Causal Inference Meets Cap-and-Trade

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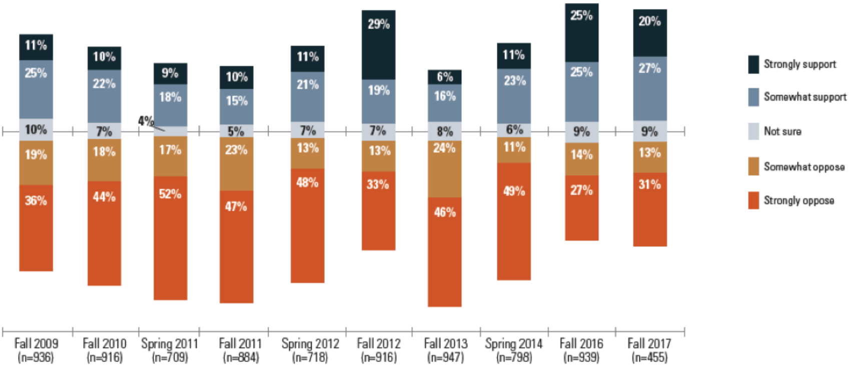
Economists love carbon pricing!

Inconvenient Truth: This love is not universal!

Figure 1. Support/opposition to a carbon tax[a]



Source: Fall 2009-Fall 2017 NSEE waves.

The trouble with carbon pricing?

From a new – provocative/infuriating–book by Danny Cullenward and David Victor:

> *The strategy that economists vehemently promote to address the climate crisis – market-based programs – hasn't been working and isn't ready to scale. The politics of creating and maintaining market-based policies render them ineffective nearly everywhere they have been applied.*
>
> *Reforms can help around the margins, but markets' problems are structural and won't disappear with increasing demand for climate solutions. Facing that reality requires relying more heavily on industrial policy – government-led strategies – to catalyze the transformation that markets promise, but rarely deliver.*

Overview

- Review the theoretical/economic argument for carbon pricing (emphasis on cap-and-trade).
- Introduce some important lines of empirical inquiry:
    - Impacts on emissions? Fowlie et al. 2012.
    - Efforts to mitigate leakage? Lo Prete et al. 2021.
    - Equity/environmental justice concerns:
        - Fowlie et al. 2012 revisited
        - Cortes-Hernandez and Meng, 2020

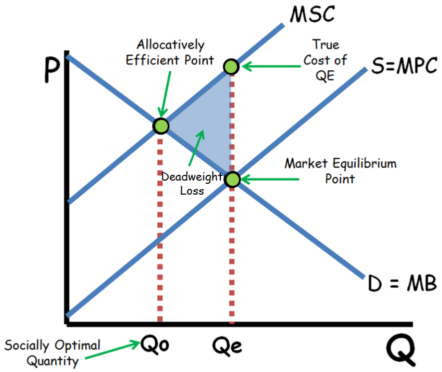
Contrast economists' prescriptions with on-the-ground policy realities.

Section 1

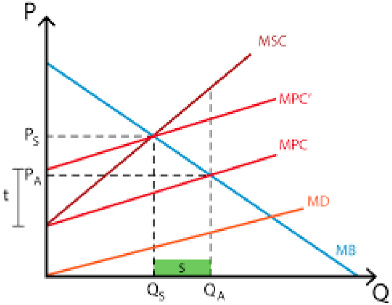
The theoretical case for carbon pricing

Why do economists lose sleep over *non-pecuniary* externalities?

- Unregulated market outcomes are not Pareto efficient.
- Economic activity could be re-organized to increase aggregate social welfare.... but this requires market intervention.



Economists' prescription?



Increase the price to reflect the monetized marginal external damage.

Theoretical motivation

A simple model to show how market-based policy incentives can achieve the socially optimal outcome:

- Many firms: $j = 1..J$ producing a homogeneous good X
- Production costs: $c_j(X_j), c_j' > 0; c_j'' < 0$
- Production generates emissions $e_j(X_j)$.
- Firms can abate emissions at a cost. Net emissions are $e_j(X_j) - a_j$
- Abatement costs are $A_j(a_j); A_j' > 0$
- Assume linear and additively separable damage function: $D = \sigma \sum_j (e_j(x_j)) - a_j)$
- σ is the monetized damage per unit of pollution (e.g. the social cost of carbon).

Cap-and-trade basics

- Set the emissions cap to limit total emissions to E^*.
- Distribute a number of permits equal to E.
- Make these permits tradeable.
- To comply, each regulated source must hold permits to offset uncontrolled emissions.
- Compliance cost minimizing firms will reduce their own emissions unless their marginal abatement costs exceeds the prevailing permit price.

Cap-and-trade and the theory of the firm

Regulator chooses total emissions E^* and allocates a corresponding number of tradable permits. Firm's profit maximization problem becomes:

$$\max_{a_j, X_j} \pi = PX_j - c_j(X_j) - A_j(a_j) + \tau(alloc_j - b_j + s_j)$$
$$s.t. e_j(x_j) - a_j \leq alloc_j + b_j - s_j$$

- $alloc_j$ is the quantity of permits allocated to the firm (lump sum)
- b_j is purchased (bought) permits
- s_j is sold permits.
- τ is the permit price.

Profit maximization under cap-and-trade

Now the firm maximizes profits subject to the constraint that it must hold permits to offset emissions.

$$\begin{aligned} L &= PX_j - c_j(X_j) - A_j(a_j) + \tau(alloc_j - b_j + s_j) \\ &- \lambda_j(e_j(X_j) - a_j - alloc_j - b_j + s_j) \end{aligned}$$

First order conditions:

$$\frac{\partial L}{\partial X_j} : P = \frac{dc_j}{dX_j} + \lambda_j \frac{de_j}{dX_j}$$

$$\frac{\partial L}{\partial a_j} : \frac{dA_j}{da_j} = \lambda_j$$

$$\frac{\partial L}{\partial b_j} : \tau = \lambda_j$$

The equilibrium permit market outcome is efficient

When the cap is set so that the equilibrium permit price $\tau = \sigma$, the market allocates abatement and production activity so as to achieve the socially optimal cap in the least costly way:

$$\frac{P - mc_j}{e_j'(X_j)} = \frac{dA_j}{da_j} = \tau \text{ for all firms}$$

At the firm-level we should see reductions in emissions and/or emissions intensity. At the industry level we could see a reallocation of production towards less emissions-intensive firms.

Key theoretical take aways?

- In theory, a cap-and-trade program can be designed to deliver an efficient equilibrium outcome.
- Key efficiency properties:
  - Firms fully internalize the emissions externality, setting marginal social costs equal to marginal benefit (product price in an efficient market).
  - Marginal abatement costs are set equal across all firms and margins. This ensures emissions reductions are achieved at least cost.
- Firms' choices of emissions (via abatement and output choices) in equilibrium is independent of any lump sum allocations of emissions permits or tax rebates.

Carbon pricing in the real world

Environmental economists have extended this canonical model to incorporate real-world constraints/complications/outcomes.

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Extensions we'll consider today:

- Jurisdictional/operational limitations that give rise to incomplete markets.
- Environmental justice/equity concerns

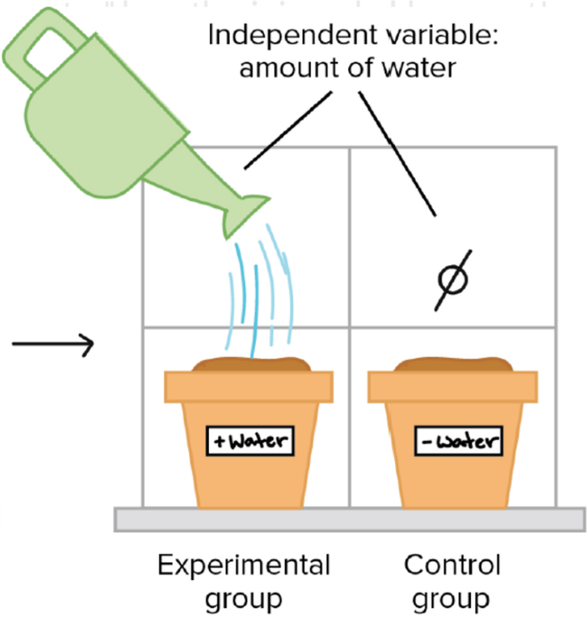
But there are many more..

- Uncertainty
- Market power
- Lobbying/political economy considerations
- Dynamics/innovation market failures
- General equilibrium impacts
- ??

Section 2

Causal inference meets cap-and-trade?

What's the ideal experimental design?

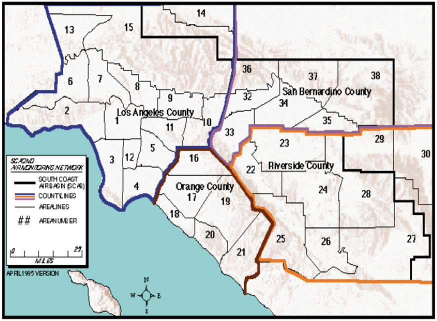


Fowlie et al. 2012

- We estimate the causal effect of a California-based emissions trading program on facility-level emissions vis a vis the command-and-control (CAC) regime it replaced.
- We exploit the fact that only a subset of industrial facilities in California were removed from CAC and required to participate in RECLAIM.
- We further investigate (crudely) how RECLAIM-induced changes in emissions are distributed across counties with different socio-economic characteristics.

Southern California's RECLAIM program

- Introduced by South Coast Air Quality Management District in 1994
- Caps NOx emissions from all point sources emitting more than 4 tons per year.
- 346 facilities are regulated under the program.
- Reclaim credit confers the right to emit 1 lb NOx in a given year.



Fowlie et al. 2012

- If you were operating in the blue area and your historic pre-determined emissions exceeded a given threshold, you were in the program.
- **Our strategy**: Exploit both the historic emissions thresholds and firm location thresholds to match establishments in RECLAIM with observationally similar, unregulated firms.

Empirical strategy

We use covariate matching to calculate counterfactual *facility-specific* emissions estimates.

- For each RECLAIM facility we generate a pool of potential controls from non-RECLAIM facilities of the same industrial classi
  fication in California ozone non-attainment areas subject to command-and-control regulation.
- From this pool we match treated and control facilities with similar pre-RECLAIM period emissions.
- We compare post-period emissions trajectories across matched RECLAIM Firms and controls.
- For all semi-parametric matching, we match with linear bias adjustment in levels and quadratic bias adjustment in logs.

Basic set-up

$$(3) \qquad \widehat{\alpha_{DID}} = \frac{1}{N_1} \sum_{j \in \mathcal{I}_1} \left\{ \left(Y_{jt'}(1) - Y_{jt^0}(0) \right) - \sum_{k \in \mathcal{I}_0} w_{jk} \left(Y_{kt'}(0) - Y_{kt^0}(0) \right) \right\}.$$

Here, $\mathcal{I}_1$ denotes the set of program participants, $\mathcal{I}_0$ denotes the set of nonparticipants, and N_1 is the number of facilities in the treatment group. The participants are indexed by j; the nonparticipants are indexed by k. The weight placed on facility k when constructing the counterfactual estimate for treated facility j is w_{jk}. Our nearest neighbor matching estimator weights control facilities according to their similarity to treated facilities where similarity is based on $\mathbf{X}$.

The standard identification concerns...

- **Conditional unconfoundedness?** Assignment to RECLAIM not random, so there could be unobserved differences that confound these comparisons.

- **SUTVA?** These control group firms compete in the same product markets as treated firms! All sorts of spillover potential (e.g. factor input prices, reallocation of production activity from regulated to unregulated facilities, etc.)

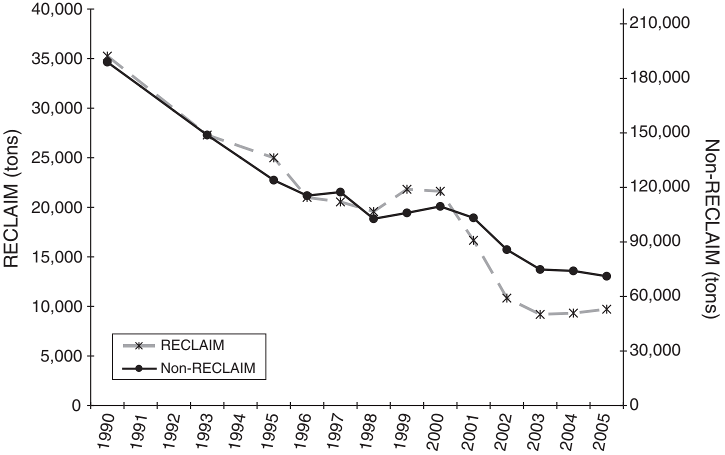
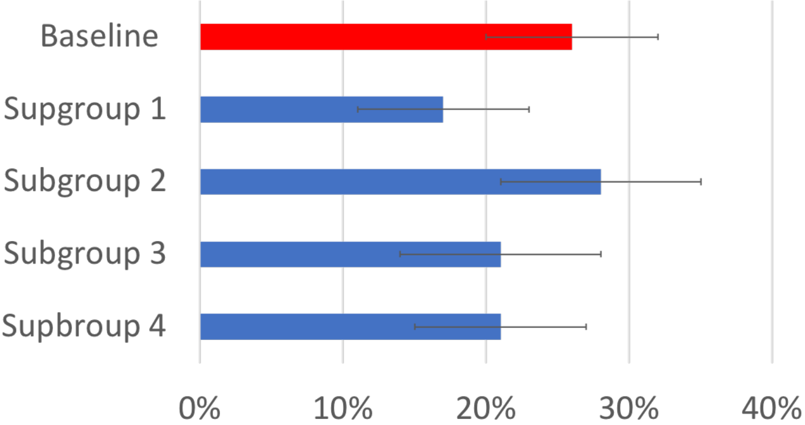


FIGURE 2. TOTAL NO_x EMISSIONS IN RECLAIM AND IN THE REST OF CALIFORNIA

Estimated average impact of RECLAIM on facility-level emissions relative to counterfactual (Fowlie et al., 2012)

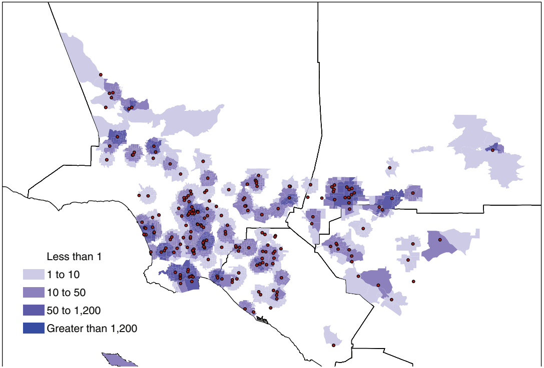


Average emissions fell 20 percent at RECLAIM facilities relative to our counterfactual.

Winners and losers?

- We find no evidence that the estimated effects of RECLAIM (relative to CAC) on facility-level emissions vary systematically with neighborhood demographic characteristics.
- We find no correlation between our estimated effects and neighborhood measures of income or percent minority.

Panel A. Actual emissions under RECLAIM



Carbon pricing and causal inference?

- We found some empirical traction within RECLAIM because it is a small local market targeting a local pollution problem. Fewer concerns about general equilibrium impacts and policy interactions.
- In most GHG emissions trading programs, all facilities are treated directly (or indirectly)! At best you identify a differential effect of direct regulation.
- AND carbon pricing is never introduced in isolation. Policy interactions are hard to disentangle....

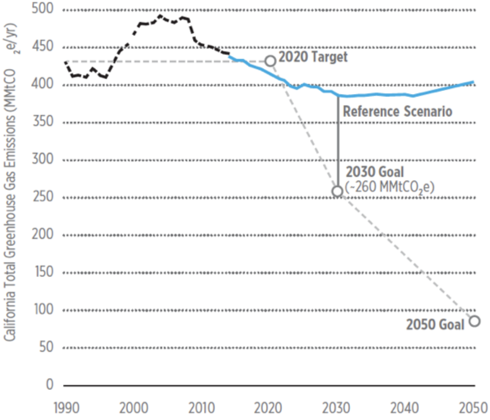
Section 3

Introducing California's GHG Cap-and-Trade Program

California

- California is on the front lines of climate change (miles of coast line, increasing forest fire risk, drought, etc.).
- California accounts for less than 0.7% of GHGs...
- To have a real climate impact, California needs to demonstrate technological and policy innovations that other jurisdictions can adopt and implement.

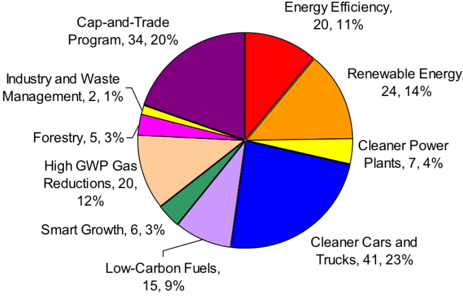
California climate ambition!



AB 32 signed into law in 2006. The black dashed line shows actual statewide emissions; the blue line shows projected emissions without further policy; and the gray dotted line shows the pathway of the state?s climate ambitions, though only the 2020 and 2030 targets are current law.
Source: California Air Resources Board, "2030 Target Scoping Plan Update Concept Paper." June 2016.

California GHG cap-and-trade

- California GHG emissions trading program covers approx. 85 percent of the state's GHG emissions.
- Carbon market gest lots of attention.. but plays a relatively small role (so far)
- Cap serves as an important belt/backstop.



Sources: California Air Resources Board, AB 32 Scoping Plan, December 2008

GHG reductions in California

Which sector has provided most of the GHG emissions reductions so far?

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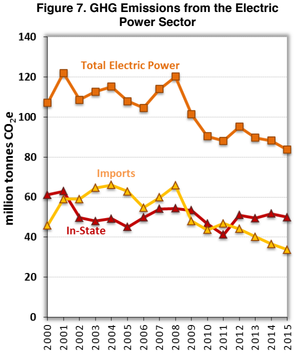
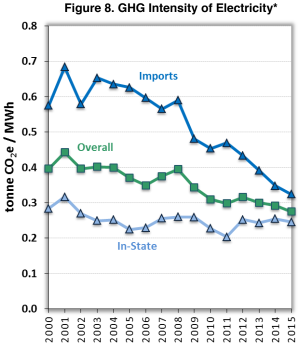
Which sector has provided most of the GHG emissions reductions so far?

- The electricity sector is the most important source of GHG reductions in California, delivering 75 percent of GHG reductions between 2006–2018.
- Over half of California's GHG reductions since 2006 are attributed to reduced emissions from electricity imports (California Air Resources Board 2020).
- GHG emissions from transportation continue to climb (through 2019). Industrial GHG emissions pretty flat.

Emissions Reductions or Leakage?





Source: CA GHG Inventory 2017

- Largest share of GHG reductions coming from electricity imports.
- Are these GHG reductions being offset by increases out-of-state?

Section 4

Emissions leakage in incomplete carbon markets

What's the problem?

- In contrast to our simple model, real-world climate policies regulate only a subset of the sources contributing to the larger problem.
- Concerns about **leakage** loom large in debates about regional climate policy initiatives..
- What is 'emissions leakage' exactly?

Name that emissions leakage channel!

There are at least three related channels through which leakage can occur.

Name that emissions leakage channel!

There are at least three related channels through which leakage can occur.

- In the short run, a shift of production activity and emissions to unregulated foreign producers.
- Over the long term, firms may relocate to jurisdictions with less stringent emissions control policies.
- If demand for carbon intensive inputs in the home country is sufficiently large to affect world energy prices, fuel prices fall, and producers in unregulated jurisdictions substitute towards these inputs (the GE channel).
- Negative leakage? Policy-induced reduction in green technology costs accelerates adoption elsewhere.

Ideally, an analysis of the potential for emissions leakage under a particular policy or program would account for all channels. Easier said than done!

California's important experiment with GHG leakage mitigation

California CAT policy is designed to mitigate leakage in the power sector...

- California defines the point of compliance to be the 'first deliverer' in the electricity sector.
- In-state generators must monitor and report their emissions following a source-based paradigm.
- Electricity importers are responsible for emissions associated with imports from out-of-state.
- Deliverers can either claim source-specific emissions factors for power imports (specified) or accept the default rate of 0.428 tons CO_2/MWh).

These import requirements create incentives for ‘reshuffling’ (a form of leakage)

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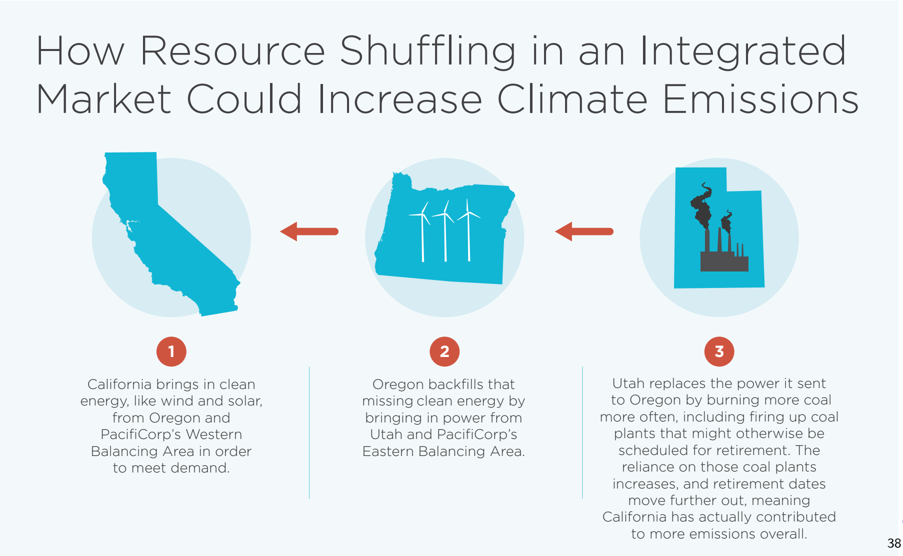
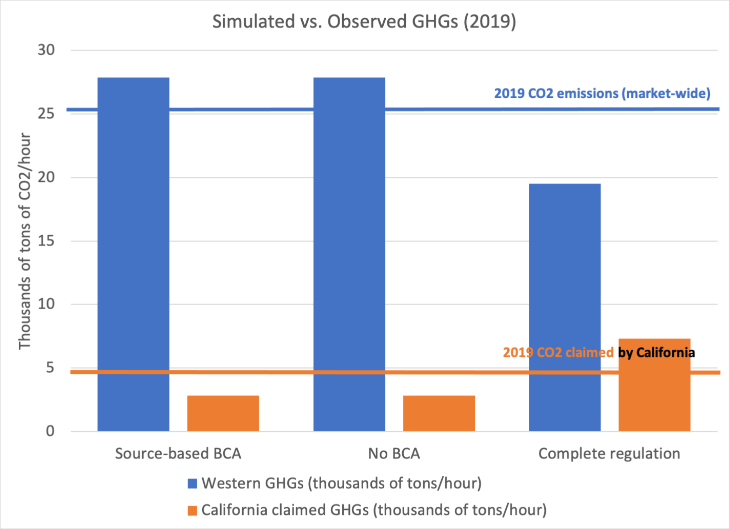


Emissions leakage in California electricity sector?

Emission leakage potential in California's electricity sector?

- Fowlie (2009) uses a partial equilibrium model to determine the extent of leakage potential under incomplete, market-based regulation of CO2 emissions in California's electricity sector.
  - Incomplete regulation (with no leakage mitigation) achieves 35 percent of the emissions reductions achieved under complete regulation.
- Chen et al. (2014) examine the impacts of alternate California cap-and-trade designs. Leakage is substantial (85%).
- Fowlie et al. (2021) calibrate a market simulation model (static) with a BCA and finds potential for complete reshuffling in WECC.

Simulated reshuffling potential



CAVEAT: simulation-based evidence on leakage is only as good as the underlying model calibration/assumptions.

An ex post leakage assessment in California

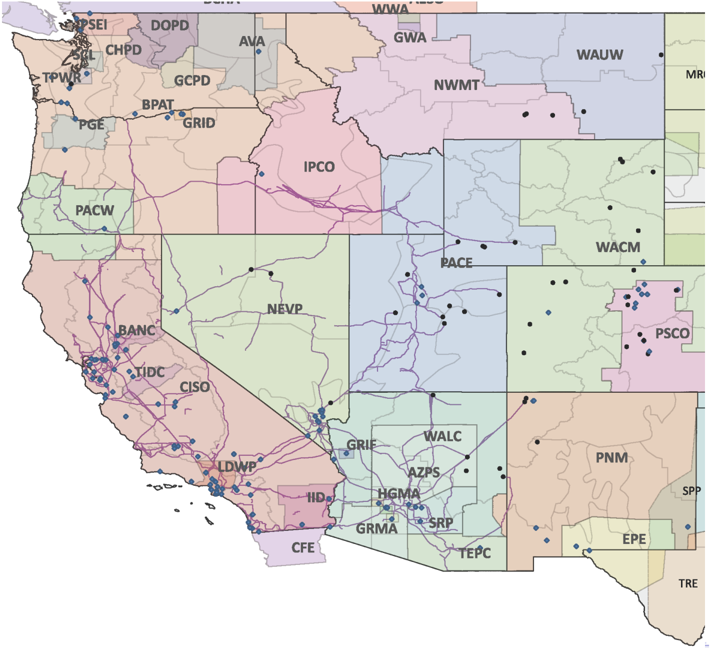
- Ideally we would look at emissions outcomes ex post and ask whether we see evidence consistent with emissions leakage.
- Fundamental empirical challenge lies in constructing a credible counterfactual against which to compare the generators impacted (directly or indirectly) by California's carbon policy.
- Why can't we do a standard DID comparison pof emissions from electricity producers inside/outside of California before/after the GHG CAT program was introduced in 2012?

Lo Prete et al. 2020

A recent paper matches power plants in the western US with similar plants in other regions in order to assess the evidence on leakage/reshuffling.

- Since reshuffling and leakage reallocate production among all plants in the western market, every plant in WECC is a directly or indirectly 'treated'.
- Let $Y_i(C)$ denote the outcome that would be realized at unit i if it is directly regulated by the CAT program.
- Let $Y_i(L)$ denote the outcome that would be realized at unit i if it is indirectly impacted by the CAT program (via California's increased demand for imports).
- Let $Y_i(0)$ denote the outcome if unit i is not impacted by the CAT regulation.

Figure 2: WECC balancing authorities in the United States, 2016



Note: Black dots represent coal-fired power plants, blue diamonds represent NGCC plants.

Empirical strategy: Lo Prete et al. 2020

Let t^0 denote a pre-treatment period and $t^{'}$ denote a post-treatment period. The DID matching estimator requires that:

$$E[Y_{t'}(1) - Y_{t^0}(0)|X, D = 1] = E[Y_{t'}(1) - Y_{t^0}(0)|X, D = 0].$$

Last lecture Trevor asked: what value does this matching estimator add over basic OLS?

Quick summary of technical note

Suppose we estimate the following regression equation using observational data:

$$Y_i = \alpha_C + \tau D_i + \beta_C' X_i + \gamma' X_i \cdot D_i + \varepsilon_i$$

Our OLS estimate of the average treatment effect can be summarized as:

$$\widehat{ATE} = P\left(\overline{Y}_T - \overline{Y}_C - (\overline{X}_C - \overline{X}_T)'\widehat{\beta}_C\right) - (1-P)\left(\overline{Y}_T - \overline{Y}_C - (\overline{X}_T - \overline{X}_C)'\widehat{\beta}_T\right)$$

- The estimate of $\widehat{\beta}_C$ is estimated using data from the control sample where the average is $\overline{X}_C$. It provides a good approximation to the conditional mean function in the neighborhood around $\overline{X}_C$.
- But if this linear approximation is not globally accurate, regression adjustments may lead to bias when the linear function $X'\beta_C$ is used to predict counterfactual outcomes in the treated population.
- Similar arguments pertain to the $\widehat{\beta}_T$

Advantages of matching algorithms

- Matching does not impose any functional form restrictions on the outcome equations. This eliminates the potential for bias due to misspecification of functional form.
- Matching algorithms force you to examine the distribution of covariates across treatment/control groups. This helps you recognize when you are relying upon parametric assumptions to construct your counterfactuals.
- Although matching and regression-based estimates can be implemented as weighted regressions, the weights differ (see note for details).

Note that matching and OLS estimates will be similar if:

- There is common support / extensive overlap in the distributions of X.
- There is little heterogeneity in treatment effects with respect to X
- The outcome regression equations are not seriously misspecified.

Empirical strategy: Lo Prete et al. 2020

The generalized DID matching estimator is given by:

$$\tau_{DID} = \frac{1}{PN} \sum_{i \epsilon I_1} (Y_{it'}(1) - Y_{it^0}(0)) - \sum_{j \epsilon I_0} \omega(i,j)(Y_{jt'}(0) - Y_{jt^0}(0)).$$

- Although we refer to this as a "matching estimator", this language is somewhat misleading.
- Matching is more accurately a *pre*-estimation data processing step that involves pruning the data based on exogenous, pre-determined covariates.
- Once this pruning is complete, the estimation can take a variety of forms .. including DID regression.

Primary estimating equation

After pruning observations that have no close matches on pre treatment variables in both treated and control groups, we econometrically estimate changes in power plant utilization in the Western Interconnection using the following DID model specification:

$$Y_{jt} = \alpha_C TREAT_{jt}^{C} + \sum_{L} \alpha_L TREAT_{jt}^{L} + \mathbf{X}_{jt}^{'}\underline{\beta} + \gamma_j + \gamma_y + \gamma_{dw} + \gamma_{sm} + \epsilon_{jt} \tag{1}$$

where j indexes a plant-technology, t indicates a period, L denotes a leaker region, and y, dw and sm stand for year, day-of-week and state by month-of-year respectively. We focus on two baseload technology types that are most likely affected by the policies (natural gas combined cycle or NGCC plants and coal-fired plants), and run separate regressions by technology.[12] The dependent variable Y_{jt} is the capacity factor of plant-technology j in period t (month, day, hour or time of day), defined as the ratio of net generation over operating capacity multiplied by total number of hours in the period. Capacity factors provide a measure of

Any questions about the empirical strategy? Any concerns?

Table 3: Econometric model results: Estimated treatment effects for NGCC plants

	(1) Baseline	(2) Robustness to hydro-nuclear and renewable generation (a)	(b)	(c)	(3) Robustness to outcome frequency (a)	(b)	(4) Robustness to clustering (a)	(b)	(5) Robustness to matching set
CA	-0.058^{**}	-0.042^{*}	-0.064^{**}	-0.030	-0.069^{**}	-0.059^{**}	-0.058^{***}	-0.058^{**}	-0.060^{**}
	(0.025)	(0.025)	(0.027)	(0.022)	(0.030)	(0.025)	(0.002)	(0.025)	(0.027)
NW	0.021	0.039^{*}	0.019	0.022	-0.001	0.020	0.021	0.021	0.015
	(0.020)	(0.022)	(0.019)	(0.020)	(0.023)	(0.019)	(0.011)	(0.017)	(0.019)
RoW	-0.015	0.002	-0.018	-0.014	-0.007	-0.016	-0.015	-0.015	-0.034
	(0.018)	(0.021)	(0.018)	(0.018)	(0.020)	(0.018)	(0.009)	(0.016)	(0.025)
SW	-0.011	0.006	-0.013	-0.010	-0.008	-0.012	-0.011	-0.011	-0.014
	(0.023)	(0.026)	(0.023)	(0.023)	(0.025)	(0.023)	(0.011)	(0.029)	(0.023)
Before matching									
CA plants	40	40	40	40	70	40	40	40	40
Leaker plants	48	48	48	48	62	48	48	48	48
Control plants	153	153	153	153	185	153	153	153	153
After matching									
CA plants	33	33	33	33	33	33	33	33	34
Leaker plants	40	40	40	40	40	40	40	40	44
Control plants	128	128	128	128	128	128	128	128	140
Number of obs	567, 484	567, 484	567, 484	567, 484	18, 199	13, 619, 137	567, 484	567, 484	616, 666
Number of clusters	201	201	201	201	201	201	6	38	218

Note: The unit of observation is plant-day for specifications (1), (2), (4) and (5), plant-month for specification (3a), and plant-hour for specification (3b). All regressions include plant, year, day-of-week and state by month-year fixed effects. Specification (3b) also includes hour-of-day fixed effects. Standard errors are reported in parentheses, and clustered by plant in specifications (1), (2), (3) and (5), by NERC region in (4a), and by balancing authority in (4b). *, **, and *** indicate statistical significance at 10%, 5% and 1% level, respectively. The number of plants before matching includes existing, new and retired facilities between 2009 and 2016, and thus differs from Table 1. In specifications (1), (2), (3b), (4) and (5), this number refers to plants reporting to CEMS; in specification (3a), it refers to plants completing the EIA-923 survey.

Table 4: Econometric model results: Estimated treatment effects for coal-fired plants

	(1) Baseline	(2) Robustness to hydro-nuclear and renewable generation		(3) Robustness to outcome frequency		(4) Robustness to clustering		(5) Robustness to matching set
		(a)	(b)	(a)	(b)	(a)	(b)	
NW	0.047***	0.050***	0.051***	0.051***	0.047***	0.047**	0.047***	0.041***
	(0.013)	(0.013)	(0.013)	(0.014)	(0.013)	(0.014)	(0.017)	(0.011)
RoW	0.044***	0.051***	0.052***	0.047**	0.044***	0.044**	0.044**	0.043***
	(0.016)	(0.016)	(0.015)	(0.019)	(0.016)	(0.012)	(0.020)	(0.015)
SW	0.059	0.075	0.063	0.030	0.064	0.059**	0.059	0.065
	(0.047)	(0.046)	(0.047)	(0.033)	(0.052)	(0.018)	(0.054)	(0.055)
Before matching								
Leaker plants	42	42	42	50	42	42	42	42
Control plants	170	170	170	192	170	170	170	170
After matching								
Leaker plants	40	40	40	40	40	40	40	41
Control plants	94	94	94	94	94	94	94	150
Number of obs	379,028	379,028	379,028	12,455	9,096,375	379,028	379,028	533,642
Number of clusters	134	134	134	134	134	6	28	191

Note: The unit of observation is plant-day for specifications (1), (2), (4) and (5), plant-month for specification (3a), and plant-hour for specification (3b). All regressions include plant, year, day-of-week and state by month-year fixed effects. Specification (3b) also includes hour-of-day fixed effects. Standard errors are reported in parentheses, and clustered by plant in specifications (1), (2), (3) and (5), by NERC region in (4a), and by balancing authority in (4b). *, **, and *** indicate statistical significance at 10%, 5% and 1% level, respectively. The number of plants before matching includes existing, new and retired facilities between 2009 and 2016, and thus differs from Table 2. In specifications (1), (2), (3b), (4) and (5), this number refers to plants reporting to CEMS; in specification (3a), it refers to plants completing the EIA-923 survey.

Implied GHG emissions leakage?

- Multiply statistically significant seasonal treatment effects by corresponding generation capacity of matched plants.
- Using technology-specific GHG emissions rates, map these changes in generation to changes in GHG emissions.
- Change in WECC emissions imputed as the change in California emissions plus the change in non-CA WECC emissions.

Leakage estimates....depressing!

Table 8: Econometric model results: Emissions and leakage based on the econometric estimates, 2013 and 2016

2013	Lower bound of the robust 95% CI	Upper bound of the robust 95% CI
Change in CA local emissions (E_1)	-4.31	0.38
Change in CA import emissions (E_2)	-5.34	-5.34
Change in CA regulated emissions ($E_3 = E_1 + E_2$)	-9.65	-4.96
Change in WECC-NonCA emissions (E_4)	4.69	11.74
- NW	2.29	4.91
- RoW	2.40	6.83
Change in WECC emissions ($E_5 = E_1 + E_4$)	0.38	12.12
Leakage $[(1 - E_5/E_3) \times 100\%]$	*104.0%*	*344.4%*

2016	Lower bound of the robust 95% CI	Upper bound of the robust 95% CI
Change in CA local emissions (E_1)	-5.33	-1.33
Change in CA import emissions (E_2)	-5.91	-5.91
Change in CA regulated emissions ($E_3 = E_1 + E_2$)	-11.23	-7.23
Change in WECC-NonCA emissions (E_4)	3.06	21.34
- NW	-6.75	-1.46
- RoW	9.81	22.80
Change in WECC emissions ($E_5 = E_1 + E_4$)	-2.26	20.02
Leakage $[(1 - E_5/E_3) \times 100\%]$	*79.9%*	*376.7%*

Note: Emissions are in million metric tons of CO_2 per year.

Thoughts? Concerns?

Parallel trends (or conditional unconfoundedness)?

Parallel trends before 2012 need not imply parallel trends after 2012. Any other big changes we should worry about?

SONGS closure in 2012

California's nuclear capacity are very different from trajectories observed in other regions.

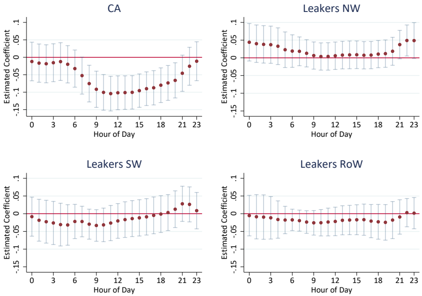
- The unexpected closure of the SONGS nuclear plant in 2012 dropped nuclear capacity in California by 40 percent!
- Nuclear capacity increases in most of the regions that comprise the control group. The biggest reduction we see in the control group is a 4 percent reduction in MRO.
- The authors lean very heavily on the symmetric structure they impose on the relationship between nuclear capacity and unit-level capacity factors
- Estimated that the SONGs closure increased in-state generation costs by 13 percent as other units were called upon to fill the void left by SONGS.

Accelerated rise of renewables

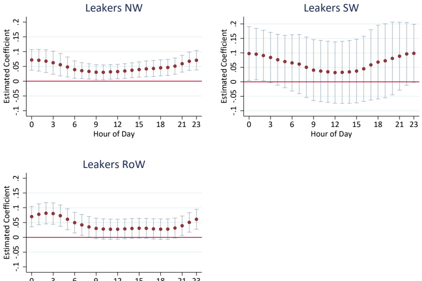
- California also pushing hard to accelerate investment in wind and solar over this time frame.
- Differential rates of RE investment could violate parallel trends assumption.
- This could also help explain the diurnal patterns we see....

Figure 4: Treatment heterogeneity by hour of day

(a) NGCC plants



(b) Coal-fired plants

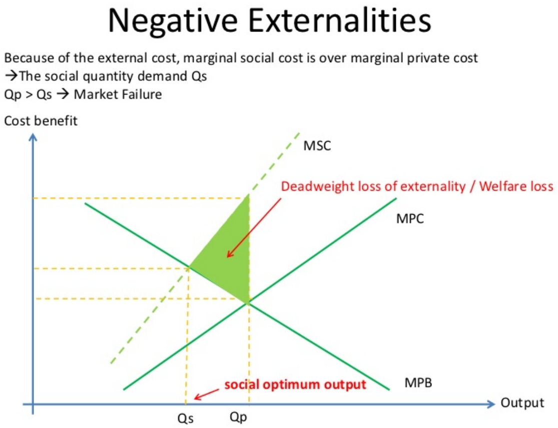


Final thoughts?

- Emissions leakage can manifest in a variety of ways when climate change regulation is ‘incomplete’.
- Causal inference is complicated. SUTVA violations abound. And it can be hard to disentangle the effect of policy changes from other coincident changes.
- But rigorous empirical work is important as we try to understand how real-world climate policies are working....

Section 5

Equity matters



Efficient, yes. But equitable? Politically acceptable?

Equity-oriented concerns about market-based regulation

- In principle, market-based mechanisms could exacerbate - versus mitigate- pre-existing exposure inequalities.
- The flexibility inherent in market mechanisms could allow plant managers to make abatement decisions on the basis of political/discriminatory motives (versus pure cost minimization.
- More affluent neighborhoods may be more effective at pressuring plant managers to invest in abatement versus purchasing permits.
- Marginal abatement costs may be lower in more affluent neighborhoods (seems unlikely).

Equity matters

- **Conjecture**: Economists are too focused on efficiency when it comes to emissions pricing.
- **Economist's defense**: Hakuna matata! Efficiency and equity are separable under carbon pricing (recall the independence property!)
- **Catch** 1**:** 'Fair' redistribution requires that we can estimate/anticipate the incidence of a tax or trading policy...not easy!
- **Catch** 2**:** Given systemic inequities, disadvantaged groups are rightly concerned that compensating transfers will not happen.
- **Catch** 3**:** Hard to pin down an unambiguous notion of fair and equitable?
- **Going forward:** (I think) economists need to place more emphasis on equity implications.

Spend some time unpacking this...

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GUEST POST

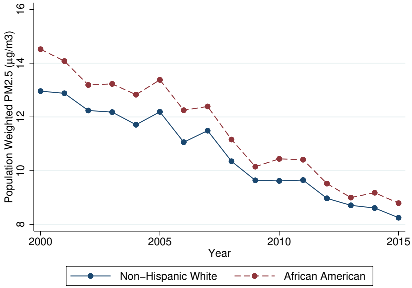
Cap-and-trade? Not so great if you are black or brown

By Laurie Mazur on Sep 16, 2016

Environmental justice

- The environmental justice movement and associated scholarship has drawn attention to striking inequities in exposure of low income and racial minority communities to many forms of pollution.
- Low-income communities continue to bare a disproportionate air pollution burden(see e.g., Currie, Voorheis, Walker, 2020).

Figure 1: Trends in Pollution Exposure by Race



What does local air quality have to do with carbon pricing?

- There is an indirect, but important, connection between local air pollution exposure and global climate change mitigation.
- Greenhouse gas emissions (GHGs) are often co-emitted with other pollutants that contribute substantially to local air quality problems.
- Local air quality "co-benefits" have played a critical role in building political support for climate policy.

Why have environmental justice (EJ) advocates opposed market-based emissions regulations?

Environmental Justice Advisory Committee on the Implementation of the Global Warming Solutions Act of 2006:

> *It is market-based decisions, within a framework of structural racism in planning and zoning decisions, that has created the disparate impact of pollution that exists today; relying on that same mechanism as the "solution" will only deepen the disparate impact.*

Why have environmental justice (EJ) advocates opposed cap-and-trade?

Manuel Pastor:

> *Indeed, trading is justified on the grounds that reducing pollution is more efficient in some locations compared to others, and thus where reductions will occur is a decision such a system leaves in the hands of the market and business people – neither of which have any incentive to lower emissions in order to benefit the low-income and minority communities hit hardest by concentrated pollution.*

Two key threads to the EJ opposition

1. **Distributive justice** A market-based allocation of permitted pollution need not be fair and equitable.
2. **Procedural justice:** Marginalized communities are (understandably) distrustful of policy solutions that rely on market-based mechanisms to determine winners and losers.

Hecht (2011) writes:

> *By their nature, trading programs leave little to no opportunity for community input. This may be the [environmental justice] community's most fundamental objection to trading programs.*

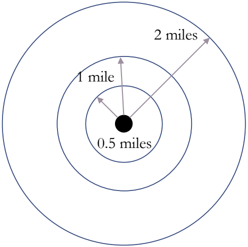
Assessing the evidence

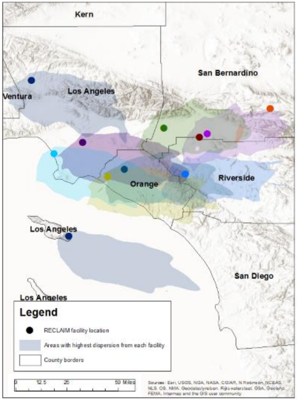
How have disadvantaged communities fared under emissions trading programs? Let's review the evidence...

1. Fowlie, Holland, and Mansur (2012): RECLAIM program
2. Grainger and Ruangmas (2017): RECLAIM revisited
3. Mansur and Sheriff (2021): RECLAIM re-revisited
4. Cortes-Hernandez and Meng (2020): California's GHG cap and trade revisited

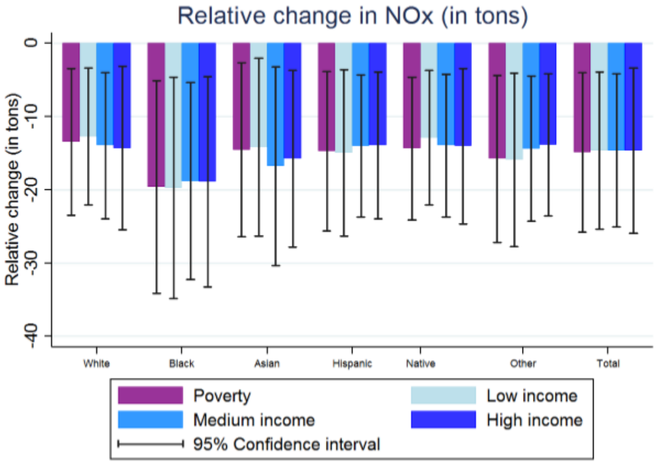
Grainger and Ruangmans (2017)

- Grainger and Ruangmas build upon the analysis of Fowlie, Holland, and Mansur (2012) by amending how treatment areas are defined
- Instead of concentric circles, they use a dispersion model (HYSPLIT)





Grainger and Ruangmans (2017)



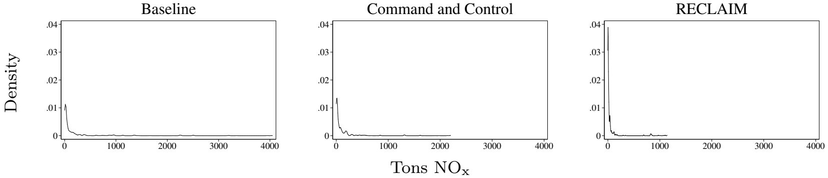
Notes: See text for details. Each bar represents the average relative change in NO_x emissions (in tons), weighted by each demographic group. Relative changes weighted by demographics are calculated from $\sum_f (R_f D_f)/\sum_f D_f$ where R_f is relative change for each facility f, and D_f are affected people in each demographic group from facility f. Relative change is the difference between the actual change in emissions and counterfactual change in emissions, which is the average change in emissions of control firms. Relative changes

Mansur and Sheriff (2021)

- In the environmental economics literature, standard approach to environmental justice questions estimates correlations between environmental damage, race, income.
- But how do we rank policy alternatives that generate different distributions (of emissions reductions, for example)?
- These authors argue that analyses of distributional changes needs a foundation in individual preferences:

The problem we examine is how to rank alternative distributions in a manner that is both welfare significant while imposing as little structure as possible on preferences.

FIGURE B1. DISTRIBUTIONS OF CUMULATIVE NO_X EMISSIONS OVER CENSUS BLOCK GROUPS



Notes: Kernel density estimates based on number of 1990 census block groups with strictly positive RECLAIM exposure. Tons NO_X indicates the total average annual emissions summed across all facilities within 3km of a census block group centroid. Baseline is 1990–1993 emissions. RECLAIM is actual 2003–2004 emissions. Command and Control is counterfactual 2003–2004 emissions based on matched facilities in California ozone nonattainment areas that did not participate in RECLAIM.
Source: Author calculations based on data from California Air Resources Board.

How to compare?

Mansur and Sheriff 2021

- Define an explicit relationship between alternative distributions of environmental impacts and well-defined preferences over the distributions.
- Main contribution: Provide a way to rank alternative policy instruments from a distributional perspective (by adapting approaches commonly used in the income distribution literature).
- Normative foundation rooted in the 'veil of ignorance'. Vector of exposures generated by a policy can be framed as an ex ante lottery. Ranking distributions is equivalent to determining which lottery would be preferred by a representative agent.
- Apply their approach to our old RECLAIM paper: Ask whether the trading program had adverse environmental impacts on MLI populations relative to CAC.

New tools, old question

- Authors use analytical tools from the income inequality literature.
- Generalized Lorenz Curves impose minimal preference structure and can simultaneously account for differences in average exposure and the degree of inequality.
- Constructed by scaling a standard Lorenz curve (which plots the percentile of the population on x-axis and the cumulative income share on the y) by the mean of the distribution.
- The height reflects the level while the convexity reflects the inequality.

Key findings

- RECLAIM reduces average exposures for all groups and reduces exposure inequities.
- In this context, their generalized Lorenze metric suffices because every individual group is better off under RECLAIM versus CAC alternative .
- When GL curves cross, we will need fancier tools...

RECLAIM summary

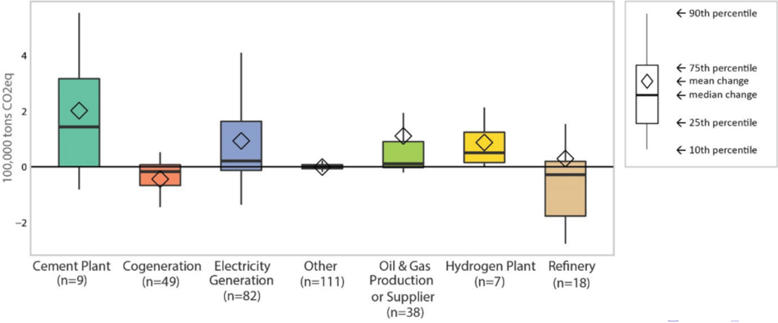
- Southern California's RECLAIM program provides a useful test case for evaluating EJ concerns about the distributional implications of emissions trading.
- There is little/no evidence to suggest that RECLAIM systematically favored the White or high income groups over minority or low income groups.
- This finding further strengthened in a new paper by Mansur and Sheriff (2020)
- The current EPA wrestling with questions of how to formalize and operationalize EJ priorities in policy analysis. Is this more technical line of inquiry worth pursuing further?

California's GHG emissions trading program

- EJ opposition to emissions trading has been particularly prominent in the context of California's GHG cap and trade program.
- Recall that a reduction/reallocation of GHGs can change the spatial distribution of local air pollution because GHG abatement can also reduce emissions of local air pollution precursors.
- EJ concerns nearly halted renewal efforts in 2017.
- The program requires participation by all stationary GHG sources emitting 25,000 metric tons $CO2_e$

Carbon trading, co-pollutants, and environmental equity: Evidence from California's cap-and-trade program

- Cushing et al. (2018) compare GHG emissions at regulated facilities during the first two years of the program (2013-2014) against emissions at those same facilities in the years preceding (2011-2012).
- The figure below shows the average change in emissions by sector. Positive emissions indicate higher emissions, on average, during the post-policy implementation period.



What can we learn from a pre-post comparison?

The California Environmental Justice Alliance concludes:

> *(This report) demonstrates that polluters using the cap and trade system are adversely impacting environmental justice (EJ) communities. The system is not delivering public health or air quality benefits, not achieving local emissions reductions, and it is exporting our climate benefits out of state.*

Thoughts?

Correlation does not imply causation

- Relative increases in emissions fueled concern that California's cap and trade program is making things worse in disadvantaged communities.
- But it's important to remember that this pre-post comparison can confuse the effects of a policy change with the effects of other factors that are also changing over time.
- Potential confounds include a major power plant closure and the differential impacts of the recession on different industrial sectors.

How might you refine this analysis?

Hernandez-Cortes and Meng (2021)

- Investigate whether the pollution exposure gap between disadvantaged and other communities in California has widened or narrowed as a result of the GHG cap and trade program.
- They use a difference-in-difference design to estimate the average causal effect of the program on facility-level emissions.
- They use a pollution transport model (Hysplit) to simulate the downwind impacts of emissions reductions on air quality.
- 'Treated' installations are the GHG emitters regulated under C&T.
- The control group is comprised of smaller emitters who fall below the CT threshold.

Authors tackle two empirical challenges:

Authors tackle two empirical challenges:

1. Isolate the causal effect of the cap-and-trade program from potentially confounding macro-economic changes and overlapping policies.
2. Map policy-induced changes in emissions to changes in local pollution exposure.

I want to add a third. Whether a market-based policy widens or narrows the EJ gap depends on the joint spatial distribution of polluting facilities, abatement costs, and disadvantaged communities. This is a story about heterogeneous treatment effects....

Step 1: Estimate ATE on annual emissions

Specifically, let j index facilities. $C_j \in \{0,1\}$ is GHG C&T regulatory status with $C_j = 1$ indicating facility j is regulated.[16] For facility j in year t, Y^p_{jt} is annual emissions of pollutant $p \in \{GHG, PM_{2.5}, PM_{10}, NO_x, SO_x\}$. Because emissions exhibit a skewed distribution and contain zero values, we apply an inverse hyperbolic sine transformation, which like a log transformation lends a percentage effect interpretation, but with the added advantage of retaining zero-valued observations (Bellemare and Wichman, 2020). To examine differential emission trends driven by the C&T program, we estimate the following specification:

$$asinh(Y^p_{jt}) = \kappa^p_1[C_j \times t] + \kappa^p_2[C_j \times \mathbf{1}(t \geq 2013) \times t] + \phi^p_j + \gamma^p_t + \nu^p_{jt} \tag{1}$$

Facility-specific dummy variables ϕ^p_j removes time-invariant determinants of pollution p for facility j. Year-specific dummy variables γ^p_t remove common determinants of emissions affecting all sample facilities in year t, such as California-wide economic conditions.

Some research design details

- Remove electricity generators and refineries (which comprise most of the GHG emissions) from the sample.
- Restrict sample to facilities with sample average annual GHG emissions below the 75th percentile.
- Sample contains 106 regulated and 226 unregulated facilities.
- Estimate an average treatment effect (averaging across heterogeneous facilities).

Step 2: Use the estimated ATE to construct facility-specific emissions impacts

Use estimated regression coefficients to impute facility-specific emissions changes induced by policy.

[19] Specifically, C&T-driven emissions is:

$$\widehat{Y}_{jt}^{p} = sinh\left(\widehat{\kappa}_1^p[C_j \times t] + \widehat{\kappa}_2^p[C_j \times \mathbf{1}(t \geq 2013) \times t] + \widehat{\phi}_j^p\right) * e^{(RMSE)^2/2)}$$

where hat notation indicates estimated parameters and RMSE is the root mean squared error from equation (1). In theory, the hyperbolic sine transformation can generate negative emission values. In practice, our benchmark model predicts negative emissions for 1%, 1%, 0.2%, and 0.3% of sample observations for $PM_{2.5}$, PM_{10}, NO_x, and SO_x, respectively. We replace these negative values with zeros.

Because facility-level FE are included, policy-induced changes vary across facilities (despite assuming a common ATE).

NB: Imposing a common percentage reduction to all emitters regulated under cap and trade will mechanically narrow the EJ gap if large emitters are upwind of disadvantaged communities.

Step 3: Use HYSPLIT to simulate particle transport

Figure 1: Modeling air pollution exposure driven by the cap-and-trade program

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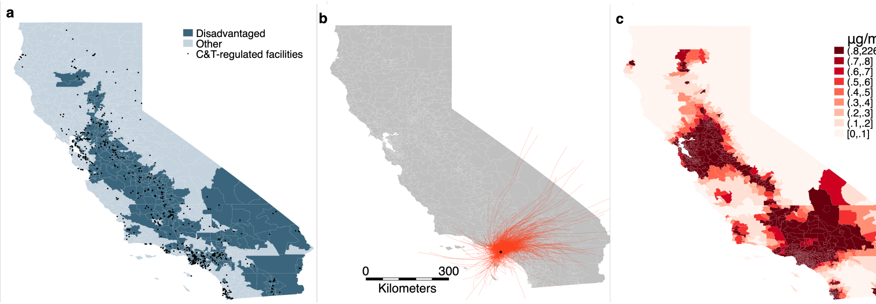


Figure illustrates how facility-level pollution emissions is converted to average daily zip code-level pollution exposure using a pollution tr model. Shading in panel (a) shows California zip codes that are legally designated as disadvantaged (dark blue) and zip codes that (light blue). Black dots show all stationary facilities regulated by California's GHG C&T program. Panel (b) shows HYSPLIT-generated trajectories every 4-hours from a polluting facility in Los Angeles during 2016. Panel (c) shows zip code-level average daily NO_x expo $\mu g/m^3$/day) during 2008-2017 driven by facilities regulated by California's GHG C&T program as generated by HYSPLIT.

Step 4: Science happens

- Hysplit models particle trajectories versus pollution formation.
- Authors apply half-life parameters to convert particle concentrations to pollution concentrations.
- They also assume that once particles clear the planetary boundary layer, it no longer contributes to air pollution formation.

Step 5: Estimating the EJ gap

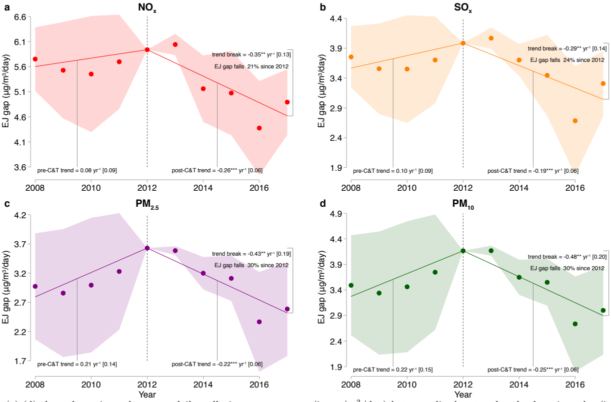
Step 3: Estimating C&T-driven change in EJ gap trends In our third step, we examine whether the C&T program altered the difference in pollution concentrations between disadvantaged and other communities, or the EJ gap. Let $D_i \in \{0,1\}$ denote disadvantaged status, with $D_i = 1$ indicating that zip code i contains all or part of a "Disadvantaged Community Census Tract," as defined by Senate Bill 535. For zip code i in year t, we take C&T-driven pollution concentration from HYSPLIT, E^p_{it}, for criteria air pollutant $p \in \{PM_{2.5}, PM_{10}, NO_x, SO_x\}$, and estimate the following specification:

$$E^p_{it} = \beta^p_1[D_i \times t] + \beta^p_2[D_i \times \mathbf{1}(t \geq 2013) \times t] + \psi^p_i + \delta^p_t + \epsilon^p_{it} \tag{2}$$

where ψ^p_i are zip code-specific dummies and δ^p_t are year-specific dummies. β^p_1, or the pre-C&T EJ gap trend, captures the linear trend in the EJ gap (from facilities that would eventually be regulated by the C&T program) during 2008-2012, before the program was introduced. A

Authors conclude that the EJ gap is narrowed under GHG cap and trade

Figure 2: Environmental justice gap before and after the cap-and-trade program



Panels (a)-(d) show the estimated average daily pollution exposure gap (in $\mu g/m^3$/day) between disadvantaged and other zip codes (i.e., "EJ gap") during 2008-2017 for NO_x, SO_x, $PM_{2.5}$, and PM_{10}, respectively. Dots show year-specific EJ gap with 95% confidence intervals. Solid lines show linear fit for EJ gap trend before (2008-2012) and after (2013-2017) the C&T program. Associated text indicates point estimates and

Comments and reactions?

Summarizing the evidence to date...

- Environmental justice (EJ) concerns are central to efforts to mitigate climate change at local and global scales.
- In California, some of the most intense conflicts over climate change policy have focused on the environmental justice implications of the GHG cap-and-trade program.
- No evidence that the RECLAIM program adversely impacted disadvantaged communities.
- Hernandez-Cortes and Meng estimate that GHG trading program narrowed the EJ gap.

What about the second EJ concern?

1. **Distributive justice** A market-based allocation of permitted pollution need not be fair and equitable.
2. **Procedural justice:** Marginalized communities are (understandably) distrustful of policy solutions that rely on market-based mechanisms to determine winners and losers.

Hecht (2011) writes:

> *By their nature, trading programs leave little to no opportunity for community input. This may be the [environmental justice] community's most fundamental objection to trading programs.*

Following...


AB 617 ELEMENTS • Focus on Community Action
Community emissions reduction programs
Accelerated retrofit of pollution controls on industrial facilities
Community-level air quality monitoring
Enhanced emissions reporting
Increased penalty provisions
Grants to local community groups