China's Recyclable Waste Ban and Pollution Relocation in the U.S.

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Department Seminar

2022

Recycling in the U.S.

U.S. Recycling Industry Is Struggling To Figure Out A Future Without China

August 20, 2019 · 3:27 PM ET
Heard on All Things Considered

SUSTAINABILITY

Recycling in the U.S. Is Broken. How Do We Fix It?

BY RENEE CHO | MARCH 13, 2020 | 63 Comments

Countries Tried to Curb Trade in Plastic Waste. The U.S. Is Shipping More.

Data shows that American exporters continue to ship plastic waste overseas, often to poorer countries, even though most of the world has agreed to not accept it.

ENVIRONMENT | PLANET OR PLASTIC?

China's ban on trash imports shifts waste crisis to Southeast Asia

As plastic scrap piles up, Malaysia and others fight back.

Recycling in America Is a Mess. A New Bill Could Clean It Up.

As programs shutter and plastic use rises in the pandemic, a New York bill to get manufacturers to pick up the recycling tab could offer a solution.

50

By Michael Kimmelman Photo Illustrations by Bobby Doherty

Published Jan. 27, 2021 Updated Jan. 28, 2021

Your Recycling Gets Recycled, Right? Maybe, or Maybe Not

Plastics and papers from dozens of American cities and towns ar being dumped in landfills after China stopped recycling most "foreign garbage."

News Articles about current recycling in the U.S.

Introduction

- Recyclable waste transfer is an important part of global pollution relocation
  - **1,000,000,000** metric tons from developed to developing countries

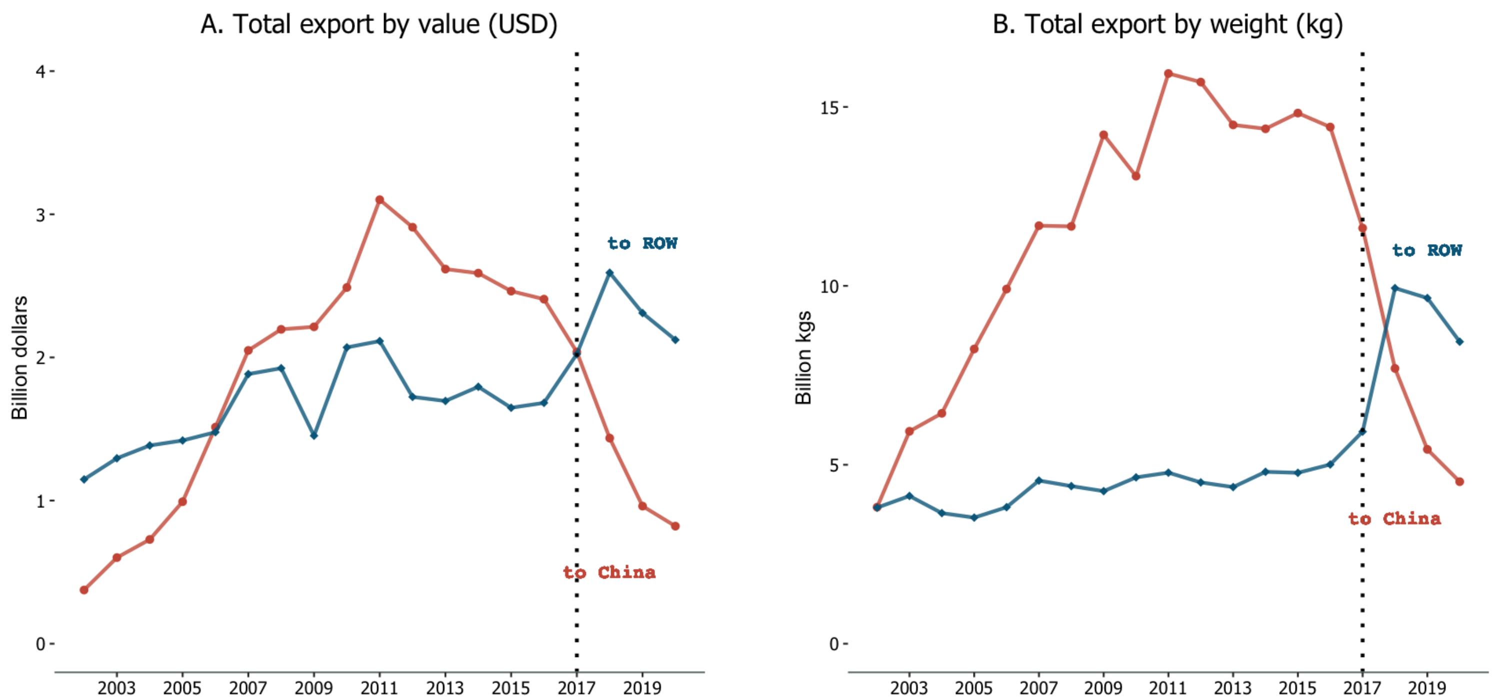
- China was the biggest importer of U.S. recyclables

- In 2017, China announced its **Green Sword (GS) Policy**, which banned almost all recyclable waste imports

- Wastes from recycling remain in the U.S.

- Considerable domestic environmental costs

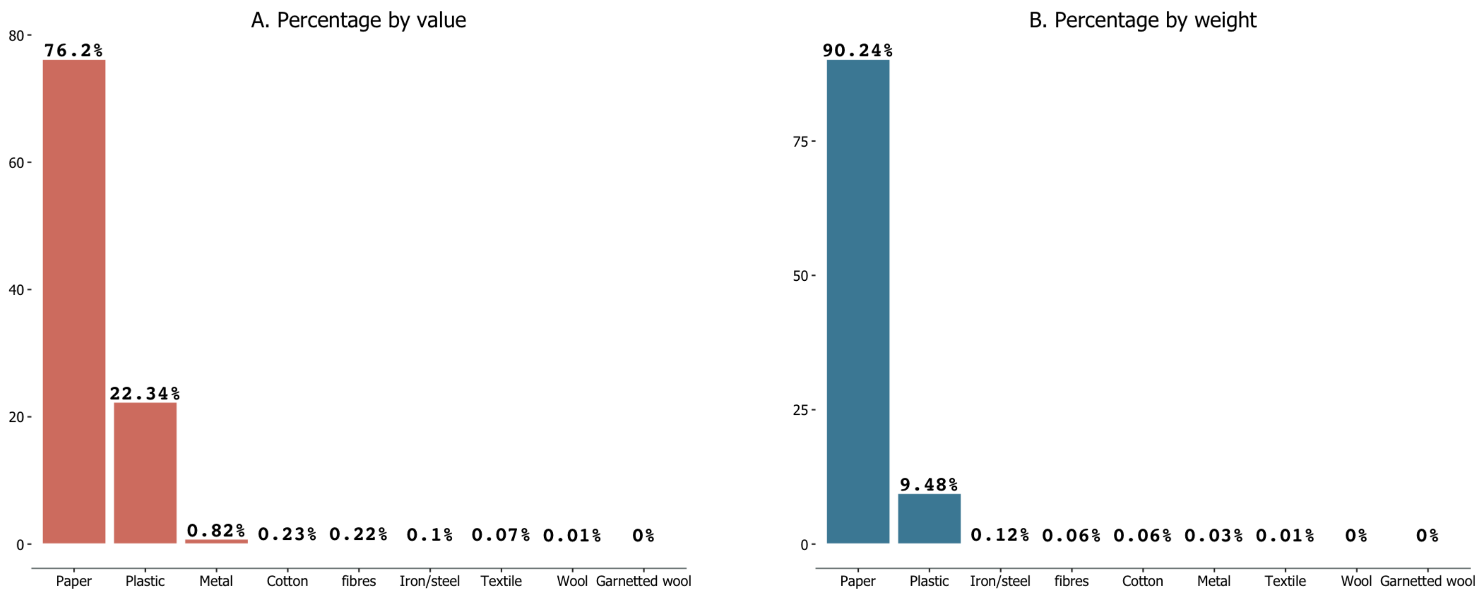
GS Policy and Trade



Data Source: USA Trade Online Data

Figure 2. U.S. Recyclable Waste Exports to China and ROW

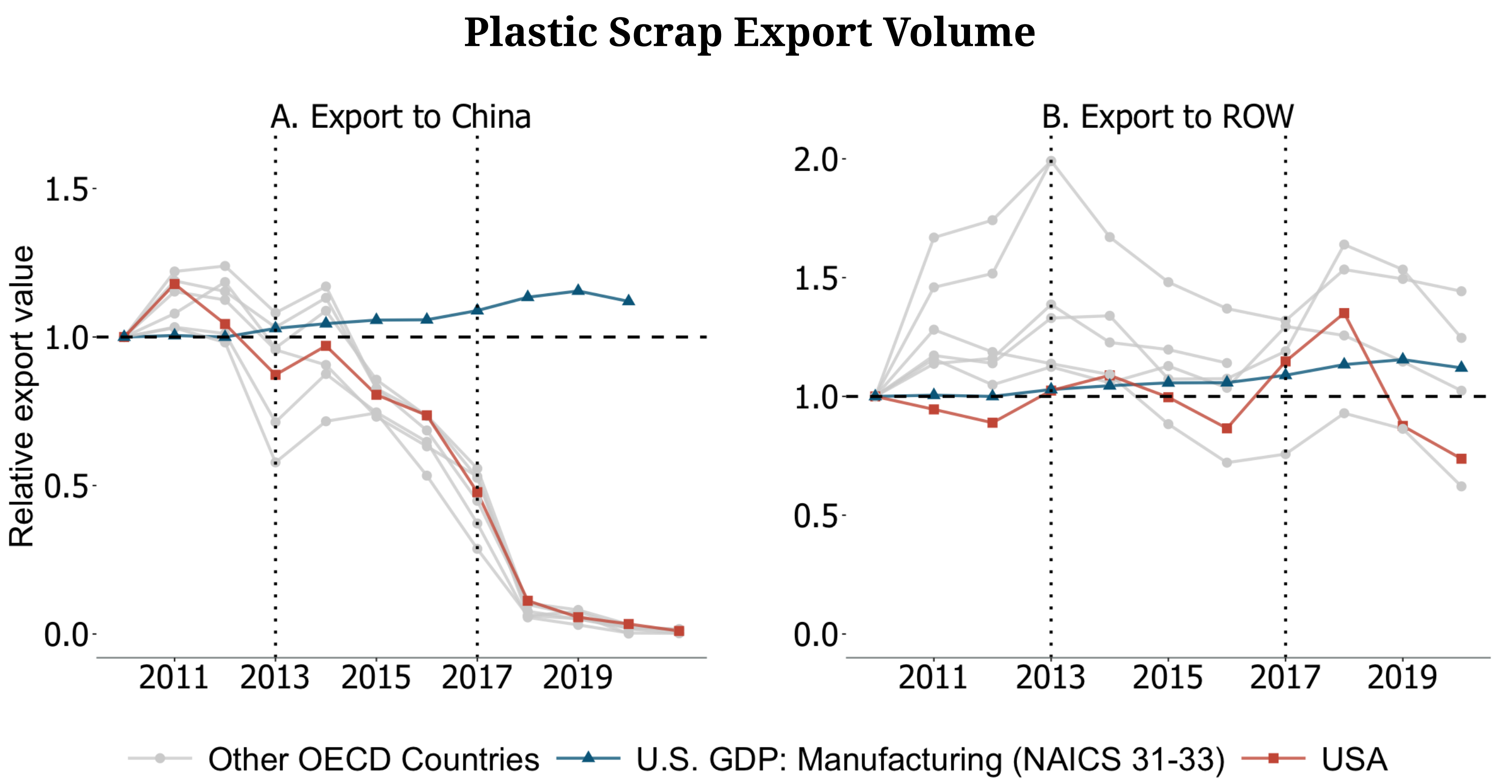
GS Policy and Trade



Data Source: USA Trade Online Data

Figure 3. Composition of Recyclable Waste Exports

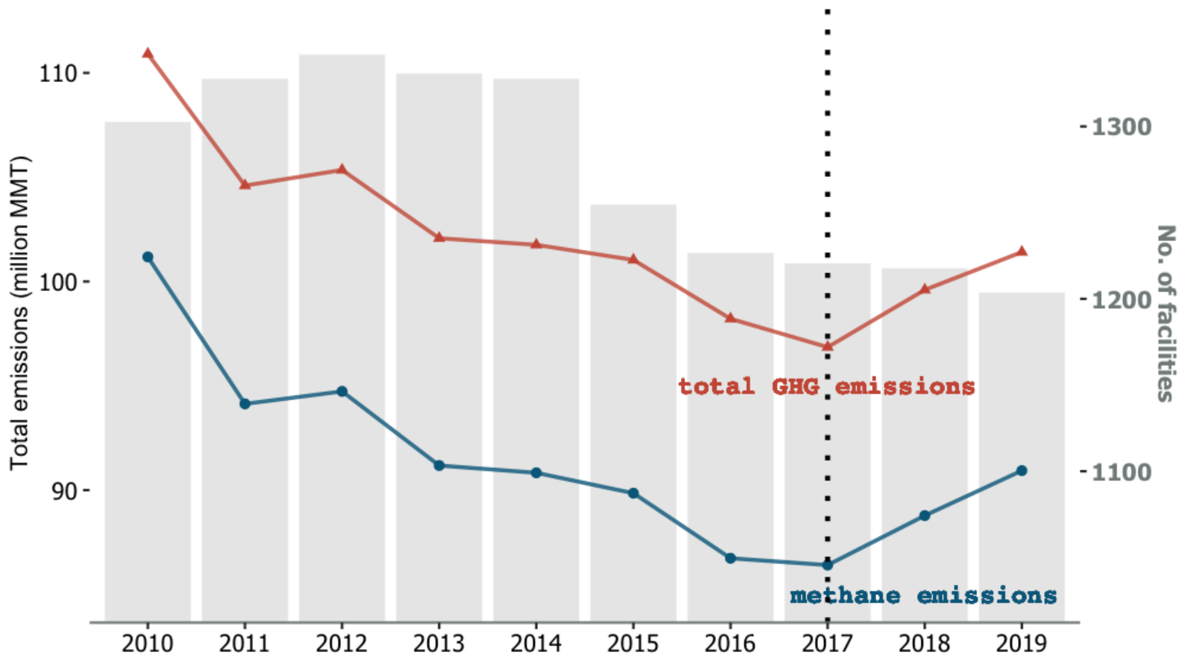
GS Policy and Trade



Data Source: UN Comtrade Data

Figure 4. Plastic Scrap Export to China and ROW

GS Policy and Emission



Data Source: US EPA Greenhouse Gas Reporting Program

Figure 5. U.S. Total Emissions by Waste Industry

Research Questions

- For the **U.S.**
  - What has been the effect of China's GS policy on **Domestic Emissions** from landfill facilities?
  - How do **Heterogeneous Changes** in emissions relate to **Trade Exposures** at state level?

- For the state of **California**
  - What are the **Distributional Effects** of the GS policy on pollution relocation for local communities at census-block levels?
  - What are the potential **Mechanisms** to explain the distributional effects in those communities?

Relevance

Recycling. *Aadland and Caplan (2006), Bohm et al. (2010), Kinnaman (2014), Kinnaman et al. (2014), Palmer et al. (1997), Palmer and Walls (1997), Walls and Palmer (2001), Macauley et al. (2003)*

→ First **quantitative analysis** of China's GS policy on the U.S. environment at the **national, state, and local community** levels

Trade and Environment. *Shapiro (2016), Shapiro (2018), Shapiro (2021)*

→ First study of the causal relationship between **trade** volume and domestic **emissions**

Pollution Displacement. *Kurz et al.(2000), Halvorsen (2010), Ashenmiller (2009), Ashenmiller (2011), Best and Kneip (2019), Berck et al. (2020), Berck et al. (2021)*

→ First empirical evidence on **pollution displacement** under exogenous policy shock

Environmental Justice. *Baden and Coursey (2002), Cameron and McConnaha (2006), Banzhaf and Walsh (2008), Depro et al. (2011), Banzhaf and Walsh (2013), Depro et al. (2015), Banzhaf et al. (2019), Ho (2020), Hernandes and Meng (2020), Shapiro and Walker (2021)*

→ First analysis on the effect of an exogenous policy shock on **racial disparity** with regard to waste transfers

Policy Relevance. RECYCLE Act of 2021, Recycling Infrastructure and Accessibility Act of 2022, the Plastic Waste Reduction and Recycling Research Act, Infrastructure Bill 2021

→ The **international context** for domestic recycling policies can no longer be ignored.

Data

- **UN Comtrade**
  - Annual exports by commodities at country level
- **U.S.A Trade Online**
  - Annual exports by commodities at state level
- **U.S. EPA Inventory of Greenhouse Gas Emissions and Sinks**
  - Annual emissions by industry at state level
- **U.S. EPA Greenhouse Gas Reporting Program (GHGRP)**
  - Annual emissions by industry at facility level
- **California Department of Resources Recycling and Recovery (CalRecycle) Disposal Flow Data**
  - Quarterly disposal flow at facility level
- Other data
  - U.S. Census racial mix at census-block level
  - ACS 5-year median income at census block group level
  - Statewide Database (SWDB) presidential election data at precinct level

1. The Effect of China's Waste Ban on Domestic Methane Emissions

Results:

- The cumulative emissions increased by more than **10 million** metric tons of CO_2 eq.
    - **11** states have seen a statistically significant increase in methane emissions
    - The more waste a state **exported**, the **greater impact** the GS policy had on the state

Why study methane emissions?

- **Anaerobic decomposition of recyclable wastes**
    - papers and paperboard (80%) and plastics (15%)

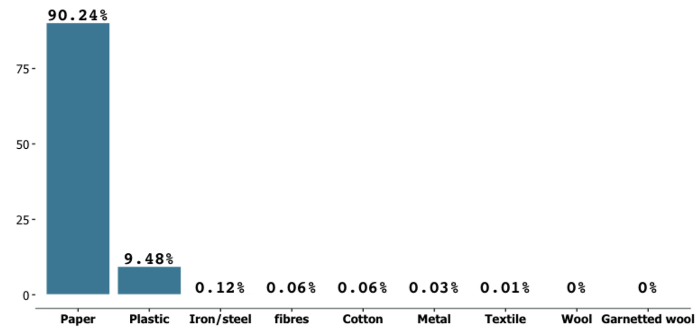


Figure A.1 U.S. Recyclable Waste Composition

Why study methane emissions?

- Anaerobic decomposition of recyclable wastes
    - papers and paperboard (80%) and plastics (15%)
- **Precursor gas of air pollutant**
    - organic hazardous air pollutants (HAP), volatile organic compounds (VOC), hydrogen sulfide, tropospheric ozone, etc.

Abernethy et al. (2021)

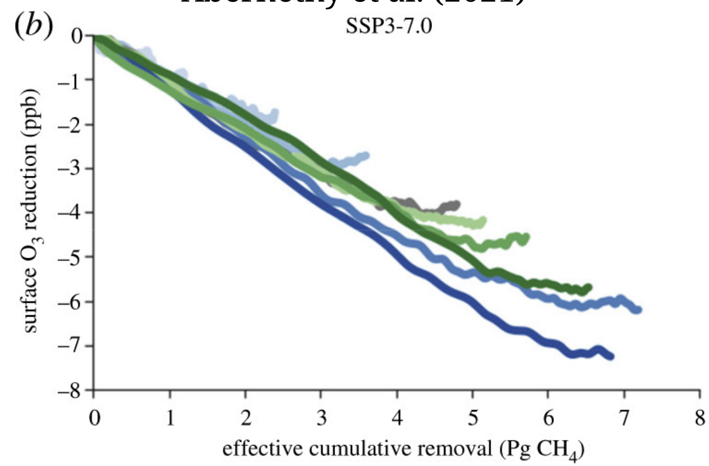


Figure A.2 Methane removal and reductions in ozone

Why study methane emissions?

- Anaerobic decomposition of recyclable wastes
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- Precursor gas of air pollutant
  - organic hazardous air pollutants (HAP), volatile organic compounds (VOC), hydrogen sulfide, tropospheric ozone, etc.
- **Water and soil pollution**
  - micro-plastic

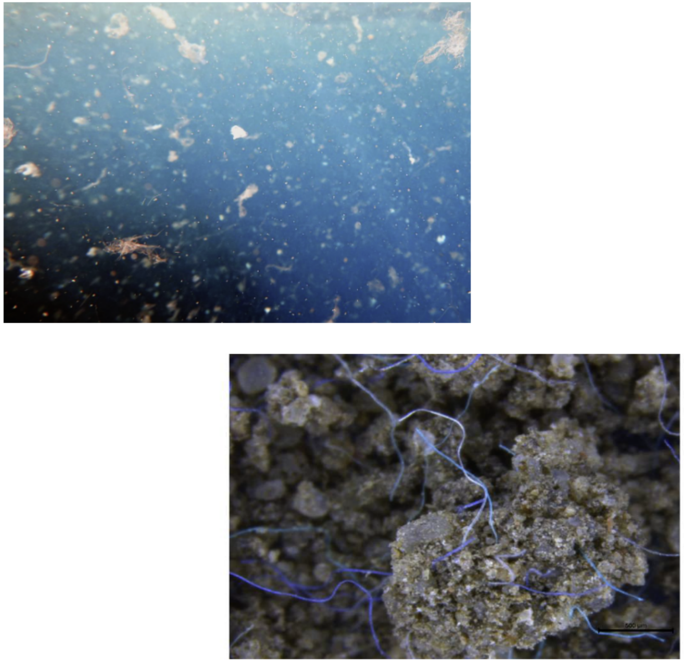

Figure A.3 Microplastic in water and soil

Why study methane emissions?

- Anaerobic decomposition of recyclable wastes
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- Precursor gas of air pollutant
    - organic hazardous air pollutants (HAP), volatile organic compounds (VOC), hydrogen sulfide, tropospheric ozone, etc.
- Water and soil pollution
    - micro-plastic
- **Extreme weather events and higher fire risk**
    - 86 times stronger than CO2

Abernethy et al. (2021)

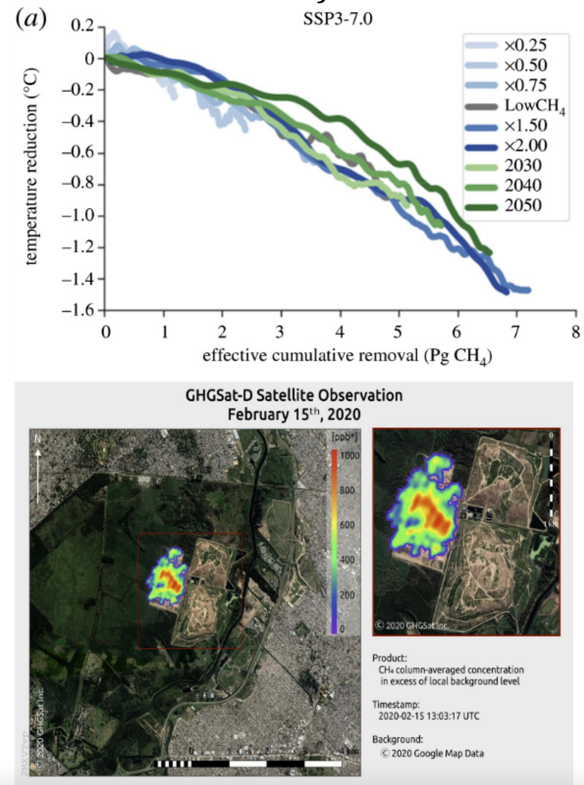


Figure A.4 Methane removal and reductions in temperature

Why study methane emissions?

- Anaerobic decomposition of recyclable wastes
  - papers and paperboard (80%) and plastics (15%)
- Precursor gas of air pollutant
  - organic hazardous air pollutants (HAP), volatile organic compounds (VOC), hydrogen sulfide, tropospheric ozone, etc.
- Water and soil pollution
  - micro-plastic
- Extreme weather events and higher fire risk
  - 86 times stronger than CO2
- **Consistently measured data from 2003 to 2020**

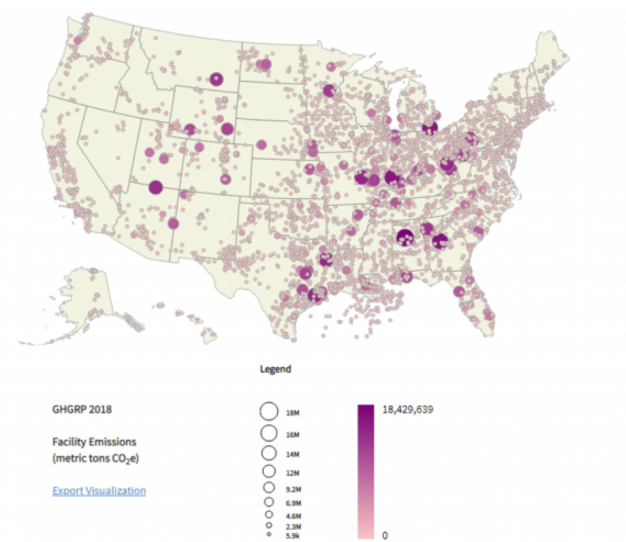


Figure A.5 EPA GHGRP data

Data

- **U.S. EPA Greenhouse Gas Reporting Program (GHGRP)**
  - Methane emissions from landfill facilities
  - 2010 to 2020 annually

- Approximately 8,000 facilities required to report emissions annually

- High compliance rates
  - no financial penalty but high reputational cost

- Covered industries include power plants, petroleum and natural gas systems, minerals, chemicals, pulp and paper, refineries, waste, etc.

- Data generation process for waste industry:
  - Facilities report annual **amounts of waste accepted**
  - Methane emissions are calculated by the U.S. EPA using a complicated model

State-level Pollution: Synthetic Control Method

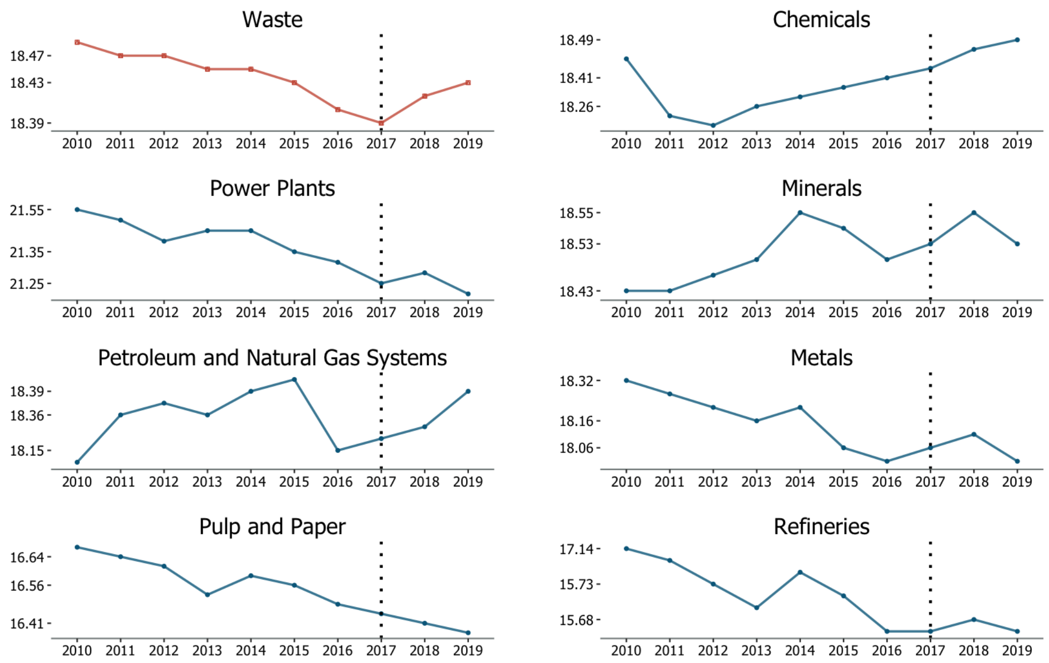
- Rely on exogenous variation in methane emissions across **all other industries** in the EPA GHGRP
  - Power plants, petroleum and natural gas systems, minerals, chemicals, pulp and paper, refineries, etc. (**not** waste)
- Take advantage of the fact that other industries which also emit GHGs were **not** affected by China's GS policy
- Use other industries (all states) as donor pool for synthetic control group
- Train the model using the pre-policy period **(2010-2017)**
  - Calculate state-industry pair weights to minimize prediction error

$$\hat{Y}_{11t}^{N} = \sum_{j=2}^{J} \sum_{s=2}^{50} w_{js} Y_{jst}$$

- Predict counterfactual methane emissions in the absence of GS policy using post-policy period (**2018-2020**)

The Effect of China Ban on State Pollution: Synthetic Control

- Rely on exogenous variation in methane emissions across **all other industries** in the EPA GHGRP



Data Source: EPA GHGRP

Figure 6. U.S. Total Emissions by Industry

Results

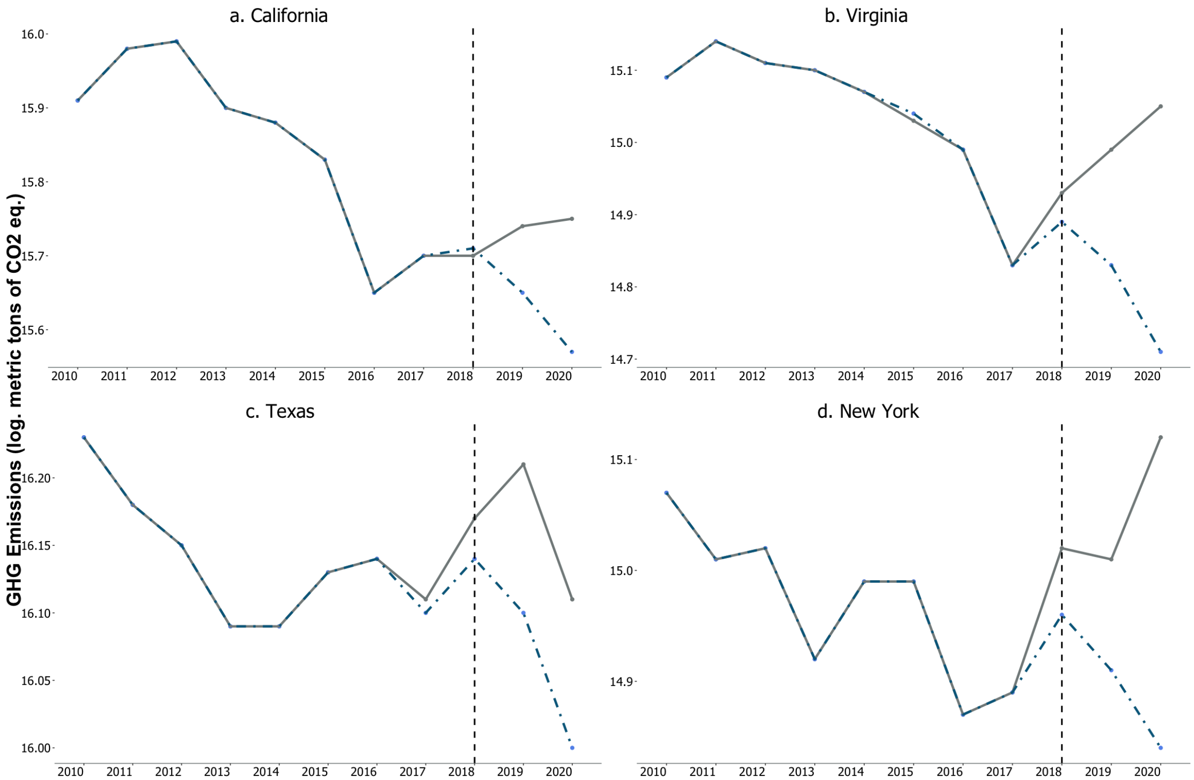


Figure 7. Synthetic Control Outcomes: four example states

Results

Figure 8. Synthetic Control Outcomes: placebo tests

Results

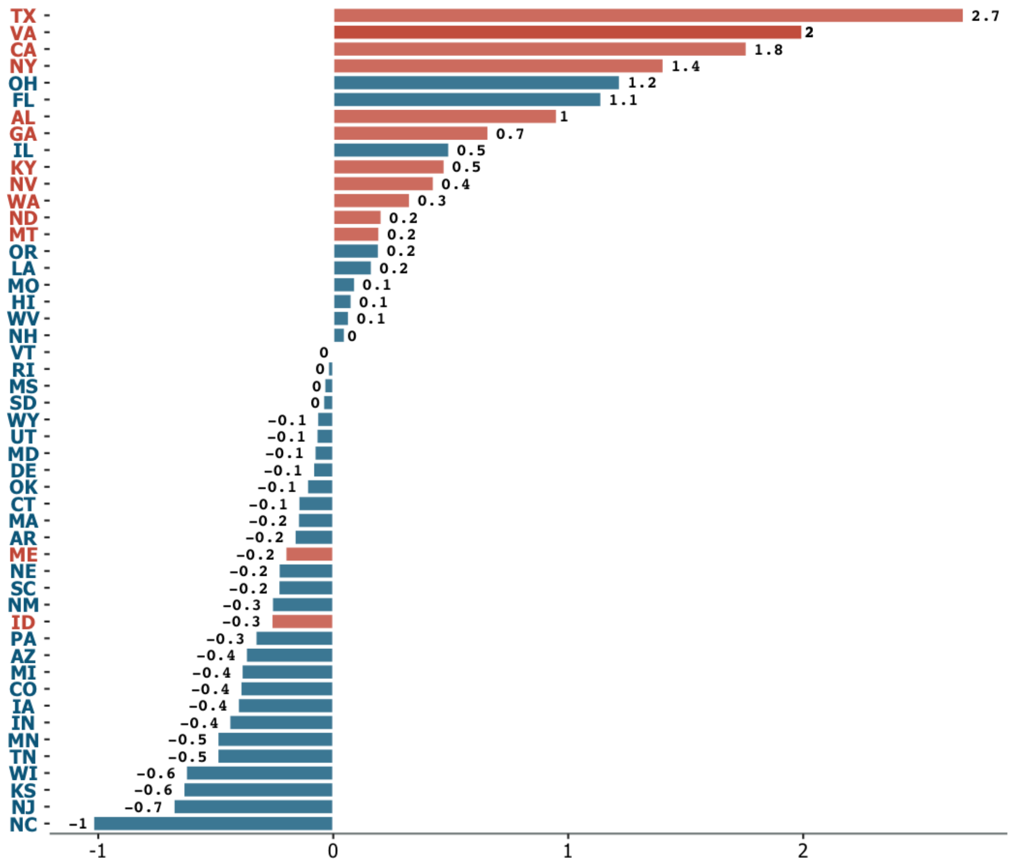


Figure 9. Net Changes of Emissions after the GS Policy (Red-significant, blue-insignificant)

State-level Causal Estimates and Trade Exposures

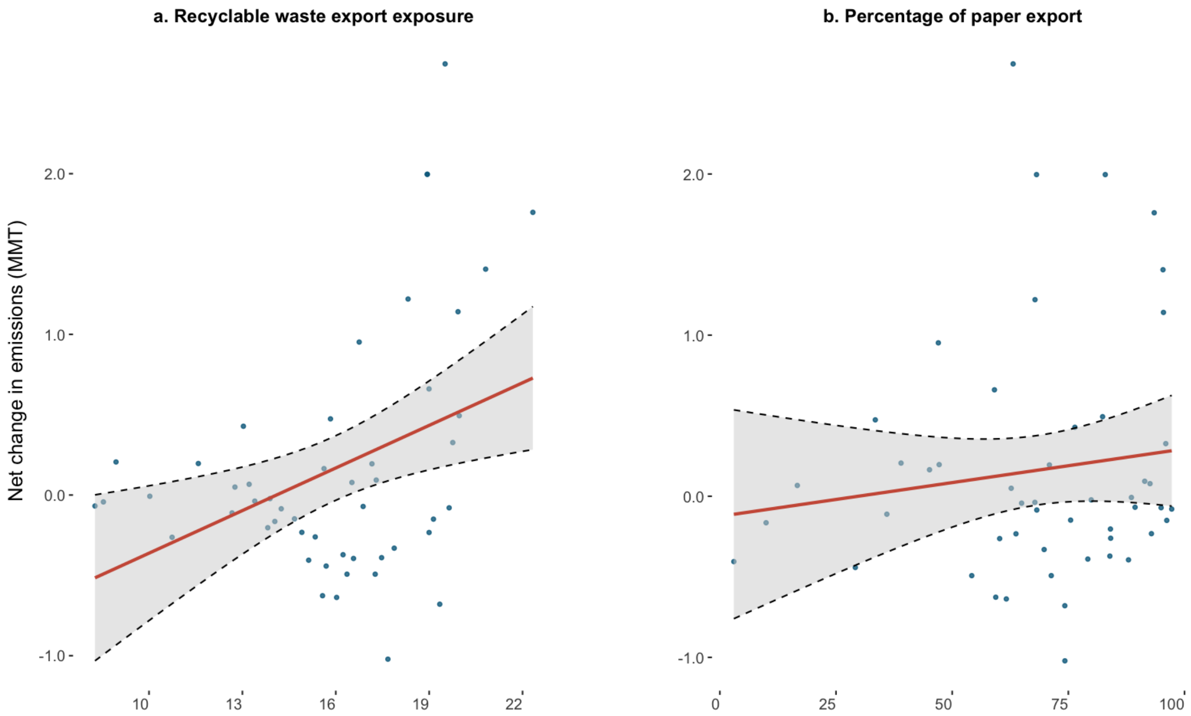


Figure 10. Correlations of State-level Emission Net Change

- ↑ **Recyclable wastes a state exported** → ↑ increase in methane emissions.

2. State-level Pollution and Waste Trade Exposure

Result:

- For every **1** additional metric ton of recyclable waste exported, the U.S. domestic emissions were reduced by **0.83** metric tons of CO2 eq.
- **12 million** metric tons of export reduction increased emissions by **11 million** metric tons of CO2 eq.

Data

- **U.S. Trade Census**
    - State-level exports from 2003 to 2019 annually
    - HS4 commodity code : 9 different types of recyclable wastes that are affected by the policy e.g., 3915 (plastic), 2619 (iron/steel slag), 2620 (metal slag), 4707 (paper & paperboard), etc.
- **U.S. EPA Greenhouse Gas Inventory**
    - State-level methane emissions by industry
    - 2003 to 2019 annually
- **UN Comtrade Data**
    - Country-level exports from 2003 to 2019 annually
    - HS4 commodity code : 9 different types of recyclable wastes that are affected by the policy e.g., 3915, 2619, 2620, 4707 etc.
- **U.S. Bureau of Economic Analysis (BEA)**
    - Annual Employment, Personal income and Consumer Expenditure at state level

Trade and Domestic Emissions

Naive OLS:

$$\Delta \text{Methane}_{it} = \alpha + \beta_1 \Delta \text{Export}_{it} + s_i + u_t + e_{it}$$

- $\Delta \text{Methane}_{it}$ = **change** of metric tons (in millions) of methane emissions from the waste industry of state i in year t, compared to last year
- $\Delta \text{Export}_{it}$ = **change** of export values (in billions \$) of recyclable wastes from state i in year t compared to last year
- s_i = state fixed effect
- u_t = year fixed effect

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- **Identification Threat**
  - Omitted variable: economics activities, etc (endogeneity)
  - Reverse causality: emission permits → waste exports
  - Supply instead of demand shock: technological improvement

Bartik Shift-Share Instrument

- Endogeneity, reverse causality
  - **Bartik shift-share instrument:** Bartik 1991, Autor et.al 2013 (AER), Wong 2020 (AEJ)

Bartik Shift-Share Instrument

- Endogeneity, reverse causality

$$IV_{it}^{Bartik} = \sum_{j} \frac{E_{ijt_0}}{E_{jt_0}} \Delta Export_{ucjt}$$

- Instrument: IV_{it}^{Bartik}

Bartik Shift-Share Instrument

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- i = state, j = recycling waste commodity

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- i = state, j = recycling waste commodity
- t_0 initial year (2004)
- $\frac{E_{ijt_0}}{E_{jt_0}}$ is the initial share (2004) of U.S. state $i^{'}s$ export to China
- $\Delta Export_{ucjt}$ Change of export weight from the U.S. to China for recyclable waste j

Bartik Shift-Share Instrument

- Endogeneity, reverse causality

$$IV_{it}^{Bartik} = \sum_{j} \frac{E_{ijt_0}}{E_{jt_0}} \Delta Export_{ucjt}$$

- Supply-side shock

$$IV_{it,others}^{Bartik} = \sum_{j} \frac{E_{ijt_0}}{E_{jt_0}} \Delta Export_{ocjt}$$

- Use values of export values from 11 other countries to China by
    - Australia, Austria, Canada, France, Germany, Portugal, New Zealand, United Kingdom, Japan, Spain, and Finland

Bartik Shift-Share Instrument

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- **2SLS**

$$\Delta \hat{Export}_{it} = \alpha + \beta_1 \Delta IV_{it}^{Bartik} + \beta_2 X_{it}^{'} + v_{it}$$

$$\Delta Methane_{it} = \alpha + \beta_1 \Delta \hat{Export}_{it} + \beta_2 X_{it}^{'} + e_{it}$$

Results

Table 1: Models to explain change in methane emissions as a function of change in recyclable waste exports

	Naive OLS	Bartik shift-share IV	Bartik shift-share IV others
Dependent Variable	Change of Methane Emissions		
	2002-2019 first differences		
Δ Export	**-0.492** $***$	-0.722 $***$	-0.893 $***$
	(0.122)	(0.114)	(0.124)
	2SLS first stage estimates: Change in Exports regressed on IV		
IV_{Bartik}		1.11 $***$	9.55 $***$
		(0.038)	(0.465)
State fixed effect	Y	Y	Y
Year fixed effect	Y	Y	Y
First stage F		50.25	34.36

Note: Each column reports a separate regression. *$p<0.1$;$^{**}p<0.05$;$^{***}p<0.01$*. The first-differenced model is like fixed effect model but with a less restrictive assumption. The intercept in this first-differenced model captures all unobserved factors that may affect the emissions but are constant over time. It also captures the linear time trend. The year fixed effects capture every time pattern other than the linear time trend.

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3. Pollution Relocation in California and Distributional Effects

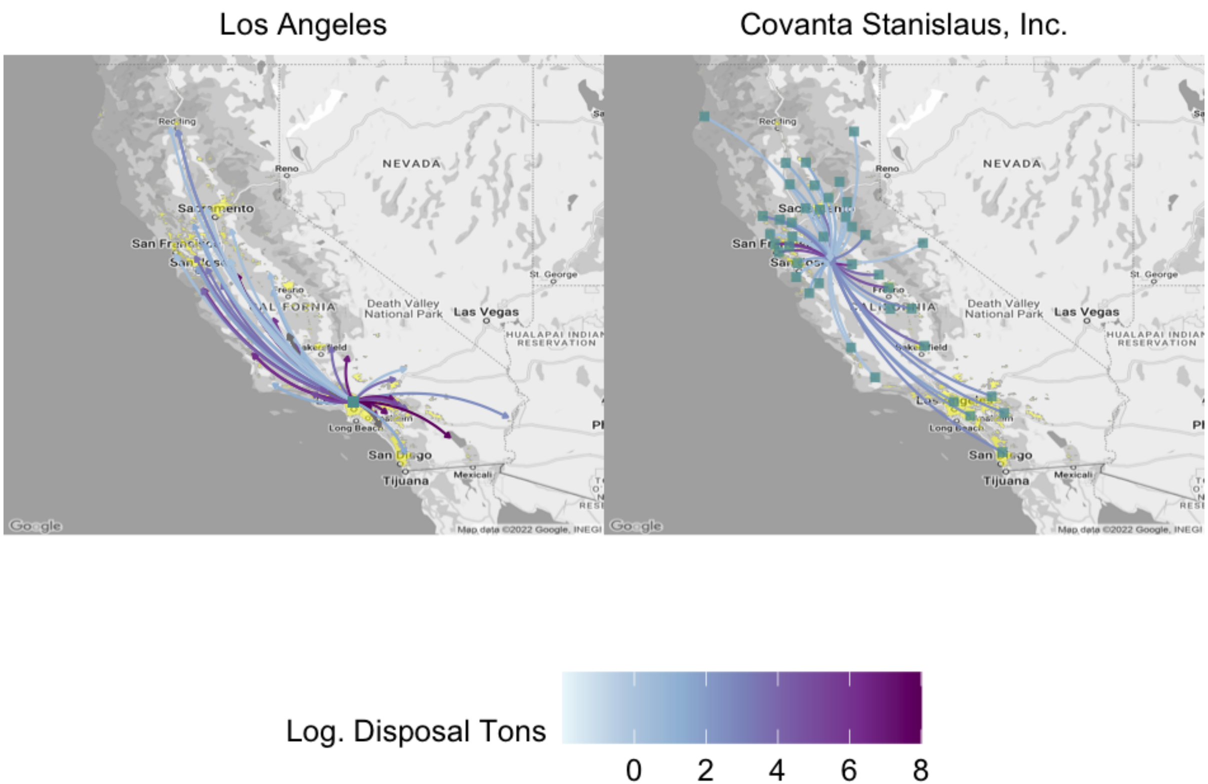
Results:

- Compare to minority communities, closer, lower-income, White communities are affected more
- Distributional effect can be explained by land costs, transportation costs, and political costs

Data

- **California Department of Resources Recycling and Recovery (CalRecycle) Disposal Flow Data**
  - Captures the amount of disposal transported (by origin jurisdiction and destination facility)
  - 2002 to 2021 (quarterly)
  - Contains 464 origin jurisdictions and 263 disposal facilities
- **Other Data Sources**
  - U.S. Census racial composition, median income at census-block level
  - Statewide Database (SWDB) election data at precinct level
  - Waste Business Journal (WBJ) waste allocation data at facility level

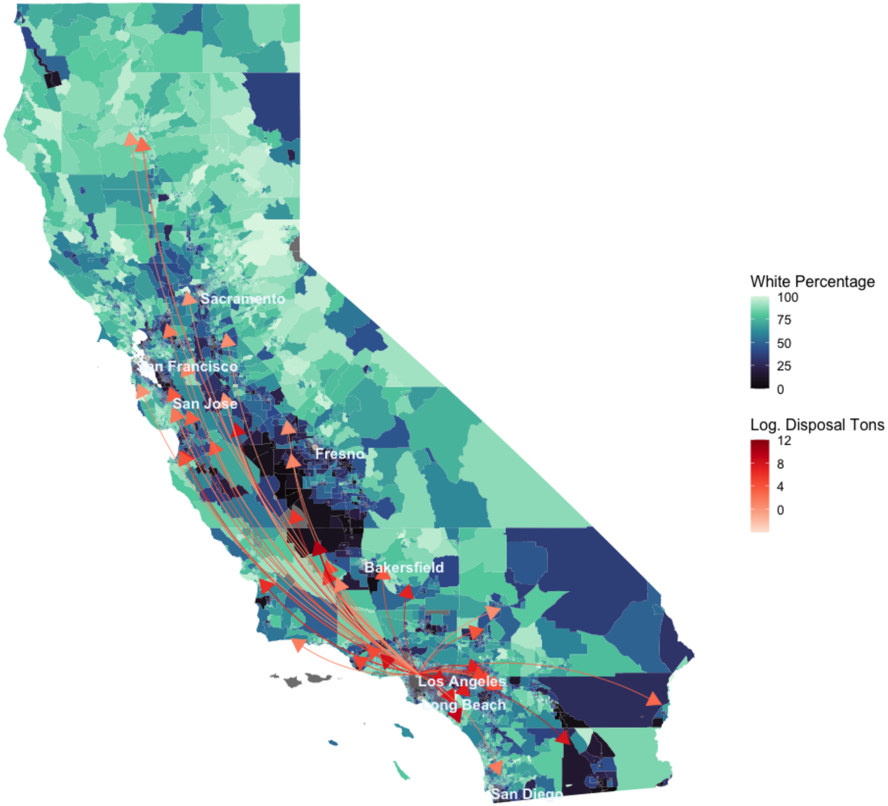
Pollution Relocation



Data Source: CalRecycle RDRS

Figure 11. Average net increase in waste flows across regions after the GS policy

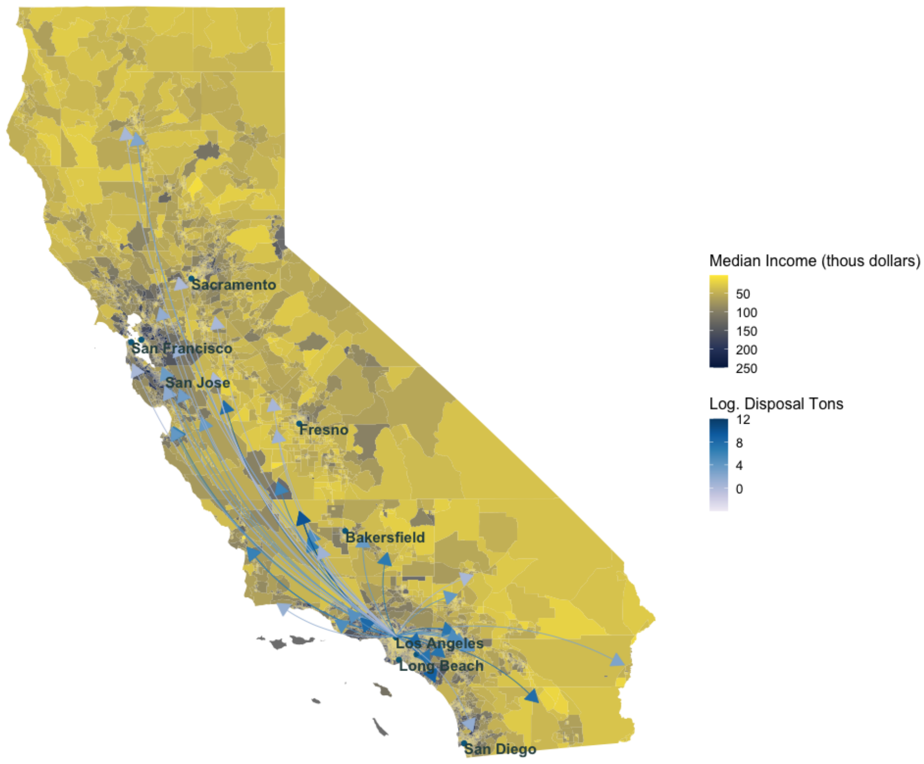
Pollution Relocation by Racial Composition



Data Source: CalRecycle RDRS and U.S. Census

Figure 12. Waste Pollution Relocation by Race

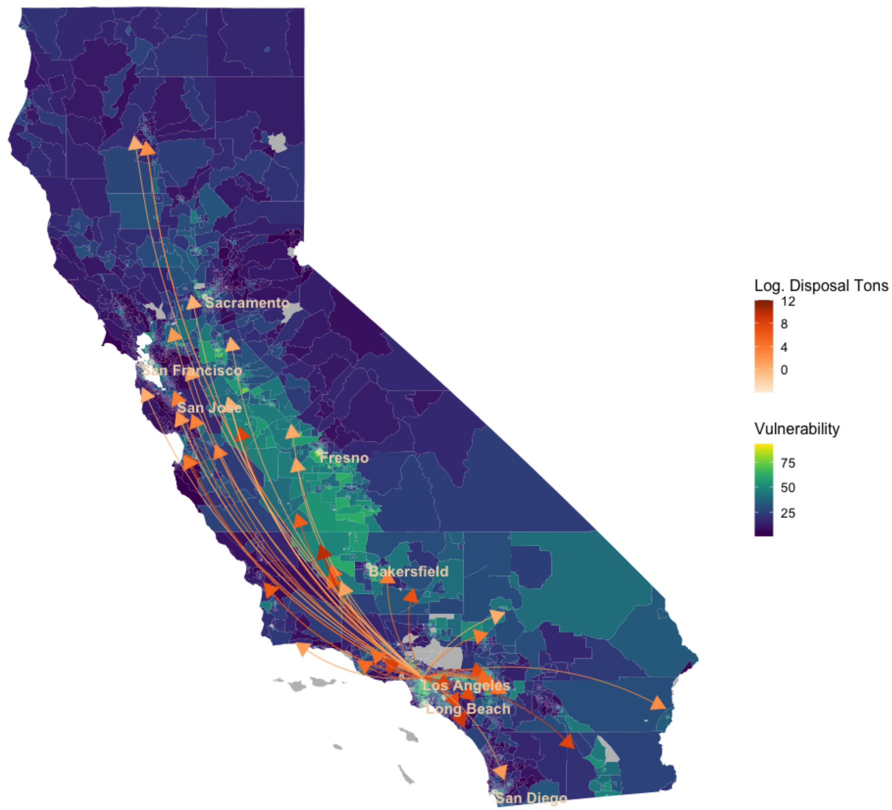
Pollution Relocation by Median Income



Data Source: CalRecycle RDRS and ACS

Figure 13. Waste Pollution Relocation by Median Income

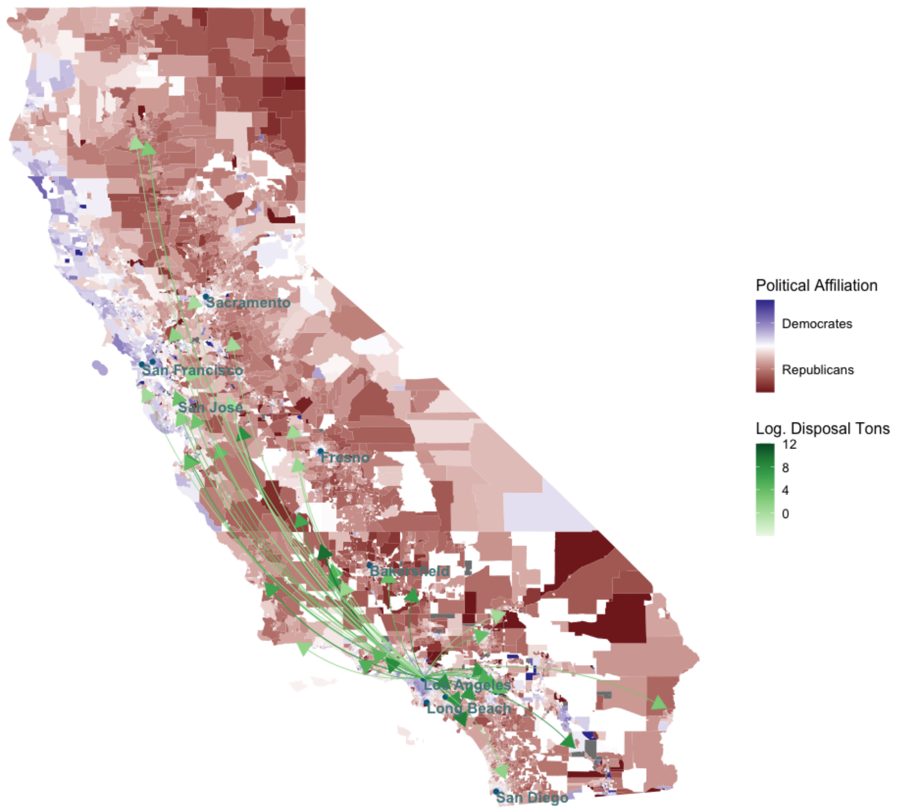
Pollution Relocation by Environmental Vulnerability



Data Source: CalRecycle RDRS and Calenvironscreen 4.0

Figure 14. Waste Pollution Relocation by Environmental Vulnerability

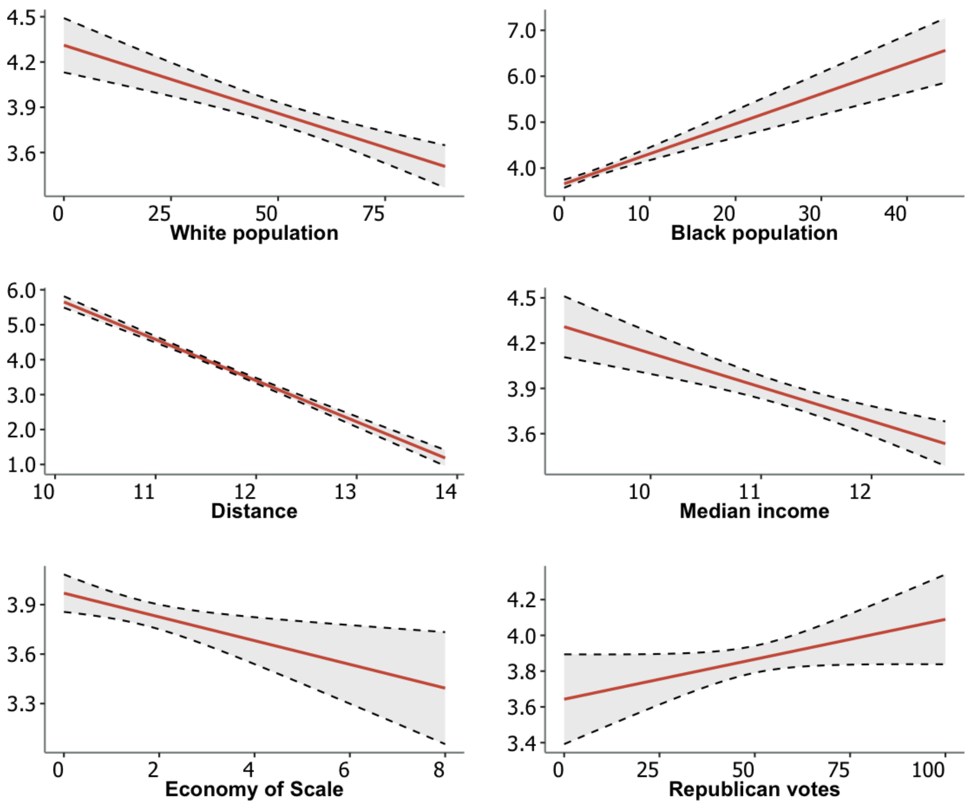
Pollution Relocation by Political Affiliation



Data Source: CalRecycle RDRS and SWDB

Figure 15. Waste Pollution Relocation by Political Affiliation

Correlations



Data Source: CalRecycle RDRS

Figure 16. Correlations of Disposal Flow and Destination Community Characteristics

Gravity-type Model

$$\text{Disposal}_{ijt} = \alpha + \beta_1 \log(\text{Dist}_{ij}) + \beta_2 \log(R_j) + \beta_3 \log(X_{jt})$$

$$+\beta_5 GS_{post} \times \log(\text{Dist}_{ij}) + \beta_6 GS_{post} \times \log(R_j) + \beta_7 GS_{post} \times \log(X_{jt})$$

$$\epsilon_o + \theta_d + \mu_{od} + \eta_t + \lambda_{odt}$$

Disposal_{ijt} = **tons of the disposal transported from origin jurisdiction** i **to destination community** j **in year quarter** t

Community j = area that is a 3km buffer within the destination facility

Dist_{ij} = distance between origin i and destination j

R_{jt} = racial compositions of destination j

X_{jt} = median income and economies of scale of waste industry of destination j

GS_{post} = dummy variable for the GS policy in effect

Fixed-effects: ϵ_o, θ_d, μ_{od}, η_t, λ_{odt} o origin county d destination county

Gravity-type Model

$$\text{Disposal}_{ijt} = \alpha + \beta_1 \log(\text{Dist}_{ij}) + \beta_2 \log(R_j) + \beta_3 \log(X_{jt})$$

$$+\beta_5 GS_{post} \times \log(\text{Dist}_{ij}) + \beta_6 GS_{post} \times \log(R_j) + \beta_7 GS_{post} \times \log(X_{jt})$$

$$\epsilon_o + \theta_d + \mu_{od} + \eta_t + \lambda_{odt}$$

Disposal_{ijt} = tons of the disposal transported from origin jurisdiction i to destination community j in year quarter t

Community j = area that is a 3km buffer within the destination facility

Dist_{ij} = **distance between origin** i **and destination** j

R_{jt} = racial compositions of destination j

X_{jt} = median income, economies of scale, and presidential vote share of destination j

GS_{post} = dummy variable for the GS policy in effect

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GS_{post} = **dummy variable for the GS policy in effect**

Fixed-effects: $\epsilon_o, \theta_d, \mu_{od}, \eta_t, \lambda_{odt}$, o origin county, d destination county.

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GS_{post} = dummy variable for the GS policy in effect

Fixed-effects: ϵ_o, θ_d, μ_{od}, η_t, λ_{odt}, o origin county, d destination county

Results prior to the GS Policy (point and interval)

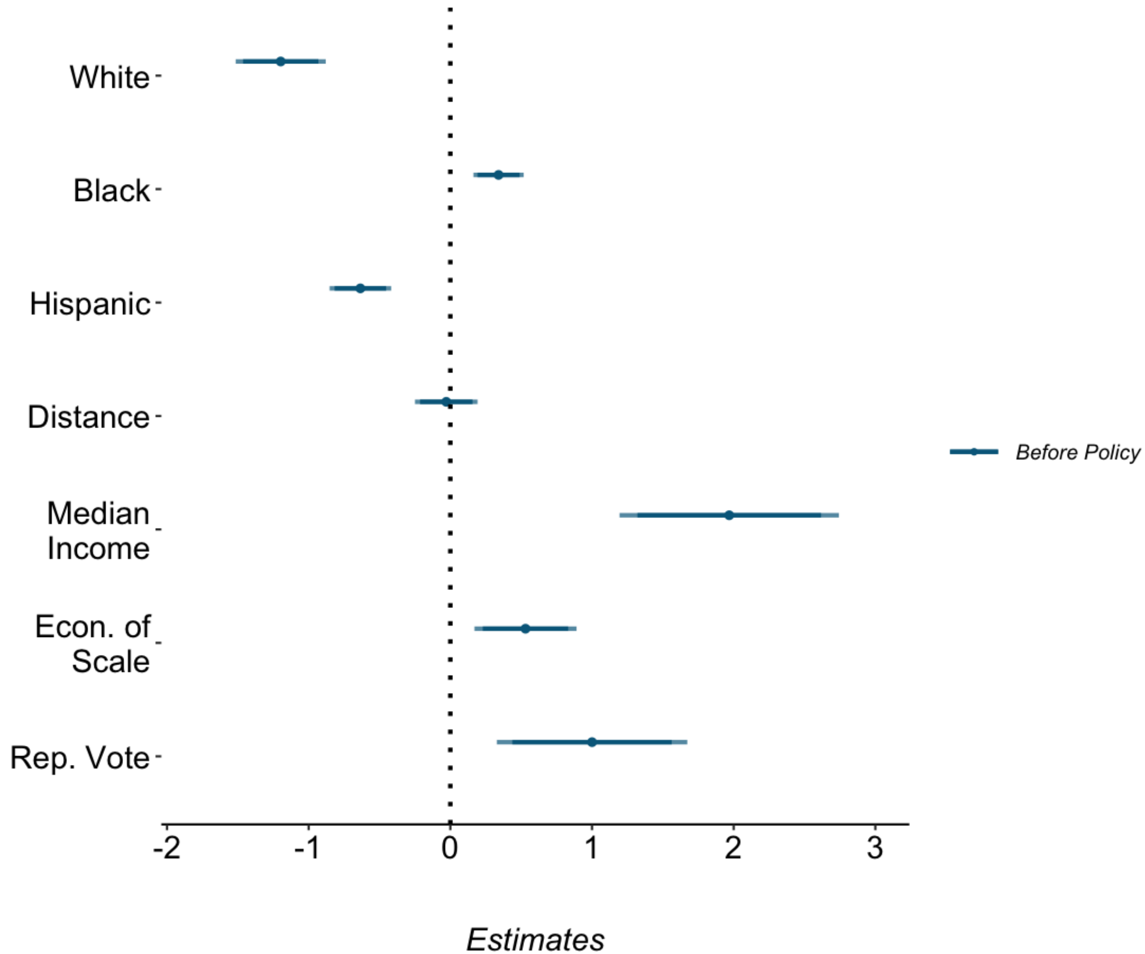

Figure 17: Gravity Model Key coefficient estimates at census-block level

Results after the GS Policy (in blue)

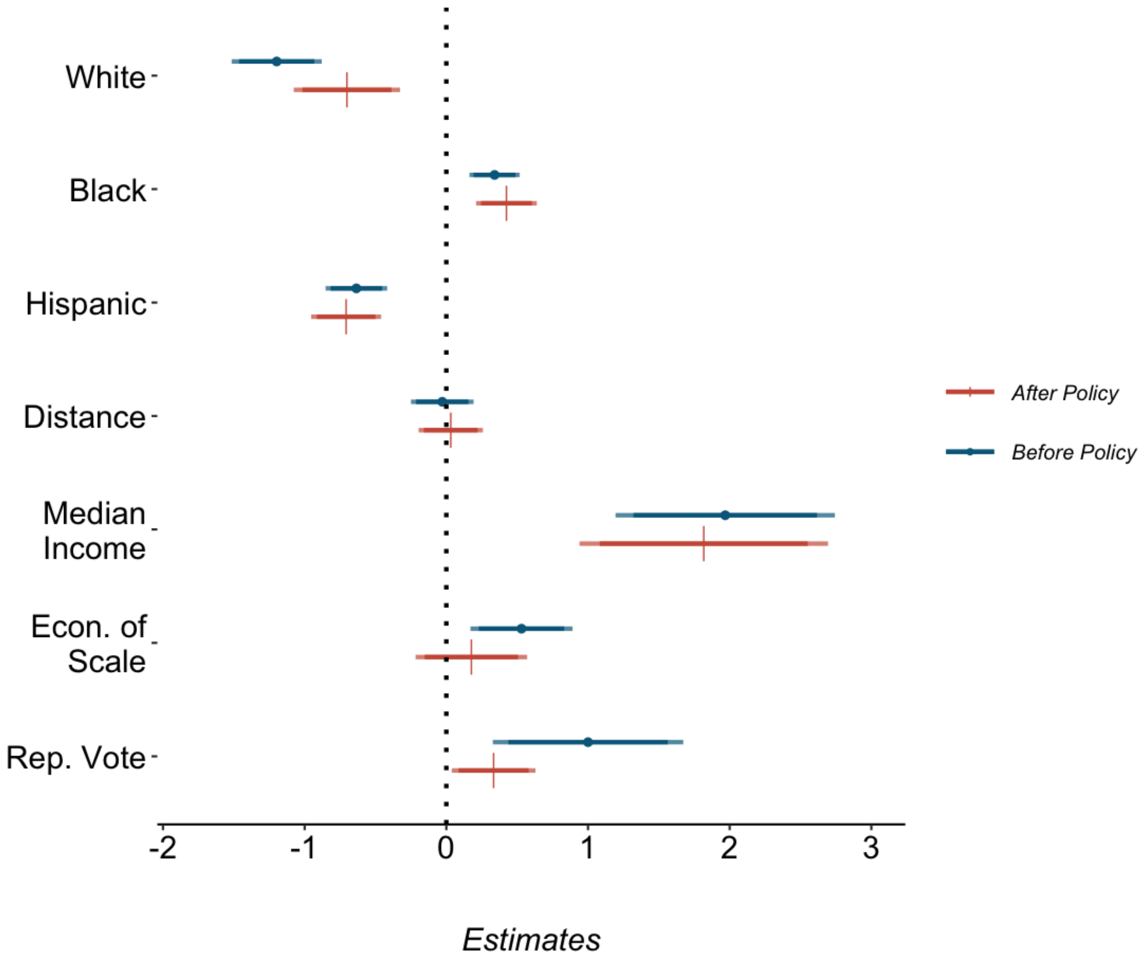

Figure 17: Gravity Model Key coefficient estimates at census-block level

Mechanism: Simple model

- Pollution relocation depends
  - Directly on total disposal generated
  - Inversely on monetary and non-monetary costs

$$TranspWaste_{ijt} = f(\underset{+}{TotalWaste_{it}}, \underset{-}{Cost_{ijt}})$$

- $TranspWaste_{ij}$ = **the waste pollution relocated from jurisdiction** i **to facility** j
- $TotalWaste_i$ = the waste pollution generated by jurisdiction i
- C_{ij} = costs of shipping wastes from jurisdiction i to destination community j

Mechanism: Simple model

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Mechanism: Simple model

- Pollution relocation depends
  - Directly on total disposal generated
  - Inversely on monetary and non-monetary costs

$$TranspWaste_{ijt} = f(\underset{+}{TotalWaste_{it}}, \underset{-}{Cost_{ijt}})$$

- Three cost metrics

$$Cost_{ijt} = f(\underset{+}{L_{jt}}, \underset{+}{T_{ijt}}, \underset{+}{P_{ijt}})$$

- $L_{ij}(Pop_j)$ = **land cost approximated by population density of destination j**
- $T_{ijt}(d_{ij})$ = transportation cost approximated by the distance origin i and destination j located**
- $P_{ij}(Vjc)$ = a political cost function w.r.t. votes in district where facility j located

Mechanism: Simple model

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  - Directly on total disposal generated
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- Three cost metrics

$$Cost_{ijt} = f(\underset{+}{L_{jt}}, \underset{+}{T_{ijt}}, \underset{+}{P_{ijt}})$$

- Political Cost

$$P_{jt} = f(\underset{-}{Votes_{jt} - Votes_{ct}})$$

- $Votes_{jt}$ = **presidential vote share of destination community j**
- $Votes_{ct}$ = presidential vote share of county c where destination community j located
- P_{jt} = absolute difference between community and county vote shares

Mechanism: Simple model

- Pollution relocation depends
  - Directly on total disposal generated
  - Inversely on monetary and non-monetary costs

$$TranspWaste_{ijt} = f(\underset{+}{TotalWaste_{it}}, \underset{-}{Cost_{ijt}})$$

- Three cost metrics

$$Cost_{ijt} = f(\underset{+}{L_{jt}}, \underset{+}{T_{ijt}}, \underset{+}{P_{ijt}})$$

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Mechanism: Simple model

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- P_{jt} = **absolute difference between community and county vote shares**

Mechanism: Political Cost

$$P_{jt} = f(Votes_{jt} - Votes_{ct})$$

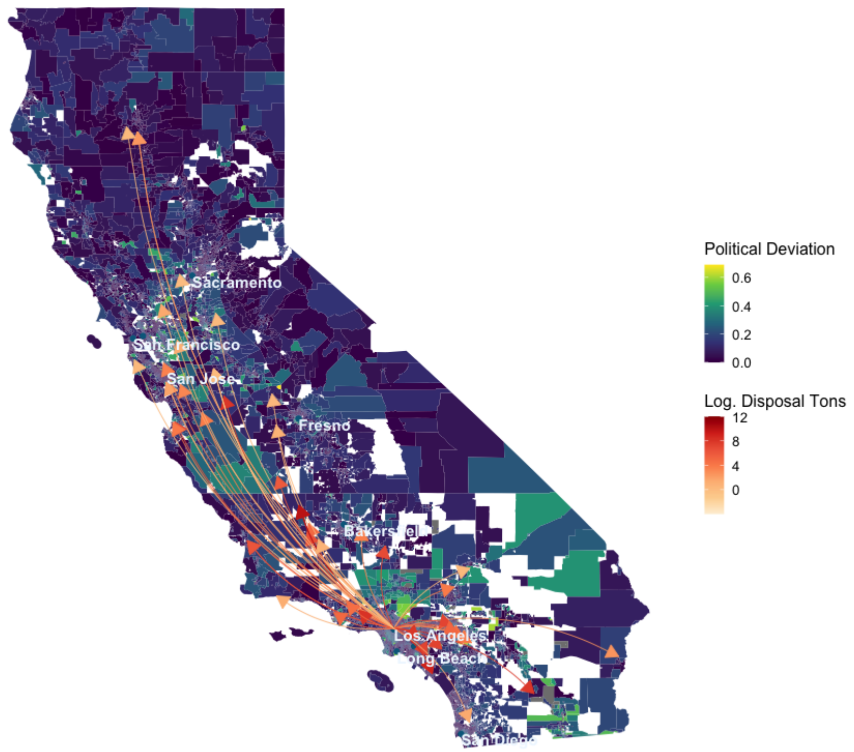
- $Votes_{jt}$ = presidential vote share of destination community j
- $Votes_{ct}$ = presidential vote share of county c where destination community j located
- P_{jt} = **absolute difference between community and county vote shares**

For example, community A's Republican vote share of 2016 presidential election was 80%. However the county's Republican vote share was 40%.

The absolutely vote discrepancy is |40% - 80%| = 40%.

- high political cost
- more different political ideology from surrounding communities
- less resistance to waste inflows

California Political Cost by Precinct



Data Source: CalRecycle RDRS and SWDB

Figure 18. Disposal Flow by Political Deviation

Mechanisms: prior to the GS policy

Dependent Variable	Disposal Shipment			
Transportation costs	-0.326***			**-0.476 * * ***
	(0.113)			(0.112)
Transportation costs x 1(post)	0.031			0.0196
	(0.049)			(0.063)
Land costs		0.019		**-0.063**
		(0.052)		(0.060)
Land costs x 1(post)		-0.017		-0.057 **
		0.020)		(0.024)
Political costs			0.028	**0.011**
			(0.041)	(0.032)
Political costs x 1(post)			-0.107 *	-0.101 *
			(0.062)	(0.057)
County fixed effects	Y	Y	Y	Y
Year fixed effects	Y	Y	Y	Y
Quarter fixed effects	Y	Y	Y	Y
R_2	0.642	0.638	0.654	0.664

Note: Each column reports a separate regression. **p<0.1;**p<0.05;***p<0.01*.

Mechanisms: after the GS policy

Dependent Variable	Disposal Shipment			
Transportation costs	-0.326***			-0.476 * * *
	(0.113)			(0.112)
Transportation costs x 1(post)	0.031			**0.0196**
	(0.049)			(0.063)
Land costs		0.019		-0.063
		(0.052)		(0.060)
Land costs x 1(post)		-0.017		**-0.057** **
		0.020)		(0.024)
Political costs			0.028	0.011
			(0.041)	(0.032)
Political costs x 1(post)			-0.107 *	**-0.101** *
			(0.062)	(0.057)
County fixed effects	Y	Y	Y	Y
Year fixed effects	Y	Y	Y	Y
Quarter fixed effects	Y	Y	Y	Y
R_2	0.642	0.638	0.654	0.664

Note: Each column reports a separate regression. **p<0.1;**p<0.05;***p<0.01*.

Conclusion

- **U.S. Domestic Emissions**
  - Decrease in exports with recyclable wastes causes an increase in emissions from the waste industry
  - Many states have seen statistically significant increases in methane emissions after the GS policy
- **California Pollution Relocation**
  - Before China's GS policy

  Waste tend to relocate to minority communities

  - After China's GS policy

  Inflows increased more for nearby lower-income white communities

  - Potential mechanism

  After GS policy shock, pollution relocated more to lower land cost but higher political costs communities

Thank you

Questions?

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szhang6@uoregon.edu

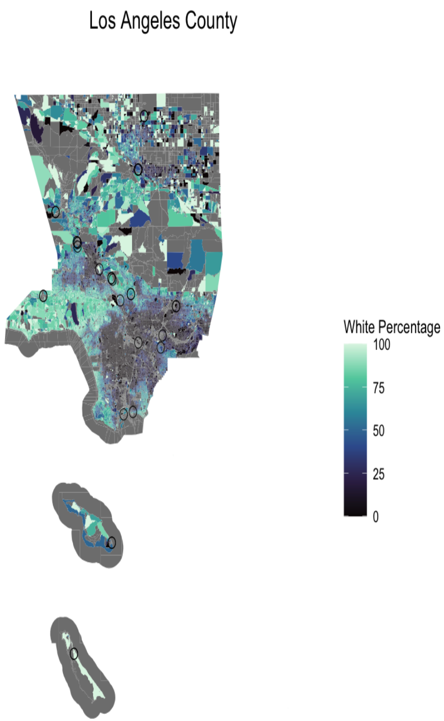
Should We Recycle?

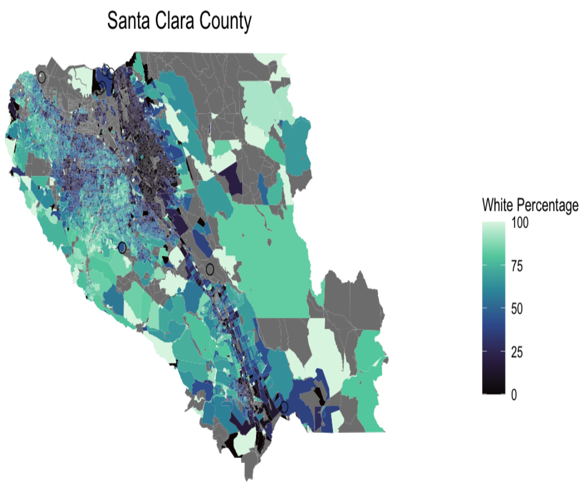
- So, Should We Recycle? July 12, 2019
- Waste Land September 11, 2020
  Won duPont-Columbia Award
- Is Recycling Worth It Anymore? People On The Front Lines Say Maybe Not. April 21, 2021
  "The Litter Myth"

Accepted Recyclables

Lane County (OR) Recycling Posters 2015 vs. 2021

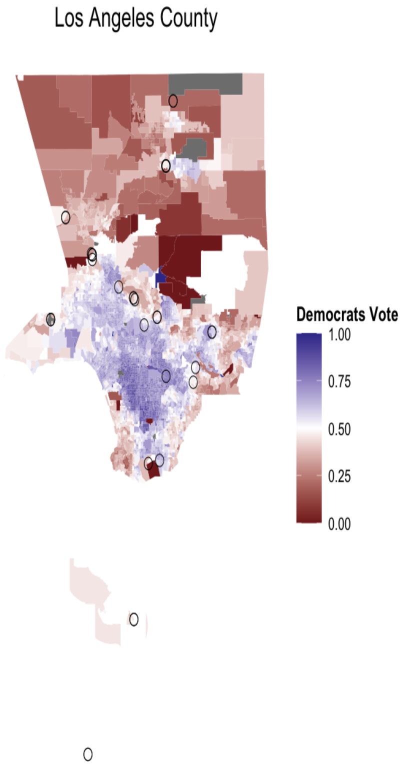
Appendix: Racial variation

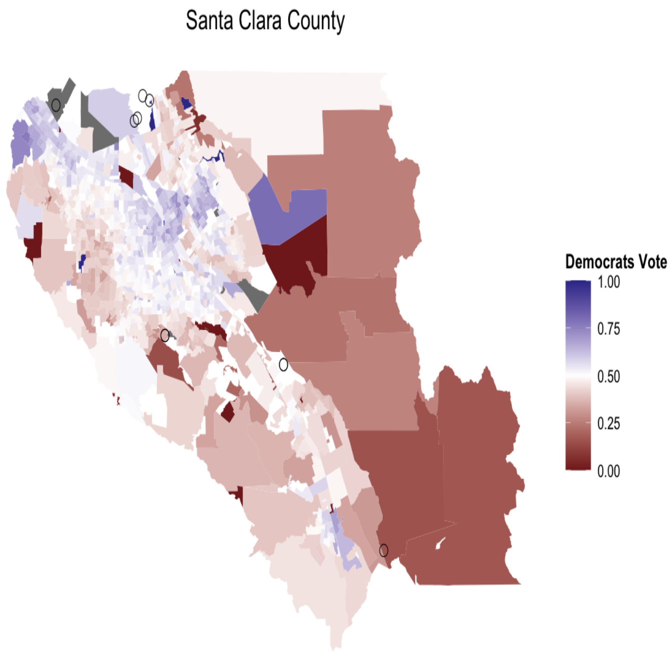




Racial variation within the county

Voting variation





Voting variation within the county