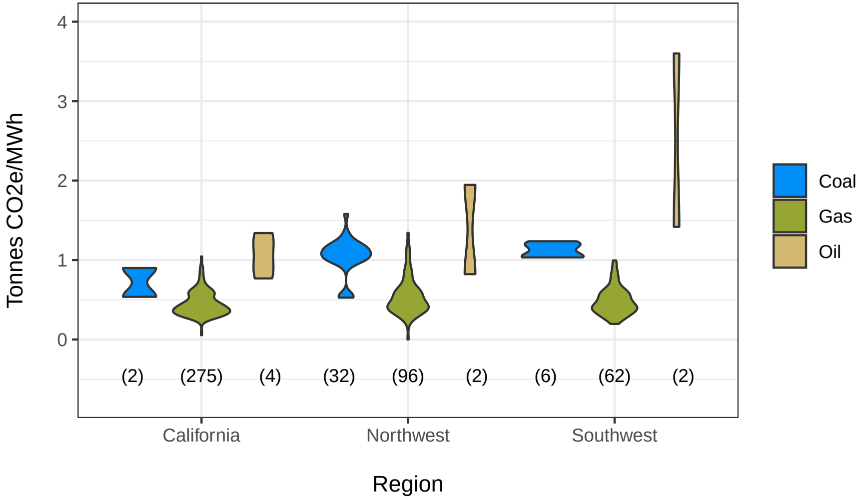
Cushing, Lara, Dan Blaustein-Rejto, Madeline Wander, Manuel Pastor, James Sadd, Allen Zhu, and Rachel Morello-Frosch. 2018. "Carbon trading, co-pollutants, and environmental equity: Evidence from California's cap-and-trade program (2011–2015)." *PLoS medicine*, 15(7): e1002604.

Hernández-Cortés, Danae, and Kyle Meng. 2023. "Do environmental markets cause environmental injustice? Evidence from California's carbon market." *Journal of Public Economics*, 217: 104786.

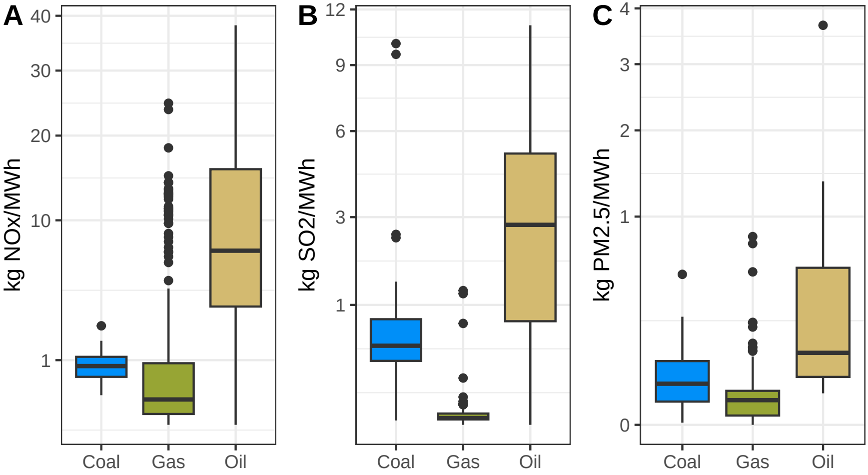
Pastor, Manuel, Michael Ash, Lara Cushing, Rachel Morello-Frosch, Edward-Michael Muña, and James Sadd. 2022. "Up in the Air: Revisiting Equity Dimensions of California's Cap-and-Trade System." *USC Dornsife Equity Research Institute*.

Weber, Paige. 2021. "Dynamic responses to carbon pricing in the electricity sector." *Working paper, University of North Carolina at Chapel Hill*.

Greenhouse Gas Emissions Intensities



Local Pollutant Emissions Intensities



Total SO_2 Emissions