Decomposing Trends in Air Pollution Disparities from U.S. Electricity

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U.S. electricity: two key developments

Emission intensities

Fuel shares
Air pollution disparity implications

Uneven spatial distribution of:

- power plants and technologies
- demographics of downwind individuals

Emerging environmental justice concern:

Pollution disparity implications of local air pollution vs. climate policies?

Potential policy implications: If pollution disparities decrease due to spatially-differentiated changes in...

1. emissions intensities → local air pollution policies
2. coal-to-natural gas switching → climate policies
This paper

Questions:

1. What happened to U.S. PM$_{2.5}$ concentrations from electricity during 2000-2018?
   - Overall
   - By racial/ethnic groups
   - By income

2. What drove trends in PM$_{2.5}$ concentration disparities? Contributions from changes in
   - total fossil fuel generation ("scale")
   - emissions intensities ("technique")
   - fossil market shares ("composition")
   - residential locations ("sorting")
Finding #1: Falling PM$_{2.5}$ concentrations

PM$_{2.5}$ concentrations from electricity have fallen by 87% overall, double the decline rate of ambient U.S. PM$_{2.5}$. 
Finding #2: Convergence in disparities

Convergence in PM$_{2.5}$ concentration gaps; 94% in Black-White gap; 92% in Hispanic-White gap.
Finding #3: Emissions intensity improvements play key role

Nearly all driven by spatially-varying emissions intensity improvements
Finding #4: Smaller disparities by income

Relatively small gap and trend by income differences
Contributions to the literature

Presence of pollution disparities

- Case studies (Bullard, 2000; Bowen, 2002; Ringquist, 2005; Mohai, Pellow and Roberts, 2009; Banzhaf, Ma and Timmins, 2019)
- Population studies (Colmer et al., 2020; Currie et al., 2021)

Role of policy in altering pollution disparities

- Local air pollution policy (Fowlie et al., 2012; Grainger and Ruangmas; Currie et al, 2021)
- Climate policy (Hernandez-Cortes and Meng, 2022; Weber, 2021)

Using a fine-resolution pollution transport model

- Addressing bias (Muller and Mendelsohn, 2007; Sullivan, 2017, Deschenes and Meng, 2018, Tessum et al., 2017)

Extending emissions decomposition approach

- Metcalf (2008), Levinson (2009), Shapiro and Walker (2018)
Data and Methods
Data

Electricity generating units

U.S. EPA Clean Air Markets Division:

- Continuous Emissions Monitoring Systems
- Electricity Generating Units (EGUs) over 25MW
- Hourly generation, fuel inputs, NO\textsubscript{x}, and SO\textsubscript{2}
- 2000-2018

EIA-860:

- Stack height, temperature, velocity, and diameter

Census tract demographics:

- 2000: Decennial Census
- 2009-2018: ACS
Demographic data (2018)

(a) Black share

(b) Hispanic share

(c) White share

(d) Median income
Data

**InMAP Source-receptor matrix** (Tessum et al. 2017, Goodkind et al., 2019)

- Models total PM$_{2.5}$ (primary and secondary)
Pollution emissions from facility $j$ in year $t$ of pollutant $p$

$$E_{jt} = \phi_{jt}^p \delta_{jt} Q_t \bigg/ \text{em. int. \ share \ total output}$$

Pollution concentrations for census tract $i$ in year $t$:

$$C_{it} = \sum_p \sum_j \frac{E_{jt}^p w_{ji}^p}{SRM}$$
PM$_{2.5}$ concentrations from electricity (2018)
Current (2018) spatial pattern (% minority)
Current (2018) spatial pattern (median income)
Method: average pollution for individual by group

Pollution concentrations for demographic group $g$:

$$C_{gt} = \frac{\sum_i C_{it} S_{git} N_{it}}{\sum_i S_{git} N_{it}}$$

Pollution disparities: $C_{gt} - C_{g't}$
Average Black individual resides in a location with 64% more PM$_{2.5}$ concentration than average Hispanic.
Actual exposure

Electricity source → \( \delta_{jt} Q_t \) → Fossil fuel generation

Emissions → \( \phi_{jt} \delta_{jt} Q_t \) → Transport

Transport → \( E_{jt}^p w_{ji}^p \) → Receptor

Geographic grids layered on Census Tract demographics
Allow only electricity production to vary over time
Scale + emissions intensity effects

Allow electricity production and emissions intensities to vary over time

Electricity source \( \delta_{jt} Q_t \) \( \Rightarrow \) Fossil fuel generation \( Q_t \)

Emissions \( \phi_{jt} \delta_{jt} Q_t \)

Transport \( E_{jt} w_{ji}^{P} \) \( \Rightarrow \) SRM

Receptor \( j', j'', j''' \)

Geographic grids layered on Census Tract demographics
Scale + emissions intensity + composition effects

Allow electricity production, emissions intensities, and fossil market share to vary over time

Diagram:
- Electricity source
- Emissions
- Transport
- Receptor
- Fossil fuel generation

Symbols:
- $\delta_{jt} Q_t$
- $\phi_{jt}^p \delta_{jt} Q_t$
- $E_{jt}^p w_{ji}^p$
- $SRM$
- Geographic grids layered on Census Tract demographics
Total effect

Allow electricity production, emissions intensities, fossil market shares, and demographics to vary over time
Results
PM$_{2.5}$ concentrations from electricity have fallen by 87% overall, while national average has fallen by 39%
**PM$_{2.5}$ trend by race/ethnicity**

Convergence in PM$_{2.5}$ concentration gaps; 94% in Black-White gap; 92% in Hispanic-White gap
PM$_{2.5}$ trend by income

Relatively small gap in concentrations by income groups over the study period
Decomposition: emissions

Emissions fell by 88% ($\text{NO}_x$) and 78% ($\text{SO}_2$).

$\text{NO}_x$: Scale effect: 4%. Emissions intensity: $\approx 86\%$. Compositional changes: $\approx 10\%$. 
Decomposition: Black-White PM$_{2.5}$ disparity trend

Black-White disparity falling, driven mostly by emissions intensity improvements.
Hispanic-White disparity falling, driven mostly by emissions intensity improvements.
Why are disparities impacted by changes in emissions intensities?

Determinants of impact:
1. Location of emission intensity improvements
2. Rate of emission intensity improvements

Relationship between where emissions intensity improvements occur, the size of improvement, and the demographic groups that are downwind from these improvements.
Why are disparities impacted by changes in emissions intensities?

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Determinants of impact:

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Relationship between **where** emissions intensity **improvements occur**, the **size** of improvement, and the **demographic groups** that are **downwind** from these improvements
Why are disparities impacted by changes in emissions intensities?

Positive relationship between counties with coal EGUs that improve \( \text{NO}_x \) & \( \text{SO}_2 \) emissions intensity and \( \text{PM}_{2.5} \) contribution to Black population
This paper quantifies recent trends and determinants of U.S. PM\textsubscript{2.5} concentrations and their disparities from electricity.

Differences in the residential locations create distinct trends for each racial/ethnic group.

PM\textsubscript{2.5} concentrations across racial/ethnic groups have converged over the last two decades but disparities still exist.

Much of the convergence can be explained by changing emissions intensities.

Compositional effects including fuel-switching and residential sorting play smaller roles.
Caveats and future work

- **Concentration versus exposure**: role of occupational exposure, access to health care, and other defensive investments.

- Impact of increasing **renewable energy** penetration across space.

- **No causal** interpretation for decomposition results.

- Characterize **equity-efficiency tradeoffs** between air pollution disparity improvements and electricity prices across various climate and local air pollution policies.
Questions?