

ONLINE APPENDICES

Robbing Peter to pay Paul:

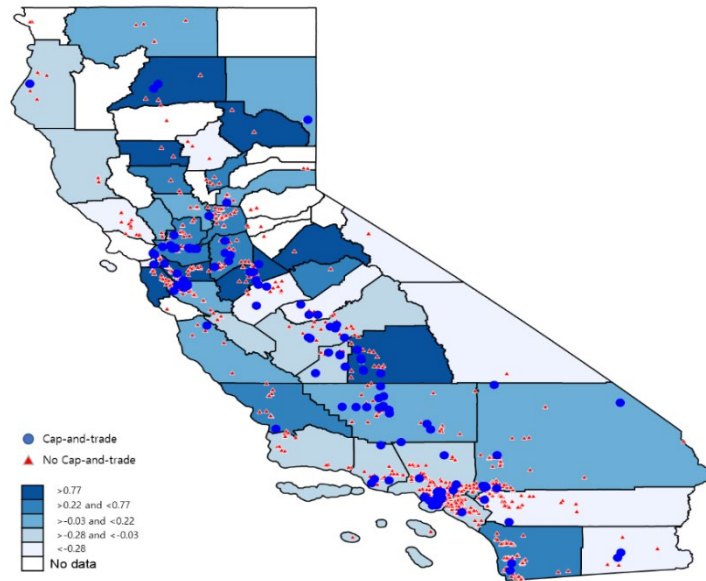
The impact of California's cap-and-trade program on toxic emissions

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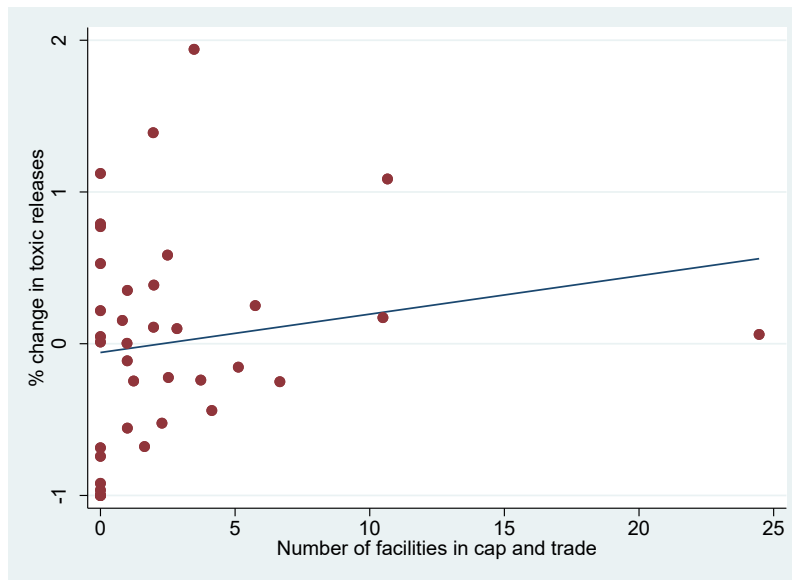
Appendix A: Changes in toxic emissions by county

Figure A1. Location of facilities in California counties



Dots (and triangles) show the location of manufacturing facilities subject (not subject) to cap-and-trade. The shading of the counties shows the % change in average annual toxic emissions in the county before (from 2010 to 2012) and after (from 2013 to 2018) the introduction of cap-and-trade program.

Figure A2. Number of facilities subject to cap-and-trade and the percentage change in county-level toxic releases after the introduction of cap-and-trade in California



Unit of analysis is a California county. Y-axis shows the percentage change in average annual toxic releases in the county before (from 2010 to 2012) and after (from 2013 to 2018) the introduction of cap-and-trade program.

Appendix B. Stringency of cap-and-trade program

Figure B.1

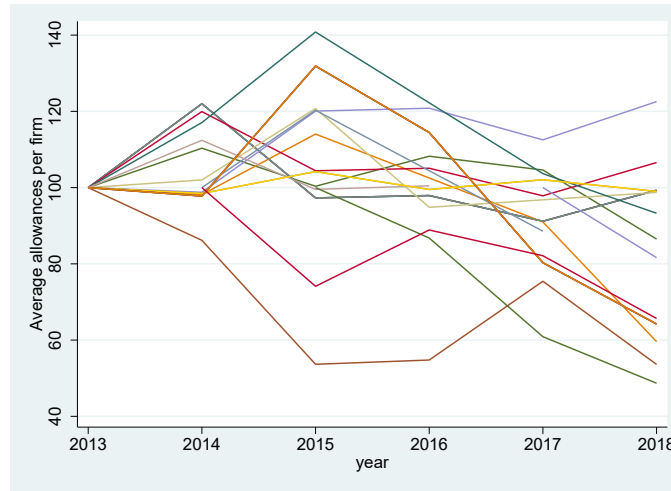


Figure shows the trend in the average of free allowances per firm allocated to a specific industry (4-digit NAICS level) in a year. Our stringency measure is the inverse of this value. To ease comparability, the graph indexes each industry's free allowances to their 2013 level, though our stringency measure is based on the actual value of free allowances.

Appendix C: Variable definitions and sources

Panel A. Dependent, Independent and Control Variables		
Variable	Definition	Source
(1) GHGs	Facility GHGs emissions (log)	EPA
(2) Toxic*	Facility toxic chemical wastes emissions (log)	EPA
(3) Stringency	# of free allowances available in a focal industry divided by # of facilities operating in the industry. For confidentiality, the CARB does not provide free allowances given to a facility.	CARB (California Air Resources Board)
(4) Employees	# of facility employees (log)	EPA,D&B
(5) # ofchemicals	# of different types of toxic chemicals processed	EPA
(6) Same owner	# of facilities owned by the same owner of a focal facility	EPA,D&B
(7) # ofstates	# of different states the owner operates owned facilities	EPA,D&B
(8) Inspection1	Whether a facility was inspected in the past 5 years by the EPA or state government	EPA
(9) EPA action1	Whether a facility received penalty or warnings in the past 5 years by the EPA or state government	EPA
(10) GHG_energy	GHGs emissions from energy generation(log)	EPA
(11) GHG_waste	GHGs emissions from waste treatment(log)	EPA
(12) GHG_prodn	GHG emissions from production process(log)	EPA
(13) Waste_gen*	Toxic chemical wastes generated in the production process (log)	EPA
(14) Waste_treat*	Toxic chemical wastes that are treated after being generated but before being emitted (log)	EPA
(15) In-state	Toxic wastes treated in-state (log)	EPA
(16) Out-state	Toxic wastes treated out-state (log)	EPA
(17) Inspection2	Whether received an inspection in that year	EPA
(18) EPAaction2	Whether received penalty/warnings in that year	EPA
Panel B. Moderating variables		
Reduction technology	Whether a facility implemented practices to prevent or reduce toxic chemical wastes entering any waste stream or otherwise released into the environment prior to treatment	EPA
County NGO	Whether a facility's local county hosts an environmental sustainability-focused NGO with a staff of over five members	GuideStar
EPA penalties	Whether a facility received penalties from EPA prior to 2013	EPA
Carcinogenic	Whether a chemical is considered to cause cancer	EPA
Bio-accumulative	Whether a chemical is classified as a Persistent Bioaccumulative Toxic (PBT) chemical that accumulates in living organisms	EPA
Reportable Quantities	The spill size that necessitates emergency reporting to EPA	EPA
Reference Concentration	Inhalation exposure to human likely to be without deleterious noncancer effect	EPA
Inhalation Unit Risks	Increased cancer risk from inhalation exposure to 1 µg/m ³	EPA
Treated owner	Whether a facility's owner owns a California facility that is affected by the cap-and-trade program	EPA

*As a by-product of manufacturing processes, toxic chemical wastes are generated. Facilities engage in treatment processes, such as incineration, chemical oxidation or biological treatment, to reduce the ultimate discharge of toxic chemical wastes into the surrounding environment (Kalnins and Dowell 2017; King and Shaver 2001). These treatment processes may take place on-site or at off-site waste treatment locations, either within or outside the state.

Appendix D: Robustness to Alternative Clustering Approaches

As discussed in the main text, our main results use standard errors clustered by state to account for potential correlation in the error terms across facilities all treated simultaneously. The table below tests the robustness of our results using alternative clustering approaches. Since these alternative approaches only impact our standard errors without changing the relevant coefficients of our *Stringency* measure, we report the p-values of each of the key coefficients across our main tables using different clustering approaches.

Panel A	Table	coefficient	P-value clustering by			
			State	EPA region ¹	Parent firm	Facility
Effect of cap-and-trade on toxic emissions	2	0.03	0.00	0.00	0.02	0.07
Effect of cap-and-trade on GHGs from waste	3	-0.01	0.00	0.00	0.07	0.06
Interaction between cap-and-trade & GHG from waste predicting toxic emissions	3	-0.004	0.00	0.00	0.00	0.03
Effect of cap-and-trade on waste releases (controlling for waste generation)	4	0.04	0.00	0.00	0.01	0.03
Effect of cap-and-trade on waste treatment	4	-0.01	0.00	0.00	0.14	0.35
Effect of cap-and-trade on instate waste treatment	4	-0.01	0.07	0.06	0.23	0.57

Panel B (Table 5-7)		Coefficient Difference	P-value clustering by			
Test for	Moderator		State	EPA region	Parent firm	Facility
Moderation of main effect by source reduction technology	Source reduction installed	0.12	0.00	0.00	0.00	0.00
Moderation of main effect by stakeholder monitoring	County NGO	0.01	0.13	0.07	0.63	0.76
	EPA penalties	0.03	0.00	0.00	0.20	0.28
Moderation of main effect by chemical toxicity	Carcinogenic	0.02	0.00	0.00	0.27	0.15
	Bio-accumulative	0.04	0.00	0.00	0.01	0.05
	Reportable quantities	0.02	0.00	0.00	0.36	0.42
	Reference concentration	0.01	0.04	0.03	0.55	0.62
	Inhalation unit risk	0.04	0.00	0.00	0.01	0.05

¹ EPA operates ten Regional offices, each of which is responsible for the execution of EPA programs within several states and territories. For more information, please see <https://www.epa.gov/aboutepa/regional-and-geographic-offices>

Moderation of effect on untreated by ownership	Treated owner	-0.05	0.00	0.00	0.00	0.00
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As this table makes clear, standard errors are generally higher when clustering by parent firm or facility level (though this does not mean that such clustering is better; see Abadie, Athey, Imbens, and Wooldridge, 2023). Though this does mean that some of the differences between coefficients across our moderation subsamples are no longer significant—specifically, we no longer see a significant moderating effect of EPA penalties and of some of our chemical toxicity measures (though results using bioaccumulative chemicals and Inhalation Unit Risk are robust)—when clustering by firm or facility, our main findings continue to be generally supported.

Appendix E: Difference-in-Differences analysis on California facilities

Table E1.

VARIABLES	CA facilities		Treated CA facilities
Stringency	0.02*** (0.01)	0.02*** (0.01)	0.04*** (0.01)
Treat*post2013		-0.06 (0.21)	
Employees	-0.09*** (0.03)	-0.09*** (0.03)	-0.18* (0.09)
# of chem	0.32*** (0.05)	0.32*** (0.05)	0.37*** (0.11)
# of subsidiaries	-0.00 (0.00)	-0.00 (0.00)	0.00 (0.01)
# of states	0.01 (0.03)	0.01 (0.03)	0.00 (0.04)
EPA action	-0.37 (0.66)	-0.37 (0.66)	
Inspection	0.25 (0.20)	0.25 (0.20)	0.63** (0.30)
Observations	5,901	5,901	764
R-squared	0.06	0.06	0.12
# of facilities	916	916	100
Year FE	Y	Y	Y
Facility FE	Y	Y	Y

Dependent variable is (log) toxic emissions. OLS panel models with year and facility fixed effects. Robust standard errors clustered by facility in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Appendix F: Robustness of Main Findings

To further test the robustness of our findings, we develop an epistemic map, showing how our result changes with various potential choices of empirical specification (King, Goldfarb, and Simcoe, 2021).

Specifically, we vary four sets of choices.

1. Sample matching
 - a. Matching I: matching criteria used in the main analysis
 - b. Matching II: matching using only emissions, employees, industry, and number of toxic chemical types
 - c. Unmatched
2. Sample exclusions
 - a. All sample facilities
 - b. Dropping firms that have facilities in both California and other US states (such firms may find it easy to shift operations from one state to the other in response to cap-and-trade)
 - c. Dropping facilities in the petroleum industry (cap-and-trade may impact the demand for oil)
 - d. Dropping facilities subject to RGGI² from the control sample (such facilities may also be subject to pressures to reduce GHG emissions)
 - e. Maximum exclusion: Dropping all facilities dropped in a, b, or c.
3. Alternative measures of facility size
 - a. Employee (main results)
 - b. Facility sale
 - c. Production ratio
4. Alternative treatment measures
 - a. Stringency

² The Regional Greenhouse Gas Initiative (RGGI) is a market-based effort to reduce GHGs from the power sector among Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and Virginia.

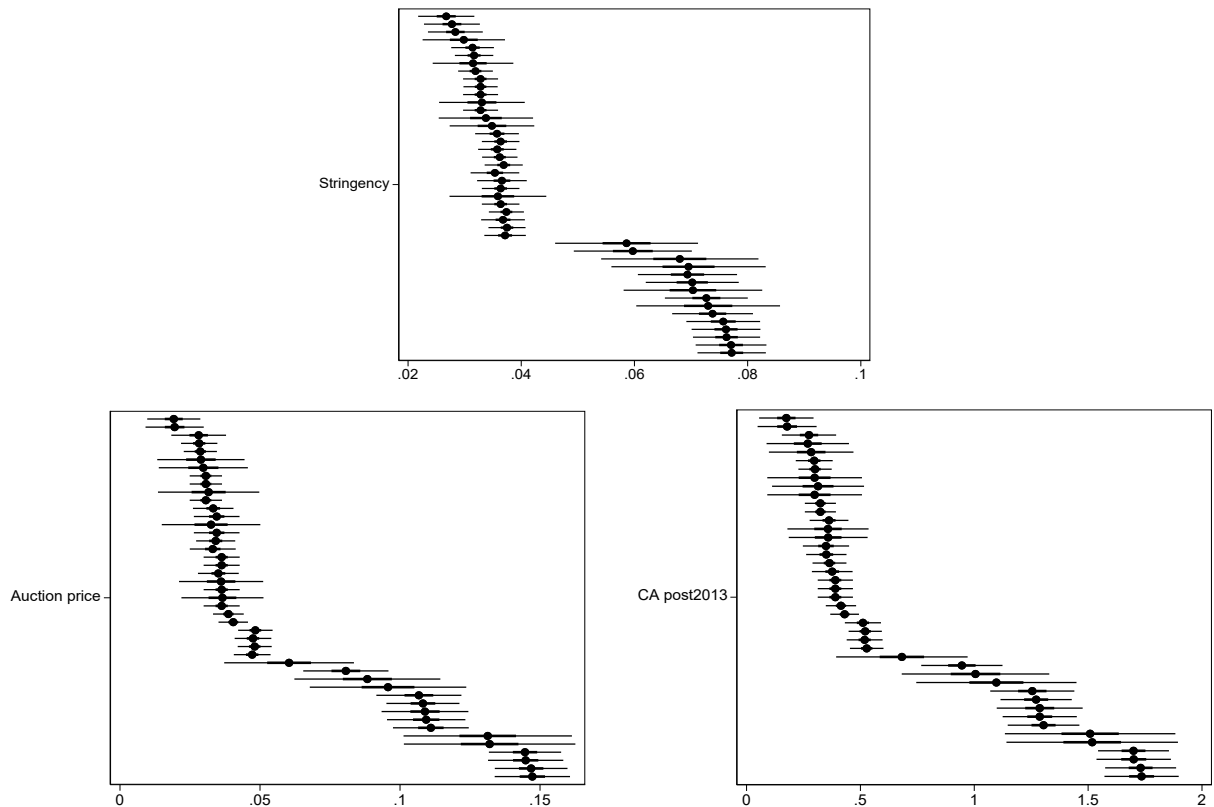
b. Binary measure: *CA_post2013*

c. Auction Price

As discussed in the main manuscript, our preferred specification uses the more stringent matched sample, without any exclusions, controlling for employees, and using the *Stringency* measure. Since the coefficients of the three treatment measures are not strictly comparable, we graph them separately. For each treatment measure we thus have (3 x 5 x 3) 45 potential sample specifications. Figure F1 plots all 45 coefficients, in order of coefficient size, with their 95% confidence intervals, for each of the three treatment measures.

As the figure shows, all 135 coefficients are significantly greater than zero, strongly supporting the robustness of our main result. In terms of economic magnitude, the point estimates of the coefficients of *Stringency* imply a 27.2 – 78.4 % relative increase in toxic emissions when a facility goes from no cap-and-trade to average stringency. Similarly, the point estimates of *AuctionPrice* imply a 21.9% - 165.6% relative increase in toxic emissions when a facility goes from no cap-and-trade to average auction price. And the point estimates of *CA_post2013* imply a 17.5 – 173.5% relative increase in toxic emissions within treated facilities following the introduction of the cap-and-trade regime.

Figure F1



Appendix G: Synthetic Control Approach

To further test the robustness of our findings, we use several variants of a synthetic control approach (Abadie, Diamond, and Hainmueller, 2010; Fremeth, Holburn and Richter 2016; Abadie, 2021). First, since we are interested in the impact of a state-level policy we conduct a synthetic control estimation at the state level, creating a ‘synthetic California’ to examine how toxic emissions in the treated state (California) were impacted relative to similar emissions in other states (Abadie et al., 2010). In creating synthetic California, we use the sum of emissions from the matched sample facilities as well as the number of these facilities in each state as the control criteria. Figure G1 shows that after the introduction of cap-and-trade, the toxic emissions from California exhibits a clear increasing trend compared to synthetic California. We include all states except Hawaii.

Next, since we do have facility level data, we construct synthetic controls for each treated facility in our sample and run analyses comparing emissions in our treated facility to these synthetic controls (Acemoglu, Johnson, Kermani, Kwak, and Mitton, 2016; Abadie, 2021). In particular, we create synthetic California facilities using these facilities’ average emissions before cap-and-trade and their industry. One challenge with doing so is that we have too many donor facilities to construct synthetic control facilities relative to treated facilities, so STATA is unable to handle creating synthetic controls if we include all potential control facilities as donors. To deal with this issue, we restrict the donor sample to facilities in specific states, using different combinations of states for robustness. Specifically, we try limiting the donor sample to two sets of states: a) Texas and New York, which we term the ‘Top Two’ states and are the states closest to California in overall economic size, and b) Pennsylvania, Ohio, Louisiana, Indiana and Illinois which we term the ‘Big Five’ states and are the states that have the most facilities in the TRI database (after Texas). We also try using all facilities in the combination of these seven states as our donor sample (Big 7). We also try limiting our donor sample by limiting the set of potential donor firms to be used to create synthetic controls to the control firms in the matched sample we use in our main analysis, effectively combining our CEM and synthetic control approaches.

Figures G2 to G4 graph the pre- and post-treatment emission levels for treated vs. synthetic control facilities using the three different donor samples (Top 2 States, Big 5 States, Big 7 States), with each set of

graphs including synthetic controls using both the full sample of all GHG reporting facilities in those states as the donor sample, and only the CEM matched reporting facilities in those states as the donor sample. Across all six graphs we see a clear pattern of a substantially increased level of emissions among treated facilities after the treatment compared to the synthetic control facilities. To further confirm these findings, Table G1 presents the coefficients and standard errors of our three treatment variables from regressions predicting toxic emissions using a sample of treated facilities and their synthetic control facilities, confirming a consistently positive and significant effect of treatment. All these results suggest that our findings are robust to using a synthetic control approach.

Figure F1. California and Synthetic California

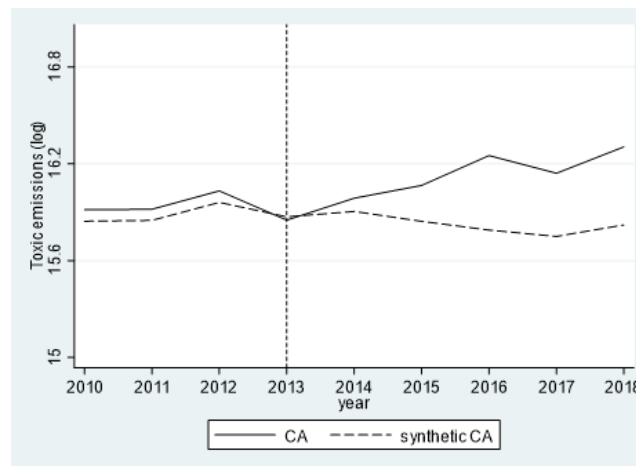


Figure F2. Donor states: Top 2 (New York & Texas)

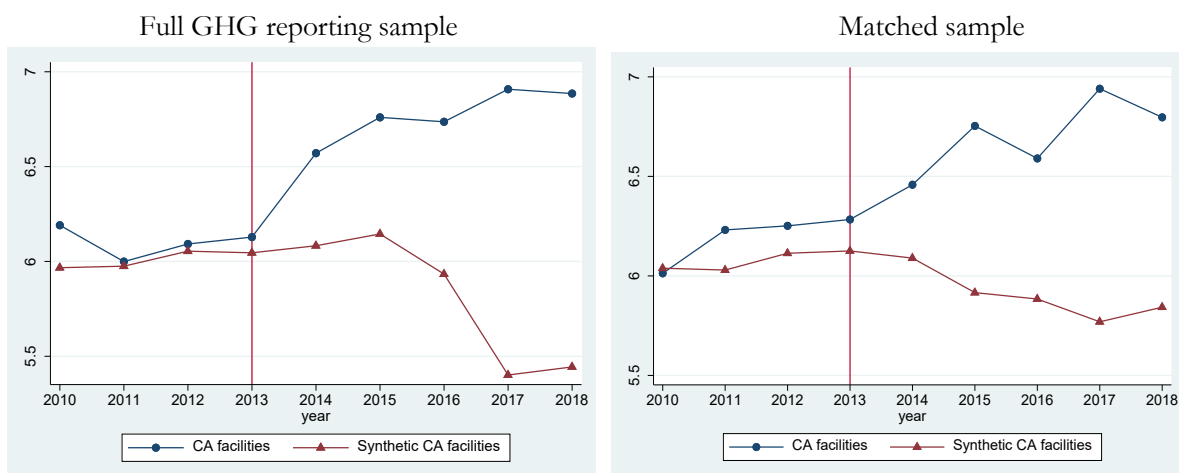


Figure F3. Donor states: Big 5 (Philadelphia, Ohio, Louisiana, Indiana and Illinois)

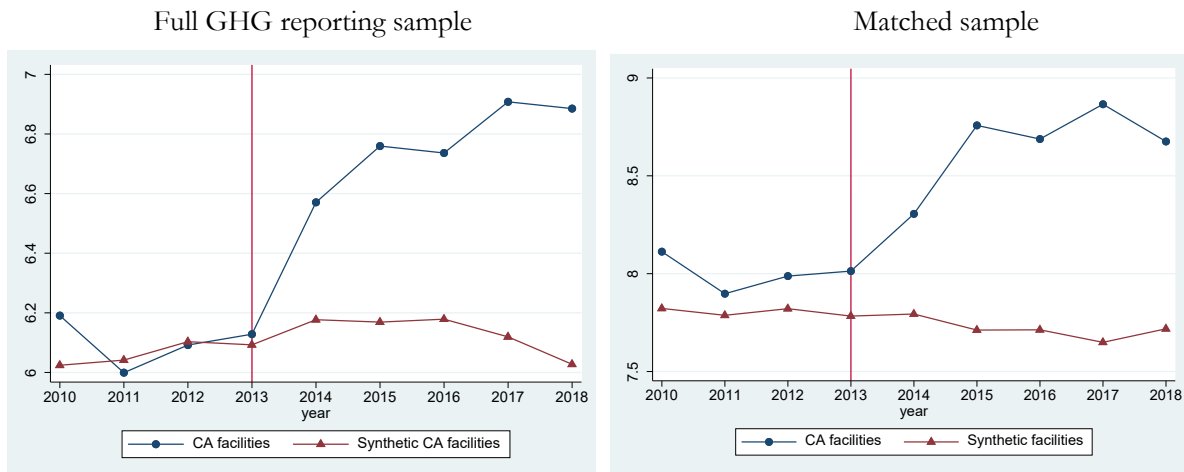


Figure F4. Donor states: Big 7 (Top 2 and Big 5)

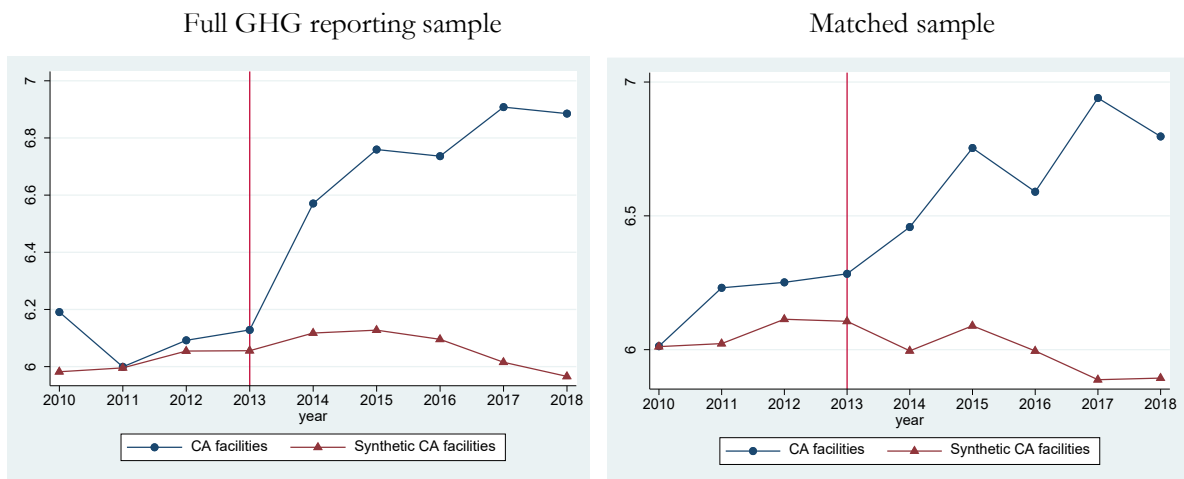


Table F1. Summary of coefficients

Donor states	1) Top 2 States		2) Big 5 States		3) Big 7 States	
Donor sample	Full GHG sample	Matched	Full GHG sample	Matched	Full GHG sample	Matched
Variables						
Stringency	0.14**(0.05)	0.11*(0.07)	0.10**(0.04)	0.12**(0.05)	0.10**(0.04)	0.10*(0.06)
CA post2013	0.73**(0.25)	0.59*(0.32)	0.50**(0.23)	0.64**(0.27)	0.52**(0.23)	0.53*(0.31)
Auction	0.07**(0.02)	0.05*(0.03)	0.04**(0.05)	0.05**(0.02)	0.05**(0.02)	0.05*(0.03)
# of obs.	1,323	891	1,341	882	1,341	891
# of facilities	147	99	149	98	149	99

We regress toxic releases on different independent variables, Stringency, CA post2013 and Auction. Year-fixed effects are included. Figures in parentheses are robust standard errors clustered by facility. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Appendix H: Alternative Explanations

In this Appendix, we briefly explore two plausible alternative mechanisms linking cap-and-trade to higher toxic emissions. One possibility is that the introduction of cap-and-trade may be accompanied by a reduction in enforcement of toxic emission regulation, either because regulators intended to trade-off lower GHG emissions against higher toxic emissions or because the administrative burden of implementing cap-and-trade left fewer resources for toxic emission enforcement (the latter is unlikely because cap-and-trade is administered by CARB while toxic emissions are regulated by the EPA, but still). To test for this we examine the effect of cap-and-trade on EPA inspections or corrective actions related to toxic emissions. The results of this analysis are shown in Appendix Table H1, which shows no evidence of a decrease in either EPA inspections or EPA corrective actions, as a result of cap-and-trade.

A second possibility is that the introduction of a new program to curb air emissions, administered by a regulatory body (CARB) focused on air quality, may have led firms to prioritize lowering air emissions relative to land and water emissions³. To test this explanation we break down toxic emissions into the types of releases—air, water, and land—to see if the toxic emission increase comes primarily for land or water release. Appendix Table H2 shows the results of this analysis. We find no support for this alternative explanation. If anything, the effect of cap-and-trade seems to most pronounced for releases of airborne toxic chemicals, while we do not see any evidence of an increase in waterborne chemical emissions following the introduction of cap-and-trade.

³ We are grateful to Mike Lenox for suggesting this possibility.

Table H1. Change in EPA actions

VARIABLES	Inspect	Action
Stringency	0.01 (0.02)	-0.00 (0.01)
Employees	-0.06** (0.03)	0.01 (0.03)
# of chemicals	0.07*** (0.01)	0.00 (0.01)
# of facilities by same owner	0.00 (0.00)	0.00 (0.00)
# of states by same owner	-0.02* (0.01)	-0.01 (0.01)
EPA_action(past 5 years)	0.25** (0.10)	
Inspection(past 5 years)		6.63*** (0.58)
Observations	8,801	8,801
# of facilities	1,100	1,100
Year FE	Y	Y
Facility FE	Y	Y

Logit model predicting probability of EPA inspection or punitive action. Standard errors in parentheses.

*** p<0.01, ** p<0.05, * p<0.1

Table H2. Types of Toxic Releases

VARIABLES	Air	Land	Water
Stringency	0.01*** (0.00)	0.01*** (0.00)	0.00 (0.00)
Employees	0.02 (0.05)	0.01 (0.02)	0.02 (0.03)
# of chemicals	0.37*** (0.06)	0.04** (0.01)	0.09*** (0.03)
# of facilities by same owner	0.01 (0.01)	-0.00 (0.00)	0.01* (0.00)
# of states by same owner	-0.01 (0.01)	0.00 (0.01)	-0.00 (0.02)
EPA_inspection	-2.64*** (0.44)	-0.07* (0.04)	-0.16** (0.08)
EPA_action	-0.28 (0.35)	-0.12 (0.10)	0.08 (0.09)
Observations	8,801	8,801	8,801
R-squared	0.11	0.01	0.02
Number of facilities	1,100	1,100	1,100
Year FE	Y	Y	Y
Facility FE	Y	Y	Y

Dependent variable is (log) toxic emissions. OLS panel models with year and facility fixed effects. Robust standard errors clustered by state in parentheses. *** p<0.01, ** p<0.05, * p<0.1

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